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GEOLOGY AND MINERAL RESOURCES OF NORTHWESTERN ALASKA

BY

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GEOLOGY AND MINERAL RESOURCES OF NORTHWESTERN ALASKA

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INTRODUCTION

PURPOSE OF THE INVESTIGATION

Late in February, 1923, President Harding, aware of the importance of anticipating and providing for the future needs of the Navy for oil and realizing that there was a vast area of unappropriated public land in northern Alaska which might contain valuable deposits of oil, issued an Executive order reserving a tract of about 35,000 square miles as Naval Petroleum Reserve No. 4. (See fig. 1.) Oil had been reported at a few places near the coastal portion of this tract, but concerning most of the inland parts practically nothing was known. The responsible naval officials decided that for the proper administration of this newly created reserve the first thing necessary was adequate geographic and geologic knowledge of the tract. The Bureau of Engineering of the Navy Department therefore invited the Geological Survey of the Interior Department to examine and report upon the area and financed the beginning of this work.

The primary underlying purpose of the recent investigations by the Geological Survey has therefore been to investigate the possibility of obtaining oil in this region. Not only was the direct question to be answered as to where, if anywhere, oil occurred, but it was also necessary to collect and bring to bear on the problem any geologic information obtainable as to the area where oil might be found, the places where more intensive investigations were justified, and the magnitude of the deposits. Furthermore, even the most preliminary consideration of the problem required considerable information regarding the general topography, geology, and geography of the tract. To supply this information necessitated the collection, both in the field and in the laboratory, of data on many different subjects, some of which had to be obtained first hand because so much of the territory was actually unknown. Therefore, while centering attention on the direct problem of finding oil, the Geological Survey parties have collected as much additional information as possible, in the belief that all of it would sooner or later be found to be pertinent

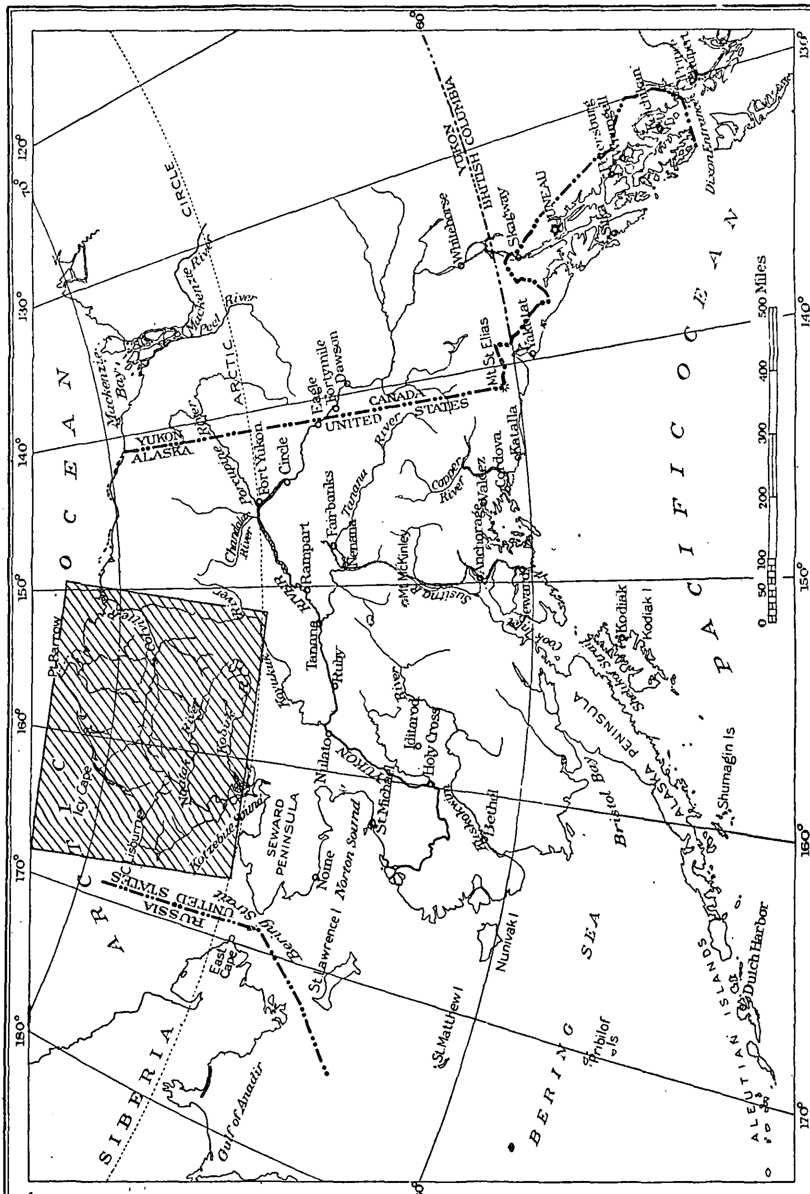

FIGURE 1.—Index map showing (by shading) position of area described

to the "classification, examination, and preparation of plans for development" of the reserve. The large body of general information thus obtained serves not only in the immediate inquiry but also contributes to the knowledge of a large part of northwestern Alaska and to the sciences of geology and geography. All the pertinent information is given rather fully in the present report, so as to be easily accessible, for many of the former records are scattered through rare volumes not obtainable except in large libraries. Furthermore, the results of most of the work done since 1924 have not been published in any detail elsewhere. Therefore the results of the recent Geological Survey work are given in this report with so much detail that, were it not for this reason, they might seem to be unduly emphasized.

ACKNOWLEDGMENTS

It is difficult to place definitely the responsibility for the preparation of the several parts of this report. In the main the geology of the Paleozoic formations was written by J. B. Mertie, jr., and a first draft of part of the section on the geology of the Mesozoic formations was prepared by W. R. Smith, while the general geography, the geology of the Tertiary and younger deposits, and the economic geology were assigned to Philip S. Smith. W. R. Smith, however, resigned from the Geological Survey in February, 1926, and Mr. Mertie has been assigned principally to other investigations since 1925, so that, except for the section on the Paleozoic geology, most of the task of incorporating the results of the later expeditions and checking over the earlier interpretations in the light of later data has fallen to the senior author. Although the actual writing of the final draft of this report was done by the two men whose names appear on the title page, the conclusions expressed are believed to be in general accord with the conclusions reached by all the geologists of the Geological Survey who have worked in this region, in so far as the data at their disposal went.

The recent surveys made by the Geological Survey in northern Alaska have been successful mainly because of the professional ability and indefatigable service of the members of the different parties, and grateful acknowledgment is here paid to them. Gerald FitzGerald served most efficiently on all four of the recent expeditions as topographer and was chief of party in the 1925 work. Sidney Paige was geologist in charge of all the parties that worked in northern Alaska in 1923, with James Gilluly, geologist, and E. C. Guerin and James Whitaker, topographers. W. T. Foran was geologist with the southern party in 1923 and, with O. L. Wix, topographer, made a most arduous exploration in 1924. R. K. Lynt was one of the topographers with one of the 1924 parties, and Walter R. Smith was the geologist of the 1925 party. All the camp hands also served effectively in putting through the work. Special mention is made of W. R. Blankenship, who was a most useful member of the parties in 1924, 1925, and 1926. H. A. Tait, F. B. Dodge, and George Clark,

of the 1924 parties; Fay Delezene, of the 1925 party; and Fred Clark, of the 1926 party, all contributed to the successful progress of the work.

The Federal and Territorial officials made the facilities of their respective organizations available to help in every way the members of the Geological Survey in this work. Among the many who thus assisted may be especially mentioned members of the Bureau of Education, particularly Capt. Frank Whitlam and associates, of the *Boxer*, and the teachers throughout the region, especially Mr. and Mrs. Cramer at Wainwright, Mr. and Mrs. Morelander at Kivalina, Peter Van der Steer at Barrow, and C. L. Andrews at Nome; the Coast Guard, particularly Captain Cochrane and associates, of the *Bear*, and Captain Ross of the Nome station; the Alaska Railroad; the Signal Corps; and the Alaska Road Commission.

In equipping and supplying the parties that outfitted in Alaska the traders and storekeepers rendered valuable assistance. Among these should be specially mentioned H. Liebes & Co., particularly through C. D. Brower, part owner and in general charge of its station at Barrow; Jim Allen, its representative at Wainwright; and H. A. Riley, of Barrow; the Northern Commercial Co. of Alaska, particularly through G. V. Goss, its former manager at Tanana; E. A. Parsons, in charge at Nenana; and H. Fleischmann, in charge at Ruby; the Midnight Sun Trading & Transportation Co., particularly through R. S. Hall, its agent, formerly of Kotzebue and later of Wainwright; Tom Berryman, of the Kotzebue Fur & Trading Co.; the Magids Bros., particularly through Paul Davidovics, their agent at Kotzebue; and H. Robinson, of Robinson & Greenburg, at Candle.

Among the other individuals and organizations to whom acknowledgments are due are the Alaska Steamship Co.; the members of the Presbyterian hospital and mission at Barrow, especially Dr. H. W. Greist, physician in charge, and Miss Florence Dakin; O. S. Weaver and Lomen Bros., of Nome; Thomas DeVane, of Ruby; Capt. Joseph Bernard, of the *Teddy Bear*; and the Eskimos Chester Sevic, of Kivalina; Johnson Kuyukpuk, of Kotzebue; and the Nashelooks, of Noatak village.

EARLY INVESTIGATIONS IN NORTHWESTERN ALASKA

It is not proposed to trace here in detail all the expeditions that have visited parts of northern Alaska but rather to pick out those that have especially contributed to our knowledge of this region. (See pl. 3.) A comprehensive summary of the early exploring expeditions was compiled by Dall,[1] and a special sketch of the

[1] Dall, W. H., Alaska and its resources, London and Boston, 1870.

exploring parties who visited the northern coast of Alaska was prepared by Leffingwell.[2] An account by Berg[3] of the Russian discoveries in the Pacific has recently been published, which lists and abstracts in English many papers that are in Russian and thus heretofore unavailable to Americans.

So far as available information shows, Semen Dezhneff was the first foreigner to see any part of what is now American territory in northwestern Alaska, when in 1648 he discovered the Diomede Islands, but he did not learn of the mainland beyond. In 1711 Peter Popoff reported seeing the Diomedes and learned of a continent beyond, but it was 1732 before any foreigner is reported to have reached this new land. In that year, according to Berg,[4] Ivan Fedoroff and Michael Gwozdeff landed near Cape Prince of Wales. The maps of their surveys were unfortunately lost, though their results appear to have been known in Europe and incorporated in the map drawn by Müller and published in 1758 by the Russian Academy of Sciences. Dall, however, gives the honor of being the first white man on this coast to Lieutenant Synd, who, he says, landed a short distance south of Cape Prince of Wales in 1767. It remained, however, for Capt. James Cook,[5] in 1778, to be the first to discover and leave a record of the parts of the area treated in this report. He named Cape Lisburne and coasted along the shore near enough to note some of the prominent points as far north as Icy Cape. It was 1816 before the next noteworthy addition to our knowledge of the geography of this region was made. In that year Lieutenant von Kotzebue[6] cruised along its southwestern coast and discovered the great body of water to which his name has been given. He mapped most of the coast from Cape Prince of Wales to Cape Krusenstern.

In 1826 Captain Beechey,[7] of the British Navy, conducted surveys that are of remarkable accuracy, considering the difficulties under which they were made, and form the basis from which practically all subsequent maps of the western coast have been made. Captain Beechey was unable to force his ship, the *Blossom*, through the ice north of Franklin Point, so that Elson, master, and Smyth, mate, left the vessel at that place in a small boat and have the honor of being the first to map the coast northward to Point Barrow. During

[2] Leffingwell, E. de K., The Canning River region: U. S. Geol. Survey Prof. Paper 109, pp. 69–92, 1919.

[3] Berg, L., Russian discoveries in the Pacific, pp. 1–26, Leningrad, U. S. S. R. Acad. Sci., 1926.

[4] Berg, L. S., The strait of Bering and its coasts before Bering and Cook [in Russian only], 1920.

[5] Cook, James, A voyage to the Pacific, 3 vols., London, 1784.

[6] Kotzebue, Otto von, A voyage of discovery into the South Seas and Bering Straits, 3 vols., London, 1821.

[7] Beechey, F. W., Narrative of a voyage to the Pacific and Beering's Strait, London, 1831.

this same year Sir John Franklin,[8] sailing westward along the northern coast of Alaska, explored that coast practically to the eastern margin of the delta of the Colville. The stretch of coast 150 miles long between the surveys of Elson and Smyth and those of Franklin remained unexplored until 1837, when the Hudson Bay Co. sent out an expedition in charge of P. W. Dease and Thomas Simpson to close this gap. They went by open boat along the Arctic coast to a point a few miles beyond Cape Simpson, where, because of difficulties of navigation, they decided to finish the exploration on foot. Simpson, with five others, started overland, each man packing a load of supplies, including a canvas canoe. After several days, in which they must have encountered almost insuperable difficulties, they arrived at Point Barrow.

With the completion of these surveys the major features of the coast were determined, though later expeditions, many of which had been organized to search for Sir John Franklin, corrected some of the errors that had been made and added many details. Those in charge of the several expeditions that visited this coast in the search for Franklin, especially Kellett, Moore, McClure, Collinson, Pullen, and Maguire, all left brilliant records of accomplishment. John Simpson,[9] the surgeon on Captain Maguire's ship, the *Plover*, however, deserves more than passing notice because apparently he was the first to record the presence of the two great inland rivers—the Kobuk and the Noatak—though only the lower parts of these rivers are shown on his maps, dated 1852 and 1854.

In the next 25 years little additional information was published regarding this region until the international polar expedition in charge of Lieutenant Ray [10] carried on work in the vicinity of Barrow from the fall of 1881 to the fall of 1883. Not only did this expedition carry on intensive climatologic and magnetic observations during its stay, but Ray explored the course of the Meade River southward practically to latitude 70° N., and his associates made valuable collections and records of many of the animals and plants of the region.

Beginning in 1883, the first explorations of the inland parts of the region were undertaken. In that year Lieutenant Stoney,[11] of the United States Navy, went some distance up the Kobuk River, and the next year he renewed his explorations up that stream to a point at least as far east as longitude 156°. In 1884 Lieutenant Cantwell, of the Revenue Cutter Service, also carried surveys up the Kobuk

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[8] Franklin, John, Narrative of a second expedition to the shores of the Polar Sea in the years 1825, 1826, and 1827, London, 1828.

[9] Simpson, John, Observations upon western Esquimaux: British Blue Book, vol. 35, pp. 917–942, 1855.

[10] Ray, P. H., International polar expedition to Point Barrow: 48th Cong., 2d sess., H. Ex. Doc. 44, 1885.

[11] Stoney, G. M., Naval explorations in Alaska, U. S. Naval Institute, Annapolis, 1900.

to about longitude 156° and when returning to the coast met Stoney upward bound. Again in 1885 Cantwell[12] and Stoney carried on further surveys. Stoney spent the winter of 1885–86 near Shungnak, on the upper Kobuk, and during the winter he and the members of his party made several trips to different parts of the region. Stoney himself went across to the Noatak and later to the head of the Kobuk, across to the Alatna, and thence to Chandler Lake. One of the most extensive of these explorations was made by Ensign (now Rear Admiral, retired) Howard, who, with only one white companion and occasional natives, went from the Stoney headquarters on the Kobuk River across the mountains to the Noatak and thence to the headwaters of the Colville, down that stream to a portage into the Ikpikpuk, and thence to Point Barrow. Unfortunately the results obtained by Stoney and his associates were not published until 1900, and during the intervening time many of the original records were lost, so that some of the details became hazy and even actual errors were introduced.

In 1885 S. B. McLenegan,[13] of the Revenue Cutter Service, who had been with Cantwell on his trip up the Kobuk in 1884, with one seaman, made an extensive trip up the Noatak River and was the first white man to traverse any considerable portion of this river and leave a permanent record of his trip. The same year Lieutenant (now Major General, retired) Allen,[14] of the War Department, made one of the most remarkable trips ever taken in connection with Alaskan exploration, the part which brought him into the region here described being on the Koyukuk from the mouth of the Kanuti to the John River. In this tract he was the first white traveler.

Little new information regarding the region was added until the discovery of gold in the Klondike brought a great inrush of prospectors to all parts of Alaska. Most of these men, as well as the later prospectors, have left few records of their trips, so that while some of them probably traversed parts of this area, almost none of them handed on their experience to others, and it is therefore not possible to record their achievements. The interest stimulated by the gold discoveries, however, led to the sending out of Geological Survey parties to carry on systematic scientific explorations of the Territory. The first of these parties that visited this region was in charge of F. C. Schrader, geologist, who, with T. G. Gerdine and D. C. Witherspoon, topographers, in 1899 started from the Yukon, ascended the

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[12] Cantwell, J. C., in Healy, M. A., Report of the cruise of the Revenue Marine Steamer *Corwin* in the Arctic Ocean in 1885, pp. 21–52, Washington, 1887.

[13] McLenegan, S. B., in Healy, M. A., Report of the cruise of the Revenue Marine steamer *Corwin* in the Arctic Ocean in 1885, pp. 53–83, 1887.

[14] Allen, H. T., Report of an expedition to the Copper, Tanana, and Koyukuk Rivers in 1885: 49th Cong., 2d sess., S. Ex. Doc. 125, 1887.

Chandalar River, portaged into the Koyukuk, and descended that river to its mouth.[15]

In 1901 Schrader,[16] as a member of the party in charge of W. J. Peters, topographer, went overland during the winter to the Koyukuk and then during the open season went up the John River, across the Brooks Range, and down the Anaktuvuk and the Colville to the coast, thence westward along the shore to the Corwin coal mine, near Cape Lisburne, where they were fortunate in finding a vessel that took them to Nome. While this party was waiting for the rivers to open Gaston Philip, one of the assistants, ascended the Alatna River nearly to its tributary, the Kutuk. During the same year W. C. Mendenhall,[17] geologist, with D. R. Reaburn, topographer, conducted a Geological Survey party from a point near Fort Hamlin, on the Yukon River, up the Dall River and thence down the Kanuti River to the Koyukuk. This party then ascended the Alatna to Helpmejack Creek, portaged across the divide to the west, and descended the Kobuk to its mouth. In 1904 another Geological Survey party, in charge of Arthur J. Collier,[18] geologist, examined the region adjacent to the coast from Cape Thompson to Cape Beaufort. The next Geological Survey expedition to this region was made in 1908, when E. M. Kindle reexamined parts of the Cape Lisburne region.

In 1910 Philip S. Smith and H. M. Eakin, geologists, went from the Koyukuk, near the mouth of the Hogatza, to the upper part of the Kobuk Basin and then descended the Kobuk to its mouth. The next year Smith,[19] with C. E. Giffin, topographer, surveyed the Alatna River, found a pass across the mountains to the Noatak, and traversed that stream to its mouth. As a result of these explorations by Geological Survey parties, reports accompanied by maps and other illustrations were prepared and published for all the trips except that of Kindle in 1908.

Covering many of the places along the northern coast of Alaska, especially in the country east of the Colville, explorations by Leffingwell and Anderson in the period from 1906 to 1914 and of Stefansson from 1908 to 1918 have added much information regarding northern Alaska, through inland as well as alongshore and offshore trips. The surveys made by the parties of the International Bound-

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[15] Schrader, F. C., Preliminary report on a reconnaissance along the Chandalar and Koyukuk Rivers in Alaska in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 441–486, 1900.

[16] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, 139 pp., 1904.

[17] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, 68 pp., 1902.

[18] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, 54 pp., 1906.

[19] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, 160 pp., 1913.

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

SKETCH MAP SHOWING PROGRESS OF INVESTIGATIONS IN NORTHWESTERN ALASKA

50 0 50 100 150 200 Miles

ary Commission in locating and marking the line between the United States and Canada in 1912 from the Porcupine River to the Arctic Ocean, supply geographic and geologic data which, although concerned primarily with the eastern part of northern Alaska, are of general interest and value.

RECENT GEOLOGICAL SURVEY INVESTIGATIONS IN NORTHWESTERN ALASKA

EXPEDITION OF 1923

The first of the recent Geological Survey expeditions to visit northern Alaska at the request and expense of the Navy Department was that sent out in 1923 in charge of Sidney Paige, with James Gilluly and W. T. Foran, geologists, and E. C. Guerin, Gerald FitzGerald, and James Whitaker, topographers. The object of this expedition was to map the coastal region from a point near Cape Beaufort to Cape Simpson and the inland country along a few of the larger streams in places as far as 65 miles from the ocean. For field work the expedition was organized as three relatively independent parties. Two of the parties left Nome July 3 on the trading vessel *Arctic* and reached Wainwright about July 23. One of these parties, in charge of Gilluly, with Whitaker, topographer, then followed the coast northward to Peard Bay, portaged across to the Inaru River, descended that stream to Dease Inlet, and ascended the Topagorok River for about 80 miles as measured along the course of that stream or 40 miles in an air line from Dease Inlet. The second party, in charge of Paige, with Guerin, topographer, followed the coast northward to Barrow and thence eastward to Cape Simpson, where the oil seepages were examined and mapped. The party then returned westward, surveyed the eastern shore of Dease Inlet, crossed the inlet and ascended the Meade River to a point 65 miles in an air line from its mouth, or about 150 miles measured along the course of the stream. The third party, in charge of Foran, with FitzGerald, topographer, left Nome July 11 on the *Teddy Bear*, which had been chartered for the field season, and began surveys near Cape Beaufort July 16. The Foran party not only mapped the coast as far north as Wainwright but also ascended the Kukpowruk, Kokolik, and Utukok Rivers for distances of 25 to 40 miles from the coast.

As a result of the work of these three parties about 2,150 square miles of hitherto unsurveyed country was mapped, and information was obtained that throws light on the geologic and physical features of probably 10,000 square miles. As a general narrative of this expedition, together with a report on the scientific and technical results, has already been published,[20] detailed descriptions may be omitted here. The data obtained by this expedition, however, have been freely drawn upon in preparing this report and will be referred to in the appropriate sections.

EXPEDITION OF 1924

WINTER WORK

The exploration of 1923 left unsurveyed a large part of the reserve which was so remote that it could not be advantageously reached from the Arctic Ocean during the short season that that coast is free from ice—perhaps 40 days during the year. To reach this inland part so that the necessary surveys could be carried on was the first problem to be solved by the expedition of 1924.

Consideration of the problem, however, had not proceeded far before it was clear that success would depend on being on the ground ready to work as soon as the snow was off the hills—in other words, getting into the region during the winter. To meet this need Philip S. Smith, with Gerald FitzGerald, topographer, left Washington the middle of January and sailed from Seattle January 19. They reached Seward January 26, and took the Alaska Railroad for Nenana but were delayed on the way by heavy storms that blocked travel for several days. Nenana was reached February 5, and transportation for Tanana, some 125 miles distant, was afforded by the regular horse-drawn mail stages, which are simply open wagons on runners capable of hauling a ton or so of supplies and mail. Roadhouses along the trail at distances of about 20 miles provided shelter and food for the travelers. During most of this stage of the trip very cold weather was experienced, the thermometer standing on many days at 50° below zero.

Tanana was reached February 11, and at once a start was made in assembling the necessary supplies and equipment needed for the six months the expedition would be in the field. Through effective cooperation with the Northern Commercial Co. of Alaska, with which contracts were made to furnish most of the material needed by the expedition, groceries and food supplies were selected and packed to meet trail conditions, special clothing was made by natives living in the neighborhood, and dog teams were procured from points as much as 150 miles distant. Inasmuch as other technical members of the expedition would not arrive from Washington before the later part of February, it was deemed expedient to take advantage of the exceedingly good weather that prevailed to send

[20] Paige, Sidney, Foran, W. T., and Gilluly, James, Reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, 32 pp., 1925.

forward as much of the freight and supplies as possible as early as they could be prepared. Six dog teams, each consisting of a sled with trailer and each drawn by 15 dogs and carrying loads of 1,000 to 1,500 pounds, were dispatched from Tanana under the leadership of George Clark February 17 over the old mail trail that strikes across country from Tanana to Allakaket, on the Koyukuk River, 125 miles distant.

In the meantime J. B. Mertie, jr., geologist, Richard K. Lynt, topographer, and Frank B. Dodge and Harry A. Tait, recorders, who had left Seattle, February 9, had arrived at Seward and were proceeding to Tanana over the route followed earlier by Smith and FitzGerald. This party brought with it all the necessary surveying instruments and technical equipment, together with four Peterborough cedar freight canoes that had been specially built for the party and were nested in a single crate. This party reached Tanana February 26, and the outfit was reassembled so that it could be transported over the poor trails that would be found farther on. Special bobsleds, drawn by 15 dogs, had been constructed for the transportation of the crate of canoes, and three sleds, each drawn by 13 dogs and with a trailer attached, were in readiness to transport the necessary camp equipment and supplies of the combined parties. Additional camp hands, Walter R. Blankenship, John A. Swenson, and Titus Nicolai, had been engaged.

The survey party left Tanana February 27, following the route earlier traversed by the freight outfit, and reached Allakaket March 7. From Allakaket the course lay up the Alatna River, which, from previous explorations by the Geological Survey, was known to head in the mountains that form the divide between it and the streams that flow north into the Colville and ultimately to the Arctic Ocean. Inasmuch as the freighting crews had to make double trips over most of the route up the Alatna and also had to break trail, the members of the scientific section were able to overtake the freighters a short distance south of the Unakserak River, a tributary of the Alatna which enters that stream about 85 miles in an air line northwest of Allakaket. The Unakserak was found to afford a suitable route into the mountains, and consequently a route up this stream to search for a pass was chosen. About 15 miles in an air line above the mouth of the Unakserak is the extreme northern limit of spruce timber, and a base camp was established at that point, so that surveys could be started and the surrounding region explored to find the most suitable pass across the mountains. A gap having an elevation of about 3,700 feet was found 8 miles northwest of this camp. The freighters, having brought their loads to the point called for in their contract, were dismissed and sent back to Tanana. George

Clark was relieved from duty with the freight outfit and attached to the party that would spend the rest of the season in examination of the reserve, and John Swenson and Titus Nicolai were relieved of duty with the scientific party and returned to Tanana with the freighting outfit.

Topographic and geologic surveys were commenced; ties with the earlier surveys near the mouth of the Unakserak were made, and explorations were pushed northward. While this technical work was in progress, freighting of the supplies across the mountains into the Colville drainage basin was actively carried on, and by April 2 all the equipment and supplies of the expedition were across the range and on April Creek, a stream that flows into the Killik River, a tributary of the Colville, which in turn flows into the Arctic Ocean. Firewood was so scarce on April Creek and so small in its headward portion that the expedition was compelled to move down the valley to its junction with the Killik River before a suitable camp site could be found. At this place the stream appeared to be large enough to allow the use of canoes during the open season. Here a headquarters camp was established, and this was the center from which explorations were continued until the spring break-up. While the nontechnical members of the party brought all the supplies to this headquarters camp, the technical members were more or less constantly off on side trips, each lasting a week or 10 days, exploring various parts of the adjacent region. As a result of these winter surveys several thousand square miles of hitherto unmapped and undescribed country was visited.

Early in May the rigors of winter had largely disappeared. Much of the snow on the adjacent hills had melted, and bare patches appeared at many places. Soon afterward birds that had wintered in more southern regions put in their appearance, and flocks of ducks and geese could be heard whirring northward over the camp. Many of the birds that had wintered in the region, such as ptarmigan, began to change to their summer plumage. Patches of slush appeared in low places, and suddenly, May 19, a loud roar announced the breaking of the ice on one of the small streams in the neighborhood. From then on water began to run in several of the channels of the stream near camp, and by May 30 sufficient water was running by the camp to permit abandonment of the winter headquarters and the undertaking of the second stage in the exploration of the region, by the use of canoes. All the paraphernalia that had been essential for travel with dog teams and under winter conditions was discarded.

SUMMER WORK

EASTERN AND CENTRAL PARTIES

In order to increase the area covered by surveys the general plan for the summer work was to split the winter party into two independent units each consisting of a geologist, a topographer, a recorder, and a camp hand. One party was to descend the Killik as rapidly as possible to the Colville and then turn westward, exploring the headwater region, while the other would proceed downstream more slowly, surveying the region in greater detail, and on reaching the Colville turn eastward and explore that part of the Colville Basin. According to this plan Smith, Lynt, Dodge, and Clark formed what is here called the central party and Mertie, FitzGerald, Tait, and Blankenship formed the eastern party. Each party took two canoes. At the start the volume of the Killik was too small to permit free use of the canoes, and it was necessary to drag them many miles over shallow gravel bars, everybody wading in the icy water from ankle to waist deep. In this manner progress in an air-line distance of about 10 miles was made downstream until the large amount of anchor ice rising from the bottom of the stream presented hazards that made immediate progress impossible. Within a day, however, this ice had run by, so that the downstream journey was resumed, and below Easter Creek, the volume of the stream having increased, it was possible to ride in the boats most of the way, to camp M June 9, with only occasional jump-offs to hold the boat in bad riffles.

Progress downstream was not nearly as rapid as had been anticipated, however, for below camp M June 9 a morainic belt stretched across the country, and where it had been cut across by the stream boulders of all sizes and shapes obstructed the river downstream for many miles. Furthermore, many so-called "overflow glaciers" or "aufeis" presented great difficulties to navigation. Many of these overflows formed areas several miles long and a mile wide, through which the stream flowed in numerous small channels which had been cut down through the ice to the gravel. In these channels the stream undermined the ice until blocks 5 to 8 feet thick and 100 feet or so in length toppled off and fell into the stream with a great roar, producing a huge splash and swell that was dangerous to passing small boats, even though they were not directly struck by the falling ice. Both above and below the mouth of the Chandler River the Killik split into numerous small channels, so that in places there was not enough water to float the boats, and they had to be dragged by hand over the shallow stretches.

The central party reached the junction of the Killik and the Colville June 18 and started at once on the upstream journey. The current of the Colville is so swift that no progress could be made rowing, paddling, or sailing, and it was necessary to haul the boats by means of towlines attached to the bow, one man hauling on the towline while the other steered and poled from the rear of the canoe. In this way both boats were worked upstream to a point 20 miles up the Etivluk River. Because of the frequent stops necessary for geologic and topographic observations and wading in the cold water for 8 or 10 hours a day, it was seldom possible to make an average air-line advance of more than 5 miles a day. The country adjacent to the river, however, was so low that the general features of a strip 20 to 50 miles wide could be learned from these observations.

Early in July, having surveyed as much of the central part of the Colville Basin as the available time warranted, the party began the exploration of the Awuna River, a western branch of the Colville, with a view to finding a pass by which to cross from the basin of this stream into the basin of the Meade or the Ikpikpuk. The Awuna River is relatively sluggish, and progress up it could be made largely by paddling and poling the canoes. After a point nearly due south of the lower mapped portion of the Meade River and not more than 50 miles distant from it was reached a route was found by which the boats and supplies could be portaged to a northward-flowing stream. In making this portage a small stream was first followed for a few miles until it became so small that it was necessary for the members of the party to pack on their backs all the expedition's supplies and carry them bodily across the divide. A portage of 8 or 10 miles over a pass 1,400 feet above sea level was made, and on July 29 the entire outfit, boats and equipment, was on a northward-flowing creek, which at that time was believed to flow into the Meade River. This stream near its head was so small that in many places it was considerably narrower than the boats, and only by tilting them on their sides and then by sheer main force shoving them along could they be moved ahead. After proceeding in this way a few miles the volume of the stream increased, so that the men could ride in the boats and carry all the supplies in one load.

The condition of river travel improved greatly with each day's descent, but the party had the disappointment of finding that instead of continuing its northerly and westerly course the stream, after 10 or 15 miles, swung sharply to the east and continued in that direction, indicating that it was not tributary to the Meade River but to the Ikpikpuk. On August 5 a fair-sized tributary from the east, later named Maybe Creek, was reached, and men's footprints on the near-by bar and monuments and signals on the near-by hills unmistakably indicated that the eastern party had descended that branch and was farther down the Ikpikpuk. The central party then hurried ahead and on August 8 came up with the eastern party in camp on the Ikpikpuk at the mouth of the Price River.

During the time that the central party had been following the route described in the preceding paragraphs the eastern party, according to the plan originally outlined, had descended the Killik and experienced many of the same difficulties until they arrived at the Chandler River June 18. Here the party halted in the downstream journey in order that a side trip up this stream could be made. The Chandler River was swift and shallow so that after lining a canoe upstream for about two days, in which an air-line distance of only 7½ miles had been made, the party decided that progress by that method was too slow. Consequently superfluous supplies were cached and the journey was continued on foot, each member packing the necessary supplies and equipment on his back. In this manner the party reached the northern front of the mountains and ascended one of the hills, from which the general features of the region could be mapped. Unfortunately, during most of this trip the weather was stormy, and distant points were obscured by clouds and rain. On completion of this work the party returned rapidly to the mouth of the Chandler River, and on July 1 they resumed the journey down the Killik River and the next day reached the Colville.

The Colville was in a good stage of water, and after working downstream an air-line distance of about 30 miles Mertie and FitzGerald made several long cross-country trips northward to search for a practicable route to some stream tributary to the Ikpikpuk. A route was finally found by way of the tributary of the Colville from the north that enters that stream near camp M July 11 and was later named Prince Creek. Progress up the lower 15 to 20 miles of this stream presented few difficulties, but farther up the stream became small and extremely tortuous, so that progress was slow. Finally at camp M July 18 further ascent of Prince Creek was abandoned and a portage of about 5½ miles (air line) was made to a point on the tributary of the Ikpikpuk at camp M July 26. On this portage all the supplies and equipment had to be carried by the members of the party, and several round trips had to be made, so that it was July 29 before the portage was completed.

Under normal conditions the stream at camp M July 26 is probably too small to allow the use of canoes, but fortunately there had been a period of heavy rains while the portage was in progress, so that the party was able on leaving the camp to travel in the canoes with their full load. The stream, which they named Maybe Creek, continued to improve as the party descended, and after a day and a half the Kigalik River, a large tributary from the west, swelled the volume, so that further progress down the Ikpikpuk to camp M August 7 was interrupted only by the delays incident to surveying.

The combined party set out August 9, working as a unit to complete the survey of the Ikpikpuk. However, August 11 they reached a point where the Ikpikpuk splits, and it seemed desirable for Smith and Dodge to traverse the eastern channel while the rest of the party went down the western channel. The western groups reached the mouth of the river August 15 and tied in with the monuments left the preceding year by the Geological Survey parties that had mapped the coastal portion of the region. They then crossed Dease Inlet and skirted the coast to the cape about 10 miles west of Christy Point. At this point a launch sent out from Barrow to hunt for any of the crew that might have landed from the *Lady Kindersley*, which was in the ice off the coast, hove in sight, and arrangements were made with the captain for transportation to Pergniak, the so-called Hunting Beach on Elson Lagoon, about 5 miles north of Barrow. On arrival at this point the ocean ice was found to be jammed so tight against the beach that further progress with the boats was impossible. The Geological Survey members therefore walked overland to the trading station at Barrow, which they reached late August 21.

The party that followed down the eastern channel of the Ikpikpuk made only a time and compass survey of that route and August 13 came to the shores of Smith Bay, a few hours earlier having passed a small community of Eskimos, the first people that had been seen since leaving the Unakserak in March. From the coast the party proceeded by canoe along the shore, hastily visiting the oil claims in the vicinity of Cape Simpson and, until storm bound, skirting the sand reefs and islands that lie some distance off the coast. They then followed the southern shore of Elson Lagoon until they also arrived at Pergniak, where they cached much of their equipment and walked to Barrow, arriving late in the afternoon of August 22.

At Barrow it was learned that the *Arctic*, the ship on which the expedition had planned to return to Nome, had been crushed and sunk by the ice early in August; furthermore, that the trading vessel *Lady Kindersley* had been caught in the ice and was in distress off Point Barrow. The Coast Guard vessel *Bear*, which ordinarily visits Barrow during the open season, had been badly damaged by the ice, so that it had been forced to turn south for repairs. Fortunately, however, a vessel of the Bureau of Education, the *Boxer*, was lying under the lee of Point Barrow and would transport the party to Nome as soon as the rescue of the *Lady Kindersley* crew had been effected. Late in August the northerly wind, which had been jamming the ice against the coast for several weeks, abated and finally swung to the south, so that the ice began to loosen and move away from the coast and long leads of open water began to appear. Following one of these leads, the *Boxer* put out from Point Barrow and got within 5 miles of the ill-fated *Lady Kindersley* and picked up her crew, who had traveled the intervening distance over the ice dragging canoes. The *Boxer* then immediately worked out of the ice and arrived in Barrow August 31. The shipwrecked crew of the *Arctic* and the members of the Geological Survey party were then taken aboard, and the *Boxer* steamed southward the evening of September 1, stopping a short time at Wainwright September 2 and at Point Hope September 3, and reaching Nome early September 5.

On arrival at Nome the party learned that no boat would sail for Seattle until October, so in order to avoid that long wait all the members except Mertie and the two camp men went to St. Michael on the *Donaldson*, thence up the Yukon and Tanana Rivers on the *Dr. Martin*, *Governor Davis*, and *Governor Jacobs* to Nenana, thence on the Alaska Railroad to Seward, and sailed on the *Northwestern* for Seattle, which they reached October 13.

WESTERN PARTY

According to arrangements made early in 1924 before the winter parties left for the field, additional work was planned in the western part of the reserve during the summer season. For this purpose a party was to go by sea to Wainwright with instructions to make a traverse southward from that place to some point on the Noatak River. William T. Foran was assigned to this work as the geologist and chief of party, with O. L. Wix as topographer. In order to become familiar with the inland route through Alaska Foran went to Nome by way of Seward, the Alaska Railroad, and St. Michael as soon as the ice on the rivers had broken. He arrived at Nome June 16, where he joined the other members of the party, who had sailed direct from Seattle to Nome, leaving June 1 and arriving June 13. The ice conditions in Bering Sea and the Arctic Ocean were reported to be particularly bad, and it was not until July 19 that the party, consisting of Foran, geologist; Wix, topographer; H. Lonseth, rodman; H. G. Hughes, boatman; and F. W. Belgard, cook, got away from Nome on the small gasoline launch *Amy*, which had been chartered to go to Wainwright. Gales and heavy ice caused many delays. Near Point Lay a heavy piece of ice jammed between the propeller and rudder, stripped the gear, broke a propeller blade, and bent the crank shaft. Near Icy Cape the two technical members and the rodman left the *Amy* in a skiff, with a small supply of food, instruments, and equipment, and reached Wainwright Inlet July 30 and were joined a few hours later by the *Amy* with the other members of the party.

Topographic work was commenced at once and was tied to the surveys made in 1923 on Wainwright Inlet and at the mouth of the Kuk River. While the rest of the party was engaged in preparing canoes and equipment for the trip southward, the topographic survey was continued northeastward along the coast to Franklin Point and the entrance to Peard Bay. This coastal work was completed August 4, and the next day the party, to which two Eskimos had been added, started up the Kuk River. Several days were spent in exploring the different tributaries, and finally the Kaolak was selected as affording the best route and was ascended to its head. A portage of 6 miles was made to the Utukok, and August 17 all hands and equipment were on that stream. Geologic and topographic work was carried southward, until at the forks of the Utukok, which was reached August 22, the stream became too small to allow further canoe transportation. A considerable part of the supplies and equipment, together with one canoe, was therefore cached at this place and the remaining outfit was packed up the stream, which the party called Disappointment Creek, and across the low divide to the next stream to the south, which proved to be the Colville.

It was a severe disappointment to learn on reaching this river August 30 that its course was eastward and not southward, as another portage must be made to get into a stream flowing southward into the Noatak. The party continued southward up Meridian Creek, reaching the small lake at its head September 3. Here several days were spent in exploring the adjacent region and in bringing back from the cache near the forks of the Utukok some of the food that had been left behind. On September 8 the camp on the lake was abandoned and the portage across the divide between it and the Nimiuktuk was undertaken. The party with outfit reached the headward portions of the Nimiuktuk September 12. Their difficulties were not over, however, because owing to the lateness of the season the water was very low and for most of the way was frozen, so that even while going downstream it was necessary to back-pack the boat and supplies. Finally, on September 16, about 6 miles above the junction of the Nimiuktuk and the Noatak, boating water was reached. The members had been on a meager allowance of food for several days, but on reaching water in which they could again use their canoe and the outboard motor, which they had carried during all their portages, they felt that the end of the trip was in sight, and in three days of downstream travel from the mouth of the Nimiuktuk they reached the Noatak Mission, where they could obtain some supplies.

The village of Noatak was left September 20, and Kotzebue was reached September 21. Storms and the ice conditions necessitated remaining at this village until October 1, when the seagoing tug

Kobuk was chartered to take the party to Nome. After encountering heavy ice in Kotzebue Sound, the tug reached Nome October 3, and on October 15 the party obtained transportation on the steamship *Victoria*, which arrived at Seattle October 24.

This trip, which involved a traverse of 170 miles (air line) between Wainwright and the junction of the Nimiuktuk with the Noatak, necessitated an almost continuous portage of about 60 miles, in which three divides were crossed, one of them about 4,000 feet above sea level, in the short time between August 5 and September 16, and was an achievement that could have been carried through only by the indefatigable efforts of every member of the party and by the resourcefulness and indomitable pluck and generalship of Foran, the leader.

EXPEDITION OF 1925

Geologic investigations in Naval Petroleum Reserve No. 4 were continued in 1925 by a party in charge of Gerald FitzGerald, topographic engineer, with Walter R. Smith, geologist. This party left Washington February 20 and Seattle February 28, and arrived at Nenana on the Alaska Railroad March 10. At this place W. R. Blankenship and Fay Delezene, who were to assist in camp duties, joined the party with two dog teams and the necessary equipment for the trail. The party left Nenana March 13 and made the trip along the Nenana-Nome mail trail to the head of Norton Bay and thence to Kotzebue, a distance of about 725 miles, which was covered at an average rate of more than 27 miles a day. At Kotzebue necessary supplies and equipment were obtained, as the party would be unable to purchase additional supplies until they returned to the coast in the fall. Several natives and their dog teams were hired to help in freighting some of these supplies into the mountains that form the southern boundary of the reserve, from which the new work of the season was to start.

Leaving Kotzebue April 15, the route led northward up the Noatak River to the Kugururok, a tributary from the north that enters near longitude 162° W., and the new surveys of the expedition were commenced. Topographic surveys were started from landmarks near the canyon of the Noatak that had been located by C. E. Giffin in 1911, and geologic observations were made so as to tie the new work to that done by Philip S. Smith in 1911.

The party pushed up the Kugururok until the later part of April, when a pass across the mountains was found that led to the drainage basin of the Utukok, a stream on the north side of the mountains, which empties into the Arctic Ocean near Icy Cape. From then on every effort was made to move the camp supplies forward so that they would be in the Colville drainage basin before the ice broke in the spring and at the same time to survey as large a tract of adjacent territory as possible. Both objects were successfully accomplished. A low pass from the Utukok to the Colville was found, and all supplies were placed far enough down the Colville so that canoes could be used when that stream became free of ice. One of the canoes used by the party had been hauled in from Kotzebue with the other supplies. The second canoe was one that the Geological Survey party under Foran had cached on the Utukok the previous year, when they encountered unexpectedly difficult and long portages.

The ice on the Colville broke so that a canoe was used May 30, the same date that the Killik River, the tributary of the Colville on which the expedition of 1924 made its winter headquarters, had broken the year before. With the opening of the river dog-team work ceased, and the party worked downstream, making numerous back-packing trips into the country 20 miles or more from the river and thus widely extending the area covered by the surveys. On these side trips the headwaters of the Kaksu River and more of the basin of the Awuna River, whose lower part was ascended by the central party of the 1924 expedition, were mapped. In this way the party descended the Colville to the Etivluk River, a tributary from the south near longitude 156°, whose lower course was traversed by the Geological Survey party in 1924. At this point, which was reached July 12, junction was made with the surveys of 1924, which had covered most of the eastern part of the basin of the Colville as far east as its tributary the Anaktuvuk. The party under FitzGerald therefore turned southward, ascending the Etivluk and mapping the country on both sides of the stream. During this upstream journey the dogs were used with good effect for hauling on the towlines of the boats. By the time the party had reached the camp of July 25 the stream had become so small that each day it seemed likely that only a little more progress could be made with the boats. The rainy weather, however, kept the stream at a good stage of water, and by the occasional use of a shovel to widen out narrow points in the channel the boats were successfully worked upstream. For several miles above camp G July 27 the stream was little more than a gully cut through the turf, just wide enough for the canoes to pass through and with very little current. About 3 miles above camp G July 28 it was found to issue from a lake about 1½ miles in diameter. This lake proved to be situated almost precisely on the divide between the Colville and the Noatak, and a portage of about 1,000 yards from its south end brought the party to a stream tributary to the Aniuk River, which flows into the Noatak a little west of longitude

158°. The Aniuk was followed down without much difficulty until on August 10 its mouth was reached, and the surveys were tied with those made in 1911 by Smith and Giffin.

The party quickly dropped down the Noatak, making practically no stop except for camp at night, and arrived at Kotzebue August 22. Here connection was made with the *Boxer*, and through the courtesy of the Bureau of Education the party was taken to Nome, where, after less than a day's delay, they obtained passage on the *Victoria*, of the Alaska Steamship Co., for Seattle.

As a result of these explorations about 6,500 square miles of hitherto unknown country was mapped with the accuracy required by reconnaissance exploratory standards. A much larger area was observed, so that its general aspects are known at least sufficiently well to be of considerable assistance in planning further work in the region and in interpreting the results already obtained. Although in general the work is regarded as of an exploratory standard, most of it was really done in much greater detail. Practically all the topographic work was executed by plane-table and micrometer-traverse methods on a field scale of 1:180,000, though the data are incorporated in the map that forms Plate 1 of this report, on a scale of 1:500,000. At frequent intervals during the work observations for latitude and azimuth were made with a transit. When computed these observations coincided very closely with the positions determined by the other methods. The position of the mouth of the Aniuk as determined by this party checked so closely with its position as determined by Giffin that probably few intermediate points are more than a mile out of position east or west and probably not as much as a mile out north or south. During the winter the novel expedient was adopted of making the micrometer bases of snow and placing a piece of colored cloth on the mound facing toward the point from which the back sight on the base was to be made. This expedient was necessary in order to provide signals in a region where timber is entirely absent and where, except in the valley bottoms near the streams, even good-sized bushes are extremely scarce. A number of the low station marks made of brush and used as micrometer bases by the party that surveyed the Noatak in 1911 were still standing. Elevations were determined throughout the area surveyed, and the relief was sketched with 200-foot contours.

The geologic observations permitted the mapping of the formations encountered in the area topographically surveyed and disclosed the continuation of many of the formations already recognized elsewhere by the preceding parties. Several new interpretations of certain geologic phenomena were made which added materially to the knowledge of the geologic history of the region. These are discussed in more detail in the appropriate portions of the report, but here it may be mentioned that one of the most significant points noted by the geologist was the fact that the rocks of Lower Cretaceous age had been affected by a greater degree of mountain building than the younger rocks. No new definite signs of oil were observed, but even this negative evidence, together with the more complete determination of the character of the Mesozoic rocks made by this expedition, is of material value in determining the possible oil resources of the region.

EXPEDITION OF 1926

Although much of the area of the reserve had been explored by the survey expeditions of 1923, 1924, and 1925, there were still large unvisited tracts which might shed important light on the main problem. Therefore, early in 1926 another party in charge of Philip S. Smith, geologist, and Gerald FitzGerald, topographer, was dispatched to survey an area lying between the Point Hope and Cape Lisburne regions and the Noatak and extending along the western margin of the reserve, together with such supplementary surveys into hitherto unmapped areas adjacent to large streams as time permitted. The party sailed from Seattle February 13 for Seward, whence the geologist and topographer traveled over the Alaska Railroad to Nenana, which was reached February 23. Here two teams of 10 dogs each were purchased, and Fred Clark was attached to the party as camp hand. With a light equipment the expedition left Nenana February 27 to follow the Nome-Nenana mail trail to the head of Norton Sound and thence to branch off for Kotzebue on the mail trail that cuts across the eastern neck of Seward Peninsula and then skirts the coast. At the head of Norton Sound the party was joined by W. R. Blankenship, who served during the rest of the field work as cook and camp hand. The run from Nenana to Kotzebue, a distance of about 725 miles, was made in 27 days, on three of which the party could not travel because of storms, at the rate of about 30 miles a day of actual travel. Throughout most of the trip the weather was excellent and trail conditions good. Road houses at which board and lodging could be obtained are situated about every 25 miles, so that in this part of the journey it was not necessary to camp out or carry many supplies except bedding and a little food for the dogs.

At Kotzebue, which was reached March 25, food and equipment sufficient to supply the party for about five months were bought, and two Peterborough canoes that had been sold at auction by the Geological Survey parties in 1925 were repurchased. After all these articles had been sorted and put into shape for trail conditions, a number of natives were hired to assist in freighting the supplies to Kivalina, a small settlement on the coast about 90 miles northwest of Kotzebue. Smith and the freighters left Kotzebue March 30, and the rest of the party left the next day, following the Barrow-Kotzebue mail trail and the general route used for travel along the coast. On arrival at Kivalina arrangements were made for striking off across country with the object of placing the bulk of the equipment across the mountains, so that, when the ice on the streams broke in the summer, the canoes could be used for the further explorations. In accordance with this plan the freighters, together with Blankenship and Clark and an Eskimo guide, Chester Sevic, who had herded reindeer in that region, left Kivalina April 3. The geologist and topographer remained at Kivalina to make the necessary observations for commencing the new surveys and then started northward along the route broken by the freighters. On April 12, when they were some distance up the Kivalina River, the freighters with Clark returned, having placed the supplies on the Kokolik River and left Blankenship to safeguard them. After the freighters had been discharged the work of surveying the country adjacent to the route was continued as rapidly as possible, but there were numerous delays owing to howling storms and biting winds, so that it was May 10 before the surveys were brought up to the cache which had been established on the Kokolik River. By that time travel was beginning to be difficult because of the melting snow and the softening of the ice, but FitzGerald with Clark moved farther up the Kokolik to map more of its headwaters, while Smith and Blankenship established a new camp (P May 15) farther down the river, at a point where it was believed better conditions for the use of the canoes would be found. This was the place where the break-up was awaited and where the use of dog teams and sleds was discontinued. During many of the succeeding days the weather was bad and little could be accomplished in surveying the surrounding country.

On May 23 FitzGerald and Clark returned and reported that for almost 10 days it had been impossible to see anything because of the clouds and storms in the mountains, and as many of the streams were beginning to carry a large volume of water they had been forced to give up the attempt to map more of the mountains that form the Noatak-Kokolik watershed.

During the severe gales that had accompanied the stormy weather one of the canoes had been badly damaged, so that the next few days were spent in repairing it and making ready to leave this camp for the downstream journey as soon as conditions were favorable. By May 29 the river at the camp was practically free of ice, but a short distance downstream, where the valley walls narrow so as to form a mild canyon, the ice still held and there was little or no surface water. At last, on June 5, after waiting impatiently for several days, the start downstream in boats was made. The break-up was not marked by a wild period of running ice in the river; instead, the ice rotted out by water flowing over it or was undercut by water flowing under it until it collapsed and was carried away. Many of the huge snowdrifts along the walls of the gorge, where thus undercut, fell with stupendous splashes into the river and were a source of danger to the boats. This was especially notable at camp P June 15, where great blocks of drifted snow and ice, many of them 20 to 50 feet high and 100 yards long, fell at frequent intervals with roars that could be heard for long distances.

The current of the river was swift, but there were few rapids or obstructions to navigation, so that the journey could have been made in a few days if it had not been necessary to stop frequently to make geologic observations or to establish topographic stations. As it was, the junction with the surveys of the lower part of the Kokolik made in 1923 by FitzGerald and Foran was effected June 17, and the closure was found to be excellent. Before leaving Washington it was believed that it might be advantageous to portage from this point to the Utukok, and thence to the Kaolak, as the coastal area north of the mouth of the Kokolik as far as Wainwright had already been surveyed in 1923. In the field, however, this plan seemed a less desirable way of reaching the unsurveyed country west of the Kaolak than continuing down the Kokolik, and then proceeding by the Arctic Ocean and the lagoons to Wainwright. The latter plan gave a down-grade and sea-level route which avoided all portages, would allow the making of larger collections of rocks, would not force the party to discard valuable supplies and outfit to lighten the loads, and if conditions were favorable would probably take less time.

The party reached Point Lay on the coast June 20, and found that the ocean was still ice bound, with no open water in sight. Fortunately there was a good deal of open water in the lagoon back of the reef; and, although much of the anchor ice in the lagoon still held, there was enough water covering it to allow the boats to proceed. Many parts of the lagoon, however, were so shallow that there was not enough water to float even the shallow-draft canoes, and further progress could be made only by all hands wading and hauling on the boats. In fact, in several places no progress could be made even where all four men hauled on one boat at the same time, and in such places it was necessary to unload most of the articles from one boat into the other, drag the lightened boat ahead a hundred yards or so, and transfer the load from the rear to the forward boat by back packing, and then repeat the process. These shallow places occurred very irregularly, so that many times the boats were aground a mile or more from either shore.

The north end of the long series of lagoons on the west coast is near Kilimantavi, which was reached June 28. Here further progress was blocked by the ice pack of the ocean, which was jammed up against the shore, leaving no open water in sight. The ice was much broken, however, and as it would probably go out quickly as soon as the wind was favorable, camp was established, and another period of waiting ensued. After a few days a strong east wind opened up some leads through the ice near shore, but it made the sea too rough for travel in the canoes. Finally, on July 5, it became possible to push ahead, and by wriggling through narrow leads and occasionally shoving aside an obstructing cake of ice the party reached Wainwright inlet but found progress up that body of water blocked by ice.

While waiting for the ice in the inlet to open up the first ship of the season arrived July 7 with mail and newspapers from the States as recent as May 26. This was an exceptionally early arrival. On July 8 the party started up Wainwright Inlet to survey the Avalik River and adjacent region. The season, however, had been unusually dry and all the streams appeared to be in exceedingly low stages, so that a short distance beyond the mouth of the Kaolak riffles and bars at short intervals made progress by rowing impracticable. Above this point advance could be made only by tracking the boats or wading alongside and lifting and hauling on them. In this way and often making an air-line distance of only 3 or 4 miles a day, a point was reached where even this method became impracticable, as the bottoms had been almost dragged out of the boats and the wood worn to paper thinness by the constant scour on the bars, so that camp P July 18 was established. From that camp FitzGerald made traverses on foot into the adjacent country and determined its general features. Return to Wainwright was made as rapidly as conditions permitted, and the mouth of the inlet was reached July 27. During the absence of the party the sea ice had driven in again, so that other ships had not arrived, and it was not until July 31 that the Coast Guard ship *Bear* was able to break through the pack and reach Wainwright. On August 4 the ice, which had been firmly jammed along the beach, began to open up, and the next day the Geological Survey party started northward along the coast for Peard Bay. Much of the way the lead of open water was only 100 feet wide, but eventually the narrow entrance through the sand spit east of Atanik was reached, and surveys of Peard Bay and of the Kukroak River, which enters it, were started and carried as far upstream as was feasible considering the low stage of the river.

On return to the coast, as it was nearly time for the arrival of the boat on which return to Nome was to be made, Smith and Blankenship returned to Wainwright, while FitzGerald and Clark turned north to connect the topographic surveys with those made in earlier years in the vicinity of Barrow. The Smith party reached Wainwright August 12 and went aboard the *Boxer* for Barrow August 15. On arrival at Barrow it was found that FitzGerald and party had not yet arrived, and it was later learned that they were storm bound on the coast about 35 miles south of Barrow and ultimately had to return to Wainwright. Smith and Blankenship sailed south on the *Boxer*, until at Point Hope it was learned by wireless that the trading schooner *C. D. Brower* was a short distance behind and was headed directly for Nome, with the FitzGerald party, which had been picked up at Wainwright, aboard. Transfer of Smith to the *Brower* was therefore effected, and on August 25 the party landed at Nome. On September 2 they left on the *Victoria*, of the Alaska Steamship Co., for Seattle.

As a result of this trip about 5,000 square miles of hitherto unsurveyed country was mapped topographically and geologically. The topographic surveys were executed in the field on a scale of 1:180,000 with 200-foot contours by the usual methods of plane-table and micrometer traverse. Although the scale used was what is generally considered standard for reconnaissance surveys, the need of obtaining and recording as much information regarding the parts of the area remote from the general route of travel warranted sketching distant features with only the degree of refinement appropriate for exploratory surveys. This procedure appeared especially justified because the scale of publication was to be 1:500,000, which is much smaller than the standard for reconnaissance surveys. The topographic surveys were checked as to position at intervals by latitude and azimuth determinations made with an 8-inch transit. The latitude of the point at Kivalina, from which the survey was started, was determined by transit and checked by records of the captains of several vessels and from the form of the coast as shown on the published maps of the Coast and Geodetic Survey. This survey was further checked by ties with the surveys made in 1925 of points in the Utukok Basin and with those made in 1923 of the lower part of the Kokolik.

The surveys of the Avalik River were begun at the junction of the Kaolak and the Avalik, whose position had been determined in 1924 by Wix with reference to Wainwright and to the Utukok River at camp F August 16. The surveys in 1926 in the vicinity of Peard Bay were tied to the surveys that had been extended from Wainwright to Atanik in 1924 by Wix. In all places the checks proved that the surveys had been made with a high degree of accuracy, so that the resulting map everywhere maintained the standards required.

The geologic surveys were commenced at Kivalina; and fortunately throughout most of the region and in almost all the formations fossils were fairly abundant, so that the stratigraphy as indicated by areal and structural relations could be checked by them at intervals. The geologic work was tied with the observations made by P. S. Smith in 1911 and W. R. Smith in 1925 on the Noatak, by W. R. Smith in 1925 on the Utukok, by Foran in 1923 and 1924 on the Kokolik, Kuk, and Kaolak, and by Paige and others in 1923 in the vicinity of Peard Bay. Several hundred photographs of geologic and physiographic features were taken, and about a hundred specimens of rocks were collected, many of which were from fossil localities ranging in age from Paleozoic to Pleistocene.

Because of the relative simplicity of structure of the rocks over much of the northern part of the region, as well as the relation of the area surveyed in 1926 to the areas that had been surveyed before, it is possible to predict the extension of certain types of rocks far beyond the areas examined at close range and even into areas so remote that only their most general character could be seen. Therefore, although on the accompanying map (pl. 2) several large areas of unexplored country have been left without geologic coloring, there is ground for believing that the general character of the surface rocks can be surmised with a good deal of certainty, especially in most of the area lying north of latitude 69°.

RELIEF AND DRAINAGE

GENERAL FEATURES

Northwestern Alaska, when analyzed as to its topographic appearance, may be divided into four main parts, which from south to north are (1) a plateau region south of the Kobuk; (2) a mountainous highland about 150 miles wide that extends from the country north of the Kobuk to a line from 10 to 70 miles south of that part of the course of the Colville which trends about east; (3) a plateau region that extends northward from that line to a line within 10 to 50 miles of the Arctic coast, where it is succeeded by (4) a gently sloping plain that extends to the coast. In general these different units trend approximately east and west, so that their respective boundaries may be considered as roughly coincident with the parallels of 67, 69, and 70 degrees. The areal extent of these subdivisions is shown graphically by Figure 2. (See also pl. 1.) On the whole, each of the topographic provinces conforms in distribution with the larger areas occupied by rocks of relatively the same geologic age and character. Thus the southern plateau province is underlain largely by rocks of Mesozoic age that as a whole offer only moderate resistance to erosion. The mountain belt is composed dominantly of Paleozoic rocks that as a whole are highly indurated and strongly resistant to erosion. The plateau province north of the mountains, like that to the south, is composed dominantly of Mesozoic rocks that are less deformed and less resistant than those of the mountains. The surface of the coastal plain is composed principally of unconsolidated deposits that have been

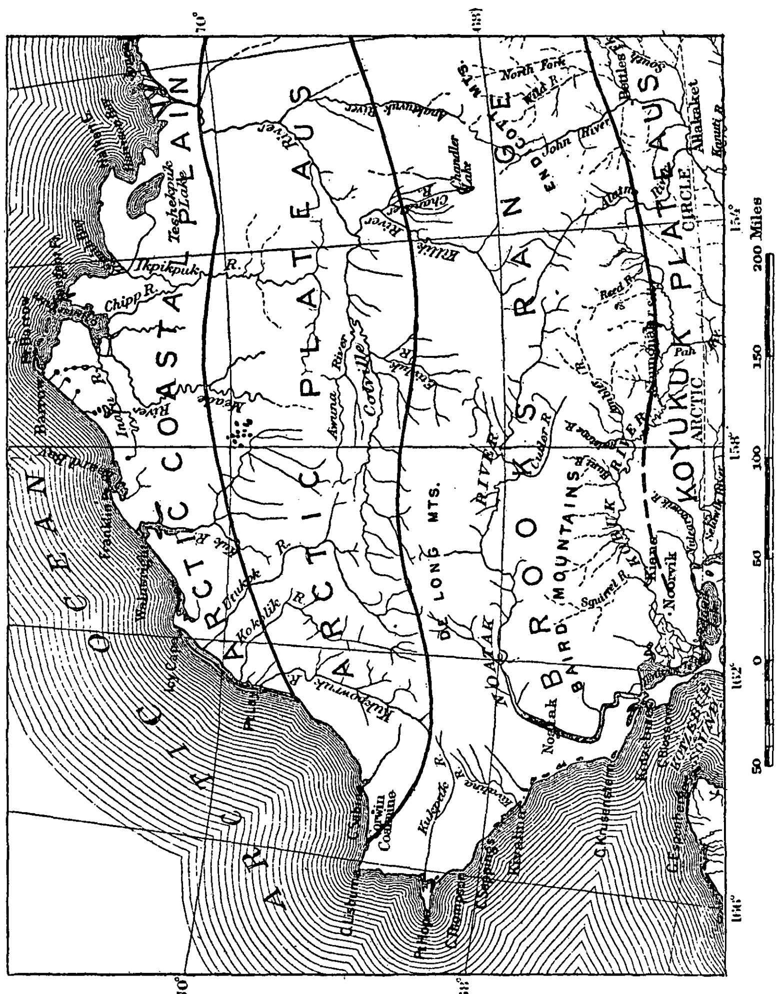


FIGURE 2.—Sketch map showing geographic provinces of northwestern Alaska

laid down mainly under marine conditions and subjected for a shorter time than any of the others to the destructive action of erosion.

Different names have been used at different times for some of these belts, but in this report the southern plateau is called the Koyukuk Plateaus, from the large river that drains much of the eastern part of that province, which falls within the area described in this report. This is the name that was given by Schrader to part of this feature in this area when he first described it in 1901, though unquestionably it is part of the major Alaskan province called by Brooks the central plateau region. The mountain province is called the Brooks Range, as that name has been adopted by the United States Geographic Board for the entire mountain belt that stretches eastward from Kotzebue Sound to the international boundary. Part of the northern plateau was first recognized by Schrader in his exploration of 1901 and when seen in the vicinity of the Anaktuvuk River was called by him the Anaktuvuk Plateau. The plateau feature, however, generally recognized through the belt defined above, has a wide extent and appears to be made up of a number of plateaus standing at different elevations, so that a less local or restricted name seems more desirable for the larger feature, and in this report the province will be called the Arctic Plateaus, local names like Anaktuvuk being reserved for the individual members of this province. The coastal-plain province has long been called by this name, with or without the qualifying word Arctic, and that practice will be followed in this report.

All these provinces except the Koyukuk Plateaus are terminated on the west by the Arctic Ocean, so that the shore line of the region differs markedly in different parts. For this reason it is more convenient to treat the features of the west coast as parts of the respective provinces that lie inland from them, rather than attempt to group all the coastal features together in a single section. Grouped in this way their distinctive characters may be emphasized without obscuring the controlling factors that cause their differences and similarities.

KOYUKUK PLATEAUS

The only part of the Koyukuk Plateaus represented in the area described in this report lies south of the Kobuk River and is recognized as extending up the Alatna River nearly as far as Helpmejack Creek and up the John River to a point above Timber Creek. This province in the vicinity of the John River was described by Schrader[21] as follows:

> It consists mainly of a rolling hilly country of known and supposed Mesozoic rocks whose hills rise to elevations of from 1,000 to 3,000 feet, while the main valley floors lie at approximately 600 feet. The general accordance in height of the hills and ridges of this province strongly suggests that the present topography has been carved from two former plateau features. Though for need of further investigation this question can not be discussed in detail in this place, it may be noted that of these two features the lower level is relatively distinct and well marked and represents the general elevation of the land

[21] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 44, 1904.

mass over the larger part of this feature. * * * For it the name Koyukuk Plateau is suggested. The higher level, which also suggests a former plateau now dissected and largely removed by erosion, lies at about 3,000 feet, but it is indefinite. Its best expression occurs along the base of the mountain, where portions of nearly flat-topped ridges rising gently northward soon merge into the foothills of the mountains, while to the south they become lost in irregular ridges and hills descending to the lower or Koyukuk Plateau.

It will be noted from the foregoing quotation that Schrader proposed the name Koyukuk Plateau for the lower plateau, but this use has not been generally followed, and, in fact, he himself described both these plateaus under the general term "Koyukuk province." Consequently the broader term Koyukuk Plateaus is used in this report. It should also be noted that very little of the area described in this report as lying within this province stands as low as 1,200 feet—the elevation of Schrader's lowest plateau—so that if that feature is represented in this area it probably coincides with the terraces or benches along the lower courses of some of the larger streams, such as the Koyukuk and Alatna Rivers.

The Lockwood Hills, south of the Kobuk, which form part of this plateau, were seen in some detail by Smith [22] and Eakin in 1910, and they report that the highest points measured were slightly less than 3,000 feet and that in places stretches of the summit extended along the trend of this range for several miles with differences of elevation of less than 200 feet.

Mendenhall, who traversed the Alatna River and Helpmejack Creek in 1901, makes no specific reference to the plateau feature in that region but notes that the mountains to the south are "conspicuously smoother and lower than those to the north." Smith, however, as a result of his traverse of the basin of the Alatna in 1911, distinguished two distinct topographic provinces, the southern one corresponding to what is called here the Koyukuk Plateaus. He described this part as follows: [23]

In the southern province the valley floor is a wide gravel-filled lowland in which the stream is incised but slightly and flows in sinuous meanders that try the patience of the traveler upstream. From this widely open, partly filled valley floor gentle slopes lead to the surrounding upland, which in few places rises more than 2,000 feet above the river. In this part of its course, although the stream is too swift to allow rapid progress to be made against it by rowing, its gradient is less than 5 feet to the mile. Here and there rocks outcrop on the two sides of the river, but the ledges form no obstruction to boats. Shallow-draft river steamboats have ascended this river as far as Helpmejack Creek but only during periods of exceptionally high water.

[22] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 23–24, 1913.

[23] Idem, p. 33.

As already noted, all of the country within the Koyukuk Plateaus province described in this report is underlain by Mesozoic rocks, mainly sandstone and shale, which, so far as known, are of Upper Cretaceous age. These rocks weather somewhat rapidly, but the more massive sandstone beds form steep slopes as contrasted with the gentle slopes that are produced where the bedrock is shale. The topography that the rocks produce, however, is everywhere relatively subdued, and nowhere are the slopes too steep to be readily climbed or to hold vegetation. Although spoken of as a plateau, relatively small amounts of the upland remain undissected, and thus the plateau character is more evident when looked at from a distance than when seen at close range. Even near at hand, however, the uplands are relatively flat and afford the best routes of travel during the summer, as they are in general fairly well drained and formed of disintegrated rock fragments, and the differences in elevation between the peaks and the sags on the ridges are usually only a few hundred feet.

The plateaus have participated in some of the later earth movements that have affected the mountain region to the north, and on the whole the larger streams that have been in existence a relatively long time, such as the Alatna and the John, flow outward from the mountains and traverse a greater or less extent of the plateaus before joining the main stream, which in this region is the Koyukuk. Farther west the Kobuk flows more or less closely along the junction of the mountain and plateau provinces and diverts all the streams heading in the mountains to the north of it, so that they do not traverse the plateau province to the south. In the early geologic history of this region this condition probably did not prevail, and certain low gaps across the Lockwood and other hills south of the Kobuk seem to mark places where streams that headed in the mountains once flowed southward across part of the plateaus.

Although the Kobuk drains a large area in the Brooks Range and only a relatively small area in the Koyukuk Plateaus, the main stream may perhaps be best described here, as it practically forms the line of separation between the two provinces. In an air line the distance is about 225 miles from its head, in the divide between it and Helpmejack Creek, to its mouth, but the river is so crooked that its length is several times that distance. It is navigable by launches and shallow-draft boats as far as Shungnak, and Mendenhall was able to use canoes without difficulty all the way to the mouth from a point only 3 miles west of the divide. One of the most noteworthy features of the Kobuk is the delta it has built out into Hotham Inlet, which is practically the only extensive delta on the whole west coast of Alaska north of the Yukon. The delta is about 35 miles long and 20 to 30 miles wide. In this area the stream splits into innumerable sloughs and channels, so that there are said to be as many as 13 separate mouths to the river, but probably only two or three are suitable for even small-boat navigation. The current of the river in its central and headward parts is so strong that progress against it can not be effectively made by rowing, and recourse must be had to poling or tracking.

The Koyukuk is the largest stream in the part of the Koyukuk Plateaus lying within the area described in this report. It is navigable by stern-wheel river steamers drawing about 2 feet of water at practically any stage as far as Allakaket and during periods of good water conditions as far as Bettles. Beyond Bettles shallow-draft scows carrying about 10 to 12 tons and towed by horses or poling boats carrying about 1 ton are used to freight supplies upstream to Coldfoot, on the Middle Fork, about 60 miles northeast of Bettles and some distance east of the area described in this report. No regular line of passenger boats is now operated on this river; the only steamboat on which passage may be obtained is owned by one of the traders, operated mainly in connection with his business, and seldom makes more than one trip a year, but an occasional boat runs on special charter.

The western part of the Koyukuk Plateaus province within the area described in this report is drained mainly by the Selawik River. Little is known of this part of the region. The only available description of the Selawik Valley is that furnished by Stoney,[24] who visited it in connection with his explorations of the Kobuk and adjacent country in 1884–1886. He states regarding the Selawik:

> Its valley is rolling but less so than the Putnam [Kobuk] and is interspersed with more lakes. The river is not so long as the Putnam [Kobuk] or the Notoark [Noatak], and its course is more winding. The current at the place where the river forks is eight-tenths knot and less lower down. Many tributaries enter from both banks; they are deep but of no great length. The banks of the Selawik are as regular as canal banks. * * * There are three outlets into Selawik Lake; the westernmost is the deepest; 2 fathoms can be carried over this bar; over the others only a few feet.

BROOKS RANGE PROVINCE

Dominating the whole of northern Alaska as the backbone that separates the waters flowing southward into the Yukon and its tributaries or westward into Kotzebue Sound from those flowing northward into the Arctic Ocean stands the Brooks Range. Although spoken of as a unit, the Brooks Range really consists of many individual mountain groups. To some of these groups distinctive names have been given—for instance, the De Long Mountains, north

[24] Stoney, G. M., Naval explorations in Alaska, pp. 55–56, Annapolis, 1900.

of the lower part of the Noatak; the Baird Mountains, between the Noatak and Kobuk in their western part; the Schwatka Mountains, between the head of the Kobuk and the Alatna; the Melville Mountains, between the Colville and the country east of the Alatna; the Endicott Mountains, in the eastern part of the mapped area; the Mulgrave Hills, between the lower part of the Noatak and the coast; the Igichuk Hills, which form the lower gorge of the Noatak; and the Lisburne Hills, which extend southeastward from Cape Lisburne. Unfortunately, however, hardly any of the original definitions of these groups stated the extent or limits of the features to which the names were given, and subsequent exploration of them in the field has not been complete enough to permit their adequate delimitation now. Furthermore, apparently the same feature has been called by more than one name, though in the absence of adequate data this is by no means always certain. Although as a general rule it is best to adopt the name first given to such a feature, in this region it is not always certain to what the original name applied, and where the first name was based on a misconception of the geography a later name may be more appropriate. As an illustration of the complexities that may arise, the following is cited as a case in point: In August, 1885, H. T. Allen appears to have been the first white man to see high mountains about 60 to 80 miles north of the Koyukuk, when he was in the general vicinity of what is now Allakaket and the mouth of the John River. Though he did not definitely describe or name them in his report, he indicated on his map a continuous chain of mountains extending northeastward from a point on the north bank of the Koyukuk in approximately latitude 66° N. to a point far beyond the area he could possibly have seen and thence eastward. On this map, although apparently referring to the entire range, the name Endicott Mountains is placed on that part of this range north of and beyond the mapped head of the Alatna (Allenkaket) and north of and beyond the mapped head of the Koyukuk, in latitude 69°, longitude 147°.

From what is now known of the geography of the region it is obviously improper to apply this name to the entire range, as it certainly does not extend as indicated by Allen. To curtail it even to that part on which the name originally appeared is also open to difficulties, especially as Schrader, who in 1901 crossed these mountains in that part, describes two axes, each of which may deserve a distinctive name, and as Stoney, who in March, 1886, explored parts of the region between the Alatna and Colville, gave the names Melville and Schwatka to parts of what may be the same mountain group.

Under these conditions it has seemed advisable in this report not to attempt to give specific names to the different mountain groups which together form the Brooks Range, but to leave this task to later investigators, who, when more complete data regarding the topography of the region is available, may be better able to define the different groups that should be discriminated. The names for some of these groups, however, have been placed on the map accompanying this report, but these names should be regarded only as indicating the general positions of mountain groups and should not form additional precedent for the retention of names that when the whole region has been adequately mapped and studied may prove to be applied improperly or to be unsuitable.

Scenically the Brooks Range is extremely attractive because of its sculpture, which has produced ragged mountain masses interrupted by steeply trenched or glacially opened-out valleys, but when compared with many other mountain ranges the Brooks Range is relatively low. Throughout its extent, from the international boundary to the Arctic Ocean, no peaks have been measured that rise more than 9,200 feet above sea level, and within the area covered by Plate 1 the highest peak that has been measured has an elevation of slightly more than 8,400 feet. This point is situated near the head of the Noatak, about 5 miles southwest of the mouth of Lucky Six Creek. This peak forms part of the high ridge that was noted west of the Alatna, where many elevations of over 7,000 feet were recorded. An 8,000-foot peak was mapped in the upper part of the Noatak about 7 miles southwest of the mouth of Portage Creek. A 7,600-foot peak was mapped at the head of one of the tributaries of the Chandler River at a point about 30 miles northeast of the winter headquarters of the expedition of 1924, and several peaks between 7,000 and 7,400 feet high have been mapped within a radius of 20 miles of the same camp.

In the vicinity of the Aniuk and west of the valley of that stream no peaks as much as 5,000 feet in elevation were recorded, though it is very probable that there may be some that equal or surpass that height in the unsurveyed region between the Noatak and the Kobuk west of the mouth of the Aniuk.

Taken as a whole, the average height of the summit of the Brooks Range from the meridian of the headwaters of the Aniuk eastward to the limits of the mapped area is probably between 6,000 and 7,000 feet. From the Aniuk westward the highest parts of the range probably have an average elevation between 3,500 and 4,500 feet, and in the extreme western part, near the coast, the highest peaks stand less than 3,000 feet above the sea.

Although the height of the peaks and the ridges makes them formidable barriers to easy traverse, there are many gaps at lower elevations by which passage of the mountains can be made with reasonable facility. Among the best routes across the mountains are the following: By way of the John to the Anaktuvuk River and across a pass that stands at an elevation of about 2,200 feet; by way of the Alatna River and its tributary Unakserak River to the Killik across a pass at 3,800 feet; by way of the side streams of the Noatak to streams tributary to the Colville across passes that, at the heads of the Aniuk, Nimiuktuk, and Kugururok, stand, respectively, at 2,200, 3,800, and 2,600 feet; by way of the Kugururok, a tributary of the Noatak, to the Utukok across a pass at about 2,600 feet, or by way of another pass at the head of the same river to the Kokolik River; by way of the Kivalina River across a pass at about 1,300 feet to the Kukpuk River, and thence by another pass at 1,400 feet to the Kukpowruk River. A good route, much used in the past, leads from the Alatna River by way of Helpmejack Creek and thence across a pass at less than 1,200 feet to the upper part of the Kobuk. A route by way of the Alatna River to the Noatak is afforded by a small tributary to the Alatna from the west about 25 miles in an air line above the mouth of the Unakserak, thence across a pass at less than 3,400 feet, and thence down Portage Creek, a tributary of the Noatak. Passes across the mountains between the Kobuk and the Noatak probably occur at the heads of many of the larger valleys, but the only ones that are definitely known to have been used are those from the Ambler and Redstone to the Cutler River and the route southward by the Ipmiluik River, which probably leads either to the head of the Kogoluktuk or to that of the Ambler River, and one at the head of the Squirrel River, by way of which pack horses are said to have been driven over into the Noatak Basin. None of these routes between the Kobuk and Noatak have been surveyed, and consequently the elevation of the passes is not known, but probably they do not stand much above 3,000 feet.

It is indicative of the complex physiographic development which the region has undergone that the highest peaks do not occur on the divides that separate the major drainage basins on the two sides of the range but instead are found on subordinate divides, as, for instance, the 8,400, 8,000, and 7,600 foot peaks already noted. Many of the peaks of more moderate elevation also occur on subordinate divides. As a result of this condition it is often difficult to recognize at a distance the actual drainage divides, and this has led some of the earlier writers to direct attention to the general uniformity of the sky line when the range as a whole is viewed from a high point. This feature is clearly exhibited in views taken by Schrader from Fork Peak, near the head of the John River, at an elevation of 6,000 feet (pl. 4, *A*), and was interpreted by him as marking an old plain which had been uplifted to form a plateau and subsequently dissected, acquiring thus a mountainous appearance. Although this may be the correct explanation of this feature, it is open to doubt, because most of the crests are undergoing such rapid destruction that they are almost constantly changing before one's eyes, so that in few places does it seem possible that the crest preserves extensive relics of a surface that may have been formed millions of years ago (pre-Neocene, according to Schrader). Nowhere on the high summits of the range was deep rock weathering observed or any alluvial deposits, such as should have been formed if the plateau had at one time been reduced nearly to a plain standing at a low level, as is required by the hypothesis that the mountains have been carved from a plain of this sort after it had later been uplifted.

Whatever may be the final interpretation of the late history of this mountain range, it seems fairly certain, as is described in somewhat more detail in the pages devoted to the geologic formations, that structurally the range as a whole is either a much crumpled and deformed synclinorium cut off to the north and south by profound faults or else a much deformed mass, the resultant of all the folding and faulting which has affected it being to give it a general monoclinal dip to the north, with variations in the rocks which compose it trending east. Under either interpretation the original drainage lines would have tended to be established in directions normal to the axis of the range and to flow northward and southward down the constructional slopes. Coincident with the drainage thus established, other streams parallel to the range were developed, mainly along belts of weak rock or lines of structural weakness. To this class belong most of the largest streams of the region, namely, the Kobuk, the Noatak, and the Colville as far east as its junction with the Anaktuvuk. Streams that appear to have had their courses directed mainly by the original constructional slopes are, on the south side, the John and Alatna Rivers and the tributaries of the Kobuk from the north, and on the north side the Kokolik and Utukok Rivers and most of the longer tributaries of the Colville from the south.

However these several valleys originated, they have undergone so many modifications since their formation that now most of their original characters are masked or destroyed by the later processes of erosion. These processes have allowed the rivers to intrench themselves, and by so doing destroy the original slopes which directed their early courses. In this process side streams have been formed along belts of weak rock, and as they developed they may even have turned aside or captured some of the less active streams that flowed down the original slopes. Then, again, many of the valleys in the mountains have had their shape and course considerably modified by the ice of the last great ice age, which formed in the highlands and flowed down some of them for many miles, scouring and thus obliterating many of the features originally characteristic of river origin, and then as the glaciers waned covering much of the existing topography with a mantle of detritus brought down by the ice and scattered broadcast by the heavy run-off that resulted from the melting of the glaciers.

Although glaciers were fairly extensive in many parts of the Brooks Range in the past, they are uncommon now. In fact, in all the region that has been traversed by the Geological Survey parties only three glaciers were seen, and none of these was more than 2 miles long. Two of these glaciers were near the high peaks at the head of the mapped portion of the Noatak, and the other was at the head of the valley that comes into the Alatna River from the west a short distance downstream from the Kutuk. (See pl. 4, *B*.) Possibly a few other glaciers may occur in some of the valleys near the head of the Noatak and in some of the higher parts of the range between the Noatak and the Kobuk, but if so they are doubtless small, because all the streams from these valleys were clear-water streams and not at all milky like those that are commonly fed by glaciers. The almost entire absence of glaciers in this region is in marked contrast with the enormous glaciers, many of which extend down to sea level, that occur 500 miles or more farther south, in the mountains of the Alaska Range. The difference between the amount of glaciation now found in these two mountain ranges and adjacent country was probably also maintained relatively the same in the past, but the ancient glaciation of the Brooks Range and adjacent regions is described in somewhat greater detail elsewhere in this report (pp. 242–247).

The only one of the three largest rivers of this region that lies entirely within the Brooks Range province is the Noatak. The distance in an air line from the easternmost mapped head of this stream to its mouth is about 220 miles, but this distance is less than that measured along the major course of the stream and is very much less than the distance measured along the actual winding channel of the river. The river has sufficient volume to be traversable by canoes uninterruptedly at least as far as its tributary Portage Creek. At its mouth there are numerous sand bars and the river is shallow, so that the channel must be followed closely to avoid running aground, but a few miles farther upstream the water is deeper, and McLenegan reported depths of 12 to 15 feet at a point about 10 miles above the mouth. Launches drawing somewhat more than 3 feet have made the trip upstream as far as the village of Noatak, and a smaller launch is reported to have gone up to a point a short distance above the upper canyon, about 10 miles in an air line east of the mouth of the Kugururok. None of the Geological Survey parties that have traversed the Noatak made any definite records of the depth of the river at different points, but it seems probable that as deep water as in many of the stretches farther downstream could be found above the canyon as far as the mouth of the Nimiuktuk, and possibly as far as the mouth of the Aniuk. In fact, the shallowest stretches of the river are in the lowland 20 to 30 miles north and south of the village, where the river splits into a great number of small channels. Canoes were used for descending the entire length of the Aniuk and for the last 10 or 12 miles of the Nimiuktuk, though doubtless a much greater length of the Nimiuktuk would have been found navigable for canoes had it not been visited so late in the season that its surface was frozen.

The region adjacent to the Noatak River was described by Smith[25] as divisible into six more or less topographically distinct parts which, for descriptive purposes, he called, from the mouth upstream, the coastal lowland, the Igichuk Hills, the Mission lowland, the second highland, the Aniuk lowland, and the headwater mountains. Viewed broadly, however, the three highland or mountain parts belong to the general highland of the Brooks Range, and the three lowlands are features that have been formed in this mountain mass by the processes of erosion and deposition. These different subdivisions therefore relate to really minor features which are much more prominent to the traveler following the river than to one viewing the country as a whole. In the highland belts the channel of the river is generally constricted and its velocity increased. As the river cuts its course through the Igichuk Hills the water flows in one channel between precipitous limestone walls in places 400 to 600 feet high. In the second highland area, extending from a point a short distance upstream from the mouth of the Kugururok to the mouth of the Nimiuktuk, the Noatak makes numerous rather abrupt bends but no well-marked meanders and through most of that distance flows in a single channel. One of the most notable features of this part of the valley is the canyon that has been carved near the west end. The walls of the canyon rise precipitously 600 to 800 feet, and the water rushes along in a narrow channel at high speed. Plate 5, *A*, shows the general appearance of the canyon and the surrounding country. The details of the geologic history afforded by the interesting section exposed in its walls are referred to in later pages of the report. In the Aniuk lowlands the course of the stream shows not only large angular bends but also numerous meanders, and the country 10 miles or so distant from the river is gently sloping except where rocky

[25] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 26–33, 1913.

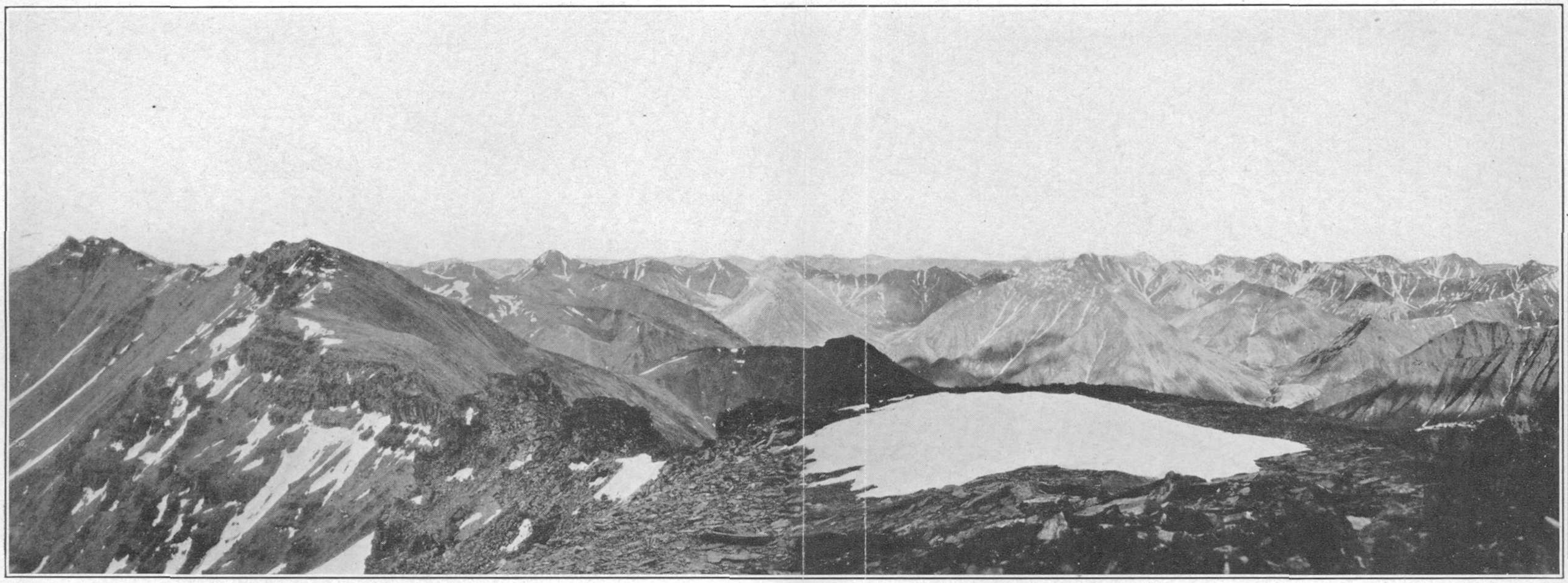
knobs project above the general level. In the headwater mountains the floor of the main valley gradually decreases from a lowland 2 miles wide, in which the river meanders in a slightly incised trench. toward the headwaters, where it is entirely occupied by the stream. Rock walls rise steeply from the valley floor, and many of them have the truncated appearance usually produced by glaciation.

The Colville River affords a more or less readily recognizable northern boundary of the Brooks Range province, though in reality the main stream lies entirely within the Arctic Plateaus and is 10 to 70 miles from the northern front of the mountains from its head to a point within 75 miles of its mouth. Its position is somewhat analogous to that of the Kobuk, near the southern border of the mountains. This stream is described in more detail in the part of this report relating to the Arctic Plateaus, but as its tributaries from the south drain most of the northern slopes of the Brooks Range some mention of them is also given at this place. The general character and appearance of these mountains near the head of the Killik is shown in Plate 5, *B*. Few of these southern tributaries of the Colville rise more than 35 miles in an air line from the north front of the mountains. The summit of the pass between the heads of the John and Anaktuvuk Rivers stands less than 15 miles from the north front. The smaller of these northward-flowing streams usually have rather steep gradients and narrow valley floors. Many of the larger valleys, however, have been more or less modified by glacial action, which has widened their floors so that the streams that now occupy them are small in comparison and straggle irregularly in trenches cut in the alluvial deposits that partly fill the valleys. Canoes have successfully been used on the Anaktuvuk River, Killik River, and Etivluk River, in the mountains and probably could have been used on many of the other large side streams had the Geological Survey parties been working in their neighborhood during the open season. The Chandler River, however, was found to be swift and turbulent above its junction with the Killik River, especially at high water, and from a point about 5 miles in an air line from its mouth to the mountains it was traversed on foot, with packs on the backs of the men.

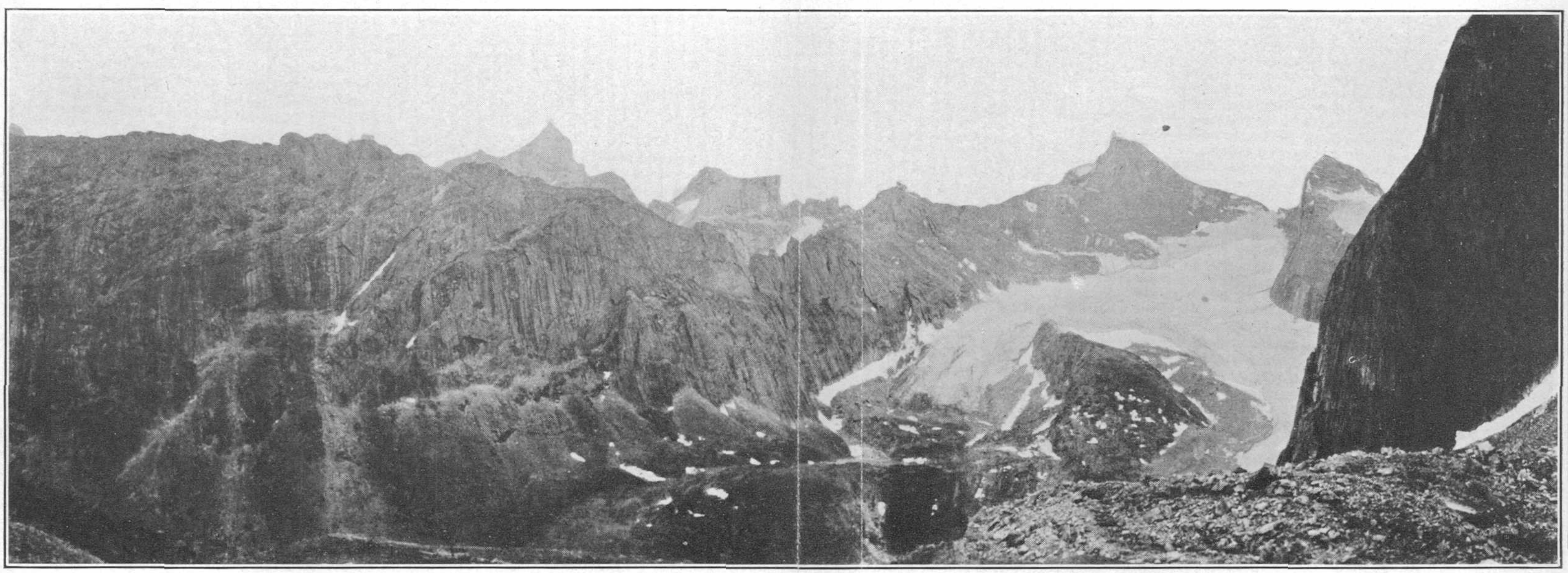
The larger of the other streams that head in the western part of the mountain province and flow directly into the Arctic Ocean are the Utukok, Kokolik, Kukpowruk, Kukpuk, and Kivalina Rivers. The larger part of the three streams named first lies north of the mountains, and within the Brooks Range they are mere mountain torrents not navigable even by canoes. The Kukpuk has a general westerly course. It rises in the highlands north of the Kivalina River, traverses a belt of lower country, and then near its mouth flows through the southward extension of the Lisburne Hills and the highlands that form Cape Thompson. Natives report that they ascend the Kukpuk in their skin boats for at least 40 miles from the coast, and from the general characters observed before the ice in the river had broken in the vicinity of camp P April 25 it seems probable that at times of favorable water a canoe could be taken at least that far upstream. The Kivalina River is a relatively small stream whose course is in general southerly, transverse to the trend of the geologic structure of the rocks of its basin. It rises in mountains like those shown in Plate 6, *A*, where the streams are swift and shallow. Under ordinary conditions, however, it is navigable for canoes as far as the narrow gorge north of camp P April 10, and natives say that they can take their skin boats at favorable stages of water some distance above the forks of the river below camp P April 14.

The only places where the highlands of the Brooks Range abut directly on the shores of the Arctic Ocean are in a stretch of 6 to 7 miles east of Cape Lisburne and thence 25 to 30 miles southward along the west coast of the peninsula and again at Cape Thompson and at Cape Seppings. At all these places precipitous cliffs, many of which are unscalable, rise abruptly from the sea to heights of 500 to 1,000 feet. Plate 6, *B*, shows a characteristic view of the cliffs in the vicinity of Cape Lisburne. Deep water for this part of the Arctic Ocean extends close into the cliffs, so that depths of 20 fathoms or more are found a short distance offshore. This coast, however, is dangerous for navigation because of the strong winds that cascade over the cliffs, the absence of harbors, the strong currents and drifting ice, and the frequent fogs. The highlands also come close to the shore near Cape Krusenstern, but long sand spits make out several miles into the ocean to form the actual cape. The landfall usually recognized here by navigators, however, consists of the cliffs by which these highlands break off abruptly to the lagoon at sea level at their foot, and a wide berth is given to them, as shoal water of less than 10 fathoms extends for more than 25 miles to the west of these cliffs. This highland that terminates back of Cape Krusenstern is the continuation of the Igichuk Hills, through which the southern gorge of the Noatak has been cut.

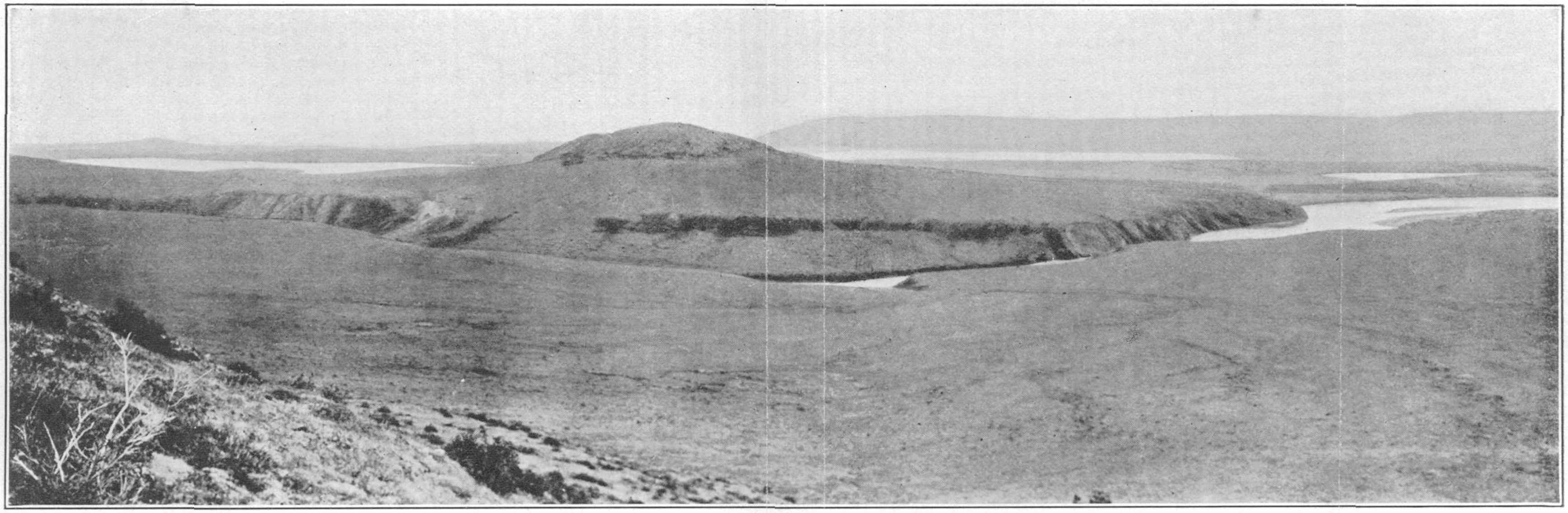
Elsewhere north of the Kobuk the highlands terminate some miles back from the coast, from which they are separated by a narrow alluvial plain. Doubtless in the past the ocean impinged directly at many places against the slopes that lead down from the highlands, but in the long time that has elapsed since then, uplift of the region and deposition of later sediments have resulted in the withdrawal of the ocean westward, until after many changes its shore line has finally attained the present position.



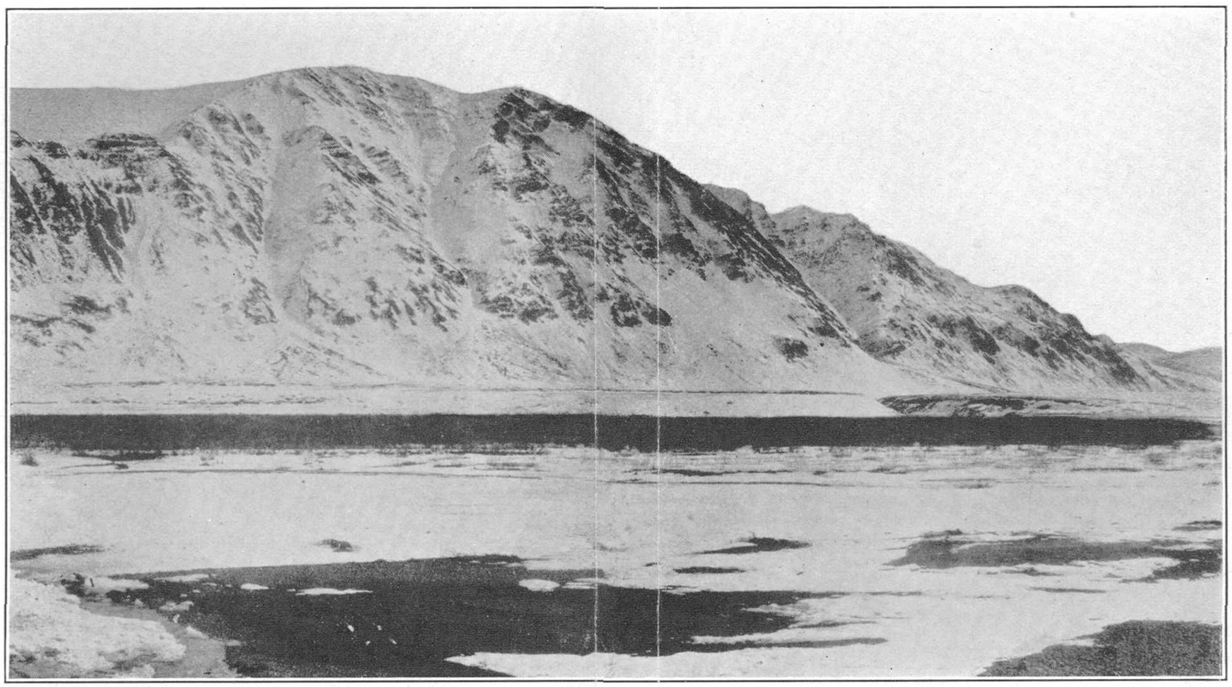
A. VIEW OF MOUNTAINS FROM FORK PEAK, NEAR HEAD OF JOHN RIVER



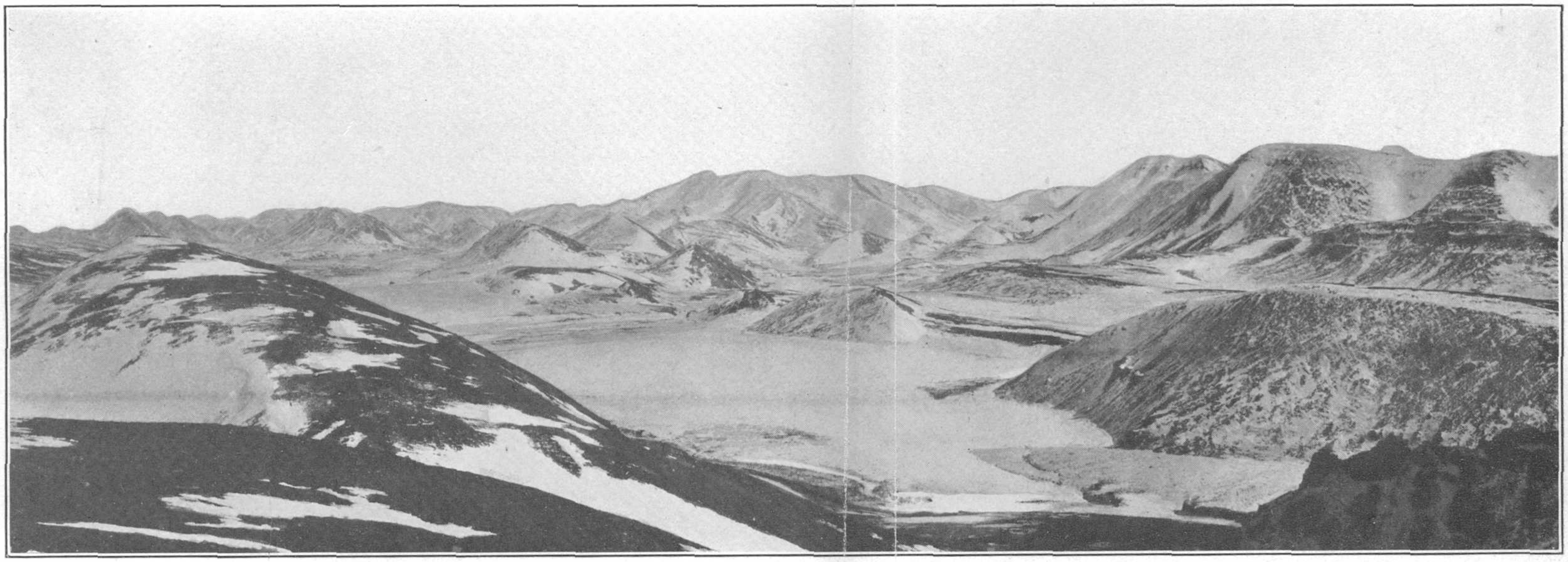
B. PEAKS AND GLACIERS EAST OF CENTRAL PART OF ALATNA VALLEY



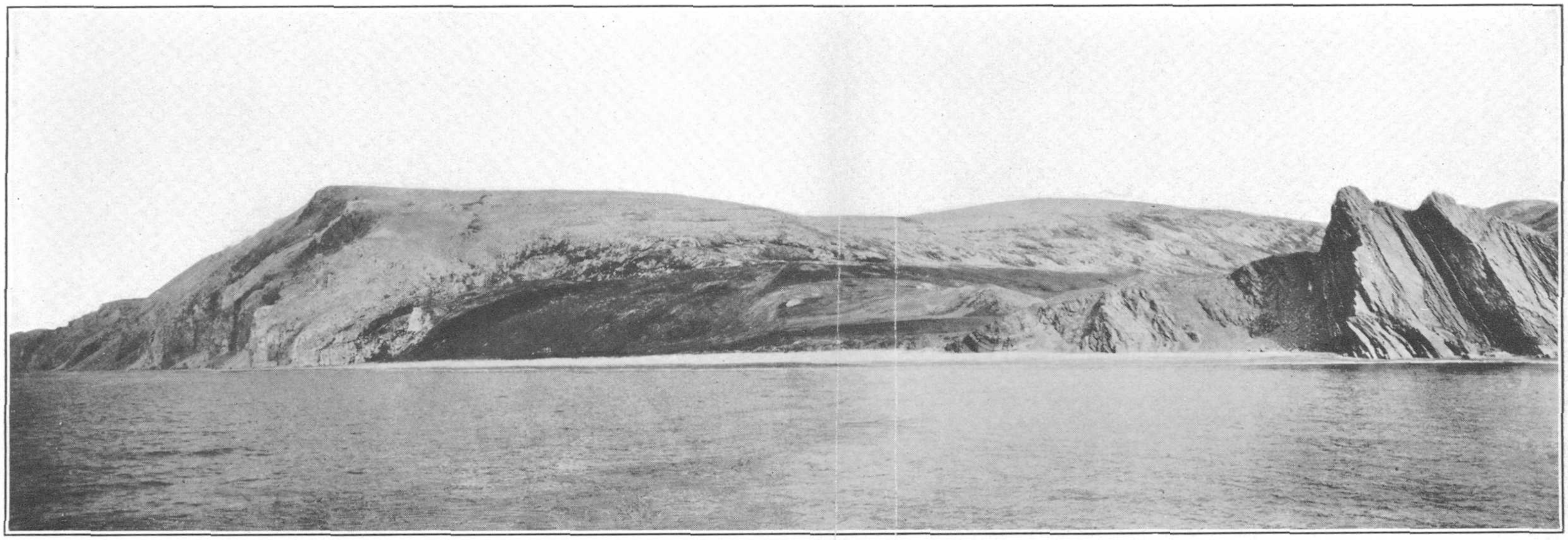
A. NOATAK CANYON AND ADJACENT COUNTRY



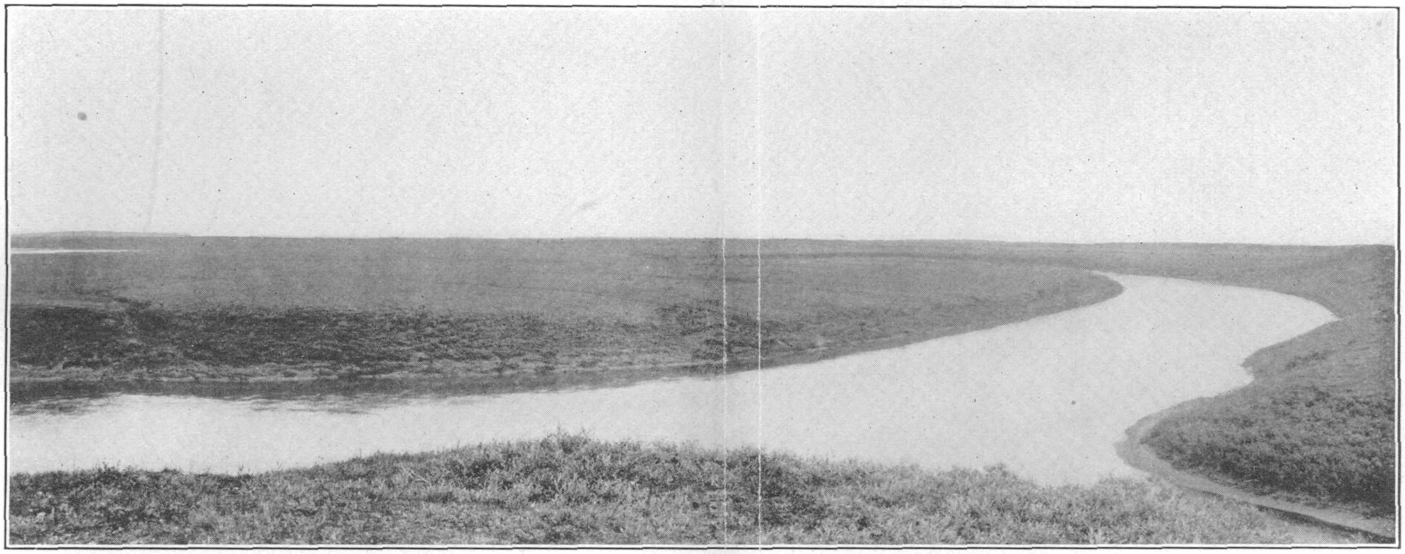
B. MOUNTAINS AT HEAD OF KILLIK RIVER



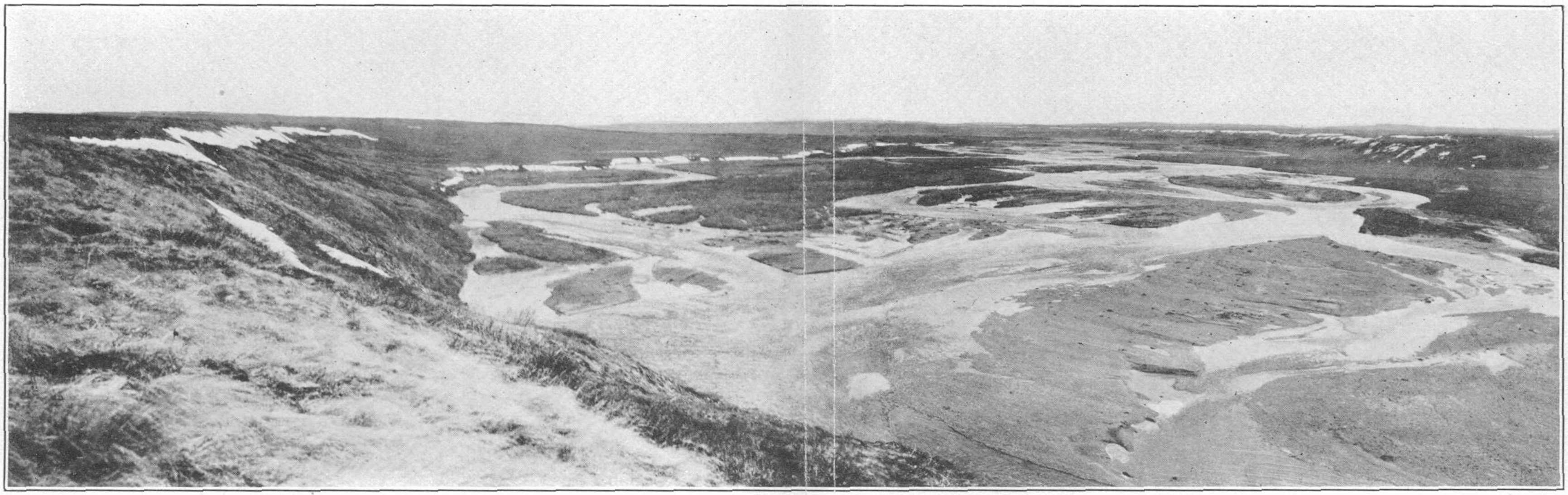
A. MOUNTAINS AT HEAD OF KIVALINA RIVER



B. SEA CLIFFS NEAR NIAK CREEK, CAPE LISBURNE REGION



A. PLATEAU REGION NEAR ITS NORTHERN MARGIN ON IKPIKPUK RIVER



B. PLATEAU REGION NEAR JUNCTION OF KILLIK AND COLVILLE RIVERS

ARCTIC PLATEAUS

North of the Brooks Range and stretching as a strip 100 miles or so wide are the Arctic Plateaus. As the name implies, this province is characterized by relatively smooth uplands in which the streams have cut down their valleys, so that from a distance the general appearance is that of a high plain, but near by it appears as a succession of gently rolling hills and moderately flaring valleys. (See pl. 7.) In many places the junction between the mountain and plateau province is abrupt, the ragged rocky slopes of the mountains giving place within a short distance to the smoother slopes of the plateaus. When viewed from the north the more or less featureless plateau is seen to terminate against the steep cliffs of the mountains. This is the condition reported by Schrader along the Anaktuvuk, where the mountains more than 5,000 feet high give place within 5 or 6 miles to an upland whose highest points stand about 2,400 feet above sea level. Near the Chandler River the mountains, which rise to an elevation of 7,000 feet, give place within about 5 miles to the plateau surface at about 3,800 feet. Along the Killik the line of demarcation is nearly as sharp, but the difference in relief is not so great, because close to the mountains a good deal of glacial material has been deposited on the plateau surface. Here, however, within 7 miles peaks between 6,000 and 7,000 feet give place to uplands that stand between 3,000 and 4,000 feet. Farther west the line of separation is not marked by as great a difference in elevation, but even there the topographic forms show a distinct difference between the two provinces.

This plateau province is composed dominantly of Mesozoic rocks of relatively low resistance to erosion. These rocks, however, consist of alternating layers of sandstone and shale, which have been folded into anticlines and synclines. As a result there are differences in their resistance to erosion, and these differences are indicated topographically by the general east-west alinement of the ridges and by the minor scarps and swales on the hillsides. Near the mountains the folding has been more intense and the beds in places stand nearly vertical, thus giving a linear character to the hills formed by the harder beds. Farther away from the mountains, where the folding is more gentle and the beds lie nearly horizontal, the hard layers form steps on the hillsides or cap the hills.

Near the mountains the highest points on the plateaus stand at elevations that in few places if anywhere exceed 3,800 feet and are usually between 3,000 and 3,500 feet. Farther north, say in the divide north of the Colville between that stream and the Ikpikpuk or between the Colville and the Utukok, the average elevation of the upland is between 1,200 and 2,400 feet, and at many places there are passes across the divide at 2,000 feet or less. Farther north the upland stands still lower. The map accompanying Schrader's report shows that near the mouth of the Colville River, at the point where the last exposures of rocks occur, the upland has an elevation of somewhat more than 400 feet. On the Ikpikpuk the elevation of the upland near the place where the last bedrock outcrops were seen along that stream was about 600 feet. On the Avalik and Kaolak the summit of the upland near its northern border was about 350 feet above sea level. On the Utukok the northwestern boundary of the plateau province stands at an elevation between 400 and 600 feet. On the Kokolik and the Kukpowruk the northern border stands at an elevation of slightly more than 400 feet. From Cape Beaufort to Wevok, in the stretch where the plateau province is terminated by the ocean, the upland is somewhat more than 400 feet above the sea.

In general, therefore, the uplands of the Arctic Plateaus may be regarded as sloping down from an elevation of 3,000 to 3,500 feet at the south to 400 to 600 feet at the north. This slope, however, is not believed to mark a plane that has been given an even tilt of this amount but is regarded rather as a surface that has resulted through long-continued erosion interrupted at times by periods of warping and uplift, so that different parts of the present surface were formed at different times by different processes. The sum total of these different events, however, has been to give a general slope downward to the north, and this has controlled the dominant distribution of the main stream lines, whereby many of the rivers have their courses parallel to this slope from the mountains to the northern margin of the plateau province—for instance, the Kukpowruk, Kokolik, Utukok, and Ikpikpuk.

The Colville, in its upper and central portions, from camp G May 24 to its junction with the Anaktuvuk, is an exception to the general rule, for its course is dominantly at right angles to this direction and parallel to the trend of the rock formations. This exception is perhaps best explained as resulting from more rapid erosion along a belt of weak rocks and favorable structure, whereby the lateral streams were able to cut headward faster and thus capture northward-flowing streams that had to carve their valleys across the structure of the rocks. According to this suggestion, it seems possible that a stream like the present Anaktuvuk River and its continuation in the present lower part of the Colville might have been able, through a side stream occupying the general course of what is now the Colville, to erode headward until it captured the Killik River, which may before that time have flowed directly northward into what is now the valley of the Ikpikpuk River. This process may have been repeated successively until, through capture, the Colville had established a course practically coincident with its present one.

Conclusive evidence in support of this explanation was not obtained in the short time that could be diverted from the field studies of more important matters, and it is offered only as a working hypothesis. In attempting to test its soundness it should be realized that the assumed diversions took place so long ago that many processes have modified the existing valleys, so that the evidence will not be at all easy to acquire or simple to interpret. In fact, certain observations already on record suggest that in the time that has elapsed changes have taken place whereby the advantage of position lies with streams other than the Colville, so that some of its acquired drainage may be captured or recaptured if the present processes continue uninterruptedly. An illustration of this condition is shown in the vicinity of camp G May 30. At this place the Colville is flowing at an elevation of approximately 2,000 feet. Within a few hundred yards to the north is the summit of a divide that stands only about 110 feet above the river. This divide separates the Colville from Disappointment Creek, a tributary to the Utukok, and the distance between the 2,000-foot contour on the two sides of the divide is less than half a mile. Thus, only a very narrow barrier now keeps this upper part of the Colville from flowing north into Disappointment Creek, for that stream has a drop of about 600 feet in an air-line distance of 7 miles, or nearly 90 feet to the mile, whereas the Colville in this part of its course drops only 200 feet in an air-line distance of 26 miles, or considerably less than 10 feet to the mile. For this reason, if normal erosion processes continue uninterruptedly, Disappointment Creek may be expected to capture part of the headwaters of the Colville, and if the explanation that the Colville long ago diverted part of the former Utukok drainage is correct, this capture would return to the Utukok an area formerly tributary to it. The general relations at this place are diagrammatically shown by Figure 3, on which the distances have been determined by measuring the air-line distance between successive contours as shown on the map.

As already stated, the Colville is by far the largest river in the Arctic Plateaus. The extreme length of its drainage area, measured in an air line from its most western tributary to its mouth, is over 275 miles; but, as the river makes many large angular bends as well as winding meanders of smaller scale, its length measured along its channel is several times that distance. At its mouth the river has built out a delta about 20 miles wide, in which there are numerous channels. Schrader notes that four mouths of the river were formerly reported but that he believes it has five or six. The depth of water in these channels is not known, but probably they are all relatively shallow, though the easternmost one is believed by Schrader to be the deepest and appears to be the largest. South of the delta the water in the river is deeper, and Schrader states that probably a small river steamboat could go a considerable distance upstream. However, in the portion of the river from a point below Prince Creek westward to a point near the mouth of the Killik River it becomes so split up and interrupted by bars that considerable difficulty would be experienced in traversing that part, even with a canoe, if the water was at the stage encountered by the eastern party of the 1924 expedition. Above the Killik River the main stream is more or less in a single channel, and its depth is greater, so that except for the swiftness of the current it could probably be traversed by a shallow-draft launch as far as the Nuka River. Canoes have been used on the Colville from the mouth to camp G May 24, and probably could have been used as far as camp G May 18, at the mouth of Storm Creek, if the river had been free of ice. Canoes have been used within the plateau province on the tributaries of the Colville as follows: The entire length of the Anaktuvuk, Prince Creek as far as camp M July 18, the entire length of the Killik River downstream from camp S April 9, the

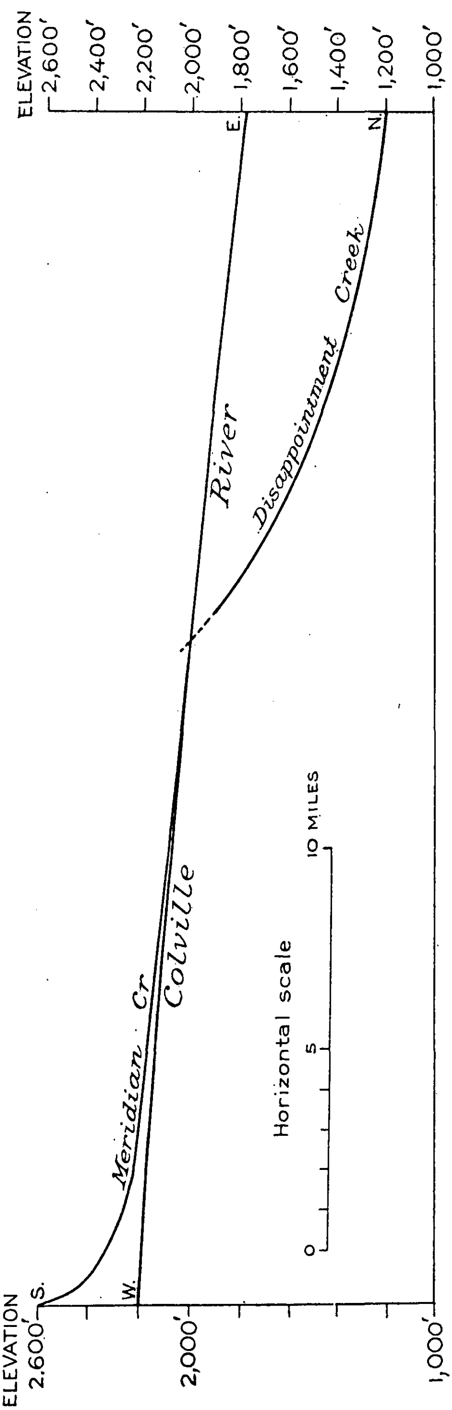


FIGURE 3.—Idealistic cross section showing relations of Colville and Utukok Valleys near camp G May 30

Chandler River to camp M June 20, the Awuna River to camp S July 17 (could have been used much farther if desired), and the entire length of the Etivluk River. Few measurements of the velocity of the current at different places along the Colville have been made. Schrader states that the current north of Ocean Point is slack, and between that point and the mouth of the Anaktuvuk is 3 to 4 miles an hour. Above Prince the current is so strong that little or no progress can be made by rowing, and when crossing the river some distance is lost even with the most vigorous use of the oars. Some of the side streams, especially those from the north, such as Prince Creek and the Awuna River, have moderate or sluggish currents through much of their courses.

West of the Colville and having considerable parts of their courses within the plateau province, though heading in the mountains, are the Utukok, Kokolik, and Kukpowruk Rivers. All these streams can be traversed by canoes, but probably none of them could be ascended any distance by launches drawing as much as 1 foot. The main stream of the Utukok was not traversed above camp F August 22, and its tributary Disappointment Creek late in the fall was too shallow to be ascended with a canoe for more than a short distance. The upper part of the valley of the Kokolik was visited by Geological Survey parties principally during the winter, when the streams were frozen, but in 1926 canoes were used below camp P May 15. However, Eskimos familiar with the region say that ordinarily later in the year the stream is so small that canoes could not be used nearly as far upstream, and the party that surveyed the lower part of this river in 1923 reported such shallow water near the later camp P June 16 that because of the short time available they abandoned the attempt to ascend the river farther and did not reach even the northern border of the plateau province as here defined. The headwaters and central parts of the Kukpowruk River were also visited only during the winter, but the impression gained at that time was that at favorable stages of water it could probably be descended by canoes from a point not far downstream from the junction of its forks, below camp P May 1.

North of the Colville and having their headwaters entirely within the plateau province are several good-sized streams—from east to west the Ikpikpuk, Meade, Avalik, and Kaolak Rivers. The course of these streams is determined in the main by the northward slope of the plateau province, but the streams have incised their courses so that their floors stand several hundred feet below the uplands. During this dissection many of the side streams have been able to erode their courses to considerable distances along the east-west trend of the weaker belts of rock. This condition is particularly well shown by the two branches of the Kigalik River and Maybe Creek, which unite to form the Ikpikpuk River. The pattern of drainage of this kind is often called trellised. The entire length of the Ikpikpuk has been traversed in canoes from camp M July 26, on Maybe Creek, and camp S July 28, on the Kigalik River, and probably a shallow-draft launch could ascend the main stream as far as the junction of these tributaries.

Little is known of the upper part of the Meade River by direct observation. Inasmuch, however, as its extreme southern part must lie in the hills seen from the head of the Kigalik River, from Lookout Ridge, and from the highest point ascended on the Avalik, there is little room to doubt that it is of the same kind of country as that seen at those places. Consequently, the mountains which have been reported to be at its head are probably only low rolling hills not more than 2,000 feet above sea level. The lower part of the Meade was ascended by one of the parties of the 1923 expedition, but probably this party did not go far within the northern border of the plateau province, and this seems to be about the highest point reached by Eskimos with their skin boats. The point reached by the Geological Survey party is described as about 125 miles by river above the mouth, and the channel there is said to be 500 to 600 feet wide,[26] though at low stages the river only occupies one-half or less of the channel. The current of the Meade River 100 miles from its mouth, also measured along the course of the river, is said by Paige to be 3 to 5 miles an hour.

Between the Meade River and the Utukok are several streams that are tributary to the Kuk River. Of these, the largest are the Avalik and Kaolak Rivers. The Avalik apparently heads in the hills north of Lookout Ridge, whose highest points rise to elevations of about 2,000 feet. This river was ascended in canoes only to camp P July 18, and even in that distance it was so shallow that the bottoms were practically worn out of the boats by scraping over the bars, as much of the way the water was only a few inches deep during the exceptionally dry summer of 1926. The highest point on the upland in the vicinity of that camp was only about 350 feet above sea level. The Kaolak was traversed by the western party of the expedition of 1924 in canoes as far as camp F August 15. From this place a portage, having an air-line distance of only 5 miles and crossing a divide only 400 feet above sea level, leads to the Utukok. The highest points in the vicinity of the Kaolak stand only about 600 feet above the sea.

[26] Paige, Sidney, and others, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, p. 8, 1925.

The only other stream of any considerable length that traverses part of the Arctic Plateaus is Pitmegea River, which drains much of the country lying north of the Kukpuk and west of the upper part of the Kukpowruk. The distance in an air line from its mouth near Cape Sabine to its headwaters west of camp P May 1 is only about 35 miles. Stockton [27] found it to have about 3 feet of water over the bar at its mouth but to be 6 feet deep inside the bar. However, a short distance farther upstream it is so beset by bars and shoals that except at periods of high water it can not be ascended. At times of especially high water the natives are said to ascend it in their skin boats for a distance of about 40 miles measured along its winding course, or to a point perhaps halfway to its head.

Through much of the distance from the vicinity of Cape Beaufort to Wevok the plateau province abuts on the shore, and the coastal features differ from those of the mountain province to the south or the coastal-plain province to the north. The uplands in this tract stand about 400 feet above the sea, so that high cliffs mark the descent from these uplands to the sea. These cliffs, however, are lower, less continuous, and less precipitous than those that mark the seaward termination of the mountains, but they are much higher and steeper than those of the coastal plain. No harbors occur along this part of the coast, and few indentations large enough to shelter even a small boat can be found. At intervals between the headlands are small beaches, and some of these extend seaward from the foot of the slopes leading to the uplands, so that the steep bluffs which probably once marked the shore are now some distance inland. This condition is well shown at Cape Beaufort, which is not marked by any bend or change in direction of the shore line but is marked by a hill about 500 feet high that now stands about a quarter of a mile inland from the sea. The water offshore from the plateau province is apparently somewhat shallower than that off most of the neighboring coast of the mountains to the south, for according to the Coast Survey charts the line separating soundings of 10 fathoms or less from those giving a greater depth is in most places opposite this province some 7 to 15 miles offshore.

ARCTIC COASTAL PLAIN

The most northern of the major provinces of northern Alaska is the Arctic coastal plain. This province is roughly triangular in outline, tapering nearly to a point at Cape Beaufort at the west, widening to a maximum width of nearly 80 miles from Point Barrow southward, and then narrowing again near the mouth of the

[27] Stockton, C. H., Arctic cruise of the U. S. S. *Thetis* in the summer and autumn of 1889: Nat. Geog. Mag., vol. 2, pp. 178–179, 1890.

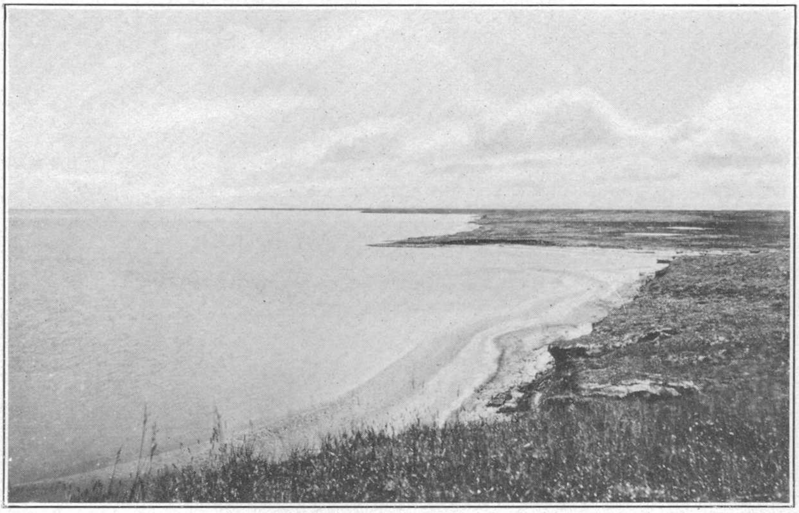
Colville, where it is only 20 miles or so wide. As in the plateau province the surface of this tract does not represent a single plain but instead is made up of a number of surfaces of erosion and deposition which have been formed during a long period of years and mark different stages of erosion and uplift. The characteristic feature of the whole province, however, is that practically everywhere its surface is formed of unconsolidated deposits that have been laid down mainly under marine conditions. These deposits have been uplifted and in part reworked and shaped by other agencies. Presumably at one time this province was similar to the present floor of the sea off this coast. Later it was uplifted and as soon as it rose above the sea was exposed to the same kinds of erosional and depositional processes that are even now tending to modify and shape its appearance. Many of its features therefore represent the inequalities that existed on its surface when it was part of the floor of the sea, others are the gullies formed by the run-off from the latest shower of rain, and between these two extremes are all gradations.

On the whole, however, in a geologic sense the province is young, and there has not yet been time for the present processes to remodel its features to fit existing conditions. Consequently large tracts have not yet acquired thorough drainage, and ponds and lakes that fill old depressions are numerous on the poorly drained uplands. Because the inland part of the coastal plain has been longest above the sea, its original surface features are most modified, and the parts nearest the coast have been affected least.

Perhaps the most striking characteristic of the coastal plain is the uniformity and monotony of its landscapes. (See pl. 8, *B*.) Except for minute minor details, its appearance is everywhere the same. Its slope is so slight that to the unaided eye it appears to stretch away to the horizon as an endless flat. Prominent landmarks are entirely absent. Owing to its featurelessness even minor elevations such as sand dunes 10 feet high appear to be notable prominences; in fact, it is said that one of the earlier explorers reported a range of mountains east of the Colville where subsequent explorations have proved that only low sand dunes exist. Over these plains the winds sweep with unbroken severity, and the traveler caught in the sudden storms that are common in the winter finds it next to impossible to get any natural shelter. In the summer the poorly drained tracts of upland afford only spongy footing, which makes travel laborious and slow, and lakes and deep sloughs necessitate circuitous deviations from direct courses.

All the large northward-flowing rivers mentioned in describing the provinces that lie south of the coastal plain traverse this plain to reach the ocean. In that part of their courses their valley floors are

A. COAST NEAR KILIMANTAVI, WITH SEA ICE LYING AGAINST SHORE AND GRAVEL SHOVED BY ICE IN THE FOREGROUND



B. COASTAL PLAIN NEAR MOUTH OF COLVILLE RIVER wider than in the plateau province, and their current is much slower. Their banks are generally not more than a few feet above the level of the water, and in times of high water in the spring much of the country near the rivers is flooded. Near the coast many of the rivers split into numerous distributaries and enter the sea by many small channels. Except at the Kuk and Kukroak Rivers and Dease Inlet the latest movement which seems to have affected the northern part of the coastal plain has been emergence. The lower part of the Kuk, however, appears to have undergone some depression at a relatively recent time, as is shown by the long estuarine character of its course from Karmuk Point to camp F August 7. The Kukroak River, which enters the head of Peard Bay, also appears to have had its lower part depressed, so that it enters the bay through a long estuary. The river at the head of this estuary is small, and in August, 1926, could not be ascended by canoe for more than 3 or 4 miles above the narrow point 5 miles above Camp P August 10. At Dease Inlet also there appears to have been some recent submergence by which this bay, nearly 30 miles long, has been formed, but the southern part has been filled to a considerable degree by the silt and other deposits brought down by the Meade, Topogaruk, and Chipp Rivers, which enter it near its head. Avak Inlet, southeast of Icy Cape, has not been examined in detail, but it, too, probably indicates some relatively recent submergence.

Almost no large streams have their courses entirely within the coastal-plain province. The Topogaruk, which was traversed by one of the parties of the 1923 expedition in canoes for an air-line distance of at least 40 miles from the coast, is probably one of the largest of the streams lying entirely in this province. It has an extremely meandering course, which makes its length from head to mouth many times the air-line distance between those points. Many of the large streams already described have tributaries that originate in the coastal plain. Among these may be mentioned the tributary of the Ikpikpuk from the east that enters midway between camp S August 12 and camp S August 13 and is said to flow from Lake Teshekpuk. The Inaru River, which is a tributary of the Meade River and joins that stream only a few miles above its mouth, drains an area 60 miles long east and west, its headwaters rising within 10 miles of Peard Bay, from which it can be reached by an easy portage. The Inaru is described as a narrow, extremely meandering stream flowing in a channel that appears in many places like an artificial ditch, it is so narrow and steep banked. It is navigable all the way by canoes and has only a sluggish current. The Kungok and Ivisauruk Rivers are tributaries of the Kuk that probably have the larger part of their courses entirely within the coastal plain.

The shore line of the coastal-plain province throughout almost the entire area shown on Plate 1 is characterized by low cliffs on the mainland and by more or less continuous sand reefs and islands off the coast or festooned from one projecting headland to the next. In its physical aspects the coast thus resembles parts of New Jersey or North Carolina. Between the reefs and the coast are lagoons that are in places as much as 5 miles wide, and the longest (that between Cape Beaufort and Icy Cape) is nearly 100 miles long. These lagoons are usually shallow, but a sufficient depth for small coastwise vessels may be found at the entrances, and skin boats or canoes can traverse them almost anywhere if the channels are followed. However, if the channel is not known, considerable difficulty will be experienced. The canoes of the Geological Survey parties frequently went aground far from the shores of the lagoons, and progress could be made only by wading and hauling the boats across the shallow places. These lagoons are of great assistance to travelers, for by using them the rougher water of the ocean may be avoided, and many times they afford a water route when the ocean is still blocked with ice.

The reefs are usually narrow, and at many places during exceptionally high water in storms the sea breaks over them. Like most reefs of this type, they have been formed mainly of the material eroded from the sea floor and scattered out by currents that flow parallel to the shore. Unlike the reefs in more temperate regions, they owe much of the material of which they are composed to ice scour of the ocean floor and the rafting of the material thus acquired into shoal water. Thousands and possibly millions of tons of material are thus added yearly to the seaward side of the reefs, and much of the coarser material found on the beaches remote from the nearest bluffs has been brought in by this process. Plate 8, *A*, shows some of the gravel ridges near Kilimantavi that were shoved up by the sea ice and left by it when it melted. In spite of the accretions to the front of the reef, through the action of waves and ice, both these processes are constantly tending to drive the reefs inshore, so that in the later stages of development of a coast of this sort reefs close in shore are generally absent. The successive stages in the geologic history of such a coast may be summarized briefly as follows: Immediately after uplift the shore is fairly regular, the slope from the coast inland is practically the same as the slope under water from the shore, and no reef is present. As waves, ice, or currents advance into the shallow water they erode the bottom, driving much of the eroded material shoreward. When this process has gone on for some time it produces discontinuous islands and reefs off the coast, which later unite and form more and more continuous reefs. If the process still continues the reefs are gradually thrown landward until at those places where the action is most intense or the mainland juts out farthest they connect with the mainland and thus disappear as reefs, and the waves and other erosive forces beat directly on the mainland shore, gradually undercutting it and making cliffs. All stages of this series of changes may be recognized at different points along the northern coast of Alaska. The earliest stage is apparently represented by the coast from Cape Simpson to Cape Halkett, where there is no reef; a later stage by the discontinuous reefs and islands between Point Barrow and Tangent Point; a still later stage by the nearly continuous reef with very small and widely separated inlets that extends southwestward from a point near Icy Cape for nearly 100 miles; and a very late stage by the reefless cliffed coast extending from Point Barrow to Skull Cliff, Icy Cape, and the region near Cape Beaufort.

CLIMATE

TEMPERATURE

As all of the region described in this report lies north of the Arctic Circle it is often wrongly regarded as a land of perpetual cold, in which none but the hardiest can live. It is a cold region, but for properly clothed and equipped persons it is by no means intolerable, and except for occasional very cold snaps, which are unpleasant in every latitude, people travel and attend to their duties with almost as little regard for the cold as most people in the northern United States. This statement of course does not mean that the temperature is not actually colder, but simply that the people have learned to protect themselves and adapt their houses, clothes, and methods of living to meet these conditions.

For many years the Weather Bureau has maintained a station at Barrow so that reliable data concerning the temperature there are available. The following table gives some of the pertinent items:

Temperature at Barrow (° F.)

Mean

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1881-1921	−19.9	−13.0	−13.1	−1.7	21.7	35.3	40.9	38.5	32.1	16.3	0.3	−15.4	10.1
1922	−7.5	−14.8	−15.5	.4	11.6	31.7	35.2	36.9	25.2	10.1	−4.3	−5.8	8.6
1923	−24.1	−14.2	−2.0	−1.4	21.5	34.1	41.2	43.6	28.2	20.6	2.6	−21.7	9.2
1924	−20.7	−26.9	−7.6	−16.1	14.2	30.8	36.9	35.4	23.8	3.8	−2.6	−9.8	5.1
1925	−29.2	−32.0	−18.8	−.4	19.0	36.6	42.2	42.3	33.8	22.8	−5.5	−15.4	8.0
1926	−14.0	−20.6	−12.7	3.9	17.2	36.6	40.6	40.0	35.6	23.0	9.3	−14.2	12.1
Means, 1881-1926	−19.6	−16.1	−12.4	−2.1	19.6	34.7	40.1	39.0	31.1	16.2	.2	−14.8	9.7

Temperature at Barrow (° *F.*)—Continued

Highest

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1881-1921	33	35	33	34	44	64	75	64	57	42	35	29	75
1922	33	24	-------	23	39	45	58	61	46	35	23	30	61
1923	21	31	-------	27	38	56	65	73	43	32	26	32	73
1924	23	14	-------	10	33	45	63	61	34	34	34	31	63
1925	6	5	14	29	37	56	69	69	51	43	9	14	69
1926	6	−3	20	23	36	65	66	69	59	39	32	10	69

Lowest

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1881-1921	−52	−55	−50	−36	−14	12	26	26	12	−25	−36	−53	−55
1922	−32	−45	-------	−25	−18	11	24	20	4	−15	−27	−38	−45
1923	−47	−48	−52	−23	−12	23	27	31	7	3	−22	−48	−52
1924	−42	−56	-------	−42	−4	14	23	26	6	−19	−35	−55	−56
1925	−52	−54	−51	−33	−16	27	28	20	16	−2	−19	−35	−54
1926	−35	−44	−41	−22	−11	24	26	26	20	5	−19	−38	−44

The highest and lowest temperatures are based on the record of 19 years. Among the many interesting facts shown by the table, the following are perhaps worthy of special note. The extreme annual range of temperature is 131°; the highest temperature recorded is practically the same amount above the mean annual temperature as the lowest temperature is below, namely, 65° and 66°, respectively; in all months of the year temperatures as high as 32° may be expected, but temperatures below freezing have also occurred in all months of the year; in all but the four months June to September temperatures below zero have been recorded; the mean temperature of each month from June to August is less than 10° above freezing, and for September it is 1° below freezing. The average of the mean monthly temperature for the four summer months—June to September—is a little more than 36°.

The temperature at Barrow is somewhat moderated by the nearness of the ocean, so that, strange as it may appear at first, greater extremes of temperature are recorded at inland points south of Barrow. Also because of the greater relief of the inland part, the minimum temperature in the plateaus and mountains is probably as low as at places in similar latitudes on the coast, if not lower. The following records of the Weather Bureau's station at Allakaket, near the southern part of the area, afford an interesting contrast with those already given for Barrow:

Temperature at Allakaket (° F.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Mean													
Means, 1907–1921	−24.2	−9.8	−3.7	16.3	41.2	55.9	58.2	51.9	39.0	17.6	−10.7	−18.2	17.8
1922	−11.6	−7.4	−8.6	20.8	35.6	51.5	51.8	51.6	38.6	27.1	−4.8	−15.8	19.1
1923	−21.0	−4.3	−3.7	15.0	40.6	58.0	60.5	58.2	41.2	30.0	−1.6	−22.3	20.9
1924	−14.8	−21.8	12.0	0	40.8	55.6	54.6	45.8	39.4	12.8	3.8	−20.7	17.3
1925	−36.6	−25.7	−1.2	21.6	46.1	57.4	56.7	54.2	44.2	27.7	.2	−19.5	18.8
1926	2.6	−16.7	10.4	25.8	42.4	58.4	59.4	------	43.7	25.4	2.4	−23.5	-----
Means, 1907–1926	−21.9	−11.6	−1.9	16.4	41.2	56.0	57.7	52.0	39.6	19.5	−7.7	−19.8	18.3
Highest													
1907–1921	32	40	44	53	77	86	88	86	79	45	33	34	88
1922	29	31	33	46	72	76	71	79	60	47	30	12	79
1923	30	36	30	41	66	88	90	83	64	55	26	19	90
1924	26	23	37	31	72	85	83	68	61	45	33	17	85
1925	4	16	28	42	73	80	79	83	59	47	30	28	83
1926	24	19	45	52	69	85	84	------	63	47	31	23	85
Lowest													
1907–1921	−70	−70	−68	−42	−17	27	27	19	−3	−41	−61	−69	−70
1922	−57	−53	−59	−33	1	30	27	17	4	−12	−50	−54	−59
1923	−69	−54	−55	−22	−11	31	33	28	18	−2	−43	−47	−69
1924	−57	−64	−41	−40	−2	29	30	21	16	−21	−32	−58	−64
1925	−61	−62	−57	−16	18	31	31	24	19	−9	−42	−60	−62
1926	−44	−55	−45	−11	22	32	35	------	22	−5	−41	−56	−56

The table of mean temperatures for the period at Allakaket is based on a broken record of 20 years. The highest and lowest temperatures are based on records of 17 and 19 years, respectively. According to these records, the extreme range of temperature is 160°, or nearly 30° greater than at Barrow, and the lowest temperature recorded at Allakaket is 14° lower than at Barrow. The lowest temperature shows a greater departure from the mean than the highest temperature, as the coldest day was about 88° below the mean, whereas the warmest was only about 72° above the mean. In all months temperatures as high as 32° may be expected, but temperatures below 32° have also been recorded in all months of the year, and in all but the three summer months June to August temperatures below zero have been recorded. The mean monthly temperature for the five months May to September is above freezing, and the average mean for the three summer months June to August is 55.2°, or more than 17° warmer than for the same period at Barrow. However, for the five winter months November to March the mean monthly temperature is −12.6° or about the same as for a similar period at Barrow. The difference in latitude between the two stations is about 4¾°, so that, computed from the records of the two places, the mean annual temperature decreases northward at a rate equivalent to about 1.8° for each degree of latitude. This generalization does not take into account the effect on the temperature produced by the highlands that lie between the two places. The elevation of Allakaket is less than 1,000 feet, though many of the mountains of the Brooks Range rise to elevations of more than 7,000 feet, and even many of the passes across the mountains are 4,000 feet above the sea. According to the formulas which are generally accepted by meteorologists, temperature decreases about 1° for each 300 to 600 feet of ascent, so that the mean annual temperature in the mountains may be 5° to 10° lower than at Allakaket.

A series of temperature observations have been made for a short time by the Weather Bureau at its station at Noorvik, near the mouth of the Kobuk. In general, the record from this place shows temperatures on the whole intermediate between those recorded at Barrow and at Allakaket. The greatest recorded range is about 141° at Noorvik, as against 131° at Barrow and 160° at Allakaket. The mean monthly temperature of the winter months is much higher than at either of the other stations, but the summer temperature is intermediate.

Temperature at Noorvik (° F.)

Mean

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1922	−1.3	0.9	−2.2	17.6	27.3	45.0	49.4	49.2	39.9	26.2	------	------	------
1923	------	------	------	15.8	38.5	52.7	57.2	60.0	41.0	31.4	10.9	−12.0	24.3
1924	−13.6	−11.0	8.6	−3.2	33.3	50.6	54.6	49.3	40.1	15.4	11.5	2.4	19.8
1925	−22.8	−15.4	4.0	20.4	41.2	54.6	55.4	54.0	41.5	27.8	7.8	−5.3	21.9
1926	4.5	−15.4	13.2	22.7	33.4	54.2	------	51.2	46.5	28.8	18.8	−15.0	------
Means, 1922–1926	−8.3	−10.2	5.9	14.7	34.7	51.4	54.1	52.7	41.8	25.9	12.2	−7.5	22.3

Highest

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1918–1921	25	34	34	42	62	84	87	85	61	45	37	36	87
1922	34	33	32	44	57	69	74	68	56	44	------	------	74
1923	------	------	------	36	64	74	82	81	66	52	32	28	82
1924	28	27	34	32	76	85	79	67	66	44	33	29	85
1925	15	18	31	40	73	76	87	79	54	42	35	33	87
1926	29	27	40	43	56	81	------	83	59	45	36	15	------

Lowest

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1918–1921	−54	−47	−43	−48	−3	27	34	31	18	−20	−33	−52	−54
1922	−33	−39	−43	−21	−2	26	34	22	17	−2	------	------	------
1923	------	------	------	−16	5	30	36	41	14	12	−20	−37	−53
1924	−50	−49	−27	−30	−2	32	33	31	25	−4	−18	−41	−50
1925	−49	−47	−37	−16	4	33	40	36	22	10	−23	−40	−49
1926	−45	−40	−22	−6	14	28	------	32	25	4	−8	−44	−45

The records obtained by the recent Geological Survey expeditions do not afford much new information on the temperature of the regions they traversed. This is due to three causes. First, observations were made only incidentally to other work and were not made under uniform conditions of exposure; second, the camps were moved so frequently that the records do not allow intercomparison; third, usually only the minimum daily temperatures were recorded, because the parties were generally on the move during the part of the day when maximum temperatures occur, and at that time suitable or uniform exposures were even less available than when the parties were in camp. In spite of the imperfections of record the following facts noted by the eastern and central parties of the expedition of 1924 may be of interest: Until practically the 1st of May the minimum daily temperature at camps in the Brooks Range did not rise above zero, and until practically the 1st of June it did not rise above freezing; the highest minimum daily temperature recorded in the plateau province was 50° for one day in July and one day in August, and the lowest minimum daily temperature was during the first week in April, when for seven days in camps in the Brooks Range the mercury stood at −32°, which was the limit of the minimum thermometer used.

Although the foregoing instrumental observations correctly express the measured temperatures of the region, a person's feelings regarding temperature do not react directly to heat and cold like a thermometer and are not susceptible of such measurements. Many factors, such as dampness or wind, modify or may actually reverse the effects of the temperature that is sensed. It is well known that a temperature many degrees below zero in quiet weather is far more agreeable than a temperature of zero or higher accompanied by strong winds. This was particularly noticed by the party in 1926 near the coast, where temperatures of 10° above zero accompanied by gales were much more uncomfortable and interfered more with the work than temperatures of 20° to 30° below zero that had been experienced in the mountain valleys to the east. A person's physical condition also has an important effect on how he bears cold. Old residents of northern Alaska say that after many years they do not stand the cold as well as newcomers. To judge from the experience of the Geological Survey members, persons in good physical condition can live in the open and sleep on the ground in tents throughout the winter with a surprising degree of comfort if they have adequate nourishing food and suitable fur clothing and fur sleeping bags. In fact, they found that during the time they were in the field fur clothes were usually too warm to be comfortable for a person physically active, and it was only when the men were inactive or riding on the sleds that such clothes were necessary. During the summer the members of the Geological Survey parties dressed in clothes of the same kind that they ordinarily wear for field work in the Northern States or southern Alaska, except for the addition of heavy woolen underwear. The natives, however, appear to wear about the same kind of clothes winter and summer. Probably this is due, as Leffingwell has pointed out, to the fact that after becoming accustomed to fur clothes one is easily chilled in ordinary garments.

The generally prevailing low temperatures have many advantages for travelers that may not suggest themselves at first thought. Among these advantages may be mentioned the fact that under this natural refrigeration most foods can be preserved in good condition for a long time. Fresh fish caught late in February immediately froze and remained in that condition until it was thawed and eaten in May. Meat was kept without spoiling indefinitely during the winter, although it often became frozen so solidly that it could be cut up only by means of a saw or an ax. The refuse from camps remained for months without putrefying. Some foods, however, do not stand freezing well, as after the water in them has become separated, through freezing, it does not reunite, so that after repeated freezings and thawings the original qualities are practically destroyed. Canned goods are especially subject to deterioration of this sort. Tooth paste and shaving cream are among the articles that lose many of their good qualities through freezing and become granulated and ineffective. Electric dry batteries when subjected to low temperatures fail to function, and their activity can be restored only by warming them. Cold interferes seriously with the effectiveness of lubricants—in fact, during the extremely cold months lubricants become so stiff that they must be removed completely from such articles as guns by a thorough washing in gasoline. Some of the instruments failed to function well owing to the stiffening of the lubricant or the precipitation of the minute particles of frost from the air they contained. This was particularly noticed in the action of the shutters of cameras, and a small moving-picture camera was entirely useless all winter from this cause. Precipitation of the moisture of the air is also a source of annoyance, as in several of the camps the inside of the tent remote from the stove became covered with a thick layer of frost that had condensed against the cold outside air. Precautions to prevent this condition are usually taken in the construction of houses by providing ventilators through which the warm, moist air may escape. Ventilation is essential not only for houses but also for clothing, as impervious clothing prevents the escape of the exhalations of the body, which then condense and form a disagreeable icy casing inside the clothing. The close yet porous texture of the skins used for clothing meets this condition admirably, but the glazed-finish leather often seen in so-called sporting clothes completely fails to ventilate properly and for that reason is actually dangerous. Condensation of air in the instruments is also a common source of annoyance but can be prevented by leaving guns and instruments outside the tent or house throughout the winter.

One of the most noteworthy effects of the cold is its effect upon the snow and sledding conditions. In extremely cold weather the surface seems gritty and is apparently made up of small, sharp, needle-like crystals of ice. These cut the feet of the dogs badly, so that they soon become sore and must be protected by dog moccasins or small canvas sacks. The rapidity with which this cutting is done is shown by the fact that experienced dog drivers report that at times several pairs of dog moccasins are worn out by each dog in a single day's travel. The needle-like snow also makes sleds drag heavily as if they were being pulled through sand, whereas during warmer weather the snow mashes down and the runners readily slip over it. During cold weather wooden strips called skis are usually bolted on the regular iron runners, as they slide more easily, but when the snow is wet it sticks to them and to the snow over which the sled is being dragged, so that progress becomes almost impossible until the wooden skis are removed and iron runners used. Iron runners are also best for use along the coasts or on salt-water ice, as they slip more easily and are not so readily broken. In fact, all the Eskimo sleds have runners of iron or bone, and runners of wood are practically unknown in the entire coastal region. The bone runners are said to slip along with the least amount of friction, and for that reason they are also especially advantageous for hauling over stretches of tundra that are bare of snow.

PRECIPITATION

Much of northwestern Alaska is arid, and throughout the greater part of Naval Petroleum Reserve No. 4 the annual precipitation probably does not exceed 10 inches. The following table shows the measurements made at the stations of the Weather Bureau at Barrow, Allakaket, and Noorvik:

Precipitation at Barrow, Allakaket, and Noorvik (inches)

Barrow

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1881-1921	0.13	0.43	0.20	0.26	0.26	0.30	0.94	0.91	0.52	0.68	0.28	0.43	5.34
1922	.13	.36	.90	.19	.03	.63	2.44	.59	.38	1.20	.54	.46	7.04
1923	------	------	------	.36	.65	.16	.53	.31	.49	1.07	.50	.37	------
1924	.47	.07	.30	.11	.26	.30	.95	1.45	.38	.14	.97	.25	5.65
1925	.12	Tr.	.45	.09	.05	.40	1.79	1.66	.95	1.65	1.09	.67	8.92
1926	.11	.16	.06	.23	Tr.	.10	.05	.47	.17	1.27	.03	Tr.	2.65
Means, 1881-1926	.16	.33	.29	.23	.23	.31	1.03	.90	.50	.86	.45	.39	5.68

Allakaket

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1907-1921	0.74	0.93	0.71	0.40	0.65	1.20	1.68	1.64	1.41	1.06	0.66	0.97	12.05
1922	1.20	.86	Tr.	.24	.09	1.66	4.34	1.69	.83	1.70	1.91	.15	14.67
1923	.76	1.79	1.80	.61	.81	1.61	1.10	1.58	3.03	.81	.05	.18	14.13
1924	.61	.32	.66	.47	.59	.95	2.48	------	.71	1.23	.80	.73	------
1925	.16	.32	.94	.13	.43	1.74	2.24	1.67	4.69	1.83	1.57	.86	16.58
1926	1.60	.12	.60	.48	1.31	.70	2.01	------	1.94	1.89	.45	.77	------
Means, 1907-1926	.78	.87	.74	.39	.65	1.24	1.88	1.64	1.62	1.17	.74	.86	12.58

Precipitation at Barrow, Allakaket, and Noorvik (inches)—Continued

Noorvik

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1919–1921	0.97	1.01	0.74	0.21	0.91	0.76	3.48	2.76	1.69	0.88	1.61	1.40	16.42
1922	1.17	1.34	Tr.	.52	.20	1.47	3.04	4.82	1.83	1.84	------	------	------
1923	------	------	------	.50	1.77	1.33	.31	1.42	3.62	1.01	.23	.52	13.05
1924	.59	.71	.67	.02	.43	2.22	3.33	5.13	1.77	.84	.91	.96	17.58
1925	Tr.	.00	1.31	.45	.80	.19	3.01	1.65	6.43	1.37	.80	.43	16.44
1926	.95	.14	.30	.28	.26	.15	------	------	2.87	1.87	.42	.68	------
Means, 1919–1926	.77	.75	.64	.30	.77	.96	2.77	3.09	2.84	1.24	.80	.77	15.70

The average precipitation at Barrow is computed from the more or less complete record that has been kept for 16 years. That at Allakaket is computed from the record that has been kept with relatively few breaks for 20 years. These measurements include both the precipitation that falls as rain and the water equivalent of the precipitation that falls as snow or sleet. From the detailed records of the Weather Bureau it is learned that the largest and smallest amounts of precipitation recorded during any one month at Barrow are, respectively, 2.44 inches in July, 1922, and traces in 12 months between January, 1902, and December, 1926; and at Allakaket 4.69 inches in September, 1925, and traces in May, 1919, and March, 1922.

At all three stations the precipitation is generally heaviest during July, the monthly means being, respectively, 1.03, 1.88, and 2.77. At Barrow 39 per cent of the average total annual precipitation falls during the three summer months; at Allakaket 38 per cent. At Barrow records for only six complete years are available for study, but for these six years the annual precipitation shows a departure from the mean annual precipitation as computed from the average of the mean monthly precipitation, based on the best partial records for 16 years, by showing an excess of 2.33 inches for 1882 and deficiencies of 1.67 inches for 1921 and 3.03 inches for 1926.

The following table shows the records for the monthly and annual snowfall at the Weather Bureau stations at Barrow, Allakaket, and Noorvik, based on incomplete records of 13, 19, and 8 years, respectively:

Snowfall at Barrow, Allakaket, and Noorvik (inches)

Barrow

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1902–1921	5.2	5.9	4.0	10.4	2.5	Tr.	Tr.	Tr.	4.8	11.0	5.0	6.6	55.4
1922	1.6	6.5	1.7	5.3	.5	0.3	9.0	0.5	6.6	14.6	8.3	8.5	63.4
1923	------	------	------	5.9	9.5	Tr.	Tr.	Tr.	3.8	11.6	4.9	.7	------
1924	4.7	.7	5.1	1.0	5.0	Tr.	.7	1.0	3.6	1.6	9.3	2.5	35.2
1925	2.0	Tr.	4.5	1.5	.4	Tr.	Tr.	0	7.9	21.2	19.0	9.7	66.2
1926	1.1	2.4	1.0	5.0	Tr.	Tr.	Tr.	Tr.	.5	19.0	.4	Tr.	29.4
Means, 1902–1926	3.8	5.4	3.5	6.2	2.9	Tr.	1.2	1.8	4.6	12.4	6.9	5.9	54.6

Snowfall at Barrow, Allakaket, and Noorvik (inches)—Continued

Allakaket

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1902–1921	13.0	15.8	14.3	6.4	0.5	0	0	0	1.2	8.8	10.8	14.6	85.4
1922	14.2	8.2	Tr.	Tr.	0	0	0	Tr.	Tr.	4.3	16.8	4.0	47.5
1923	20.0	24.6	24.6	11.0	4.0	0	0	0	3.2	7.5	.5	2.5	97.9
1924	13.5	10.0	11.0	13.0	0	0	0	------	2.5	7.2	12.0	13.5	------
1925	2.7	4.6	12.9	------	0	0	0	0	1.5	4.7	27.0	12.1	------
1926	23.0	2.5	11.8	6.0	3.0	0	0	------	2.0	24.8	6.5	12.5	92.1
Means, 1902–1926	13.6	13.9	13.5	6.8	8	0	0	Tr.	1.4	9.1	11.4	12.8	83.3

Noorvik

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Means, 1919–1921	13.1	16.7	11.6	4.0	3.2	Tr.	0	0	1.8	11.0	9.2	12.0	82.6
1922	9.0	16.1	Tr.	6.6	.5	0	0	0	Tr.	1.0	------	------	------
1923	------	------	------	6.4	5.5	0	0	0	2.5	9.0	2.6	7.9	85.1
1924	12.0	8.5	10.8	1.0	.2	Tr.	Tr.	Tr.	1.5	5.5	9.2	9.0	57.7
1925	Tr.	.0	19.1	1.0	Tr.	0	0	0	.5	2.0	4.8	4.0	31.4
1926	12.9	1.5	4.0	3.2	0	0	------	0	0	1.0	.5	5.0	28.1
Means, 1919–1926	10.0	10.9	9.8	3.8	2.0	Tr.	Tr.	Tr.	1.1	5.8	5.3	8.3	57.0

From this table it will be seen that snow may fall in every month of the year at Barrow but that it practically never occurs during June, July, or August at Allakaket, though in the mountains north of that town it falls every month of the year. At Allakaket the monthly fall of snow increases more or less regularly from September until it reaches a maximum in February and then decreases somewhat more abruptly until it becomes insignificant in May. At Barrow there is no such regularity in the monthly distribution of snow. The records show that usually the snowiest month is October, with November ranking second and April and December, having about the same amount, third. The months having the heaviest snowfall during the period for which records are available were, at Barrow, April, 1916, when 26.5 inches of snow was recorded, and, at Allakaket, February, 1920, when 47 inches of snow was recorded.

Apparently the records of the snowfall at Barrow are too few to afford an entirely reliable estimate of the average snowfall. This is apparent when the snowfall as given in the foregoing table is compared to the total annual precipitation stated in the table on page 58. For instance, if the entire precipitation for the year were tentatively considered to fall as snow, each inch would be equivalent to about 9.6 inches of snow. Obviously, however, most of the precipitation during the summer falls as rain, so that if this amount were deducted from the average annual precipitation and all the rest of the precipitation were assumed to fall in the form of snow, each inch of water would require at least 16 inches of snow, an abnormally high equivalent. A similar computation from the records at Allakaket suggests that at that place about 10½ inches of snow is equal to 1 inch of water. Both of these estimates are minima, for unquestionably some of the precipitation in the other months besides

June, July, and August is in the form of rain, and whatever further deduction should be made to allow for it would increase the number of inches of snow required to equal an inch of water. Furthermore, it is very difficult to get an accurate measure of snowfall in the region because of the driving winds. As Leffingwell[27a] has pointed out regarding his own observations:

> No attempt was made to measure the precipitation, and it is extremely doubtful if this could be done accurately. During high winds the air is full of driving snow for several hundred feet vertically, yet an open-top receptacle placed on the ground would probably remain empty, on account of the peculiar air currents.

Leffingwell estimates the snowfall in the mountains to be perhaps 3 to 4 feet, and this corresponds closely with the judgment of the members of the recent Geological Survey expeditions.

Although the foregoing instrumental observations constitute the most authoritative and reliable data regarding the precipitation of the region, they suggest an aridity far more intense than other features of the region indicate. These apparent conflicts between facts and impressions can be reconciled when it is realized that small precipitation is only one of the factors that determine the characteristics of arid regions such as the Sahara or the arid lands in the Basin province of the western United States. A region of small precipitation is usually pictured as devoid of water, but in northern Alaska water is almost everywhere. The surface of the country during the summer is commonly wet and swampy, and water stands on the surface in ponds and lakes. The streams, unless they traverse a broad belt of limestone, show no marked diminution of volume but constantly increase in size toward their lower courses. All these features are due in large measure to the permanently frozen condition of the subsoil, which makes removal of surface water by percolation and by underground migration impossible. Furthermore, the low elevation of the sun, even during the summer, prevents rapid evaporation. The rainfall or snowfall thus stands on the surface or collects in the low areas where the slope is not sufficient to induce surface run-off. Then again, the upper 6 to 18 inches of the frozen zone melts during the summer and thus produces wet, soggy footing that is most unlike any preconceived idea of a dry country. Furthermore, the precipitation does not come in deluging cloud-bursts, separated by long intervals of low precipitation, as in the countries more often referred to as arid, but comes in numerous light showers or heavy mists. As illustrative of this condition may be cited the experiences of travelers in this general region. Many of their reports are not complete enough to furnish the exact data desired, but the following table shows the number of

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[27a] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, p. 62, 1919.

days on which different travelers definitely report some precipitation. Although this table therefore only serves to indicate the minimum number of such days, it may give undue emphasis to the number of days on which some precipitation fell. This is especially true of the records of Smith and of the recent survey expeditions, for on many of the days counted the showers were not of long duration and yielded only a small amount of water. Still, they were nearly as disagreeable to the traveler as the heavier showers and left him with an impression, which is essentially correct, that he was damp much of the time.

Precipitation observed in northwestern Alaska

Traveler	Region	Days spent in region	Days on which precipitation is reported	Per cent of days of precipitation to days spent in region
McLenegan	Noatak River	40	15	37
Allen	Koyukuk River	18	6	33
Schrader	Alatna-Arctic divide	39	11	28
Smith, 1910	Koyukuk-Kobuk	77	44	61
Smith, 1911	Alatna-Noatak	64	37	58
Expedition of 1924	Alatna-Barrow	182	105	58
Expedition of 1925	Noatak-Colville	132	53	40
Expedition of 1926	Kotzebue-Wainwright	153	83	54

Foggy weather is common near the coast, especially during those periods in summer when the ice pack is close to the shore. In fact, the presence of fog offshore is often a sure indication of the nearness of the ice pack and is one of the factors that adds much to the dangers of navigation in the Arctic Ocean.

WIND

The strength and direction of the winds largely determine the time of the break-up or freeze-up of the streams and of the ocean. They very decidedly affect temperature directly, as well as have a marked influence on the effect that temperature has on people, and they probably control to a considerable degree the distribution of bushes and vegetation. At Barrow the prevailing wind, as indicated by observations of the Weather Bureau, extending over a period of nine years, is easterly, except for the months of October to December, when it is northeasterly. At this place the highest wind velocity recorded was 100 miles an hour in January, and the next highest was 71 miles an hour in February. The latter record, however, was probably not the true extreme of that particular storm, because shortly after the observation was made the anemometer was blown away. The average annual wind velocity during the two years in which continuous measurements have been made instrumentally by the Weather Bureau at

Barrow is 13.1 miles an hour. In this period the highest average hourly rate for a month, namely, 18.4 miles an hour, was in November, and the lowest, 8.4 miles an hour, in December.

At Allakaket the prevailing wind direction for the year is easterly, though in June and July it is westerly, and in November and December it is northeasterly. No records are available of either the maximum or the average hourly velocities for the different months at this station. From noninstrumental observations, however, it seems certain that the wind velocities do not average so high, nor are the individual gusts so violent as they are at Barrow.

Leffingwell states that at Flaxman Island the chief winds are from the east-northeast and west-southwest. East winds there prevail during the summer and west winds during the winter, and the strongest gales come from the west. These gales from the west usually last for only short periods, but east winds having a velocity of 30 miles an hour may last for more than a week at a time. Leffingwell also states that in the north or south valleys in the mountains calms usually prevail except during the periods when warm winds blow from the south. The experience of the recent Geological Survey expeditions hardly confirms this statement of the quietness of winds in the mountains. On many days the wind was boisterous and in no sense warm. In the mountains, however, the direction of the wind was either up or down the valleys, so that even in near-by areas entirely different winds were encountered in the valleys that had different trends. Owing to this control by the topography the winds in the mountains usually change direction 180° rather than by small amounts. In the plateau and plains regions the topographic control is much less noticeable and the winds are steadier and do not change their direction greatly within a short time.

The expedition of 1926 spent much of its time in the Arctic coastal plain and Arctic Plateaus and the lower part of the Brooks Range. On this expedition the winds were at times so violent that they seriously hampered the work by blowing the alidade off the plane table and quickly numbing the observers so that they could not maintain exposed positions. During one of these windstorms a 19-foot canoe, weighing probably 150 pounds, whose bow and stern were embedded and frozen into patches of snow, was picked up by a gust and carried many feet in the air a horizontal distance of over 200 yards before it struck the ground and rolled into the lee of a slight obstruction. Many times the wind was so strong that it swept thick clouds of dust and snow from the bars so that they totally obscured the view, and again it tore newly formed ice an inch or two thick off the streams and ponds.

The snapping, slatting, and popping of the tents during these windstorms was incessant and so vehement that the sensation was described at the time "as if a giant washwoman was scrubbing and wringing out a tubful of very dirty clothes." The wind drove the fine particles of snow even through the very close texture of the balloon-silk tents, into closed and fastened valises, and into sacks that were reasonably securely tied. Curiously, the most violent windstorms occurred with rather a high barometer, and although sometimes the barometer showed drops of more than three-fourths of an inch of mercury, these occurred usually during good weather and at least several days before a storm. Life in the open is practically impossible during severe windstorms, and according to those who have lived long in the region, both whites and natives, the only thing for a traveler to do when caught out in such weather is to crawl into his sleeping bag or such other protection as is available and await the abatement of the storm. This procedure was probably all that preserved the Barrow mail carrier in 1925 when, being overtaken by such a storm, he dug his way into a snowdrift and remained there for many days. One of the members of the 1926 Geological Survey expedition, a man who had lived for nearly 30 years in central Alaska and carried mail during all kinds of weather on the Yukon, after having experienced some of these storms near the northern coast, said that although he had been out in temperatures scores of degrees lower and had worn clothes of the same kind, he had never suffered so much and should never work again in that kind of a climate without a complete set of fur clothing—a thing practically unheard of in central Alaska.

OPENING AND CLOSING OF NAVIGATION

Undoubtedly the most important events of the year in northern Alaska are the opening and closing of navigation. On the coast the open season means the time when vessels from the outside can traverse the water of the Arctic Ocean, and inland it means the time when boats can travel freely on the streams. The dates of opening and closing of ocean navigation differ greatly in different years, because a great many different factors combine to produce the result, and as they are all variables they seldom if ever combine in exactly the same proportions. In the Arctic Ocean wind is perhaps the most important agency in dispelling the winter's ice, but the same wind that drives the ice from the Alaskan coast may jam it more densely on the coast of Siberia, so that at the same time different parts of the coast may be in very different stages of freedom from ice. In favorable seasons boats can get to Kotzebue early in July, to Wainwright by July 20, and to Barrow by August 1. In 1921 the sea ice broke on July 23, but in 1922 it was August 21 before the first boat reached Barrow. In 1924 the first boat did not reach Barrow until August 7, and the ice came back again within a day or two, so that the vessel was caught in the ice and sunk a short distance south of the town a few days later. So far as could be learned, the ice then kept solidly packed against the coast at Barrow until about August 25, when it began to open a little; by August 30 it was far enough off the coast for boats to get to Barrow, and it stayed in this position for several weeks. In 1926 an exceptionally favorable opening of the ice pack allowed the first vessel to reach Wainwright on July 7 and Barrow more than a week later, but the ice soon closed in again, so that the *Bear* did not reach Wainwright until July 31, and it was August 10 before she got to Barrow and then only after breaking ice for days and smashing her way in and having to pull out again almost at once, as the ice set in and threatened the ship.

Early in the spring or summer, before the large ice pack leaves the coast, there is often considerable open water between the shore and the heavy ice, so that shallow-draft boats, by keeping close to the shore, can travel long stretches before the sea ice breaks. It is thus possible for small boats to travel along much of the northwestern coast early in July. Relying on this condition, the expedition of 1926 traveled in canoes from the mouth of the Kokolik to Wainwright along leads in the ice of the lagoons and of the ocean and were able to reach Wainwright several days before the first ship from the outside. However, the water in many places was so shallow and the lead of open water so narrow that it would have been impossible to take much larger boats through at that time. In fact, at several places the ice was jammed so solidly against the shore that the expedition had to camp and await for several days the formation of a lead by which it could proceed. An annoying feature of thus traveling along the coast was that while an offshore wind tends to drive the ice seaward and thus open a lead, it also drives the water offshore. As a result of this condition, the expedition was held up several days at Kilimantavi, not only by the ice that had grounded on the coast but also by the lowering of the sea level a couple of feet by the offshore wind. In thus traveling in the early spring along the coast the entrances through the reefs are especially difficult places to get by, as they are usually beset by strong currents, which carry large quantities of ice either into or out of the lagoons. Furthermore, as pointed out by Leffingwell, near the time of the break-up of the ice on the ocean the weather becomes raw, windy, and foggy, so that it is especially disagreeable if one gets wet, as is almost inevitable when traveling in a small boat under the conditions described above.

The ice pack is almost always within a relatively short distance of Barrow, and the oldest Eskimos say that in some years it has failed to move off the coast far enough to allow navigation. Possibly this is true, but if so it is so rare an occurrence that in no year in all the period when white men have been in the region has the sea ice failed to open, although, according to Captain Healy, in 1884 it was impossible for a vessel to sail eastward around Point Barrow. The other points at which the ice pack hangs longest in the spring are Blossom Shoals, near Icy Cape, and the Seahorse Islands, off the entrance of Peard Bay, and all mariners experience a feeling of relief when these foul grounds are safely passed.

The time of closing of ocean navigation in the fall is also variable. According to the Weather Bureau records, the ocean closed in 1920 on October 9; and the same authority states that in 1921 the ice pack became visible on the horizon at Barrow on September 7, but it drifted off and on shore at intervals during October and November, although open water prevailed most of the time until December 13, when young ice formed solidly as far as the eye could see. It must not be assumed from this statement, however, that the Arctic Ocean is open to vessels anywhere near as late as this, for ordinarily vessels plan to be west of Point Barrow and headed southward early in September. Leffingwell states that after the middle of September new ice may form at any time and that the ocean waters crust over several times before they become permanently icebound. During this period travel is at a standstill, because the ice is too thick for progress by boat and yet not strong enough to be safe for sleds. By the middle of October coastal travel with sleds and dog teams becomes again feasible. Stefansson states that in 1908 his vessel became icebound in Smith Bay September 7, on September 10 the ice was so thick that he used sleds between the ship and the shore, on September 17 the ice was strong enough to allow freighting to be carried on, and for the rest of the season the bay was icebound.

Perhaps the most authoritative statement on the general ice conditions and the time of the closing of the season for ocean navigation near Barrow is the following statement in the United States Coast Pilot:

> Beyond Icy Cape there is always danger to vessels, and strangers should be cautious and careful in going there. In the lead of open water between the pack and the shore the current is swift and nearly always carries drift ice, and vessels rarely reach Point Barrow at any time without encountering some ice. The ice can not be forced, and vessels should not venture into small leads

between the pack and shore ice. * * * Navigation east of Point Barrow is such that it should only be attempted by those having experience.

As a rule, the pack does not come down on Point Barrow before the latter part of September, but in 1897 it came down the first of September, and, in general, except for whaling vessels, whose officers are men of long experience in judging ice, weather, etc., September 1 is as late a date as vessels should remain in that vicinity. About this time, or a little later, young ice begins to make in the lagoons, along the shore, and around the old ice, though it is not likely to form in the open sea until the last of the month. The young ice makes stronger and spreads over the open sea with the advancing season. It is dangerous to vessels and will very quickly cut through one not sheathed to withstand it. Ordinary vessels should be out of Kotzebue Sound by September 15 to 20 and out of the Arctic by October 1. The whaling vessels make it a rule to be ready to leave there about October 10, and though there may be times when they stay later, these are exceptions.

According to captains long familiar with these waters, navigation is attended with considerably greater risk than in otherwise similar waters tributary to the north Atlantic Ocean, because from Bering Strait northward for some distance the trend of the currents is in general northward, so that the route by which a ship penetrates into the pack may become blocked in the rear, whereas on the Atlantic side, as the current is in general southward, there is less danger from this cause. In other words, if a ship becomes unable to proceed in its northward course on the Atlantic side, it can usually back out and will be assisted to get clear by the currents, whereas on the Pacific side it may be hampered by ice that has been swept in behind it and also have to fight against the set of the currents and the ice. As an indication of the hazards of navigating these waters, it is understood that in general the summer rates of marine insurance increase successively by steps of about 1 per cent between Cape Prince of Wales, Cape Lisburne, Icy Cape, Wainwright, and Barrow.

Break-up of the ice on the rivers proceeds in general from the head toward the mouth, so that even in a single basin several days may elapse between the break-up at different points. In the mountains and in places where the streams freeze solidly to the bottom there is no break-up in the strict sense. In such places the water from the melting snow collects in the bottom of the valley and runs over the surface, gradually cutting a channel through the ice until it reaches the bedrock or gravel floor. Then undercutting by the stream and melting by the air causes blocks of ice to break off and be carried downstream. In this way the channel of the stream and later the floor of the valley are widened out and freed of ice. In the break-up of the larger streams, however, when the volume of water running under the ice increases, the ice is bulged up and put under strain until it ruptures. Then a wild, crashing torrent of ice blocks and water sweeps down the stream, overriding low banks, twisting and plucking out bushes, here and there jamming and producing a pond upstream from the barrier until it finally acquires sufficient head to burst the dam and carry the process of break-up farther down. Ice as much as 5 feet thick forms during the winter on the streams in northern Alaska, so that the noise, confusion, and appalling power of the streams when they break can be imagined, though they can not be entirely realized by anyone who has not actually seen the break-up.

The winter headquarters camp of the expedition of 1924 was in the region where the break-up was due mostly to the action of cutting through, but one of the small streams near that camp broke with a roar like a landslide that could be heard for miles and piled up a windrow of broken ice like levees along its banks. A few miles below the winter headquarters farther down the main stream, where the river had had a true break-up, large blocks of ice were stranded far up on the banks, and bushes were twisted off or barked and bent down by the flood of ice and water that had overrun them. Almost the entire time the expedition of 1924 was in the Colville Basin it had difficulty in finding suitable camping places near the river, because of the thick coating of mud that the high water of the break-up had left over the entire country, which stands 10 to 15 feet above the usual level of the river.

The point where the expedition of 1926 awaited the opening of boating water on the Kokolik River was also above the place where the stream was large enough to have a true break-up. Instead, the ice gradually rotted or was cut out until the channel became clear. Because of this condition it is difficult to state a precise time when the river opened. For many days there was more or less running water near camp, though later this again became covered with ice during cold spells. At the same time, however, the river a few miles farther downstream remained icebound for weeks after considerable open water had been seen at camp P May 15. Usually the cutting through of the ice in the headward portion of streams takes place soon after any considerable volume of water commences to flow. As more and more water is furnished the river rises, and high water does not occur until several days later. During this high stage the river undercuts the snow drifts and banks, thus augmenting its volume and widening its channel. After the collapsing snow banks cease to add materially to the streams and the run-off from the hills decreases, the volume of the river begins to decrease until it reaches a normal stage.

A noteworthy feature of many of the northern rivers consists of the tracts, many of them several miles long and a mile or so wide, along their courses that during the winter become filled with ice through the freezing of the water that overflows them. These look like ice-covered lakes and are often locally spoken of as "glaciers," though of course they are not. Leffingwell adopted the name aufeis, proposed by Middendorff, for these heavy deposits of ice on the flood plains, and that name will be used here. The process of their formation is in general as follows: When a stream has completely frozen over, water seeping along beneath the ice or from the banks may produce sufficient pressure to fracture the ice and escape through the weak places. This overflow water itself soon freezes and thus forms a new skim of ice, which in turn may be broken or coated over as the pressure again increases. In this way the process continues until the ice is too thick to be broken or the flow of water decreases to such an extent that it can pass through the gravel or in an unfrozen zone under the ice. Several of these large deposits of aufeis were seen in the valleys of the Killik River and a few other streams that are tributary to the Colville, as well as on the Kivalina River, but none of any size were noted on the Kokolik, Utukok, or Ikpikpuk. In the spring high water apparently many of these aufeis deposits are entirely submerged, for mud, boulders, and driftwood are found on their surfaces.

This was the stage of the first aufeis deposit traversed north of the winter headquarters of the expedition of 1924. (See pl. 9, *A*.) Soon, however, the sheet of water becomes restricted to definite channels, owing to the irregularity of the surface of the ice, and these channels intersect in intricate patterns similar to those of braided streams flowing through a flat gravel plain. At first these channels are hemmed in by ice walls (pl. 9, *B*), but soon the water cuts through to the underlying gravel and begins to undermine the ice. When sufficiently weakened by undermining, great blocks of ice fall suddenly, throwing huge masses of ice 5 to 8 feet thick into the stream. Navigation under these conditions is hazardous, not only because of the possibility of being directly struck by the falling ice but also because of the waves thrown up as the masses fall into the water or the chance of being struck by floating ice carried down by the current. This was practically the condition of the aufeis that was traversed on the Killik River above and below the mouth of the Chandler River on June 10 to 13. (See pl. 9, *C*.) At a still later stage the only aufeis remaining consists of pieces far up on the bars, out of reach of the streams, that slowly melt during the summer. (See pl. 9, *D*.) The normal structure of the aufeis is horizontally layered, with the component ice prisms standing vertical. At places the successive layers are separated from one another by open spaces in which icicles hang down like stalactites or columns. The building up of these accumulations of aufeis undoubtedly has a marked effect in producing the abnormally broad-floored valleys that are characteristic of many northern streams. This is due to the random and rapid change in the position of the streams which are annually obstructed by these ice deposits and which on resuming flow the next year take new positions as outlined above. Successive stages in the disappearance of the deposits of aufeis are shown in the series of views forming Plate 9.

An interesting feature of these aufeis deposits consists of the ice mounds or bulges which, according to Leffingwell, are usually formed during the early part of the winter. Several of these hummocks were seen, especially toward the lower or northern limit of the aufeis tract a few miles north of the winter headquarters of 1924. A characteristic view of one of these mounds is shown in Plate 10, *A*. Some of the mounds rise 10 feet above the level of the adjacent ice. Their longer dimension is usually parallel to the axis of the valley in which they occur, and several of the mounds seen were more than 200 feet long. Usually a partly open fracture or group of fractures extends parallel to the longer axis, and several radial fractures extend normal to this direction. The ice exposed in these bulges is usually of a deep-blue color and laminated parallel to the outer slopes of the dome. The ice is unusually compact and is of such especially good quality for camp uses and so readily quarried that trips of several miles were made to the nearest mounds to get the ice needed. Pebbles and boulders as much as 6 or 8 inches in diameter were at places embedded in all parts of the ice, as if they had been picked up from the bottom during the process of freezing and then buried by the further accumulation of ice both above and below them.

A rather unusual opportunity of seeing at close range one of the features connected with the last stages in the freeing of the rivers and lagoons from ice—namely, the rising of anchor ice from under the water—was afforded near camp S June 1 on the Killik River. When the party approached this place the water was seen to swirl suddenly in so unusual a manner that it seemed to forebode trouble, and the party landed immediately and got the boats into a safe position. Hardly had this been done when a black tangle of willow roots and ice began to rise, and this was followed by more violent agitation of the water and a sheet of ice more than 100 feet long and several yards wide rose almost at the men's feet. For the next few minutes small pieces of ice rose or actually sprung a short distance out of the water, owing to the momentum with which they rose and the drive of the current. The surface of this anchor ice was covered with gravel and small pebbles and matted masses of vegetation. Soon afterwards the turbulence of the river at this place ceased, but all day chunks and masses of ice that had been derived by similar action from points farther upstream or that had broken from the aufeis deposits floated by the camp. A view of a large mass of anchor ice that had just risen is shown in Plate 10, *B*.

Records regarding the exact date of the breaking of most of the northern rivers are lacking. Howard reports that in 1886 the Ikpikpuk broke near Kigalik June 2 to 8, the river rising 6 feet on June 6. Stoney, who was camped on the Kobuk River during 1886, reports that in that year the ice began to break on the Kobuk May 19 and the river was free of ice by June 6. Grinnell reports that ice began to break on the Kobuk May 24, 1899, and the river was free of ice by May 31. The mouth of the Kobuk, however, is inaccessible from the sea until much later, so that in 1885 ice remained in Hotham Inlet until July 8, and in 1888 it was July 13 before a landing could be made at Cape Blossom, though in 1899 there was a channel open through Hotham Inlet by July 1 and a boat that wintered at Chamisso Island was able to reach Kotzebue on July 8. According to Schrader, ice broke on the Koyukuk at Peavey, about 20 miles (air line) above the mouth of the Alatna, May 19, 1899, and in 1901, at a point somewhat farther up the same stream, it broke May 29 and the river was free of ice by June 6. In Schrader's report it is stated that in 1901 the ice broke on the Colville July 16. This statement appears to refer to the ice on the coast, or "July" may have been a typographic error for June. According to Leffingwell, the Canning River breaks out about May 20, and he believes that many of the streams in that region break at about the same time, though in some of them, including the Canning, large deposits of aufeis remain until late in the season. Leffingwell states that in July, 1908, the Canning River near its fork was flowing through a narrow canyon in a field of ice more than 12 feet thick.

The following record was furnished by the Weather Bureau station at Allakaket for the dates of the opening of the Koyukuk at the mouth of the Alatna: 1917, May 19; 1918, May 27; 1919, May 14; 1920, May 25; 1921, May 18; 1922, May 21; 1923, May 18; 1924, May 19.

Near the headquarters camp on the Killik River in 1924 the first small side stream broke May 19; a trickle of water coming down on top of the ice of the main stream valley reached camp May 25; a strong stream of water carrying small blocks of ice was running by the camp May 28; and the camp was abandoned and the party started downstream in boats May 30.

The expedition of 1925 reported that some surface water was running May 13 at the camp on Driftwood Creek, a tributary of the Utukok. To the east, however, in the Colville Basin, the creeks did not have much water running in them until May 19, and on May 20 the surface water had again frozen solidly and remained frozen until May 25, when there was some surface run-off. By May 27 the river was running bank full at camp G May 24, and on May 30 canoes were first used. The river continued to rise, however, so that the highest water did not occur until June 8.

The expedition of 1926 reported that when it reached the Kokolik River May 10 the snow was soggy and there was so much water on the ice of the river that a crossing had to be sought with considerable care. Later, when camp was moved to camp P May 15, the sleds broke through the ice at several places, and shortly after that ice re-formed on the river and lasted until May 22. On May 23 gales tore the new ice off the river, and from that time on there was always some running water near camp, but in the narrow part of the valley, 6 to 8 miles farther north, the river was bridged by snow and ice as late as June 2. On June 4 the water in the river at camp rose nearly a foot, on June 5 the winter camp was abandoned, and the expedition was able to use canoes all the rest of the way down the Kokolik River. The highest water came June 8, and after that date no more ice was seen in the river.

The closing of the streams in the fall extends over a period of many days, during which travel is especially difficult. Stoney reports that in 1885 ice formed on the lakes near the Kobuk September 23 and along the river by September 25 and that it was frozen so solidly by October 18 that it could be crossed. Grinnell reports that in 1899 the Kobuk was full of ice October 15 and that by October 21 the ice was 1 foot thick. Schrader notes that in 1898 ice was running in the Koyukuk at Peavey September 20. On his traverse from Wainwright to the Noatak in 1924 Foran found the streams tributary to the Utukok either so small or so frozen that he was unable to use a canoe south of his camp of August 24 on Disappointment Creek until he reached his camp of September 15 on the Nimiuktuk River. However, he was able to use the canoe the rest of the way down the Noatak to Kotzebue. Kotzebue Sound was partly closed by ice October 1, 1924, and it was only by chartering a special boat that the party was able to procure transportation to Nome. The regular mail boat had already been caught in the ice and, as was learned later, was lost. All the other recent parties were out of the region before the freeze-up, so that from their own personal experience they furnished no additional facts on this subject.

The following dates are those on which, according to the Weather Bureau records, the Koyukuk closed at Allakaket: October 28, 1916; October 17, 1917; October 19, 1918; October 30, 1919; October 4, 1920; October 10, 1921; October 21, 1922; October 27, 1923.

No continuous records of the thickness of ice formed during any one winter at a single place in this region are available. However, the expedition in charge of Ray[28] in 1881–82 made several measurements of the ice at Barrow, with the following results:

Thickness of ice at Barrow, 1881–82

On lagoon:	Ft.	In.	On Arctic Ocean:	Ft.	In.
November 1	1	¼	December 4	2	5
January 1	3	9	January 3	3	8
February 27	5	1½	February 2	4	2
April 1	6	--	March 7	5	2
May 1	6	2¼	April 2	4	11
			May 2	5	½
			July 1	5	--

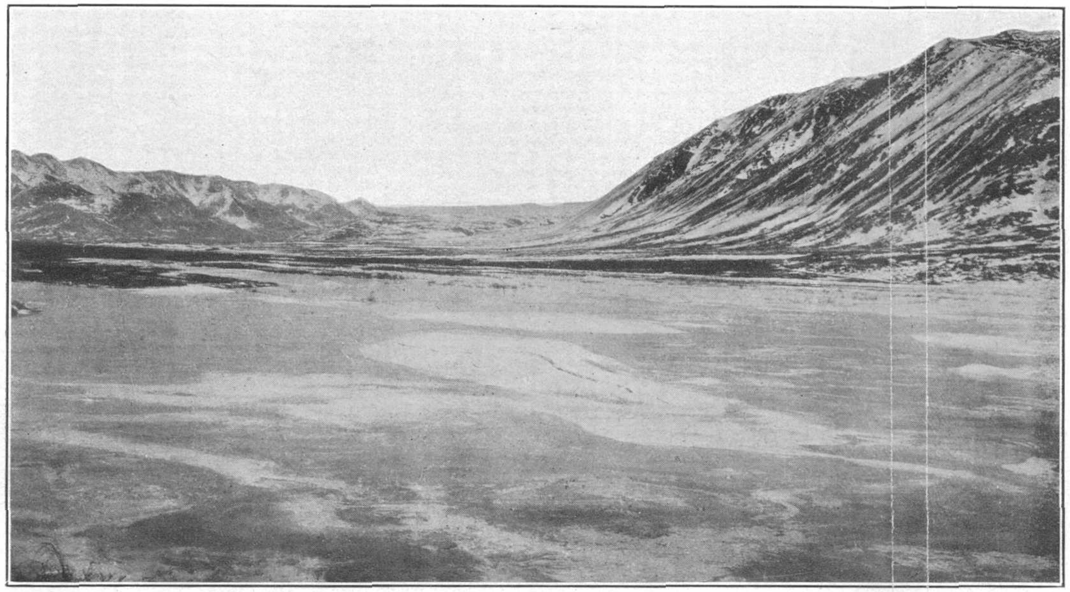
This record, together with scattered data from many sources, indicates that throughout most of northwestern Alaska the average thickness of ice formed during a winter is between 5 and 6 feet.

VEGETATION

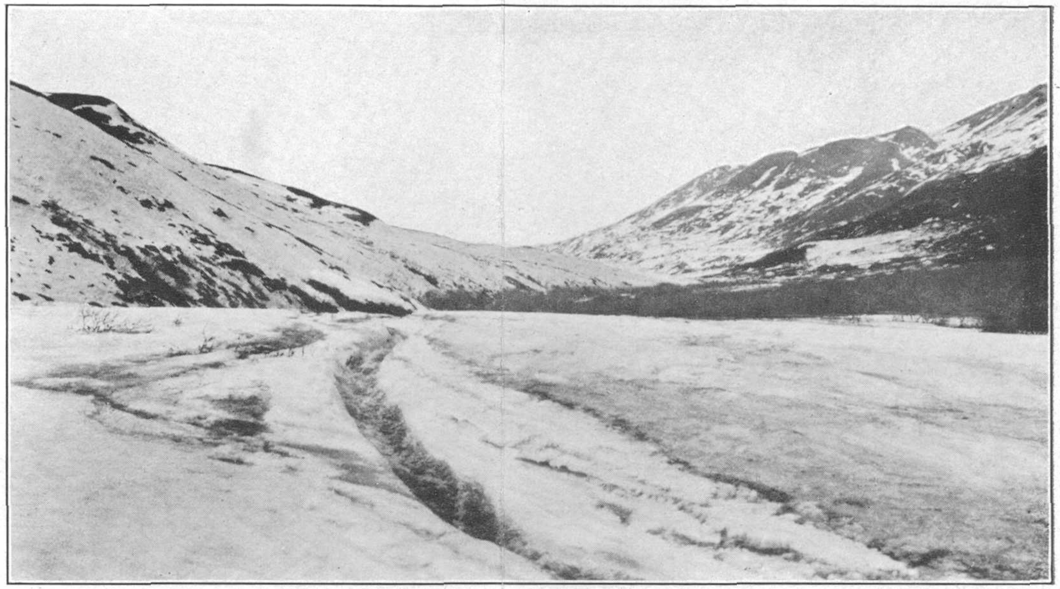
Most of northwestern Alaska lies north of the tree zone. Only in the lower lands of its southern part are there spruce or other real trees, as that term is commonly understood. The general distribution of trees in the area is indicated by Figure 4. Although in this figure several areas are shown as " unexplored " and although several other parts have not actually been visited in detail, it is believed that practically all the areas in which trees occur are fully shown and, except in the southern part, will not be materially extended when the region is more completely surveyed.

In the valley of the Alatna spruce extends within about 6 miles of the pass to the Noatak and up the Unakserak to the camp of March 17. At both of these places the northern limit of trees comes abruptly. A few hundred yards south of the actual limit the trees are of about the same size as they are for scores of miles to the south, but in that short distance they disappear entirely. On the Unakserak spruce trees 8 to 10 inches in diameter, 30 feet tall, and nearly straight, which apparently have suffered little from strong winds or cold climate, were found at camp March 17, but 100 yards beyond there were not even dwarf trees or any signs that there had been trees within many miles. Plate 11, *A*, shows the last of the spruce that were seen on the Unakserak, and it will be noted that the trees are of good size as compared with the tents and are quite symmetrical. This same condition prevails on the Alatna above the Unak-

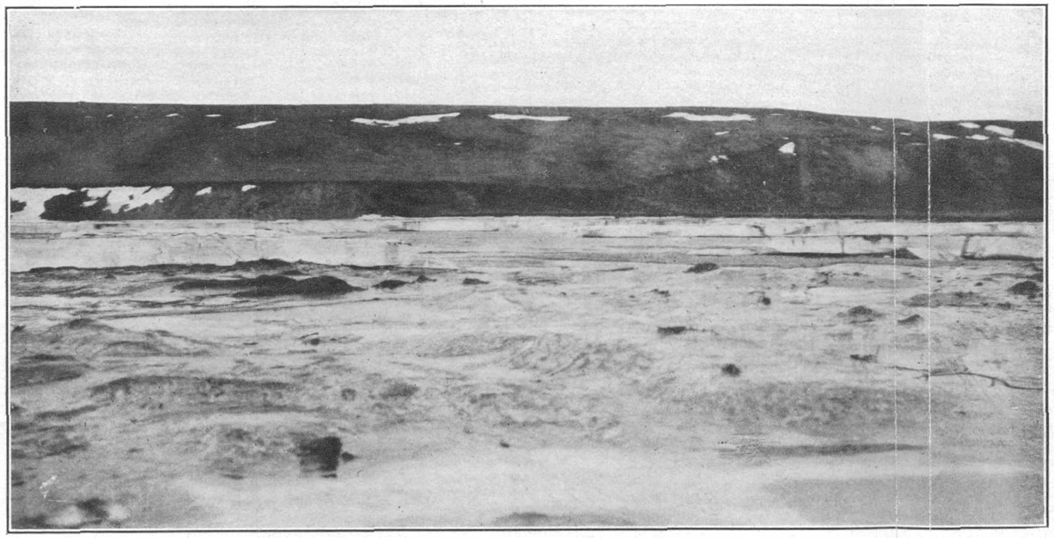
[28] Ray, P. H., Report of international polar expedition to Point Barrow, 1881 to 1883: 48th Cong., 2d sess., Ex. Doc. 44, 1885.



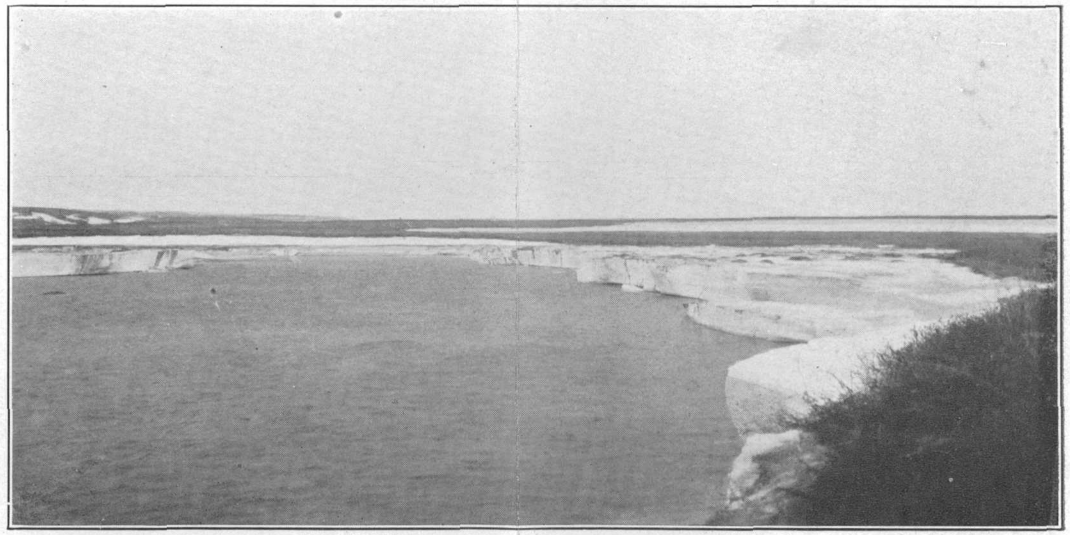
A. ICE PRACTICALLY UNERODED, WATER FLOWING OVER SURFACE AS SHEET



B. WATER BEGINNING TO COLLECT IN CHANNELS CUT TO A SLIGHT DEPTH IN ICE

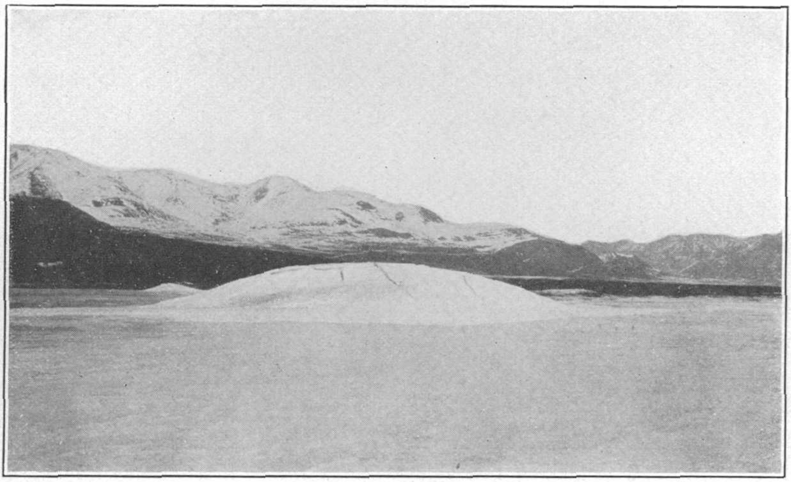


C. LARGE CHANNELS CUT THROUGH ICE TO GRAVEL, INTERVENING ICE BLOCKS UNDERMINED AND CARRIED AWAY, AND MUD AND DETRITUS ON TOP OF ICE

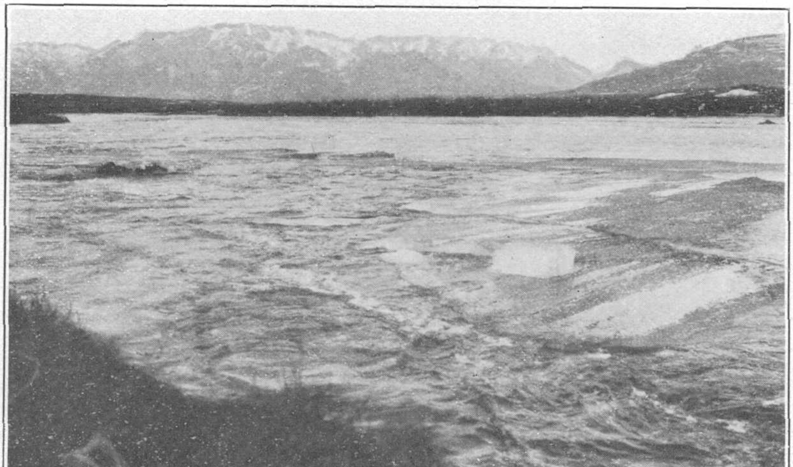


D. WIDE CHANNELS FORMED, AND INTERVENING ICE BLOCKS HAVE DIMINISHED GREATLY IN SIZE

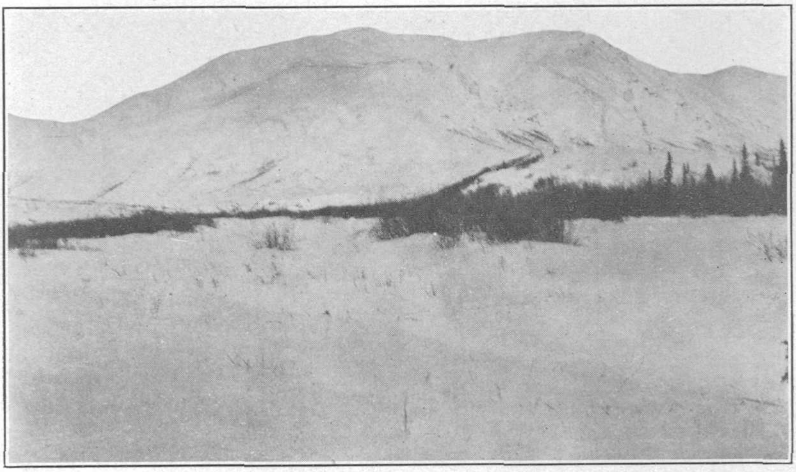
AUFEIS DEPOSITS ON KILLIK RIVER



A. ICE DOMES ON AUFEIS DEPOSITS, KILLIK RIVER

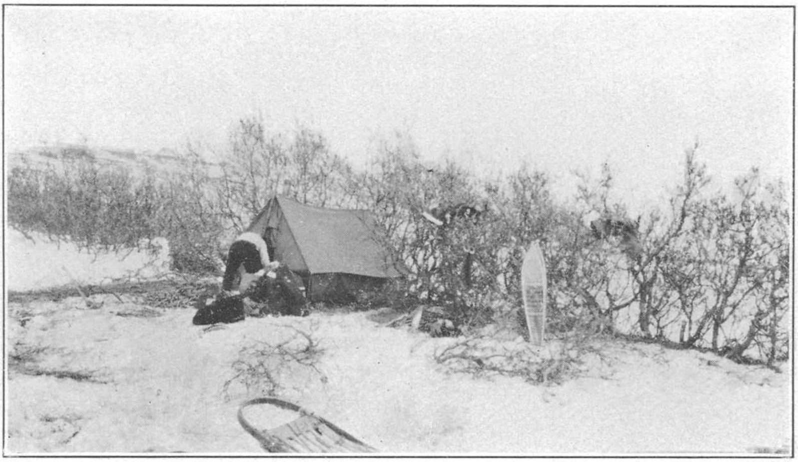


B. ANCHOR ICE THAT HAD RECENTLY RISEN FLOATING DOWN KILLIK RIVER



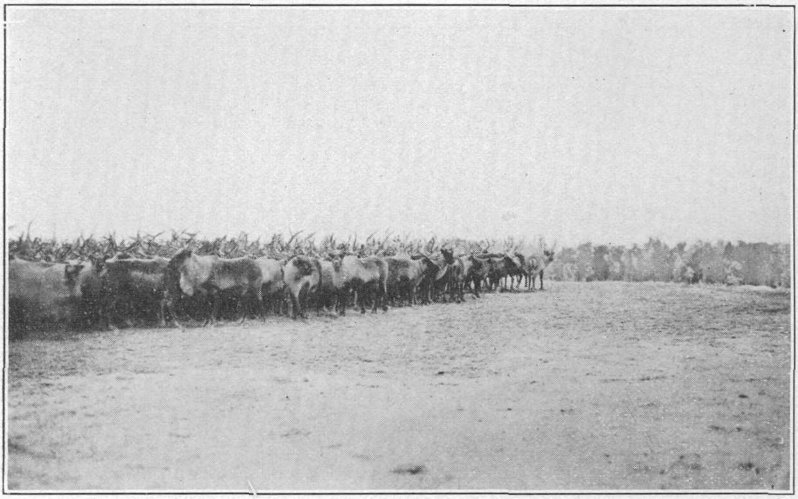
A. SPRUCE NEAR NORTHERN LIMIT OF TREES ON UNAKSERAK RIVER

B. SPRUCE IN CENTRAL PART OF KOBUK VALLEY NEAR SHUNGNAK



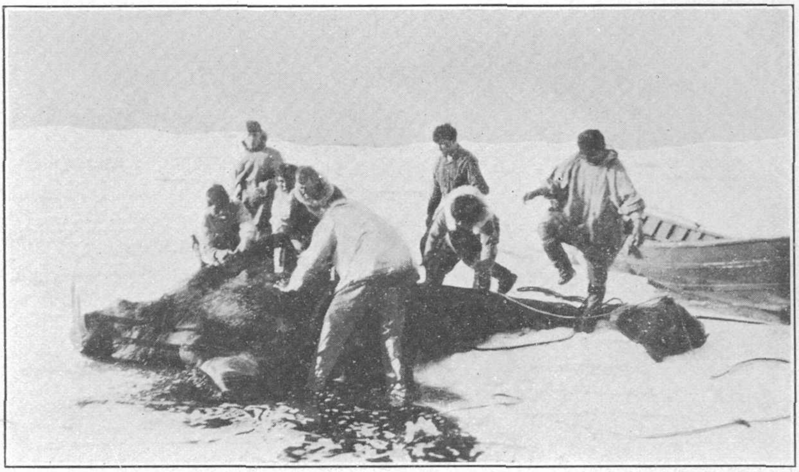
A. MODERATELY LARGE WILLOWS ON KIVALINA RIVER

B. TYPICAL VEGETATION ON UPLAND OF PLATEAU NEAR HEADS OF ETIVLUK AND ANIUK RIVERS



A. REINDEER IN CORRAL BUILT OF ICE SLABS NEAR BARROW

Photograph by F. C. Dakin.



B. CUTTING UP WALRUS ON ICE NEAR BARROW

Photograph by Tom Brower.

serak, and when that region was surveyed in 1911 was described as follows: "The northern limit of trees is so sharply defined as to make a decidedly abrupt break, which seems to have been controlled by some other factors than temperature and elevation." On the Noatak no spruce occurs anywhere east of longitude 161° 30′ or north

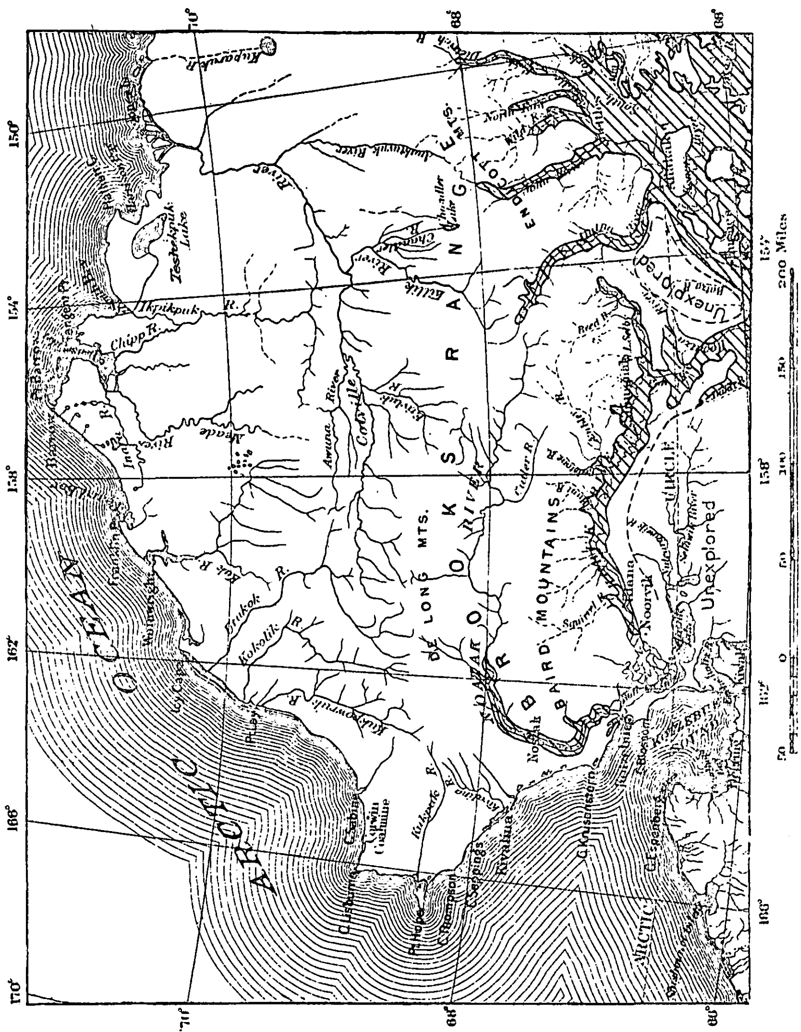


FIGURE 4.—Sketch map showing distribution of spruce (shaded area) in northwestern Alaska

of latitude 68° 13′. At the eastern limit of spruce in that valley the trees are 8 to 12 inches in diameter and grow as a narrow fringe along the well-drained river banks. Farther down the Noatak spruce is found almost everywhere in the lowland near the river to a point within a few miles of the mouth, where the ground becomes wet and spruce is absent. On the Noatak the sudden disappearance of spruce is also notable, for in an earlier description of that region [29] is the following statement:

> The large size and sturdy growth of the trees, even near the borders of the unforested areas, is striking. Fully as large and vigorous trees were seen within 15 miles of the extreme limit of timber as anywhere else in the region, although the place was fully as high, as much exposed, and had a soil not differing radically from that of the neighboring [unforested] tracts.

Latitude is not the controlling feature in this distribution, for much of the eastern part of the Noatak Basin lies south of the limit of spruce in the western part, and some of it lies south of the latitude in which spruce grows on the Alatna and its tributary the Unakserak. On the Kugururok River the expedition of 1925 found spruce extending within about 4 miles of camp G April 26, or approximately to latitude 68° 13′, which is farther north than any other point at which spruce has heretofore been reported in northwestern Alaska.

Spruce grows in many of the valleys other than the Alatna which are tributary to the Koyukuk. Thus Schrader states that on the John River his party passed the northern limit of spruce near their camp of July 8, which was situated almost exactly at latitude 68° north. This point is considerably north of the point where the last spruce was seen on the Alatna and is fully as high in elevation.

Throughout the lowland of the valley of the Kobuk spruce is found extensively. The largest trees usually do not exceed a foot in diameter, though Stoney reported measuring one 80 feet tall and 80 inches in circumference at the base and 68 inches in circumference 6 feet above the ground. Spruce does not extend up the slopes of the hills to elevations of more than 2,000 feet and is absent even at lower elevations in those places where the ground is swampy, as in the delta, and on some flats in the central portion of the valley. The general character of the timber in the vicinity of Shungnak is shown in Plate 11, *B*.

Practically the only other large trees that grow in the region are the birches, and their distribution coincides more or less closely with that of the spruce. In the regions where spruce is abundant the birch usually extends to a somewhat higher elevation on the hillsides than the spruce, but near the northern limit of trees the birch usually disappears first. None of the foregoing remarks refer to the dwarf or prostrate varieties of birch, as these are found far beyond the area in which trees grow. The natives value the birch highly, as its wood is much in demand for the manufacture of snow-

[29] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 51, 1913.

shoes and other gear, and its bark was formerly much used for boats and receptacles.

Along the Arctic coast, and in the lower courses of many of the streams entering the Arctic Ocean, spruce and other large trees are found as driftwood that has probably been brought from the Yukon or the Mackenzie or some of the other streams along which spruce grows abundantly, and thence carried by ocean currents to the places where it is now found. Some spruce logs were also found several score of miles back from the coast along the Ikpikpuk and Meade Rivers, and were probably originally brought in the same way, but were buried in the coastal-plain deposits when they were formed and later were uncovered through the uplift of these deposits and the consequent erosion of the streams in whose valleys the logs are now found on the bars. Possibly some of the spruce now found as driftwood on these streams may have grown in the protected valleys north of the Brooks Range that have not been explored. If so, it must have grown 100 miles north of any known spruce, and therefore this explanation is not regarded as probable, especially as no spruce, either growing or as driftwood, was seen at any place visited in the upper part of the basin of the Colville River

Throughout the area north of the limit of spruce to points within a few score miles of the coast willow bushes grow along the courses of most of the streams. The character of the vegetation in many different parts of the area is shown incidentally to other features in all the pictures accompanying this report, but special attention may be called here to the group of large willows near the headquarters camp of the expedition of 1924 (pl. 5, *B*) and the almost entire absence of bushes in the areas shown in Plates 7, *A*, and 12, *B*. Plate 12, *A*, shows a camp site on the Kivalina River that was selected because the bushes there were considerably larger than elsewhere in the neighborhood, though the tallest were not 10 feet high. Usually, if carefully sought for, willows are found to be plentiful enough to furnish fuel for ordinary camp needs but not enough for long sojourns or for many people. It is rather astonishing how much wood can be found, even in an apparently unpromising place, when it is vigorously hunted. For instance, a side camp was established on the upper part of the Killik River 10 to 12 miles southwest of the winter headquarters of the expedition of 1924, in a clump of willows that when first seen was judged to contain probably only enough fuel to supply camp for a couple of days, and yet a camp of four men stayed there nearly 10 days and then abandoned it, not because the wood had given out but because the work had been completed. Although the many pictures taken by the different parties north of the Brooks Range show only sparse and stunted willows, at many of these same places wood was sufficiently plentiful to seem entirely adequate for the needs of the camp. This holds true only as regards summer travel, however, for during the winter, when there is much snow on the ground, many of the willows are hidden, as they are most numerous in those places where they are likely to be covered by drifts. On a winter trip down the Killik to a point 10 to 15 miles below the mouth of Easter Creek it was concluded that there were not enough willows to maintain a camp there for more than a few days, but when the same place was visited after the snow had gone a plentiful supply of wood was found. Possibly the conclusion reached during the winter trip to this place would have proved as erroneous as that already cited regarding the camp on the upper part of the Killik River, but obviously there is much less wood in sight during the winter, and a cautious traveler would do well to carry enough dry wood to start a fire quickly and to maintain it until sufficient other wood is gathered. In fact, during the winter most Eskimos carry Primos stoves and kerosene when traveling and do not depend on the necessity of finding sufficient wood for cooking.

In a few places the willows are so small that it is necessary to twist handfuls of twigs into bunches so that they will burn satisfactorily, but usually enough wood could be gathered in an hour within a hundred yards or so of a carefully selected camp to provide fuel for supper, the evening, and breakfast. For use in most of the Geological Survey's camps practically all the wood collected was dry, and the parties were generally able to avoid using green wood. Many of the dry willow sticks were drift that had been brought down during the spring high water and left stranded on the banks or entangled in the thickets of growing willows. The ice during the break-up kills or injures many of the willows lying in its path, so that there is much more dead wood available than would be formed by the natural death of the bushes. Perhaps it is this process that in part controls the present distribution of the willows. Certainly various factors, the interaction of many of which are not yet understood, must be invoked to explain the distribution of the larger willows. Large willows may be found in widely separated places with apparently widely different physical or climatic conditions and may be absent in near-by areas where conditions appear essentially the same. At the headquarters camp on the Killik River there was a thicket of large willows, many of which were 20 feet high and 3 to 5 inches in diameter. At a point a few miles downstream and extending thence for a score of miles the bushes were not more than a fraction as high. Still farther downstream good-sized willows like those at the winter camp again became plentiful and continued throughout most of that part of the Colville surveyed by the central party.

Southward up the Etivluk the large willows became fewer and fewer, until south of camp S July 8 they were absent, and throughout the rest of that valley only small bushes were available for fuel. Even on the Noatak side of the divide large willows did not appear on the Aniuk above a point near the mouth. For miles up the Awuna River the willows were only a few feet high and of small diameter and formed a fringe near the river at most not more than a few yards wide. Then near the Lookout River, the tributary that comes in from the southwest about 30 miles in an air line from the mouth, willows 15 feet or more high and 4 to 5 inches in diameter appeared. In most of the rest of the valley of the Awuna there are no large willows, but near the junction of the Kigalik River and Maybe Creek, in the Ikpikpuk Basin, are willows as large as any seen elsewhere in the entire region, or even larger; in fact, some of them had to be split to be used in the camp stove. Large willows of this sort were found for several miles down the Ikpikpuk, but then suddenly, without any discoverable cause, they ceased, and only low bushes line the stream for the next score of miles, and at about 70 miles from the coast even these became so scarce and small that they could not be relied on for camp fuel.

On the Kokolik, Kukpowruk, and Utukok Rivers most of the willows or other bushes suitable for fuel are small, and the places where they are sufficiently abundant for camp uses are considerable distances apart. On the whole their distribution resembles that in the poorer parts of the Colville Valley already described. The ceaseless struggle to procure sufficient firewood was strikingly illustrated at Kivalina, where, during the season when no driftwood can be got from the sea, the natives spend nearly half their time in collecting willow sticks some distance up the Kivalina Valley and bringing them in by dog team a distance of 10 miles or more, and the supply from this source, which was never large, is of course being constantly depleted.

Paige, who surveyed the lower part of the Meade River in 1923, states that the stunted willows began to appear on that stream a few miles inland from the ocean, and at 50 to 80 miles inland, measured along the winding course of the river, they were sufficiently abundant to be relied on for fuel. Leffingwell notes that in the region east of the Colville the coastal plain is devoid of even bushes, but that in the valleys of the upland stunted willows occur and increase in size toward the mountains. Within the mountains on the old gravel bars larger willows become common, but even there they rarely exceed 12 to 15 feet in height.

Catkins were noted on the large willows near the headquarters camp of the expedition of 1924 about the middle of May and were conspicuous by May 24. The willows in the central part of the Colville Valley, however, did not show many leaves until nearly the middle of June, and it was well into July before they appeared to be in full leaf. In 1926 the first willow leaves noted were seen on bushes in the Kuk Valley July 9, though they may have been out somewhat earlier, as before that time the party had been traveling along the coast, where all vegetation is extremely small and backward.

Other bushes or small trees that in places grow to sufficient size to furnish camp fuel are cottonwoods and alders. Alders grow in thickets and clumps near the larger streams in much the same fashion as the willows, but they are not nearly as abundant and never grow as tall. Alders were particularly common in the Kobuk and Noatak Valleys above the general limit of the spruce and birch trees. North of the Brooks Range alders were seen in the central part of the Colville Basin, but they practically disappeared west of the mouth of the Awuna River. They were absent from the upper part of the Kigalik River but reappeared abruptly a short distance above the junction of that stream and Maybe Creek and continued several miles northward to a point near camp M August 4, from which northward they became insignificant as a source of fuel. Cottonwoods were not seen in many places in the naval petroleum reserve, though they were frequent in both the Kobuk and Noatak Valleys, to the south, and in the Noatak Valley trees 6 inches in diameter were measured near the mouth of Midas Creek. The most southern locality for cottonwood in the region drained by the Colville River and its tributaries was a short distance south of the headquarters camp of the expedition of 1924 on the Killik River. Only a few small bushes, however, grow at this place. These were in bud about May 20. Farther down the Killik River, near the mouth of the Chandler River, cottonwoods grow in close association with the larger willows and are therefore not conspicuous of themselves. A few isolated cottonwoods were seen at intervals up the Awuna River, and a good-sized clump of them was found near the mouth of Lookout River, the southwesterly tributary of that stream. Some cottonwoods mixed with the larger willows were noted on the Ikpikpuk. Large driftwood stumps and logs of cottonwood are fairly common on the coast and probably had a source similar to the spruce driftwood already described. Leffingwell notes the occurrence of cottonwood on the Canning River.

Over the larger part of the country north of the mountains and in the lower tracts within the mountains and plateaus the dominant plants are grasses, sedges, mosses, lichens, and prostrate bushes. Plate 12, *B*, shows a view of the character of the vegetation near the heads of the Etivluk and Aniuk Rivers that, except for details, is representative of thousands of square miles in the plateau and plains provinces. These plants form a cover over the entire country, so that only very steep slopes are free of vegetation. Here and there on the crests of the higher ridges, where the soil is thin and well drained, the plant covering is sparse and does not form a continuous mat. Where this cover of vegetation is thick it retards the thawing of the frozen ground beneath and holds a great deal of the precipitation that falls. It thus becomes a veritable spongy cushion into which and the underlying thawed unconsolidated deposits the traveler may often sink half leg deep and through which he finds walking most tiresome. At many places hard tufts of grass, the so-called "niggerheads" of the north, make walking especially difficult, because the tufts sway underfoot and are too irregularly spaced to permit uniform steps, and the lower ground between the tufts is especially swampy and soft.

In the Kobuk Valley pack horses can be used almost everywhere during the summer and can subsist themselves well on the grasses that can be found practically anywhere except on the more precipitous rocky slopes. Probably sufficient horse feed could be found in the Noatak Valley to supply the needs of a small pack train if some care were taken in the selection of camp sites. Although there is some grass almost everywhere in the Arctic plateau and coastal region, it seems to be of poor quality and not abundant enough to be relied on for feed for horses worked like the animals used in other parts of Alaska on trips of the Geological Survey. It is true that at a few places, especially in a rather narrow fringe between the water and the thickets of willows, some grasses of the kind suitable for horse feed were seen. Near the mountains also suitable grasses appear to be more abundant, and it is believed that if the traveler were able to keep in the foothills and could determine his stopping places mainly with reference to the grass, it might be feasible to use pack horses during the summer, especially if enough grain could be carried to permit a good feed of it at least once a week. The length of time, however, that horses could successfully forage for themselves on the northern flanks of the mountains, even under most advantageous conditions, would probably not be more than two months. It is true that a pack horse was used by the Geological Survey party in 1901 at the heads of the John and Anaktuvuk Rivers, but this was for only a short time and not under the usual conditions of reconnaissance and exploratory surveys covering a broad area. The International Boundary Survey also used pack horses for much of the work north of the Porcupine River to the Arctic Ocean. The northernmost point reached by that survey, however, lies about in the latitude of the central part of the Colville Valley, and most of the boundary country lies on the southern rather than the northern slopes of the Brooks Range. Furthermore, it is understood that several hundred tons of horse feed was used to supplement the forage which the horses were able to obtain. All these conditions, therefore, do not negate the general conclusion that the use of horses for surveying most of the country north of the Brooks Range is not believed to be practicable.

The writers, of course, do not have expert knowledge regarding the food value of the vegetation for other animals, but they are of the opinion that reindeer could be successfully pastured throughout much of the plateau and plains region. In fact, several herds of reindeer, numbering in all many thousand animals, now find suitable grazing at different places in the coastal region from Smith Bay to Kotzebue and in the inland region on the Noatak, Kobuk, and Selawik Rivers. So far as was apparent the vegetation and other conditions that undoubtedly would affect reindeer throughout most of the plateau and plains provinces are not greatly different from those that prevail at places where reindeer are now successfully herded, not only within the petroleum reserve but elsewhere in northern Alaska as far south as St. Michael.

Plants yielding berries that could be used for food grow throughout the region. Blueberries and cranberries were reported by Smith to be abundant in the Alatna and Kobuk Valleys, and these berries, together with currants and salmonberries, are plentiful in the low lands of the Noatak Valley and form an important part of the food supply of both whites and natives. Howard, on his trip through the Colville Basin in 1886, noted the curious fact that his party obtained many berries [blueberries?] early in May in the lower part of the Etivluk Valley. According to his account the berries ripen in the fall, at about the time that the snow comes, and then freeze on the bushes and are covered by the snow. In the spring, as the snow disappears, the berries are uncovered and are then gathered, mainly by the women. He states that these berries tasted especially good. The members of the expedition of 1924 saw blueberry bushes at a number of places in the Colville and Ikpikpuk Valleys, but even toward the middle of August they bore only small green berries, which could hardly be expected to mature before winter set in. So far as could be learned the native berries do not contribute much to the food supply of the people in the northern parts of the area. The members of the expedition of 1923 report that in the region they traversed blueberry bushes were seen at a number of places, but even as late as they were in the region (early September) the berries were small and immature. The expedition of 1925 did not find berries abundant anywhere in the Colville Valley, though they recognized blueberry bushes there, but reported excellent blueberries on the Aniuk and elsewhere in the Noatak Valley. Leffingwell does not specifically mention berries in the area with which he was familiar, and probably they are unimportant as a food product though they may grow there.

Salmonberries were ripe and fairly abundant along the upper part of the Awuna River in the later part of July and on Birthday Creek and at many places along the Kigalik River in August. The leaves of this plant were also seen at so many other places that it is probably a common plant throughout the region. Cranberries are found at many places throughout the partly drained areas of the coastal plain. The recent Geological Survey expeditions, however, have been so adequately provided with dried fruit that they paid little attention to the distribution of edible berries.

The only other plant growing wild in the region that is known to be used for food is called by the natives "mashu." This, according to Anderson, is the root of a knotweed belonging to the genus *Polygonum*, probably of the species *P. bistorta* or *viviparum* or *fugax*. This root, which is eaten either raw or boiled, is said to taste much like a sweet potato. Howard notes that at his camp of May 12, on the Colville below the mouth of the Etivluk, the natives accompanying him dug many mashu roots, which he found very succulent and tender, and that later this root became his principal food. He further relates that on his journey down the Ikpikpuk the natives stopped frequently to dig this root.

In the extreme southern part of the area described in this report some food plants have been successfully grown in gardens. Such gardens have been seen in the Koyukuk Basin near Allakaket and on the Alatna River near the mouth of the Nahtuk River; at several places on the Kobuk from Shungnak to Noorvik; and on the Noatak at the village and near the mouth of the Kelley River. Even at Barrow lettuce and radishes are grown in some of the houses under practically hothouse conditions. At none of these places, however, are crops produced that make any considerable contribution to the food supply of the neighborhood. The plants grown require a great amount of attention and special protection, and in spite of the greatest care many are lost through the rigors of the climate. It therefore seems improbable that agriculture or farming will ever be developed in this region. Such plants as may be raised for food will probably be grown more as an agricultural stunt and as a diversion rather than as a profitable commercial business.

Flowers appear almost as soon as the ground begins to become bare and are of great variety and brilliant color. On June 1, 1924, May 29, 1925. and June 2, 1926, the first flowers were noted by the Geological Survey parties, and these were large purple and white members of the anemone family. From that time until the parties left the region in the fall flowers added much to the beauty of the landscape. In fact, the abundance and showiness of the northern flowers is one of the most striking features of the region. Schrader, on his trip up the John River and down the Colville, collected more than 50 different distinctive flowers, among them representatives of such familiar plants as the anemone, poppy, mustard, saxifrage, rose, and aster families. A list of the plants collected by his party is published in the report of the trip.[30] In the report of the work of the international polar expedition [31] are also many notes on the plants of the region. Although the reports of the Canadian Arctic Expedition were primarily designed to treat of the natural features of the Arctic coastal region of Canada, they abound with much information that is pertinent to the near-by parts of Alaska, and in fact many of the observations recorded in those volumes were made at places within the area described in this report. Only a part of the strictly botanic results of that expedition have yet been published,[32] but some of the general volumes on the results of this expedition incidentally give many data on the plants of the region.

WILD LIFE

ANIMALS

No attempt was made to observe closely the animals that live in the region, and the only new information contained in the following statements is based on casual notes made in the course of the geologic studies that were the main object of the investigation. The principal interest in the animals, therefore, was due more to their relation to the food supply than to zoologic or biologic problems.

Throughout the mountains of the Brooks Range the larger of the wild animals that can be counted on to furnish meat are mountain sheep. As already reported by other travelers, sheep meat is the most satisfactory of the wild meats, as it satisfies as well as appeals to the appetite. A full-grown sheep dresses on the average 75 to 100 pounds. Most of the animals seen lived in the higher, more inaccessible parts of the mountains, where low vegetation is exposed on wind-swept areas. Sheep tracks, however, are occasionally seen in the lowlands, where the animals had evidently crossed from one group of mountains to another. As a rule the animals were wary, but their curiosity was easily aroused, and when they were disturbed

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[30] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 130–134, 1904.

[31] Ray, P. H., Report of international polar expedition to Point Barrow, 1881–1883: 48th Cong., 2d sess., H. Ex. Doc. 44, 1885.

[32] Maconn, J. M., and others, Botany: Canadian Arctic Expedition, 1913–1918, Rept., vols. 4 and 5, Ottawa (in press).

they usually would run only a short distance and then turn around to look at the intruders. Even the noise of the shooting did not scare them so much that they would run for long distances, but after a few days' absence they would return to the general region from which they had fled.

Sheep are not now common in the vicinity of the Kobuk, though they are reported by Mendenhall and others, especially in the hills near the head of that stream. Their scarcity is indicated by the fact that the natives living in the central part of the Kobuk Valley usually make trips to the Noatak for their sheep meat. The distribution of sheep in the Noatak Basin was described in 1911 by Smith [33] as follows:

> Sheep are so numerous in the headwater mountains that natives from places as far away as the Kobuk make annual trips to them for their winter's supply of meat. Near the camp of August 1 [3 miles below the mouth of the Ipmiluik River] four natives from the Kobuk were met on such a hunting trip, and many sheep horns discarded by other hunting expeditions were found along the banks of Twelvemile Creek. Ipmiluik, the name of the river that joins the Noatak near the camp of August 1, means sheep and refers to the fact that this is the route followed on the journey from the Kobuk after sheep. On the hill opposite the mouth of Twelvemile Creek, near the head of the Noatak, sheep trails are so numerous that the zigzag lines can be seen for several miles. Sheep were also obtained on the hill on the south side of the river opposite the mouth of Midas Creek.

In crossing the mountains at the head of the Kugururok in 1925 the Geological Survey party saw many sheep tracks, but the animals were all traveling westward. The expedition of 1926 did not get into the high mountains of the western part of the range and did not see any signs of sheep. Captain Hooper mentions seeing and hunting sheep near the Corwin coal mine in 1881, though from later accounts it seems probable that now there are no sheep in that region and probably none within 50 miles or more. Many of the old ladles and similar utensils seen near Point Hope were made from the horns of mountain sheep.

Sheep were common in many of the mountains in which the tributaries of the Koyukuk from the north rise, but through being hunted they have gradually been driven into the more inaccessible parts. They are still abundant enough to afford considerable meat to the prospectors in the more remote camps. Sheep were seen at a number of places in the valley of the Alatna. Small bands of sheep were seen in the valley of the small tributary from the west below the Kutuk and in the hills around the Alatna-Noatak divide and also east of the river near that place, and prospectors report

[33] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 50, 1913.

that they are plentiful in the hills at the heads of the Nahtuk and the Kutuk. The expedition of 1924 found sheep fairly common throughout many of the hills that flank the Unakserak. At the time that the party was in the valley (the middle and later part of March) the sheep were scattered in small units consisting of only a few animals each, and the females were exceedingly thin and scrawny.

In the Colville Basin sheep have been seen by members of the Geological Survey parties only in the mountains adjacent to the Killik River, but in that region they were fairly numerous. The largest group was seen on April Creek and consisted of about 35 females and lambs. Near this same place in the hills on the opposite side of the valley was a flock of about a dozen males. Early in May the females were beginning to lamb, and before the parties of the expedition of 1924 had left their winter camp the last of May apparently all the young had been born. Almost no twins were seen, and both the ewes and the lambs appeared to be in poor condition, as if the preceding winter had been unusually severe.

In the region east of the Colville, Leffingwell[34] states:

> Dall's sheep formerly were abundant everywhere in the mountains, but they have already been cleaned out from the lower parts of the larger rivers. The writer saw none below the forks of the Canning and none below Lakes Schrader and Peters, on the Sadlerochit. There are still a few on the headwaters of these rivers as well as on the Hulahula, but the natives can no longer depend upon them for a food supply.
>
> Until recently the Jago and Okpilak Rivers were taboo, and the sheep there were undisturbed. The writer's party was the first to go far within the mountains on the Okpilak. Sheep were constantly seen, as many as 40 or 50 in a day. The high Romanzof Mountains will always be a refuge, so that the sheep will not be entirely exterminated.

North of the Brooks Range to points within a short distance of the coast, caribou are the chief source of fresh meat. No large herds of these animals were seen in this region, though possibly this was due to the fact that the Geological Survey members were on the caribou range during the summer, when the animals are grazing as individuals or small families before bunching up in large groups, as they commonly do later in the fall. The largest number seen in one group was a herd of about 150 on the Colville some distance above the mouth of the Etivluk. Those seen near the mountains were in general much larger than those in the lower country to the north. A bull that was killed on the Killik River dressed between 175 and 200 pounds, but he was an exceptionally large animal. Most of the full-grown caribou are not difficult to approach during the summer.

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[34] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, p. 63, 1919.

Although the meat forms a welcome addition to the regular food supply of travelers in the region, it does not seem to have the sustenance or satisfying quality of wild-sheep meat. During the summer practically all the caribou were infested with grubs. Mosquitoes bothered the caribou greatly, and during the time when these pests were at their worst, the later part of July and the early part of August, the caribou were constantly rubbing against the brush and thrashing their heads around to rid themselves of these insects. Their grazing was thus interfered with, and as a consequence the animals became poor and thin.

No caribou were seen on the Killik above camp S June 5, but old antlers that had been shed by caribou were found at several places in the hills and farther south. For instance, numerous horns were seen in the hills near camp S June 1 and up the southwestern tributary about 10 miles above the winter headquarters of the expedition of 1924. Along the main valley of the Colville River caribou were seen almost every day, and on many of the tributaries, such as Prince Creek and the Awuna River, they were common. Caribou were fairly numerous in the northern part of the valley of the Etivluk but became scarcer upstream, though a few animals were seen at the very head and over on the Aniuk side of the divide. On the Utukok the most southern locality where caribou were seen was on Meat Mountain, north of camp G May 10. On the Kokolik River caribou were seen in the hills south of camp P May 12 and east of camp P May 15, also west of those camps on Poko Mountain and along the course of the Kokolik northward to a point within a few score miles of the coast. A few caribou tracks were seen in the upper part of the valley of the Kukpowruk near camp P April 28, but the parties that surveyed the lower part of the valley of this stream did not report any caribou in that area. Farther west in the valley of the Kokolik some animals that may have been strays from the reindeer herds near the coast were seen.

Caribou were found on the Ikpikpuk as far north as the Price River and near its main tributaries, Maybe Creek and the Kigalik River. Paige reports caribou on the Meade River near the highest point reached by his party on that stream. Caribou or stray animals from the reindeer herds were seen on the Kukroak, Avalik, and Kaolak Rivers. Leffingwell notes that in the Canning River region west of the Colville, although the barren-ground caribou are the most abundant animals, they have become much reduced in numbers, and the few bands that come over the divide from the Yukon side are soon rounded up and killed or driven back through the mountains.

Caribou are extremely scarce now in the Noatak Valley. Smith reported in 1911 that caribou were seen midway between the Aniuk and Nimiuktuk, but when the Geological Survey expedition went through this part of the region in 1925 they saw none of these animals, though they did see a few near the head of the Aniuk and two or three near the mouth of that stream.

Mendenhall states that herds of caribou are reported in the hills between the Kobuk and the Koyukuk, but that the Kobuk natives generally have to go to the head of the John River or the Noatak to get the caribou skins they need for clothing. Schrader makes no special mention of caribou on the John River, though he records killing some near the divide between that stream and the Anaktuvuk. No caribou were seen in the Alatna Valley by any of the Geological Survey parties that have traversed it since 1901, and there are no reports of others having seen caribou wintering in this valley. Probably such caribou as remain in the Koyukuk region live much of the time in the plateau province and migrate into the hills when the mosquitoes and flies are bad in the summer and then wander back into the lower hills of the plateau province in the fall.

The reindeer to the uninitiated appear to be essentially the same as the caribou, though they are usually somewhat smaller and of lighter weight, and many of them have spotted coats instead of the uniformly colored coat of their wild relatives. Already there are extensive herds of these animals in this region, and their further propagation and development bids fair to be one of the productive industries of northern Alaska. Herds are now maintained at many places near the coast, all the way from the mouth of the Colville to Kotzebue and thence southward beyond the area described in this report. The largest of these herds contain several thousand deer. According to Palmer,[35] the herds near Barrow contain about 10,000 deer, those in the vicinity of Wainwright about 7,000, those in the vicinity of Point Hope and Kivalina about 10,000, and those in the vicinity of Kotzebue Sound about 34,000. Practically all these herds are held by Eskimos under allotment, and many of them are operated by companies instructed and more or less informally supervised by the school teachers of the districts in which the herds live. Many problems in successful management and exploitation still await complete solution, but these animals are even now most valuable in furnishing meat, clothing, and transportation, and doubtless they can be developed to make even greater returns in these ways. Strays from these herds are found in the neighborhood of many of the places where the reindeer have been herded in the past, and caribou are reported to come into the herds on occasions. In future exploratory work of the United States Geological Survey in the

[35] Palmer, L. J., Progress of reindeer grazing investigations in Alaska: U. S. Dept. Agr. Bull. 1423, p. 2, 1926.

areas where horses can not be used and where dogs are extremely expensive because of the amount of food they require, it would be extremely valuable to experiment with reindeer as pack or draft animals.

The absence of timber throughout most of the area makes it difficult for the natives to build suitable corrals for handling the reindeer and has led to the extensive use of driftwood for this purpose. Even suitable driftwood, however, is not everywhere at hand, and this has resulted near Barrow in the utilization of the local material that is available—ice. For this purpose the natives in the fall cut slabs of ice 6 to 8 feet long and a foot or so thick, which they stand on end, inclosing a tract several hundred yards in diameter, in which the deer are herded. Plate 13, *A*, shows a corral near Barrow built in this way of ice slabs, with part of one of the herds.

Some black and brown bear live in the southern part of the region. In the vicinity of the Kobuk River the bear have practically disappeared, and it is only in the more remote parts of the valley of that stream that they may occasionally be found. In the Alatna Valley only a few black bear have been seen by any of the Geological Survey parties, though during the summer evidence of their presence was fairly common. Neither Smith in 1911 nor any of the recent Geological Survey parties report having seen any bear in the Noatak Valley, though Smith states that bear tracks could be found on almost every sand bar below the Nimiuktuk and that apparently the tracks were made by brown bears.

North of the divide of the Brooks Range the only land bears that were seen by the expedition of 1924 were a small brown female and her cub prowling around the cliffs near the junction of the Killik and the Colville. Bear tracks, however, were fairly numerous near the aufeis deposit north of the headquarters camp of the expedition of 1924, where the bear had apparently been digging for mice or other small animals, and there were innumerable footprints on the mud downstream from the Killik and near the mouth of the Etivluk and for some distance up the Etivluk. The only bear reported by members of the expedition of 1925 was a small black one that was seen near the head of the Aniuk, though many tracks were noted farther down that stream. A good-sized brown bear was seen in the hills east of camp P June 12 in the central part of the Kokolik Valley by one of the members of the expedition of 1926. Possibly the reason that more bear were not seen by the recent Geological Survey expeditions was that they were in the country best suited to bear mainly in the winter, when the bears were hibernating. The absence of easily procurable fish in the streams and the lateness with which berries mature throughout most of the Arctic plateau and plain provinces may explain the scarcity of many bears in those regions.

In addition to the bears already noted, many polar bears live on the ice near the coast and rarely go more than a short distance inland. Formerly a number of these bears were killed each year, but lately the price paid for their hides has been so little that the natives find it hardly pays to hunt them. In 1926 only one or two polar-bear skins were brought in to the traders at Barrow and Wainwright.

Moose were once fairly plentiful at several places in the upper Koyukuk Valley and on the Kobuk, but they are extremely scarce now anywhere within the area described in this report. It was therefore with considerable surprise that signs of these animals were noted in the valley of the Killik River near the mouth of the Chandler River, thus confirming the early statement by Mendenhall that natives reported moose as far north as Chandler Lake. Near this place two females were seen, and an antler was found that had been recently shed by a male. There is a considerable growth of large willows near this place, but it is 60 to 80 miles north of the nearest timber and is a most unusual place to find these animals.

In the inland parts of the region foxes are among the commonest of the smaller animals, and their pelts are a source of wealth. In the region traversed by the expedition of 1924 red, cross, and black foxes were seen at many places, but no white fox. Their trails were conspicuous in the snow over all the lower tracts, and, although the animals were wary, they often followed the sled trails for miles and sometimes robbed the traps only a short distance from camp. On the Etivluk a fox ran ahead of the geologist for a couple of miles, never more than 100 yards away and often only a few feet, stopping at intervals to bark and snarl at the intruder, who noisily followed him and returned his barks with shouts. Fox dens were seen at many places in holes under rocky cliffs and in holes in the ground near low knobs such as were numerous at many places along the hillsides in the valley of the Colville. The foxes kill a great many ptarmigan and other small birds and animals, and during the spring bunches of feathers that mark their past lunching places are conspicuous along many of the valleys.

Many white foxes are killed each year near the coast, and their pelts probably furnish the most valuable revenue of the region at this time. In 1924 several thousand white-fox skins that had been brought in to the traders as far east as Barter Island were received at the trading post at Barrow, and every year many hundred white-fox skins are taken along the coast of the region described in this report. Neither the expedition of 1924 nor that of 1926 reported seeing any live white foxes in the region they traversed, but the members of the expedition of 1925 saw several far inland on the northern slopes of the Brooks Range. Two were recognized in the hills between the Kiligwa and Nuka Rivers, 4 to 5 miles south of camp G June 16, on the Colville; one was seen some distance up the Etivluk in the vicinity of camp G July 17; and one was noted about 6 to 8 miles north of camp G May 30 on Disappointment Creek, a tributary of the Utukok River.

Rabbits are usually very numerous throughout the lowland areas, but their trails are not conspicuous except during the period when there is snow on the ground, and as the Geological Survey parties were plentifully supplied with meat of other kinds there was little incentive to search for them. As a consequence the records contain very little information about rabbits except in the vicinity of the winter camps. Along the Alatna rabbits were numerous, and a dozen or so could be rounded up at almost any time in the thick patches of brush along the river. At the headquarters camp on the Killik rabbits were also numerous, and a short trap line that was put in near that camp yielded in three weeks several score of them. On the Kivalina, Kukpowruk, and Kokolik Rivers signs of rabbits were occasionally seen, but they were by no means as numerous as in the basins of the eastern or southern streams. None of the large Arctic hares were seen by members of the Geological Survey expeditions. Ray, who lived at Barrow for two years, did not see any of them but states that natives reported them as common in the valleys of the Meade and Colville Rivers.

Other animals whose pelts are valuable for clothing and which have been reported or seen by Geological Survey members in the region are lynx, mink, marten, muskrat, squirrel, and wolverine. For a long time the lynx and mink from the Selawik and the lower part of the Kobuk were said to be among the finest of their kind in the world. Wolverine fur is especially prized by the natives as a trimming for their hoods and cuffs. These animals were seen near the head of the Alatna, their tracks were noted on the Killik, and one was killed by natives on Tupikchak Mountain, near camp P May 15 on the Kokolik. Marten were reported by earlier Geological Survey parties in the valleys of the Noatak and the Kobuk. Muskrats are especially numerous along the lower courses of the Selawik, Kobuk, and Noatak Rivers. Squirrels of several kinds live in the southern part of the region. The commonest in the timbered areas of the Kobuk and of the Alatna is a small red one, but the so-called parkie squirrel, which lives in holes in the ground or in the crevices of rocky knobs, was noticed most frequently in places in the Colville Valley and on low knobs near the head of the Ikpikpuk. Another fur that is also much prized for making parkies or shirts that will shed rain is furnished by the "siksikpuk," a groundhog-like animal which also makes its home on rocky knobs and whose strident chattering can be heard on the crest of almost every ridge. A number of these animals were killed by natives in the hills near camp P May 15.

There is reason to believe that all these animals were formerly much more numerous than at present, but they have been hunted until they have been driven farther and farther into the less accessible areas, and now the trapping industry is rather small, though still one of the main sources of wealth. Doubtless, if properly regulated, it could be developed to be still more productive.

From time to time wolves have been reported in the region. Thus in 1926 a wolf is said to have been killed in the upper part of the Noatak Valley, and Ray reported that in 1881 wolves were seen near Barrow when he was there. None of these animals, however, or even their tracks were seen by members of any of the recent Geological Survey parties.

Porcupine are common throughout the wooded region of the Kobuk, Noatak, and Alatna, and one of these animals was found wandering some distance north of the timbered region at the head of the Unakserak.

Shrews and small mouselike animals were noted at a number of places, and the holes they dig in the banks were common along the Killik and Ikpikpuk Rivers. One of these little animals, a particularly black-coated one, was seen running over a snow bank in the valley of the Killik April 10.

In the waters off the coast of northwestern Alaska there are many aquatic mammals that contribute a considerable part of the food and supplies of the people. In the past whales were perhaps the most valuable of these animals, but with the present small use of whalebone and whale oil the prices paid for these commodities are so low that the whaling industry in these waters fails to attract many white followers. Only a few whales are now caught by the natives, and those that are obtained are so rare that they serve as an excuse for rather widespread rejoicing and celebration, which takes the form of feasting, dancing, and indulgences in many of the old native games. Many kinds of seals are fairly numerous and furnish oil, meat, and skins, which are almost indispensable to the Eskimos. Most seal are caught during the spring on the ice near the leads of open water. The large seal called by the Eskimos "ugruk" is much sought for its skin, which is used to cover their native boats and for the soles of their muckluks, or water boots. Walrus is another aquatic animal that is common off the western coast of northwestern Alaska. (See pl. 13, *B*.) The members of the expedition of 1923 saw many of these animals and shot several as they followed the southern margin of the ice northward in the summer of that year. While the expedition of 1926 was in the vicinity of Wainwright the natives brought in many walrus that they had killed on the ice a short distance offshore, and when the *Bear* arrived its officers reported passing a herd numbering thousands between Icy Cape and Wainwright. Many walrus that are wounded during these hunts are not recovered at the time by the natives but later die, and their bodies are brought ashore by the winds and currents. Dead walrus that had floated ashore in this way were found at a number of places along the beach between Wainwright and Peard Bay by the members of the Geological Survey party of 1926. According to Leffingwell [36] walrus hardly ever go east of Point Barrow, though he states that he "found one dead and two alive less than 50 miles west of Flaxman Island. During the six years no others were seen by natives. Some natives had never seen any during a lifetime on the coast."

BIRDS

Birds are numerous throughout northwestern Alaska during both summer and winter, and many of them are not only a source of food but their skins are used by the natives for parts of their clothing and for decoration of many of their small articles, such as bags and trimmings. Fortunately, many of the birds of the region have been studied, identified, and described by qualified ornithologists, so that in this report only a few notes made by members of recent Geological Survey expeditions are given. Those who are specifically interested in the birds of the region should consult the more comprehensive reports, reference to which is here given. The birds of the southern part of the region, which may be considered as including all of the mapped area southward from Point Hope and at least as far east as the head of the Kobuk, were, so far as known, described by Grinnell [37] in a paper in which he not only lists 150 species but gives detailed notes regarding many of them and a bibliography of 18 other papers relating to birds of this region. Notes on the birds of the northern part of the region are perhaps most available in a report by Murdoch,[38] who identified 54 species. Another valuable reference list is that prepared by Anderson,[39] who wrote the reports

[36] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 63–64, 1919.

[37] Grinnell, Joseph, Birds of the Kotzebue Sound region: Cooper Ornithol. Club of California Bull., vol. 1, pp. 1–80, 1900.

[38] Murdoch, J., Report on birds observed at Point Barrow during the stay of the polar expedition in 1881–1883: 48th Cong., 2d sess., H. Ex. Doc. 44, 1885.

[39] Anderson, R. M., in Stefansson, V., My life with the Eskimo, pp. 436–527, Macmillan Co., 1913.

on the natural history collections made by himself and Stefansson in their explorations in northern Canada and adjacent regions in 1908–1912. This list contains notes on 170 species of birds, some of which, however, do not live in a region topographically or climatically similar to northwestern Alaska. More complete and up to date than any of these, however, is the report by Anderson and Taverner [40] now in preparation, which will doubtless include the most complete and authoritative treatment of the birds of this region.

Although the birds of the region are therefore already fully covered in published reports, the following scattering notes may be of some interest as pertaining to tracts not hitherto reported on and preserving a record not otherwise available. No attempt has been made to systematize these notes, nor are they to be regarded as complete.

In the winter snow-white ptarmigan were seen in flocks of hundreds on the Alatna, Unakserak, and Kokolik and almost everywhere in the headward portion of the Killik River. Early in May their heads and necks had begun to become dark with summer plumage, and by May 18 on the Killik in 1924 and May 5 on the upper Utukok in 1925 their feathers, as far down as their shoulders, were brown. By that time the large flocks had begun to break up into small family groups, and their mating calls resounded throughout the brush and along the bars, often within a few paces of the tents. On June 4 a ptarmigan nest with eggs in it was found in the grass on the banks of the Killik River, and on June 24 and 27 ptarmigan were seen on their nests on the Colville near the Kurupa and Awuna Rivers. In the nest near camp S June 26 were 8 eggs nearly hatched.

Next to ptarmigan the most abundant birds are ducks and geese. The first of these visitors in 1924 passed northward over the camp May 7, in 1925 May 15, and in 1926 May 10. After those dates flocks were seen at intervals during the next few weeks. It is significant to note that Howard, who passed through the Colville region in 1886, reported that the first goose was seen that year May 11 and that geese were plentiful the last week of May. Ray reports seeing an eider duck flying north at Barrow April 27, 1882, and he saw large coveys of these ducks May 12. Several different species of geese were seen, but the inexpertness of the Geological Survey members prevented identification of the different kinds. Emperor geese, which are supposed to have a distribution restricted to the Yukon Basin and near-by areas, were definitely recognized at several places in the basin of the Colville north of the mountains as far upstream as the mouth of the Kurupa River and as far downstream

[40] Anderson, R. M., and Taverner, P. A., Birds of western Arctic America: Canadian Arctic Expedition, 1913–1918, Rept., vol. 2, pt. B, Ottawa (in preparation).

as Prince Creek. A pair of these birds spent most of the day within a few hundred feet of camp S June 28, near the mouth of the Awuna River.

Near the coast in August ducks were especially numerous, and along the west shore of Smith Bay and along the Arctic Ocean from Cape Simpson to Tangent Point, especially in the evening, the water was in places literally black with thousands of ducks. Along the sand reef from Point Lay northward almost every hummock of grass had served as a nest for ducks and other shore birds and the eggs found in them from the middle of June to the early part of July formed a most welcome addition to the food supply of travelers, both natives and whites.

A flock of five large swans was seen at close range on a small lake near camp S June 4. A lone swan circled the party for an hour or more on the Kokolik above camp P June 17, and several were seen on the small pond and flying overhead at camp P May 15, farther up the Kokolik.

During the time spent in the headquarters camp on the Killik in 1924 Canadian jays or camp robbers were constant neighbors. These birds flew around the tents, picking up scraps of meat or other food that was handy, and many of the bushes within a hundred yards of camp had little caches of food that had been hidden in them by these birds. As spring advanced other land birds became common. In 1924 snow birds were seen early in May. On May 16 ravens or crows were heard cawing, and on the next day it seemed that winter was practically over, because the robins fluttered and sang in the bushes near camp. From then on birds became more numerous and kept up a constant chatter or song. Owing to the almost continuous daylight in May the birds were quiet very little of the time—in fact, an entry in the diary for May 24, 1924, notes that the birds were still singing at 11.30 in the evening.

Among the commonest of the other land birds seen during the summer were hawks, owls, and eagles. It seemed as if almost every rocky bluff along the Colville was the site of a hawk's nest, and the parent birds were constantly alert to divert geologists away from the rocks near their home. The hawks early in the season built their nests, which were roughly constructed of twigs on the ground amidst shattered rocks. Hawk's eggs were found near the winter headquarters on the Killik as early as May 21, 1924, but even as late as the middle of August some of the young had not yet left the nest. The first hawk's eggs found in 1926 were collected on the Kokolik June 6. The hawks kill many other birds and small animals, and their lookout posts near their nests are usually littered with the feathers and bones of their victims. Owls were most numerous near the coast, and in that region of little topographic relief they looked like large white boulders until the boats came within a short distance of them, when they lazily rose and flapped away for a quarter or half a mile and settled again on a dry hummock.

FISH

The waters along the coast of northwestern Alaska and many of the streams afford fish that form a welcome addition to the local food supply. Salmon is probably the most important fish in the southern part of the region, and grayling and whitefish are the most abundant in the inland streams.

Kotzebue is the center of the salmon-fishing industry in the summer, but salmon are caught in the Kobuk at least as far upstream as Kalla, and on the Noatak McLenegan noted a camp near the Nimiuktuk that was occupied only during the salmon run. A few salmon apparently are caught as far north as Point Hope, but beyond that point they are rare. It is true that a king salmon is reported to have been taken near Barrow, but Dr. E. W. Nelson,[41] of the Biological Survey, regards this report as unreliable. Leffingwell [42] mentions having seen only two lots of salmon during his entire sojourn on the extreme north coast of Alaska. One of these lots consisted of five fish that he identified as small humpback salmon, and the other was a single large dead salmon of unknown species. C. D. Brower, in charge of the trading station at Barrow, states that almost every year a few silver salmon are caught at Pergniak, near Barrow.

Except in the vicinity of Kotzebue, salmon are not abundant enough to serve as feed for dogs, and northward along the coast either seal or walrus meat is most extensively used for that purpose.

Another fish that lives in the coast waters and is much esteemed for its food value is the so-called salmon trout that is caught in great numbers on the coast near Kotzebue and in the lagoon back of Kivalina. This fish was so plentiful that a packing plant was operated at Kotzebue for several years but was later closed down as the run of fish decreased. Salmon trout weighing as much as 3 or 4 pounds each are also reported to have been caught near Shungnak, on the Kobuk, and in some of the neighboring streams. In the waters all along the western coast tomcod are numerous. Many of these fish are caught by jigging for them through the ice during the winter and spring.

Leffingwell notes that during July and August fish are abundant everywhere along the north coast of Alaska. They are less abundant west of Harrison Bay than to the east, but he states that at most

[41] Evermann, B. W., and Goldsborough, E. L., The fishes of Alaska: Bur. Fisheries Bull., vol. 26, p. 246, 1907.

[42] Leffingwell, E. de K., U. S. Geol. Survey Prof. Paper 109, p. 66, 1919.

places east of Harrison Bay it is possible in a short time to catch, with a gill net having a $2\frac{1}{2}$-inch mesh, more fish than can be eaten. He further states that the best fishing places known to him are at Oliktok, Beechey Point, and Brownlow Point, all of which are east of the region specifically described in this report.

Grayling is the principal fish found in the smaller inland streams and is believed to be sufficiently plentiful in all the clear-water streams to be relied on for food. In fact, it is difficult to recall a clear stream of any size in which grayling were not found when carefully searched for, though it must be confessed that because of the abundance of supplies of other food and because of other interests fish were not generally sought. Not only were grayling seen at a number of places during the summer, but even in the winter they were found in deep holes where the stream was not frozen solidly. Such a place was found a couple of miles north of the winter headquarters of the expedition of 1924. At this place there was a narrow lead of open water 5 to 10 feet wide and perhaps 100 to 200 yards long in which at least 400 grayling were caught with artificial flies, home-made nets, snares of copper wire, and even by grabbing them in the bare hand.

Large whitefish live in the waters of the Koyukuk and are especially abundant near Allakaket, where they are caught in great numbers in traps set through the ice. They are also said to be abundant in many of the lakes, especially those near the Kobuk, and are much prized for food. A small whitefish about the size of a grayling is found in a great many of the small streams under conditions essentially the same as those favorable for grayling.

Mendenhall states that numbers of pike are caught in the delta portion of the Kobuk, and this fish was also shot in Lake Takahula, in the basin of the Alatna.

Before the natives had the white man's gear for fishing, their hooks, lines, and other tackle were made from local material. Along the coast their nets were made of thin strips of whalebone, sealskin, or caribou sinew, and inland they were made from the tough interior fiber that lies under the bark of willow roots. The sinkers were usually made of pieces of caribou horn or of pebbles. Small floats for the nets were made from pieces of driftwood, but the larger ones were frequently made of blown-up bladders. The hooks of the Eskimos were usually barbless and were made from pieces of walrus tusk or other suitable bone. Even now many white people report that fish may be caught with these ivory hooks when they can not be taken with other kinds of hook or bait. The Eskimo fish lines were made of thin strips of whalebone or some of the heavier lines from the hide of the ugruk. Some fish and even whales were obtained with spears that had stone, bone, or ivory points fastened to wooden shafts.

Probably the most comprehensive memoir available that describes the fishes of this region is the one by Evermann and Goldsborough [43] already cited. In this report are listed and described 36 species from an area described as "the Arctic Ocean streams including the Mackenzie and all other tributary waters in Alaska." This area therefore includes a considerably greater tract than is covered in the present report, though it is believed that in general the climatic and other features are essentially similar. As a result of many years of exploration of northern Canada and adjacent parts of Alaska, the Canadian Arctic Expedition (1913–1918) is now preparing a report on the fish of that region which, when it is published, will doubtless contain the most comprehensive and authoritative data on the subject.[44]

OTHER WILD LIFE

To one unfamiliar with the region the number and variety of the lower animals that inhabit it may be surprising. Over the land in the summer time are swarms of insects ranging from flies and mosquitoes to vivid dragon flies and butterflies, and in the waters are crustaceans, mollusks, echinoderms, and representatives of many of the other phyla and classes. So numerous are many of these that in the order of Lepidoptera alone—the butterflies and moths—the Canadian Arctic Expedition [45] lists and describes 13 families, 62 genera, and 114 species, which were collected in northern Canada and adjacent regions that may be considered more or less identical with the Alaskan region which forms the subject of this report. Other volumes of the Canadian Arctic Expedition have been published or are in preparation, which describe all the other forms of life collected by that expedition and which should be consulted as affording most detailed information regarding a more or less analogous region, as well as incorporating references to most of the pertinent literature on the kinds of life described.

Little notice was paid by the Geological Survey expeditions to these lower animals in the field except as they thrust themselves on the attention. Of those the men were thus forced to notice, mosquitoes were undoubtedly the most numerous. These pests are extremely active in the Kobuk and Noatak and adjacent areas early in June and keep up their harassment until well into August, but north of the

[43] Evermann, B. W., and Goldsborough, E. L., op. cit., pp. 219–360.

[44] Johansen, F., Fishes: Canadian Arctic Expedition, 1913–1918, Rept., vol. 6, pt. A (in preparation).

[45] Gibson, Arthur, Insects—Lepidoptera: Canadian Arctic Expedition, 1913–1918, Rept., vol. 3, pt. 1, 58 pp., Ottawa, 1920.

mountains, although a few were seen as early as the later part of May, it was well into July before they became really objectionable. From that time on until the middle of August, unless the weather is stormy, they are present in such hordes that work in the open is extremely trying, and uninterrupted sleep elsewhere than inside completely mosquito-proof shelters is impossible. Even the caribou are tormented by them so badly that they can not graze in peace but are constantly tossing their heads, rubbing against brush, or wandering in search of a breeze. Along the coast the mosquito scourge is not so bad, for there is almost always a breeze there that drives the insects to seek shelter in the vegetation. As a protection against these insects it is generally necessary to wear veils and gloves.

A number of different kinds of flies were also noted in the region. The first fly noted in the open in 1924 was seen May 20, and within a week they were very numerous and had blown fresh meat so badly that it had to be destroyed. In 1926 flies were so numerous by May 28 on the Kokolik that it was necessary to cover up meat to preserve it from their attack. In this connection it is interesting to note that Howard reports that on his trip in 1886 flies appeared in the Colville and Ikpikpuk Valleys May 20. Grinnell[46] reported mosquitoes on the Kobuk May 24, 1899.

Along the coast the beaches are usually strewn with remains of crabs, starfish, jellyfish, mollusks, and other forms of sea life. Collections of some of the smaller commoner forms were made while awaiting the withdrawal of the sea ice. Although all the forms have been reported from other places, the following lists of species identified by W. H. Dall may be of interest as relating to collections made by Sidney Paige in 1923 and by P. S. Smith during the expedition of 1926 from points not hitherto recorded:

Peard Bay, near Point Barrow (26AS89):
- Peronidia lutea Gray.
- Macoma balthica Linnaeus.
- Venericardia alaskana Dall.
- Serripes grönlandicus Gmelin.
- Natica sp. cf. N. (Cryptonatica) clausa Broderip and Sowerby.
- Tachyrhynchus erosus Couthouy.
- Balanus sp.
- Echinoderm cf. Echinarachnius parma.

15 miles southwest of Wainwright Inlet (26AS98):
- Mytilus edulis Linnaeus.
- Modiolaria nigra Gray.
- Monia macroschisma Deshayes.
- Pecten (Chlamys) islandicus Müller.
- Astarte borealis Schumacher.
- Cardium ciliatum Fabricius.

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[46] Grinnell, Joseph, op. cit., p. 78.

Cardium californiense Deshayes.
Serripes laperousii Deshayes.
Macoma carlottensis Whiteaves.
Siliqua media Gray.
Cyrtodaria kurriana Dunker.
Mya truncata Linnaeus.
Admete couthouyi Jay.
Volutomitra alaskana Dall.
Buccinum glaciale Linnaeus.
Buccinum polare Gray.
Buccinum angulosum Gray.
Buccinum normale Dall.
Buccinum tenellum Dall.
Chrysodomus solutus Hermann.
Chrysodomus sp.
Pyrulofusus harpa Mörch.
Liomesus nassula Dall.
Neptunea pacifica Dall.
Neptunea multicostata Eschscholtz.
Boreoscala greenlandica Perry.
Trichotropis bicarinata Sowerby.
Natica (Cryptonatica) clausa Broderip and Sowerby.
Margarites sordida Hancock.
Rhynchonella psittacea Gmelin.
Idothea sp.

20 miles southwest of Icy Cape (26AS99):

Mytilus edulis Linnaeus.
Astarte bennetti? Dall.
Astarte borealis Schumacher.
Mya truncata Linnaeus.
Plicifusus arcticus Philippi.
Plicifusus sp. undet.
Buccinum tenue Gray.
Buccinum glaciale Linnaeus.
Buccinum plectrum Stimpson.
Buccinum polare Gray.
Buccinum normale Dall.
Buccinum angulosum Gray.
Trichotropis bicarinata Sowerby.
Margarites sordida Hancock.
Modiolaria nigra Gray.
Pecten (fragment) cf. P. islandicus Müller.
Cardium ciliatum Fabricius.
Serripes grönlandicus Gmelin.
Venericardia crassidens Broderip and Sowerby.
Venericardia crebricostata Krause.
Siliqua media Gray.
Zirfaea gabbi Tryon.
Rhynchonella psittacea Gmelin.
Admete middendorffiana Dall.
Chrysodomus borealis Philippi.
Chrysodomus solutus Hermann.
Neptunea dalli Kobelt.

Neptunea pacifica Dall.
Neptunea cepula Sowerby.
Boreoscala greenlandica Perry.
Natica (Cryptonatica) clausa Broderip and Sowerby.
Amauropsis purpurea Dall.

Wright Point, Dease Inlet (Sidney Paige, 1923):

Retusa semen Reeve.
Lora harpa? Dall (decorticated).
Admete middendorffiana Dall (Young).
Admete couthouyi Jay.
Beringius marshalli Dall (Young).
Beringius indentatus Dall.
Aulacofusus sp.
Chrysodomus saturus Martyn.
Chrysodomus saturus Martyn, variety.
Buccinum normale Dall.
Tachyrhynchus polaris Beck.
Cryptonatica clausa Broderip and Sowerby.
Euspira pallida Broderip and Sowerby.
Amauropsis purpurea Dall.
Margarites sp.
Astarte borealis Schumacher.
Astarte borealis var. semisulcata Leach.
Astarte alaskensis Dall.
Venericardia alaskana Dall.
Venericardia paucicostata Krause.
Axinopsis viridis Dall.
Serripes grönlandicus Gmelin.
Liocyma beckii Dall.
Tellina lutea Gray.
Macoma brota Dall.
Macoma carlottensis Whiteaves.
Mya intermedia Dall.
Mya truncata Linnaeus.
Saxicava arctica Linnaeus.
Foraminifera.

SETTLEMENTS AND POPULATION

COAST SETTLEMENTS

All the permanent settlements in the region are strung along the coast or along the larger rivers, which form natural routes of travel. Altogether, however, there are probably not more than 200 white persons living within the entire region described in this report, so that even the largest of the settlements are only small frontier towns. In addition to the whites, there are several thousand Eskimos along the coast and Indians in the inland region, and many of these have their more permanent abodes in or near the white settlements, though for a large part of the year many of them are away on hunting or other expeditions.

Kotzebue, the largest of the coast towns, serves as a central point to which most supplies from the outside are shipped for use and distribution to the outlying parts, which are relatively easily accessible to it by the coastal waters or by the large rivers—the Kobuk, Noatak, and Selawik—that reach the coast near it. It has no harbor, and vessels drawing much more than 6 feet must lie 10 miles or more south of the town, near Cape Blossom, and lighter their cargoes from there. Kotzebue Sound is usually closed to ocean transportation from the later part of September to the early part of July, so that during the winter the only ordinary means of transportation available is by dog team or on foot. During the summer a mail boat makes trips from Nome to Kotzebue about twice a month and affords an easy means of transportation for passengers and freight. Usually at least once during the summer a large ocean freighter sailing from Seattle visits ports in Kotzebue Sound. It is understood that the customary fare from Nome to Kotzebue is $25 for each passenger and $20 a ton for freight. Freight shipped direct from Seattle is also carried for about $20 a ton. Several of the trading companies maintain their own boats, which stop at odd times at Kotzebue. During the winter the mail is brought by dog team along the trail that leads from Bonanza, near the mouth of the Koyuk River, at the head of Norton Sound, crosses the neck of Seward Peninsula to Candle, and thence skirts the coast to Kotzebue. At Bonanza this trail joins the main Yukon-Nome trail, so that incoming mail from the States goes directly to Kotzebue without going to Nome, as it formerly did. The winter mail service is usually contracted for on the basis of two round trips a month. Wireless communication with Kotzebue is available through a station maintained by the Signal Corps of the Army.

The town consists of about a score of frame buildings or cabins and a great number of sod huts, tents, and other temporary habitations of the natives. It has a permanent white population of about a dozen persons, but there are always many natives in it, and during the summer several hundred natives are camped in and near it. In former days natives from points as distant as Siberia, together with those living inland on the large rivers, used to congregate during the summer at Kotzebue for fishing and trading.

The Territory maintains at Kotzebue a school for white children and those of mixed blood, and according to the governor's report for 1926 the school had an enrollment of 18 children. The Bureau of Education also maintains a school for the children of natives, with an enrollment of more than 60.

Four stores do business in Kotzebue, and each year about 600 tons of supplies are distributed by them and in exchange they take in many furs. The stores at Kotzebue and in fact most of the stores throughout northwestern Alaska are better stocked than stores serving numerically similar communities in the States. This is because their customers desire and use a great diversity of articles, and there is almost no chance to replenish supplies economically except on orders, sent out many months in advance, that are delivered during the short open season. An idea of the completeness of the stocks carried by these stores may perhaps be best shown by the fact that the Geological Survey expeditions of both 1925 and 1926 purchased practically all their supplies and equipment, except instruments and special tents, at Kotzebue. The prices were reasonable and the foodstuffs furnished to the expedition of 1926 were of excellent quality and of great diversity. There is a road house at Kotzebue where travelers can be well taken care of at the usual Alaskan rates.

Northward along the coast the next settlement at which there are any white people is Kivalina. The main activities at this place are the school maintained by the Bureau of Education, which has an enrollment of about 25 children, a store operated by the natives in connection with their reindeer business, and a branch store of one of the Kotzebue traders that is in charge of a native. The old settlement at Kivalina appears to have been situated near the north end of the lagoon, about 10 miles from the present site, which is near the southern inlet into the lagoon on an exposed spit that is being destroyed more or less rapidly by the sea. The schoolhouse, the homes of a couple of native families, and the store are the only frame houses in the town, the others being constructed mainly of sod or driftwood and during the winter being almost hidden in snowdrifts. The location of this town appears to offer no striking natural advantages, though it is well placed for getting into the back country by way of the Kivalina River and is about the nearest point on the coast across country to the settlement on the Noatak. It is also more or less centrally placed with respect to the reindeer range that is used by the local herd, and fish are said to be particularly numerous near the mouth of the Kivalina River. Fuel, however, is extremely scanty, except for the occasional driftwood that can be picked up on the coast or stunted willows that grow 10 to 20 miles up the river.

Every 10 to 20 miles in the 90-mile stretch between Kotzebue and Kivalina are native camps where shelter can be obtained. The first one north of Kotzebue is the reindeer camp at Shishaluk, near the mouth of the Noatak and about 18 miles from Kotzebue. There is another camp in a little gulch near the bluffs inland from Cape Krusenstern; a hut at a place locally known as Kilikmak, about 25 miles north of the cape; a Government shelter cabin about 16 miles southeast of Kivalina; and an old reindeer camp at Onalik, midway between the Government cabin and Kivalina.

Northwest of Kivalina the next town of importance is Point Hope, on the long sand spit that juts far out into the ocean. At this place there are only a few whites, but there are many natives whose number fluctuates greatly from one season to another. Point Hope contains a school maintained by the Bureau of Education; and an Episcopal mission in charge of an archdeacon, who is also able to minister to some of the physical needs of the people as a physician. There are a two-story frame house and several other frame buildings at this place, but most of the natives who live here permanently have sod huts. Only one store is maintained in Point Hope, and apparently it carries only a small stock of goods and only the more essential staples. No road house or stopping place for travelers is regularly operated, but the open-handed hospitality of the north always makes travelers welcome, and provides means of feeding and sheltering them while in the village. This place is one of the oldest settlements on the coast, and in the old whaling days it was the rendezvous where many ships congregated. The old burying ground surrounded by a palisade formed of hundreds of bones of whales is a unique feature of the village. Along the coast within 6 or 8 miles of Point Hope are a number of minor settlements that sprang up principally during the days of great whaling activity and have been given distinctive names such as Coopers, Jabbertown, and Tuckfield. Most of these places are now practically deserted, with only a family or two living in them permanently.

In general, the village of Point Hope is advantageously situated because it is near sealing, whaling, and fishing grounds and opposite the mouth of the Kukpuk, the largest river in the vicinity, which affords an easy route into the interior. The strong currents along the coast here are undoubtedly one of the features that have made this place especially favorable for hunting the sea animals. The narrowness of the spit makes it possible for the natives to launch their boats during almost any kind of weather by dragging their boats to whichever side of the spit is to the leeward, but even during moderately calm weather there is usually so much surf that getting in or out in small boats is likely to be sloppy. East of Point Hope, in the hilly country back of the sand spit, a herd of reindeer are grazed and give employment to a number of natives as herders and afford a source of income through the sale of meat and skins. In detail, however, the settlement is not so fortunately placed, for being on a low sand spit it is without protection from the violent winds and storms that sweep the coast, and even an adequate water supply is difficult to obtain. It is built on the soft sand, so that even footpaths between the different houses and huts are hardly marked on the ground, and even marsh grass grows but scantily on the spit.

North of Point Hope there are no settlements of whites until Wainwright is reached. There are, however, a number of shelters and small settlements at several points. Thus at Wevok, about 2 miles east of Cape Lisburne, are a couple of houses and some old abandoned sod huts. This settlement is near the point where the winter trail that strikes inland south of Cape Lisburne, in order to avoid the treacherous ice and the wild winds of the cape, comes out to the coast again. At 25 miles east of Wevok is the Corwin coal mine, where there is a house and where a watchman is in more or less continuous residence. An old settlement of small size is reported near the north end of the small lagoon 10 miles north of Cape Beaufort, but no details are available regarding it, though it is understood that now no one lives there permanently. A number of native caches have been built on the sand spit at the second opening through the reef south of Point Lay, and a house stands on the mainland shore about 10 miles south of the mouth of the Kukpowruk River, at a point called Naokok, which is evidently a well-known landmark for travelers.

At Point Lay there are several frame houses and many old huts, now in various stages of disrepair. Point Lay is marked by a curious knob, which, though it rises to a height of less than 20 feet, is a conspicuous landmark. The settlement is advantageously placed for travel along the coast, in the lagoon, or up the streams that afford natural routes into the interior. The old settlement at this place seems to have been built mainly on the higher ground, but the present-day settlement is a short distance north of this knoll and appears to be more or less permanently the home of about a dozen natives. About 15 miles north of Point Lay two frame houses have recently been built on the reef near the site of some old sod huts, at a place that is locally known as Naparuacheak.

Near the mouth of the Utukok there are a great number of abandoned sod huts and igloos that mark the site of what was once a native village of considerable size, known as Tolageak. Apparently, however, no one has lived there recently, though signs of its use as a temporary camp site for travelers were evident.

The settlement at Icy Cape is situated on the low headland that forms Icy Cape. For several years a school was maintained by the Bureau of Education there, but as the school population consisted of less than a dozen children and as available funds were needed more urgently elsewhere, the school has remained closed for several years. Besides the schoolhouse, there are one or two other good houses and a number of sod houses and igloos. About 40 natives live in the settlement at least part of each year. A branch of one of the Wainwright stores is maintained at Icy Cape, but it carries only a small stock of goods, so that often before navigation opens in the spring its stock is exhausted. A herd of several thousand reindeer is pastured on the mainland a short distance from the settlement, and a more or less permanent camp for the herders is maintained at Akeonik, near the head of the lagoon 3 or 4 miles south of Icy Cape.

About 50 miles northeast of Icy Cape is Wainwright, one of the largest villages on the coast, consisting of a school, two stores, and a score or more houses which range from well-constructed buildings of dressed lumber to sod hovels, not to mention many tents. The white population usually consists of a storekeeper and the schoolmaster and his wife, but late in 1926 a white nurse from the hospital at Barrow was added to this small group. According to the Bureau of Education the school registration is from 50 to 75, and there are probably 100 or more adult natives who live in the neighborhood. A herd of reindeer is pastured in the country back of the town, and another part of the Wainwright herd is pastured in the rolling country back of Kilimantavi, about 20 miles southwest of Wainwright. Tending these deer, hunting inland, and fishing and hunting in the waters and on the ice off the coast form the principal activities of the natives at Wainwright. Coal crops out on the Kuk River 20 to 35 miles south of the town, and many of the natives make trips there during both the summer and the winter to get fuel for their own use and for sale to the traders.

About 3 miles southwest of Wainwright, near the entrance through the sand spits to Wainwright Lagoon and the Kuk River, is a small settlement first started by Dr. Roald Amundsen when he was investigating airplane navigation in his projected attempt to fly over the pole in a heavier than air machine. This settlement, which was called Maudheim, was subsequently vacated by him and later taken over by one of the trading companies for a store. This place has many natural advantages over the site of Wainwright, as the lagoon forms an advantageous shelter for small boats as compared with the exposed coast at Wainwright, and in addition it is nearer to the coal deposits and the route into the interior by way of the Kuk and on the whole has a less swampy site for buildings.

Along the coast in both directions from Wainwright are the sites of old settlements. To the southwest the largest settlements appear to have been at Metlatavik and Kilimantavi, though now at neither of these places are there permanent buildings that are occupied. At Kilimantavi, however, when that place was visited by the Geological Survey party in 1926, before the sea ice had gone far offshore, a camp of reindeer herders with their families had been established, and it was evidently a much-used stopping place for travelers along the coast. Northwest of Wainwright a number of huts that at the time of the Geological Survey visit in 1926 had no one living in them, though apparently they were more or less constantly occupied, are situated at the place called Atanik, near the point where the sand spit that forms the northwestern boundary of Peard Bay joins the mainland. A very large old settlement that has long been abandoned except for temporary traveling parties was noted on the first island east of the first inlet to Peard Bay, between Atanik and Franklin Point. According to natives, this place was called Pingashugaruk, and apparently as many as several hundred people had lived there at one time.

About 9 miles south of the extreme northern point of Alaska is the settlement of Barrow. (See pl. 14, *C*.) This town is really divided into two more or less distinct parts, separated from each other by a lake about one-third of a mile in diameter. The southeastern part consists of the school, hospital, church, and related activities, and the other part comprises the trading post and many of the native houses. The church and hospital are maintained by the Presbyterian Church and are in charge of a minister who is also the doctor, with his wife and a hospital staff consisting of a head nurse and one or more white assistants, together with such native helpers as are required. This establishment is a source of enormous benefit to the dwellers in any of the territory within a radius of several hundred miles. The United States Bureau of Education maintains a school at Barrow, with a white man as school-teacher, who is usually assisted in his duties by his wife or other members of his family. About 90 school children are enrolled in the school.

The trading post has long been established and is in charge of a white man, with one or two white assistants and such Eskimo helpers as are required from time to time. At present the post office is conducted by the manager of the store, who is also United States commissioner and the general "head man" for the entire region. Mail for Barrow is brought during the open season by boat from Nome whenever an opportunity offers, usually at most two or three times a summer. In the winter mail is brought two or three times by dog teams that connect with the other mail routes at Kotzebue and thence skirt the coast, passing through Kivalina, Point Hope, Wainwright, and the other villages already mentioned. For some time there was considerable agitation to have a wireless station established at Barrow, and in 1928 a station of the Signal Corps was established at that place.

The United States Weather Bureau maintains a fairly completely equipped station at Barrow at which many valuable records of the various climatic elements are collected. The observations at this station are usually made by the wife of the minister.

No regular road house is operated at Barrow, but travelers can usually be taken care of at the trading post. The customary charge of a dollar for each meal or a bed is the same as is charged in more accessible parts of Alaska. All food, except meat, must be shipped into the region, and the customary freight charge from Seattle to Barrow is about $50 a ton, to which must be added the cost of packing the goods from the beach to the place where the supplies are to be used or stored. Practically all the water used for household purposes by the whites is obtained winter or summer by melting ice that has been cut during the fall and winter on the lakes back of the town, hauled in by dog team, and stored until needed. Many of the better houses are heated by coal stoves, supplemented by kerosene heaters. Most of the coal and all of the oil is brought in as freight from the States. Most of the buildings are lighted by gasoline or kerosene lamps, but the hospital and adjacent buildings are lighted by electricity supplied from storage batteries that are charged by a generator driven by a gasoline engine. There are practically no roads or even clearly marked footpaths. A few of the principal buildings are connected by short plank walks, but in the main the people tramp over the loose sand or marshy tundra and in going from one part of the town to the other must wade nearly half leg deep across the little stream that forms the outlet from the lake.

In addition to the 10 or 12 white people who live at Barrow, there are several hundred Eskimos who live more or less permanently in or near the town. The main activities of the natives are hunting, both on the land and sea, but they obtain occasional employment from the whites, and the current wages are about $5 a day, payable in trade goods. Their houses range all the way from good frame houses to sod huts or tents.

Just east of the extreme tip of Point Barrow is Nuwuk, a small settlement consisting entirely of natives. Its population fluctuates considerably, depending on the hunting conditions, but usually it consists of 50 to 100 persons. At the head of Elson Lagoon, about midway between Nuwuk and Barrow, is Pergniak, or Hunting Beach, where many families of natives congregate during the summer for hunting. The sand reef at this point is not more than a hundred yards wide, so that it provides an easy portage by which advantage can be taken of the lagoon, which usually opens earlier and affords smoother water than the ocean. A short distance south of Pergniak is an old whaling station consisting of a group of half a dozen old lumber buildings belonging to Thomas Gibson, now unoccupied.

Eastward of Point Barrow almost everywhere along the coast are indications of former human occupation of the region, but most of these signs seem to have been made by traveling or hunting parties. At the end of practically every sand spit is found the site of an old camp where travelers had apparently waited for favorable weather in which to continue their journeys. The only place where any considerable settlement has been reported is at Nigaluk, a native trading place on the Colville Delta. No specific details regarding this place are available from any of the recent travelers on the Arctic coast, and, although Schrader hunted for it in 1901, he did not find it but judged it was situated on the westernmost channel of the river. A little east of the mouth of the Colville and east of the area described in this report a white trader maintains a small post near Beechey Point.

INLAND SETTLEMENTS

The only permanently occupied inland settlements within the mapped area are on the Koyukuk at Allakaket and Bettles, on the Kobuk at Noorvik, Kiana, and Shungnak, and on the Noatak at Noatak village. They are all frontier villages, each consisting at most of only a dozen or two whites and a larger number of natives.

Allakaket and the settlements above it on the Koyukuk are reached during the winter by trails that follow the river or by a mail trail about 125 miles long that strikes across country from Tanana on the Yukon and reaches the river a few miles southwest of Allakaket. During the summer the only means of reaching the upper part of the Koyukuk now is by means of the river steamer belonging to one of the local traders, which makes about one trip a season, by boat under special charter, by the long, tedious route up the Koyukuk in a poling boat, or by the cross-country Chandalar trail. Formerly, however, when mining was active, the old trading companies used to run river boats on a more or less regular schedule the entire length of the Koyukuk as far as Bettles.

The main distinctive feature of the village of Allakaket is the Episcopal mission, St. John's in the Wilderness, which for many years has effectively labored in bringing the best of the white man's knowledge to the natives. The head of the mission, with whom there is generally associated a graduate nurse, also serves as observer for the Weather Bureau station that is maintained at the mission. A store and a dozen or more well-made log cabins have been built near the mission, and the village is one of the most attractive and orderly of all that have been visited. Scores of natives, both Indians and Eskimos, live near the village and hunt in the territory contiguous to it.

Bettles, situated on the Koyukuk just below the mouth of the John River and about 60 miles above Allakaket, used to be a good-sized town when boom mining flourished, as it was at the head of steamboat navigation and was the distributing point for supplies to a large part of the surrounding country. It was also the site of a large native village. Gradually it has diminished in size until now it is mainly a warehouse point with a store, a post office, a road house, and a few houses. Wiseman, about 60 miles above Bettles on the Middle Fork of the Koyukuk, is the nearest point at which a wireless station is maintained.

On the Koyukuk during the early rush of miners into the region many boom towns sprang up. Jimtown, at the mouth of the Jim River; Soo City, a few miles farther downstream; Seaforth, midway between the Jim River and Fish Creek; Union City, at the junction of the South Fork and the Koyukuk; Peavey, 3 or 4 miles up the Koyukuk above that junction; Bergman, near the mouth of Pickarts Creek; Beaver City, on the Alatna near the junction of that stream and Helpmejack Creek; and Rapid City, 10 miles farther upstream, are all places that existed at one time but have been depopulated and are recognized now only by reference to old maps or by fast-disappearing evidences of old camps.

On the Kobuk the largest inland village is at Noorvik, where the Bureau of Education has established a school and hospital that were designed to be models, and where the California Society of Friends maintains a mission. This village is near the head of the delta, about 60 miles from Kotzebue. During the summer it is reached by small launches that run at irregular times up the river, and during the winter the mail is brought to it once a month by dog teams. There is, however, always more or less travel to and from points on the Kobuk. A doctor and nurses are attached to the hospital and are of inestimable service, as they serve a territory within a radius of many hundred miles. The superintendent of the schools of the northern district and a school teacher and his family are usually the only other permanent white residents of the town, but there are several hundred natives. The school registration is by no means constant but probably ranges in the neighborhood of 100. Formerly a radio station was operated at this place, but it is understood that this station has been discontinued since the Kotzebue station was opened. The buildings at Noorvik have electric lights, and there are plank sidewalks and many other improvements not customary in remote settlements. A sawmill is also operated here.

About 25 miles farther upstream, at the junction of the Squirrel River and the Kobuk, is Kiana, a small settlement comprising a Territorial school, the headquarters of the commissioner of the district, a store, and a few cabins. This town was originally a native camp, but with the discovery of gold in the hills to the north a mushroom village of whites sprang up, which has gradually diminished as the rush subsided.

The next village upstream at which white people are found on the Kobuk is Shungnak, which is a short distance above Dahl Creek, or about 10 miles above Fort Cosmos, Stoney's winter headquarters when he explored part of the region in 1885–86. When this place was visited by Smith in 1910 it contained a mission, a school, a store, and several native huts. It is understood, however, that since that time the village has grown considerably in size, but even now only a few white people live there permanently, though there are possibly a dozen prospectors who live on the creeks within a radius of 15 miles. At Shungnak several small gardens are successfully cultivated and furnish carrots, turnips, potatoes, cabbages, and similar hardy quick-growing vegetables, which form a welcome addition to the local food supply.

At a number of places in the Kobuk Valley signs of old habitations that are now deserted were seen. The largest of these appears to have been near the mouth of the Pah River, which affords an easy route southward into the Koyukuk Valley. Stoney[47] mentions a settlement, "Sulookpowwick," near the mouth of the stream flowing into the Kobuk from Lake Selby, which he says was the most eastern settlement on the Kobuk. A short distance above Shungnak is Kalla, which is said to be the place where most of the natives of the central part of the Kobuk go for fishing during the season when the salmon are running. Plate 11, *B*, shows some of the natives catching salmon with nets near this place.

In the valley of the Noatak there are no settlements in which any white people permanently reside. The largest village is the mission, which is about 45 miles in an air line upstream from the mouth of the Noatak and has a population of several hundred natives. The Bureau of Education has a school there that is in charge of two very competent natives; the school population is about 40. A reindeer herd is pastured near the village in charge of native herders. There are two stores which carry small stocks of supplies; one is the so-called native store, which is operated in connection with the reindeer industry, and the other is a branch of one of the Kotzebue stores. Throughout the rest of the Noatak Valley signs of former settlements are rare. Stoney mentions the villages of Aniuk, probably near the mouth of the river of that name; Shotkoaluk, some 10 miles farther upstream; and Nimiuk, near the stream that is shown on his map leading to Riley Pass. Neither of the last two village sites was

[47] Stoney, G. M., Naval explorations in Alaska, pp. 45–51, 1900.

recognized by the Geological Survey parties, and their location is uncertain. McLenegan[48] did not mention any occupied villages in that part of the river below the Aniuk which he surveyed. The only sites of old settlements mentioned by Smith were one near the big bend 10 miles north of the mouth of the Cutler River, one a short distance below the Kugururok, and one 10 miles northwest of the gorge of the Noatak through the Igichuk Hills.[49]

No detailed information is available regarding the village on the Selawik River, though it is known that the Bureau of Education maintains a school there. This school is usually in charge of a white teacher and there is also a store in the village. The school population is about 40.

On the Colville within the area seen by any of the recent Geological Survey expeditions there are not only no settlements but also no signs of recent human habitation. In fact, even signs of old habitations are rare. Near the small canyon of April Creek a short distance above the winter headquarters of the expedition of 1924 were a number of willow frames of huts that did not appear to have been occupied for a score of years, and buried in the moss that had sprung up were some discarded utensils which, from their workmanship, had apparently been brought there from the coast. An old rusty windlass bucket nearly buried in the gravel of a small creek near camp M June 13 on the Killik River was probably left by the party of prospectors reported by Schrader as having been in the region in 1903. Old chopping for firewood and more characteristically old willow stumps that had been sawed off were seen at a number of places, and on many of the prominent knobs north of the Brooks Range are lookout stations that had been used long ago by natives when hunting caribou. Signs of an old settlement consisting of 15 to 20 igloos were noted on the Colville near camp G' June 19 and also a group of four or five igloos near camp G June 25, but all of these were in ruins and had not been used for a long time. The point on the Colville from which the old route led from that stream to the Ikpikpuk was not well marked but apparently was near camp S June 26. On the south side of the Colville at this place were two old willow frame hovels and numerous discarded utensils, among them tin cans and stovepipe that had not yet entirely rusted away. There were, however, no signs of a large old settlement such as Howard described at the place where he waited for three or four days when he made his remarkable trip in 1885–86. Several other villages farther up the Colville and its tributary the Etivluk were mentioned

[48] McLenegan, S. B., Exploration of Noatak River, in Report of the cruise of the Revenue Marine steamer *Corwin* in the Arctic Ocean in the year 1885, pp. 53–80, Washington, 1887.

[49] Smith, P. S., U. S. Geol. Survey Bull. 536, p. 45, 1913.

by Howard, but at most of these sites even vestiges of these former habitations had practically disappeared. For instance, at the junction of the Etivluk and the Colville, where Howard spent five days in the village of Etivolipar, there were no signs of a former settlement that could be recognized from the Geological Survey boats. Farther up the Etivluk, near the stream that enters it from the west near camp G July 17, are some ruins that may mark the site of Tooloouk, noted by Howard as a village of 10 huts with about 70 natives. Both Stoney and Howard mention the village of Issheyuk, which was situated near the head of the Etivluk and consisted of about 15 huts. The precise area in which this village might have been located was probably not traversed by the Geological Survey parties, but it is certain that there is there now no village that has recently been occupied and no natives living in that neighborhood.

On the Awuna River a short distance above its junction with the Colville some exceptionally well fashioned stone spearheads were found near an old native camp site, and on the summit of Birthday Pass, about a mile east of the point where the Geological Survey's route crossed, were sods that had evidently been cut to bank around the bottom of a small tent.

In the basin of the Ikpikpuk a few miles above the junction of the Kigalik River and Maybe Creek is an old ruined village that appears to mark the north end of the portage from the Colville. This place must have been at one time the home of numerous natives, as is indicated by the worn-out and discarded gear and the ruins of houses, many of which were dug down several feet below the terrace flat on which they were built. Large willow tripods, evidently used for hanging up meat, showed that this place had probably been last used by hunters, but the rotten condition of the rope and canvas which together with willow withes had been used for fastening the legs of the tripods proved that they had not been used for many years. A few miles farther downstream, at the junction of the Kigalik River and Maybe Creek, there are indications of a formerly very populous settlement. This is undoubtedly the village noted by Howard in 1886 as Kigalik, which at the time of his visit consisted of 30 tents and 50 natives. No huts remain, and the tract does not appear to have been used even by chance travelers for many years.

Farther down the Ikpikpuk signs of former small settlements become increasingly evident, but at all the places the huts were in ruins and had not been used for a long time. Midway between camps S August 12 and S August 13, a short distance above the junction of the large clear-water stream that comes in from the east, a traveling party of Eskimos were camped. These were the only people that were seen in the entire basin of the Colville or Ikpikpuk during the nearly six months the Geological Survey party of 1924 was in the region.

No records are available of any settlements on the Meade River, and none were seen by the Geological Survey parties. Doubtless in the past there have been temporary camps here and there along the river, but none of them seem to have been permanent or to have been occupied by many people.

On the Kukroak two or three huts were noted a few miles above camp P August 9, but they were deserted and appeared to have been used only rarely by hunting parties during the winter.

Signs of former habitations were seen at a number of places along the Kuk River and its tributaries. None of these, however, were occupied at the time the Geological Survey parties were in the region, and no natives were seen. The largest old settlements noted were at Anaktook and Kangik, and people probably still live in these places during the winter. Farther up the Avalik signs of native camps were seen at several places, but above the northern fork they were mostly made by small bands of hunters.

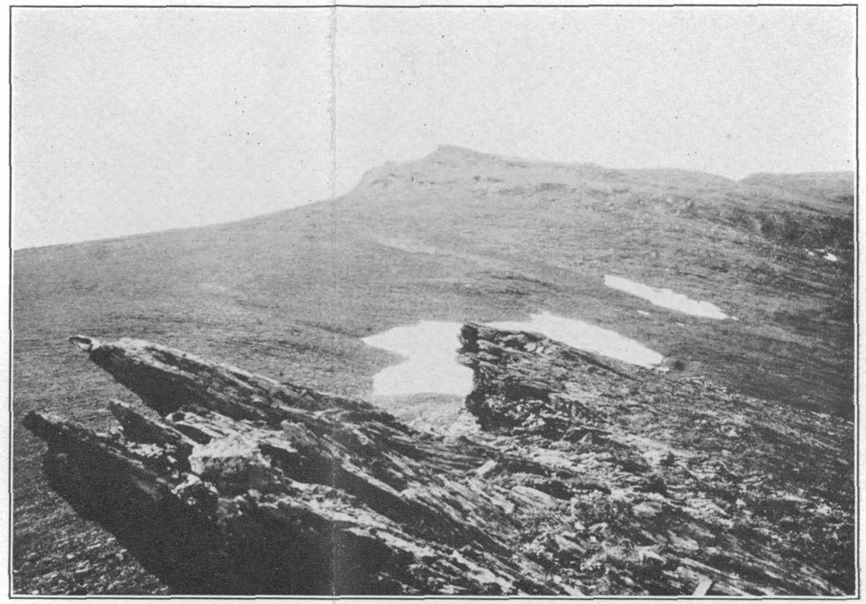
The same general conditions prevailed in the valleys of all the other rivers flowing into the Arctic Ocean. On none of them were there any occupied settlements, and on few of them were there signs of camps that had been used for any length of time recently. Sod huts and igloos that had rather recently afforded shelter for hunting parties or trappers during the winter were seen on the Kokolik between camp P June 15 and camp P June 16, on the Kukpuk between camp P April 25 and camp P April 26, and on the Kivalina at several places both above and below camp P April 10. On the Kukpowruk all the way from the coast to the Amatusuk Hills deserted igloos were more numerous than on any of the other streams. Many of these were in ruins, but several of them had apparently been used by natives within a year.

DESCRIPTIVE GEOLOGY

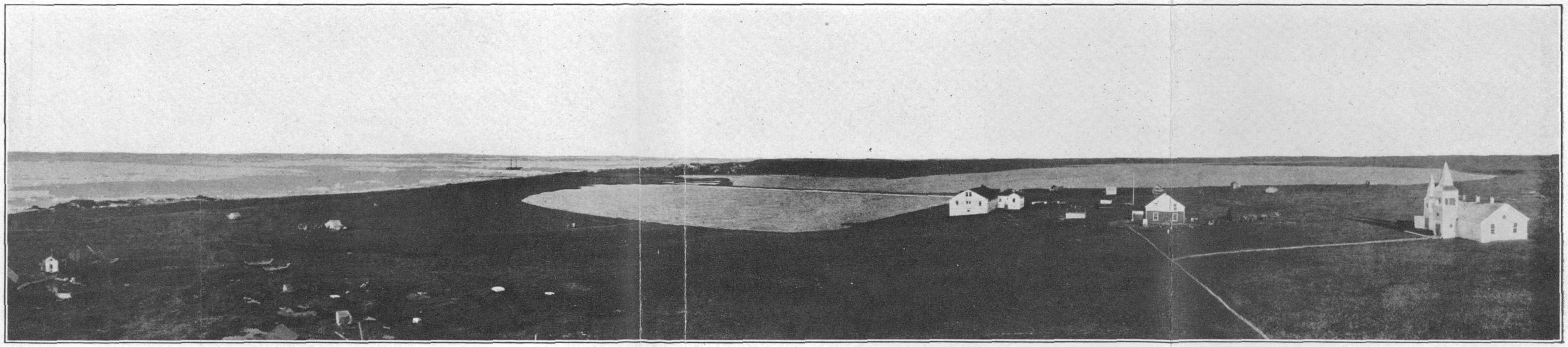
GENERAL FEATURES

Rocks representing a number of different formations that range in age from early Paleozoic if not pre-Cambrian to Recent are found in different parts of the region. The interpretation of the facts that they disclose permits the geologist to determine the long series of events that have happened in the region and thus reconstruct in greater or less detail its history. This history includes long periods during which beds of sand, mud, and other sedimentary materials were laid down in the sea and on land, molten igneous rock was intruded deep underground and flowed out on the surface, many of these materials were consolidated into hard rocks, these rocks

A. TYPICAL EXPOSURE OF SCHIST NEAR ALATNA RIVER



B. HILLS WEST OF WESLEY CREEK, NEAR SHUNGNAK



C. SETTLEMENT AT BARROW

Era	Period	Epoch	NORTHWESTERN ALASKA P. S. Smith and J. B. Mertie, jr., this report.	CHANDALAR-KOYUKUK REGION J. B. Mertie, jr., U. S. Geol. Survey Bull. 773, pp. 215-263, 1925.	CANNING RIVER REGION E. de K. Leffingwell, U. S. Geol. Survey Prof. Paper 109, 1919.	PORCUPINE VALLEY REGION E. M. Kindle, Geol. Soc. America Bull., vol. 19, pp. 315-338, 1908.	EAGLE-CIRCLE DISTRICT J. B. Mertie, jr., U. S. Geol. Survey Bull. in preparation.
CENOZOIC	Quaternary	Recent	Sand, gravel, silt, and ice wedges or masses of fluviatile, marine, glacial, and lacustrine origin laid down on the land and in the shallow waters off the coast.	Sand, gravel, and silt, dominantly laid down on flood plains of present streams and on their valley slopes. Detritus derived through glaciation and attendant processes and widely distributed through these processes.	Sand, gravel, silt, mud, and ice wedges, of marine, fluviatile, and composite origin. Glacial and related deposits extending from Pleistocene to present.	Not described though obviously present.	Sand, gravel, silt, and mud, dominantly of fluviatile origin.
		Pleistocene					
	Tertiary	Pliocene	Nonindurated stratified slate-colored or ash-colored calcareous sediments near mouth of Colville. Formerly treated as upper part of "Colville series."	Sedimentary deposits not recognized. Basaltic lavas and intrusive rocks.	Shale, near Collinson Point and in adjacent part of Camden Bay region. Slightly consolidated. Fossils indicate temperate climate.	Successive basaltic lava flows with intervening accumulations of soil and forest growth. ? Soft shale and marl with lignite beds. In places show dips of 20°	Basic intrusive and effusive rocks.
		Miocene	? Conglomerate, sand, and shale, dominantly of terrigenous origin, containing small coal beds. Poorly consolidated except in Kobuk Valley.		? Sandstone at Peard Bay. Fairly hard gray-green sandstone. Little deformed. No fossils found in these rocks. ? ?		
		Eocene					Eocene and Upper Cretaceous rocks. (Sandstone, graywacke, shale, grit, and conglomerate. Principally of nonmarine origin.) ?
MESOZOIC	Cretaceous	Upper	Sandstone and shale of marine origin with some bentonite beds near top. Dominantly sandstone and shale of terrigenous origin with numerous thick coal beds. Sandstone and shale principally of marine origin.	Sandstone, shale, and conglomerate, thoroughly indurated and considerably folded and faulted. (?)	Not recognized.		
		Lower	Sandstone and shale with minor beds of grit. Marine. Universally much deformed. Massive conglomerate member near base. (?)	[Shale, sandstone, and conglomerate forming Koyukuk group in region to the south.]	(?)		Slate and sandstone typically developed along Yukon River near mouth of Kandik River.
	Jurassic	Upper	Sedimentary representatives believed to be absent throughout northwestern Alaska but possibly present as Corwin formation in Lisburne region. (?)	Jurassic sedimentary rocks not recognized and probably absent. Batholiths of granodiorite and related rocks possibly intruded during this interval.	Ignek formation (Jurassic?). (Black shale with some sandstone and coal beds. In part marine; in part terrigenous deposits.)		Jurassic sedimentary rocks not recognized and probably absent. Batholiths of granitic rocks probably intruded during this interval. (?)
		Middle			Granitic intrusions of uncertain age.	No Mesozoic sedimentary beds recognized.	
		Lower			Kingak shale (Lower? Jurassic). (Black shale with marine fauna.)		
	Triassic	Upper	Chert, limestone, and shale. Marine. Highly deformed.	No Triassic rocks recognized.	Shublik formation. (Dark limestone, shale, and sandstone. Abundant marine fauna. Equally deformed with Paleozoic rocks.)		Shale and thin-bedded limestone.
		Middle	Unknown anywhere in Alaska except from a single piece of float found in Seward Peninsula.		Not recognized and probably absent. (?)		Not recognized and probably absent. (?)
		Lower	Unknown anywhere in Alaska. (?)				
PALEOZOIC	Carboniferous	Permian	Not recognized in region but may be present and overlapped by later rocks of Mesozoic age.	Not recognized. (?)	Sadlerochit sandstone. [Originally assigned to Pennsylvanian but now regarded as Permian.]	Shale overlying limestone. [Both originally called "Upper Carboniferous." Fossils from limestone later determined to be Permian.]	Massive white limestone of Nation River.
		Pennsylvanian			Greenstone intrusive and effusive rocks.		Sandstone, shale, grit, and conglomerate of Nation River. Principally nonmarine.
		Upper Mississippian	Lisburne limestone, of marine origin. (Limestone and chert.)	Limestone in remote parts of Brooks Range, not critically examined.	Lisburne limestone. (Dark limestone at base overlain by light-gray limestone containing abundant fossils and some chert.)	Limestone and shale resembling similar series at Calico Bluff.	Limestone and shale of Calico Bluff, along Yukon River.
		Lower Mississippian	Noatak formation. (Sandstone and shale, principally of marine origin but contains small coal beds. Includes chert conglomerate formerly called Stuver "series.")	Upper Devonian or Mississippian rocks, not separated. (Chert, quartzite, calcareous black shale, impure limestone, and cherty grit.)	?	Quartzite, sandstone, and shale, carrying fossil plants.	Shale and chert typically developed at N. end of Calico Bluff. Rampart group, basic lava, slate, and chert.
	Devonian	Upper	Sandstone, grit, and shale.		Black shale with subordinate beds of sandstone. Complexly folded and faulted.	Brown shale with some basic lava flows.	Not recognized as sedimentary rocks. Ultrabasic intrusives possibly injected during this interval.
		Middle	Not specifically identified but probably present and included with the general group of Devonian rocks.	Slate and sandstone with thin limestone layers. Contains fauna of limestone at mouth of Salmontrout River.	?	Salmontrout limestone. (Light-gray to blue, weathering to buff.) No angular unconformity at base.	Chert, cherty grit, and slate, along international boundary Basic volcanic rocks with interbedded limestone exposed at Woodchopper, on the Yukon. Limestone on international boundary containing Salmontrout fauna.
		Lower	Not recognized anywhere in Alaska and probably absent in this region. (?)	Not recognized; probably absent.		Missing. ?	Missing. (?)
	Silurian		Slate, schist, and metamorphic limestone designated undifferentiated Silurian rocks. Skajit limestone. (Metamorphosed and recrystallized limestone.) ?	Silurian limestone. Crystalline and semicrystalline limestone and dolomite. ?		? Graptolitic shale overlying magnesian limestone and dolomite which carries Niagaran fauna. ? Not recognized.	Limestone, slate, and related rocks. Limestone of White Mountains. Massive limestone. Early Silurian not recognized and possibly absent (?)
	Ordovician	Upper			Neruokpuk schist. (Quartzite and quartzite schist, with some conglomeratic beds.) Metamorphism intensely greater than in any of the other rocks. Contacts with other rocks apparently in all places fault contacts. Two belts of schist discriminated in field but this division not retained in report and both described as unit of pre-Carboniferous age.		Limestone along international boundary and in Ruby district. Richmond fossils.
		Middle				Hard bluish-gray limestone with a few oolitic bands. Contains fossils of Mohawkian age.	Calcareous tuff underlain by basaltic lavas and tuffs, in White Mountains. Mohawkian (?) fossils.
		Lower	Early Paleozoic or older rocks: Quartzite, quartzite schist, quartz-mica schist, calcareous schist, carbonaceous schist, chloritic schist, phyllite, hornblende schist, albite schist, interbedded crystalline limestone, and undifferentiated basic volcanic rocks of greenstone habit. Includes part of former "Totsen series" of John River region and certain of the so-called "undifferentiated schists" of the Kobuk and Noatak Valleys. At least one strongly indicated unconformity is present, and doubtless others occur but have not been distinguished.	Early Paleozoic rocks, consisting of mica schist, phyllite, carbonaceous schist, gneiss, and basic igneous rocks of greenstone habit. Includes rocks formerly called "Rapids schist" and "Lake quartzite schist"; these names subsequently abandoned.			Limestone and graptolitic slate, along international boundary. Normanskill fossils. Argillite and slate of White Mountains. Beekmantown fossils.
	Cambrian	Upper				? ?	Limestone along international boundary. Upper Cambrian.
		Middle					Limestone along international boundary. Massive limestone, underlain by argillite and thin-bedded limestone. Yukon River below Eagle. Middle and Lower Cambrian.
		Lower		?		Pre-Ordovician rocks. Quartzite with some slate, shale, and limestone.	Red beds, probably underlain by graywacke, conglomerate, argillite, and phyllite.
Pre-Cambrian (?)			?	Quartzite schist and quartzite (Birch Creek schist?).	?	?	Quartzite, quartzite schist, quartz-mica schist, mica schist, carbonaceous and calcareous schist, sericite and chlorite schist, hornblende schist, amphibolite, and granitic gneiss.

CORRELATION TABLE OF GEOLOGIC FORMATIONS IN NORTHWESTERN ALASKA AND ADJACENT REGIONS were subjected to enormous earth stresses and strains whereby they have been folded into mountains, broken, bent, and dislocated, and all the time they have been undergoing erosion and weathering by the same agencies as are now modeling the surface features, together with other agencies that were more active in the past than now. Much of this history is still only obscurely determined, for each subsequent event tends to obliterate the record of the earlier ones, so that many of the older events are now determinable, if at all, only by more intensive and extensive studies than the Geological Survey has been able to give to them in the investigations that form the basis of this report. The story that has been thus revealed is of interest not only because it is fascinating in itself but also because it is of service in unlocking the secret of the occurrence of some of the mineral resources of the region, as deposits of certain types have been found to occur in rocks of certain composition and age or under certain geologic conditions. It is proposed in the following pages to describe in some detail the distribution, lithology, structure, age, and correlation of the different formations that have been distinguished in the region and to summarize the geologic history indicated by these formations.

In order that the general subdivisions that will be used in these descriptions may be readily followed, the accompanying correlation table (pl. 15) is introduced to afford a more or less graphic representation of the successive formations and their relationship to one another. This table also shows the interpretation of the relation of the rocks and events in northwestern Alaska to those in near-by regions, notably the upper Yukon Valley, the Chandalar-Koyukuk region, and the Canning River region. The size of the individual blocks in this table is not intended to indicate proportional length of time or thickness of the different formations, and therefore the table should not be read as if it were drawn to any scale. For instance, the time represented by the Tertiary and Quaternary is probably only a small percentage of the time represented by the pre-Cambrian, and doubtless something like the same discrepancy exists between the thicknesses of deposits laid down in the two intervals of geologic time.

Another feature of this table that may need explanation is the difference that is intended to be shown by the use of the wavy line separating successive units. The wavy line is intended to indicate that the two units are separated by a stratigraphic break, either an angular unconformity or a gap in which certain beds represented elsewhere are absent. Where the wavy line cuts diagonally across one or more blocks it indicates that the unit above the wavy line rests directly upon the unit below the wavy line. Where, however, the wavy line is diagonal, but in the block to the left the possible occurrence of rock of that age is shown, the diagram should be interpreted to mean that probably the interval represented marks an unconformity, but if further exploration should disclose rocks that belong in that interval they would, of course, terminate the unconformity. As an example, in the diagram the lines in the column for the Chandalar-Koyukuk region indicate that no rocks have been recognized in the interval extending from the top of the Mississippian to the Upper Cretaceous. Near that region, however, there are Lower Cretaceous rocks, which may possibly extend into the Chandalar-Koyukuk region. If such should prove to be true, the wavy line indicating unconformity should be stricken from the Lower Cretaceous box, and the diagram would then be read as showing unconformity between the upper Mississippian and Lower Cretaceous.

The age of certain of the formations has not been determined with such precision that they can be assigned to a single period or epoch. To express this condition graphically brackets have been used. Thus in the column for northwestern Alaska the age of certain Tertiary rocks has not been determined closer than that they are fairly well up in the Eocene or rather low in the Miocene, or they may extend through this range. This uncertainty is indicated by bracketing these portions of the Eocene and Miocene boxes. Where considerable doubt exists of the limits that should be included in a bracket, that doubt has been indicated by breaking the bar of the brace and inserting a question mark in the gap. An illustration of this practice is shown on the diagram by the treatment of the early Paleozoic or older rocks, whose upper and lower limits are uncertain. The necessity of bracketing certain rock units necessarily throws doubt on the position of any unconformity that may occur above or below them. Consequently, in a few places it has been necessary to bracket also the position of certain of the unconformities. As an example, if the Eocene-Miocene rocks of northwestern Alaska, already referred to, should turn out to be Eocene, the indicated unconformity probably occurs between the Eocene and Miocene. If the rocks, however, prove to be in part Miocene, that unconformity is above the interval occupied by these rocks. However, from the information at present available it is highly improbable that the unconformity is higher than the middle of the Miocene epoch or lower than the top of the Eocene.

All the formations have been distinguished on the geologic map (pl. 2) so far as its scale permitted and the data available allowed. There has, however, constantly arisen the necessity of subordinating detail in order to clarify the broader relationships and in order to bring the whole treatment into general agreement. As a result, the map has been made primarily to bring out these larger relationships as definitely as practicable, discussion of the uncertainties or alternative interpretations being confined to the text. For this reason the text and map supplement each other and should be used together rather than independently.

EARLY PALEOZOIC OR OLDER ROCKS

DISTRIBUTION

The early Paleozoic or older rocks crop out in a belt 5 to 50 miles wide, which trends about east across the southern part of the region covered by this report. The diversity in width of this belt is due in large measure to the varying degree in which erosion has removed the Mesozoic rocks that overlap the older rocks on the south. To the east of the area here considered the early Paleozoic or older rocks are exposed continuously through a wide belt of country as far as the international boundary, and to the west they veer southwestward and extend into Seward Peninsula.

The early Paleozoic or older rocks presumably everywhere underlie the younger rocks at various distances beneath the surface, and they may, therefore, by locally accentuated folding or faulting, combined with erosion, crop out as isolated patches among the younger rocks. Subsequent detailed mapping in this region will doubtless reveal such occurrences of these older rocks.

LITHOLOGY

The older rocks of this region were first systematically studied by Mendenhall[50] and Schrader[51] in 1901 and were subsequently studied in more detail by Smith[52] in 1910 and 1911. It should be noted, however, that the rocks here discussed as early Paleozoic or older rocks include only the lower part of those embraced under the designations undifferentiated metamorphic rocks, metamorphic complex, or "Totsen series" in the earlier descriptions. Fossils have subsequently been found in the upper part of these metamorphic rocks as originally mapped, and the beds at higher portions are therefore now differentiated and will be described separately. No new descriptive data were collected by the recent Geological Survey parties regarding these older rocks, though later work in other parts

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[50] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, pp. 31–37, 1902.

[51] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 58–60, 1904.

[52] Smith, P. S., and Eakin, H. M., The Shungnak region, Kobuk Valley: U. S. Geol. Survey Bull. 480, pp. 281–284, 1911. Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 55–61, 1913.

of northern and interior Alaska now makes possible a new interpretation of their origin and interrelations. The description here given is therefore essentially a summary of the earlier descriptions of Schrader, Mendenhall, and Smith, so far as it has been possible to distinguish in their descriptions the data relating to these older rocks from those which apply particularly to the upper formations, now regarded as of Silurian and Devonian age.

The early Paleozoic or older rocks include quartzite, quartzite schist, quartz-mica schist, mica schist, calcareous schist, carbonaceous schist, chlorite schist, phyllite, hornblende schist, albite schist, greenstones of various types, and interbedded crystalline limestones. From this enumeration of rock types it is apparent that rocks of both sedimentary and igneous origin are included in this group, though the sedimentary rocks are more numerous than those of igneous origin, and the igneous rocks have not been separately mapped or described. In a broad way it may be said that metamorphosed quartzose rocks, including quartzite schist, quartz-mica schist, and quartzite, are more typical of the lower part of this group of rocks. Carbonaceous and chloritic schists and phyllite are also mingled with the older quartzose rocks but become more abundant higher in the stratigraphic column, toward the Silurian limestone, the lowest known formation assigned to a definite stratigraphic horizon in this region. Carbonaceous schist and crystalline limestone are also interbedded with the other schists but are more conspicuous in stratigraphic proximity to the Silurian limestone. Sheared conglomerate has been observed near Shungnak, on the Kobuk River, and also nearly north of this point on the Noatak River, but it is likely that the rock may belong to a later horizon in the Paleozoic. Igneous rocks of all ages from early Paleozoic to Recent may possibly occur in these older metamorphic rocks, but certain greenstones and their recrystallized equivalents are believed to be an integral part of the group—that is, of pre-Silurian age.

Megascopically the metamorphic rocks range in color through shades of gray, green, and brown to black, and all are sheared, foliated, and recrystallized to a greater or less degree. Most of the schists are derived from sedimentary rocks of medium to fine grain, such as sandstone, shale, and to a lesser degree limestone. The metamorphosed igneous members of the group are somewhat more distinctive in appearance. Massive and schistose varieties occur, but both are usually recrystallized.

Microscopically the variation in both original and present character is more apparent. The more common types, quartzite schist, quartz-mica schist, and quartzite, are made up essentially of quartz and mica, usually muscovite, in varying quantities. The accessory minerals include chlorite, iron oxides and hydroxides; calcite, albite, epidote, biotite, garnet, zircon, and graphite, though locally some of these constitute the essential minerals of the rocks. Vein quartz, representing several periods of mineralization, and metallic sulphides are also common; the sulphides are chiefly pyrite, but at one locality on the Alatna River bornite and chalcopyrite were also seen. One of the peculiar varieties of quartzite schist in the Alatna Valley is a recrystallized rock consisting of large individuals of quartz set in a finer matrix of quartz and muscovite. This rock in hand specimens resembles gneiss or granitic schist, but under the microscope it appears to be free of feldspar, and it is believed to be of sedimentary origin. The phyllitic rocks of the group are not essentially different in composition from the mica schist and quartz-mica schist but are finer grained and show a lesser degree of metamorphism. Calcareous schist forms a subordinate part of the early Paleozoic or older rocks, being more abundant in the metamorphic rocks of Silurian and Devonian age. The calcareous schist is in part a metamorphic derivative of thin beds of limestone in the original sandstone-shale group but has also been produced through the partial replacement by calcite of the other schistose rocks. Gradations therefore occur between calcareous schist and crystalline limestone, on the one hand, and between calcareous schist and quartzose or micaceous schist, on the other hand.

STRUCTURE AND THICKNESS

All the metamorphic rocks south of the Skajit limestone are grouped on the accompanying geologic map as a single unit, but this must be considered as a schematic device for mapping rather than a definite representation that these rocks are uniformly of the same age and degree of metamorphism. Certain evidence favors the presence of an unconformity between the Skajit limestone, of Silurian age, and the schist, as some of the schist, at some distance south of the limestone, has a more complex structure than the limestone and the schist intimately associated with it and is therefore believed to be much older and to have suffered much more diastrophism. On the other hand, other data indicate a gradual transition from the schist to the limestone. The true boundary, therefore, between the Silurian rocks and the older schists that lie below them can not be indicated with precision.

The more metamorphosed schists of the early Paleozoic or older rocks, which for the most part are believed to be at some distance south of the Skajit limestone and considerably below it stratigraphically, have a highly complex structure that is only imperfectly understood. The original bedding of these rocks has been practically obliterated by shearing and recrystallization, and in its place rock cleavage has been substituted. Moreover, observations at several localities along the south side of this belt show the presence of secondary structure of two kinds, of different age, so that it is difficult to correlate the latest rock structure with the original bedding by a study of the drag folds or by similar methods. Faulting has also contributed to the complexity of the regional structure. Finally, only a portion of this group of rocks is exposed, the southern limit being concealed by overlapping Mesozoic rocks, so that stratigraphic deductions are at best only fragmental.

It is apparent that for these reasons recognition of the present attitude of the original bedding planes, measurement of formational thickness, and a satisfactory interpretation of the stratigraphic relations between this group of rocks and contiguous formations are not at present feasible. Nevertheless, sufficient structural data have been acquired for some tentative conclusions, which will serve at least as a basis for more detailed studies.

Certain descriptive details of structure are worth recording, even if they contribute but little to a final understanding of regional structure. For example, Smith,[53] in discussing the structure of the more altered rocks in the Noatak-Kobuk region, states that the prominent visible structure is cleavage, and that in many places not only one but several structural features due to the deformation occur. He further states that it is not uncommon to see earlier cleavage planes folded and sheared by later deformation. Plate 14, *A*, *B*, shows outcrops on the Alatna River and northwest of Shungnak in the Kobuk Valley that illustrate characteristic features of these schists. Smith in the Noatak-Kobuk region, Schrader on John River, and Mertie in the Chandalar district have all recognized that the latest deformation which has affected these schists has resulted in the formation of a system of folds, whose axial planes trend about east. This determination is based in part on the strike of folded cleavage planes in the older schists and in part upon the regional trend of the contact line between the older rocks and the Silurian limestone that adjoins them to the north. Faulting, on both a small and a large scale, has been generally recognized, and little doubt can exist that this faulting occurred in several stages, which were perhaps more or less concomitant with the several periods of deformation already noted. On looking at the structural trends of these schists over northern Alaska as a whole, however, two other structural phenomena appear which do not seem to harmonize with a generalized east-west formational trend. These phenomena are,

[53] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 59, 1913.

first, to the east of the region here discussed, at about longitude 145°, the metamorphic rocks begin to trend southeastward, whereas to the west, at about longitude 160°, a pronounced veer to the southwestward takes place; second, unsystematic local discordances occur in the trend lines, which are particularly indicated by marked sinuosity of the schist-limestone contact at numerous places.

The first of these phenomena, which deals with the crescentic trend of the Brooks Range [54] and its correlation with a similar crescentic bend in the Alaska Range, is a topic that may more profitably be discussed in connection with the general geologic structure of this region. The second of these phenomena, the marked local irregularities in the trend lines, could, in general, be interpreted as the result of one or more of several geologic processes. Differential erosion, original sinuosity of contact lines due to unconformable overlap of a younger upon an older formation, systems of transverse faulting, the intrusion of igneous rocks, and composite folding with discordant axial trends are some of the causes that might be partial or complete explanations of the phenomena. Without minimizing the possible effect of the first four of these causes, it is desired to stress the probable effect of the fifth, because all who have seen these older schists are agreed that one prior cleavage has been deformed in the production of the present east-west rock structure. In Seward Peninsula, to the southwest, Smith [55] has definitely shown the existence of at least two sets of cleavages in the Solomon schist, resulting in part from two systems of folding in which the axial planes of the folds were nearly normal to one another. It is believed that the same explanation may be given of the two sets of cleavages in the older schists of this region. The older diastrophism is believed to have produced a set of folds whose axial planes and cleavage trended nearly north, and this structure was subsequently modified by a later diastrophism which deformed the preexisting cleavage and produced a new set of folds whose axial planes and cleavage now trend, in the longitude of the Alatna and John Rivers, about east.

The younger of the early Paleozoic or older rocks and the Silurian limestone that adjoins them do not appear to possess the dual cleavage of the older schists, but certain data suggest that they may have been affected in some degree by an earlier folding along north-south axes. If a series of nonpitching folds whose axial planes strike in a northerly direction are subsequently refolded into a new series whose axial planes strike in an easterly direction, the net result of the deforma-

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[54] Smith, P. S., Northwestern Alaska: Geog. Rev., vol. 15, pp. 238–239, Am. Geog. Soc., 1925.

[55] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 433, pp. 112–114, 1910.

tion will be such that on northward-dipping planes of the later structure the traces of beds in an original anticline will close toward the north, and in an original syncline toward the south. On the southward-dipping slopes of the later structure the reverse will be true, the original anticlines closing southward and the original synclines northward. If the folds of the second period of diastrophism were appressed and overturned from the north, resulting in a universal northerly dip, the traces of original anticlines would bulge southward, and the synclines northward, irrespective of what limb of the later folding is considered. Under the relatively simple conditions postulated, the contact line between two conformable formations would approximate that of a sine curve. Actually, however, folds are not infinite in extent but pitch, many of them abruptly, but all surely, even if slightly. The composite effect of two sets of such pitching folds whose axes are nearly at right angles to one another, even if the folds are unaffected by faulting, will be such that the relatively simple sinusoidal trace of a bed will be extensively modified into some intricate pattern whose shape could not be predicted without fairly detailed knowledge of the character of the two composite foldings. In general, however, the trace of a bed within an old anticline will still project northward, unless the sum of the original anticlinal pitch and the dip of the later structure exceeds 90°, which is probably seldom true.

The contact between the undifferentiated schists and the Skajit limestone shows, at certain places in northern Alaska, marked irregularities in outline, which appear not to be explicable simply as a result of the influence of topographic relief. To account for such irregularities, Mertie,[56] in a report on the Chandalar district, suggested as a possible explanation the hypothesis outlined above. It should be noted, however, that this explanation was based upon the belief, supported apparently by fossil evidence, that the limestone-schist contact in the Chandalar district is parallel to the original bedding of both schist and limestone—that is, that this contact line represents continuous deposition of changing lithologic character, or perhaps a depositional hiatus without any structural unconformity.

Within the area covered by this report, however, Schrader[57] has inferred that the schists, which he called the "Totsen series," lie unconformably above the Skajit limestone. Smith,[58] on the other hand, states that on the Alatna River the schists underlie unconformably

[56] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pp. 248–249, 1925.

[57] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 59, 1904.

[58] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 60, 1913.

the Silurian (Skajit) limestone. With conflicting data, therefore, in adjoining fields, a reasonable doubt is thrown upon the theory of composite folding, in so far as it affects the younger schists of the early Paleozoic or older group and the adjoining Silurian limestone. Little doubt can exist, however, that among the various deformational processes to which the oldest schists of the early Paleozoic or older group have been subjected, diastrophism during two periods has, at least at certain localities, induced flow cleavage or schistosity; and that the earlier of these cleavages was deformed in the production of the later one. If the Skajit limestone lies conformably or even unconformably above the youngest schist, then the schist and the limestone have also probably participated in the earlier north-south folding, even though they do not show the older cleavage. If the Skajit limestone lies unconformably above the youngest schist, then the earlier north-south folding is probably, though not necessarily, confined to the undifferentiated schists.

As might be expected, the attitude of the cleavage planes in the more southerly and presumably more deformed schists is erratic to a high degree. Schrader [59] noted this feature in the lower and more highly metamorphosed part of the schist series in the Chandalar district which he called the "Rapids schist" in the frequent reversal of the dip of cleavage planes; and this feature is also illustrated by the diversity of strike and dip of rock structure in the same area, as plotted by Mertie [60] on the latest geologic map of the Chandalar district. Closer to the limestone, however, both in the Alatna and Noatak Valleys and to the east, the cleavage planes in the schist become somewhat more uniform, approximating parallelism with the bedding. In the valley of the Unakserak River, within the schistose rocks that lie geographically between the Skajit (Silurian) limestone and the known Devonian rocks farther north, the cleavage planes dip for the most part northward at an average angle between 20° and 30°; and where bedding planes are preserved, they appear to be nearly parallel and in places coincident with the cleavage. Fossils collected from these sheared rocks in the Unakserak Valley were found to be distributed along a cleavage plane, showing definitely in this locality the real coincidence of bedding with cleavage. The common structure in these rocks is therefore that of appressed folds, overturned to the south by force applied from the north, with the development of a rough parallelism of bedding with cleavage. It is believed that the observed divergence of cleavage planes from this

[59] Schrader, F. C., Preliminary report on a reconnaissance along the Chandalar and Koyukuk Rivers, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 474, 1900.

[60] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pl. 6, 1925.

structural uniformity in the schistose rocks south of the Silurian limestone is probably due to the greater degree in which these rocks have been affected by diastrophism during one or more periods, wherein the deforming forces were applied from a different geographic direction, diverging approximately 90° from earlier structure.

Faults of the thrust type are common in the schist. For the most part the faults are probably parallel with the cleavage, and the commonly observed slickensiding along cleavage planes indicates that much of the stress has been taken up by numerous small parallel thrust faults, a distributive type of thrust faulting being thus produced. In addition, however, thrust faults of great magnitude have probably also occurred. Such larger thrust faults are suggested in the distribution of the Silurian rocks, as shown later. In addition to the thrust faults, normal faults at right angles to the cleavage and thrust-fault planes have also been observed, particularly in the western part of this area, but little is known of the magnitude of these later movements. It is interesting to note, in this connection, that in the Porcupine Valley, some 250 miles to the east of the region here considered and in the locality of the southeasterly bend of the regional structure previously alluded to, Kindle [61] found many faults of the normal type, striking about north. Kindle has also stated that this faulting appears to have been later than the regional folding. When these facts are considered in relation to the fact that north-south faults are more prevalent in the western part of the region here discussed, in the locality of a southwesterly bend of the regional structure, the explanation is suggested that the southward bend of the regional east-west structure of northern Alaska, at the east and west sides of Alaska, may have a causative relation to this north-south normal faulting. Doubtless other systems of faulting and more data on their paragenesis will be disclosed when additional work is done in northern Alaska. Traces of all the later systems of folding and faulting will probably be recognized in these metamorphic rocks, for because of their age they must have partaken in greater or less degree of all the diverse types of later diastrophic movement.

With such complex structure plainly visible, and the southern limit of the early Paleozoic or older rocks unknown, any estimate of their thickness would be so indefinite that at present it is hardly worth making. All that may be said is that the thickness of these rocks, as exposed south of the Skajit limestone in the Alatna Valley, must be at least as great as that of the Skajit, which has been estimated at

[61] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 318-320, 1908.

6,000 feet; but the total thickness to the actual southern limit of these rocks would probably be found to be several times as great.

AGE AND CORRELATION

No fossils have yet been found in the rocks of this region here classed as early Paleozoic or older, but to the east some poorly preserved fossils were found by Mertie [62] in a thin bed of crystalline limestone interbedded with the metamorphic rocks south of the Silurian (Skajit) limestone. These fossils have been referred by Edwin Kirk to the Silurian. The upper or younger part of the undifferentiated metamorphic rocks in the Chandalar district is therefore believed to be of Silurian age; and as the Skajit limestone also is of Silurian age and the lithologic change from schist to limestone in that district appears to be transitional, no structural unconformity is believed to exist between this Silurian schist and the Skajit limestone, although the possibility of a depositional hiatus is recognized. In the valleys of the Alatna and John Rivers the schist does not appear to grade upward lithologically into the Skajit limestone, and there seems to be a structural discordance in the attitude of the two formations. Both these phenomena, however, may be the result of faulting, especially as it is well recognized that the regional metamorphism becomes progressively stronger from east to west. Yet inasmuch as fossils have not been found in the schist, and as its precise stratigraphic relation to the overlying Silurian limestone is undetermined, it seems best to regard the schist as dominantly of pre-Silurian age, with the reservation that the upper part may be in part Silurian. It is not believed that any pre-Cambrian rocks are exposed in the area considered in this report, but this is only an opinion and should be regarded as such. Pre-Cambrian rocks probably do occur, however, farther south.

The early Paleozoic or older rocks here described include part of the so-called "Totsen series," a group of metamorphic rocks adjoining the Skajit limestone on the south in the valley of the John River, and part of the early Paleozoic rocks underlying the Skajit limestone in the Chandalar district. The latter were divided originally by Schrader [63] into two formations, an older called "Rapids schist" and a younger called "Lake quartzite schist," but both these names, as well as the name "Totsen series," are not used in this report, because none of the three can be defined either lithologically, structurally, or paleontologically. Still farther east, in the valley of the Porcupine River, occurs thin-bedded quartzite, with some intercalated beds of

[62] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, p. 228, 1925.

[63] Schrader, F. C., Preliminary report on a reconnaissance along the Chandalar and Koyukuk Rivers, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 473–475, 1900.

shale, limestone, and dolomite, of pre-Ordovician age, together with shale, limestone, and dolomite of Ordovician and Silurian age. These relatively unmetamorphosed rocks are doubtless the stratigraphic equivalent of certain of the pre-Silurian rocks of the John, Alatna, and Noatak Valleys. The undifferentiated metamorphic rocks may also be correlated in a general way with the Nome group in Seward Peninsula. South of the Yukon River the probable equivalent of certain of these rocks is known as the Tatalina group, which includes strata of Lower Ordovician, Cambrian, and probably pre-Cambrian age.

SILURIAN SYSTEM

SKAJIT LIMESTONE

DISTRIBUTION

Skajit formation is the designation applied originally by Schrader [64] to a great band of limestone and mica schist, which crops out in the southern part of the valley of the John River. In the present report the cartographic unit is essentially limestone, with a minor proportion of intraformational schistose beds. In order to emphasize the dominantly calcareous nature of the formation thus mapped, and at the same time exclude therefrom any schist other than the intraformational schistose beds above mentioned, it has seemed desirable to create a new cartographic unit, to be known as the Skajit limestone. In reality some extraformational schistose rocks may also be present in the area here mapped as Skajit limestone, but any such inclusions are to be ascribed to inaccuracies of mapping and not to design. As here defined the Skajit limestone occupies a belt at least 15 miles wide in the lower valley of the John River and represents one of the most prominent horizon markers in northern Alaska. From the John River it continues eastward into the Chandalar River and westward along the divide between the Kobuk and Noatak Rivers for many miles. It is believed to constitute the bedrock forming the Igichuk Hills, close to Kotzebue Sound, in the lower Noatak Valley. The known extent of this formation, therefore, across northern Alaska is about 600 miles from the Porcupine River to the Arctic Ocean.

Like the other early Paleozoic or older rocks, the Skajit limestone has been subjected to various earth movements, resulting in dislocations which have broken away parts of the formation and placed them as isolated outcrops among alien rocks. Some smaller bands of limestone in the region, which resemble the Skajit limestone but

[64] Schrader, F. C., Geol. Soc. America Bull., vol. 13, pp. 233–252, 1902; U. S. Geol. Survey Prof. Paper 20, pp. 56–58, 1904.

are separated from it, may be the result of such faulting. A probability exists, however, that such smaller bands may in part represent different and perhaps later horizons in the Silurian system, and on Plate 2 they have been mapped separately.

LITHOLOGY

The Skajit limestone varies considerably in lithologic characters, both across and along the strike, and also shows differences due to differences in the degree of metamorphism to which it has been subjected in various districts. In the valley of the John River the Skajit formation was described originally by Schrader [65] as a

> heavy bedded limestone and mica schist. Weathered surfaces parallel with the bedding and planes of movement and crushing present a silvery sheen, due to the presence of mica, while some layers grade wholly into a mica schist. On a fresh fracture surface the limestone is found to be highly crystalline, generally fine or medium grained, and of impure white or bluish-gray color, the latter apparently denoting the more dolomitic phases of the rock. It weathers to a dirty gray or light brown, sometimes tinged with red.

The massive limestone in the valley of the Alatna River was subsequently correlated by Smith [66] with the Skajit formation and described by him as in part dark in color, with bluish-white bands, in part grayish and somewhat silicified and in part brownish and weathering to a sugary sand. Mica has been recognized as a common mineral constituent of the limestone by all who have seen it, and in places it is better described as a calcareous schist. Smith states that the limestone has locally been cut by greenstone, and that tremolite and other contact-metamorphic minerals have in places been formed. Dolomitic beds are stated to be absent or very scarce. The limestone of the Igichuk Hills is essentially like that of the Alatna Valley, except that it is, if anything, even more altered and schistose and has been observed locally to carry sparsely disseminated sulphides, which by weathering give to the surface a honeycombed appearance.

To the east, in the Chandalar district, the Skajit has been described by Mertie,[67] who called it Silurian limestone, as a crystalline and semicrystalline limestone, probably dolomitic at many localities. Plate 16, *B*, shows the massive limestone as it appears in the valley of the Middle Fork of the Chandalar River, but it is equally representative of the limestone in the Alatna Valley and in the hills to the west. The usual color, both from a distance and close at hand, is

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[65] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 56, 1904.

[66] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 61–63, 1913.

[67] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, p. 229, 1925.

white or light gray, though this grades into darker colors. In some places much red and brown iron staining occurs. At one locality, on the upper part of the North Fork of the Chandalar River, where fossils were collected in 1923, the limestone on a fresh fracture is almost black and had a strong odor of decomposed organic matter, but this condition is exceptional. The limestone for the most part is massive and much jointed, but in places, particularly near the contact with the older schist, it is sheared to the condition of a calcareous schist. The rock is also much fractured in places and veined with calcite and less commonly with quartz. On the southern border of the limestone of the Chandalar Valley a band of sheared greenstone adjoins the limestone, and smaller lenses of this same material are found within the main body of the limestone, indicating a constant association of rocks of these two types. It is believed, in fact, that some of these greenstone lenses represent altered basic lava flows, although it is possible that they may have been of intrusive origin.

Still farther east buff magnesian limestones crop out in the lower ramparts of the Porcupine River Valley. Associated with these are some thin beds of shale and quartzite. It is possible that these dolomites are not exactly equivalent with the Skajit limestone, for the formation is thinner, the rocks are essentially dolomitic, and the fossils indicate a somewhat lower horizon in the Silurian.

STRUCTURE AND THICKNESS

The structure of the Skajit limestone in the Alatna Valley is much the same as that of the underlying metamorphic rocks, with the exception that cleavage is only imperfectly developed. The massive beds have either acted as a competent buttress against the tangential thrusting movements, whose effects are so pronounced in the adjoining rocks, both above and below the Skajit, or, more probably, such movements have been taken up in granulation and recrystallization of the limestone itself. To the east, however, the available evidence indicates that regional metamorphism has been less intense, and original bedding planes are commonly well preserved.

Where original bedding planes of the limestone have been distorted, and a well-developed cleavage has been produced in the less competent adjacent rocks, the available observations on the attitude of isolated bedding planes have little general significance, not alone because the complex structure deprives them of meaning but also because the scarcity of such observations renders it impossible to correlate them. The regional trend and the attitude of the cleavage and drag folds are therefore of much more importance in deciphering the formational structure in this area. The Skajit limestone, because of its lithologic character, is easy to trace across the country, and its regional trend is thus definitely established as about east. The relation of the Skajit to the overlying or underlying rocks is not yet definitely proved, but if either the upper or lower contacts of this formation indicate continuous sedimentation, or even interrupted sedimentation without any structural discordance in the adjacent formations, then detailed studies along such a contact will yield more information regarding regional structure than many sections across the limestone.

In the Alatna Valley the cleavage of the Skajit limestone strikes east, about parallel with the regional trend of the formation, but dips prevailingly north. Younger rocks adjoin it to the north, which, if considered without relation to other structural data, might point to a normal monoclinal sequence of northward-dipping rocks. But the dominant structural feature of the rocks immediately overlying the Skajit limestone is flow cleavage or schistosity, and the general dip of this cleavage is comparatively low, about 20°–30° N. Moreover, the north-south distance across the strike of the Skajit limestone in the Alatna Valley is about 20 miles. Observations in areas of less metamorphosed rocks indicate a thickness of about 6,000 feet for this formation, so that it is apparent that in the Alatna Valley a great amount of duplication of beds has occurred through close folding or faulting. The structure of the Skajit limestone and of the rocks immediately overlying and underlying it in the Alatna Valley is therefore interpreted as an appressed monoclinal sequence, consisting of close and in places nearly recumbent folds, so that cleavage and bedding are for the most part nearly parallel. It may also be that this monoclinal sequence represents the north limb of an overturned anticline of major magnitude, the south limb of which is concealed by overlying Mesozoic rocks. This structure is shown graphically in the cross section across the Paleozoic rocks, Figure 8. It is apparent, of course, that the thrust producing such an appressed structure must have come from the north.

In the valley of the John River, as recorded by Schrader,[68] the Skajit formation trends nearly east, parallel in general with the trend of Brooks Range. The north-south distance across the formation at this point, however, is 25 per cent less than in the Alatna Valley. Bedding rather than cleavage, according to Schrader, is the dominant structural feature in the limestone of the Skajit formation on the John River, cleavage having been seen only at a few localities. A well-developed system of jointing striking northeast is prevalent. The joint planes are nearly vertical, with a steep northwesterly dip, and divide the rocks into sheets ranging in thickness

[68] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 56–57, 1904.

from 1 to 10 feet. A minor system of jointing striking nearly northwest also occurs. Schrader interprets the Skajit formation in the John River Valley as structurally a broad anticlinorium, whose central part is a broad, shallow syncline. Later information, however, which has been acquired both east and west of that area, warrants a revision of his structural interpretations and indicates that the structure of this limestone on the John River can not well be much less intricate than that which has been observed in the rocks of the Alatna Valley. A second difference in structural interpretation is that the Skajit formation of the John River lies stratigraphically above the schists ("Totsen series"), which adjoin it on the south. It therefore appears logical to interpret the Skajit formation of the John River as representing one limb of an appressed monocline rather than closed structure. In the John River Valley, as in the Alatna Valley, the great distance across the outcrop is interpreted as due to repetition of beds by close folding, though the folding on the John River may indeed be of a less appressed type than that observed on the Alatna and Unakserak Rivers. It is believed, however, that at both localities the folds are overturned, and the available evidence suggests that the tangential deforming thrust came from the north.

Faults, particularly of the distributed thrust type, more or less parallel with the cleavage, are highly developed in the limestone and associated rocks directly overlying the Skajit limestone in the Unakserak Valley, and slickensiding, brecciation, and subsequent recrystallization along the cleavage cracks are some of the commonly seen evidences of the fracturing and faulting that have taken place. The faulting of the Skajit limestone appears to have resulted dominantly in minor faults and dislocations resembling joints, but traces of more intense deformation are probably also present, though doubtless obscured in large measure by recrystallization. In general, it may be said that the older or thrust faulting took place for the most part at considerable depth, as indicated by the flow cleavage that usually accompanies the faults of this type, and that the later faulting occurred mainly in the zone of fracture, when erosion had removed some of the superincumbent load from the limestone.

The structural relation of the Skajit limestone to the formations that lie to the south and north of it is doubtful, because of conflicting data and interpretations in adjoining districts along the strike. The doubtful structural relation existing between the limestone and the schist to the south of it has already been mentioned in the discussion of the undifferentiated metamorphic rocks. Schrader,[69] in the John

[69] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 57, 1904.

River Valley, and Smith,[70] in the Alatna Valley, have postulated an unconformity between the rocks to the south and the Skajit limestone; but Mertie,[71] in the Chandalar Valley, still farther east, found Silurian fossils both in the limestone that he correlates with the Skajit and in the schistose rocks lying to the south of it. The inference as to the unconformable relation is based primarily upon a greater degree of metamorphism observed in the bordering schistose rocks to the south, but the same condition prevails with regard to the schistose rocks of the Unakserak Valley, which adjoin the Skajit limestone on the north. On the other hand, the presence of Silurian fossils in the schistose rocks south of the Silurian limestone in the Chandalar Valley is not conclusive evidence, for two reasons: First, because it was not definitely determined that such Silurian fossils were older than the fossils of the Skajit; second, in overturned folds as complex as these, younger rocks might easily be infolded to the south. In fact, no absolute evidence is available to prove that the Skajit itself does not form a closed and highly appressed anticlinal fold, which would normally place younger rocks for some distance at least to the south.

Paleontologically, the apparent absence of lower Silurian rocks in northern Alaska might be cited as evidence in favor of an unconformity at the base of the middle Silurian sequence. But it is not yet certain even that the Skajit limestone includes rocks as old as the middle Silurian; and the foregoing suggestion is further weakened by the fact that farther southwest, in Seward Peninsula, lower Silurian rocks are definitely known, thus suggesting that rocks of similar age, though unrecognized as such, may also be present in northern Alaska. The exact relation, therefore, which exists between the Skajit limestone and the schistose rocks immediately adjoining it to the south is really undetermined and is subject to conjecture dependent upon the particular regional structural interpretation applied. It is believed, but not proved, that these bordering schistose rocks are really older than the Skajit limestone, which may or may not lie unconformably upon them. Without question, however, the more intensely altered schists still farther south are pre-Silurian, and are structurally unlike and doubtless unconformable with the Silurian limestone.

The relation of the Skajit limestone to the formation that adjoins it to the north is also subject to different interpretations. In the Alatna Valley, and particularly in the Unakserak Valley, a group of much metamorphosed rocks appears to lie between the Skajit and the

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[70] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 65–67, 1913.

[71] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pp. 228, 232, 1925.

known Devonian rocks, and this group of rocks seems to possess the regional structure of the Silurian limestone and schist. Structurally there is no reason for hesitating to correlate these rocks with the Skajit limestone and possibly with the schistose rocks that adjoin the Skajit limestone at its southern limit. Some poorly preserved fossils found within this group of rocks, however, have been determined as possibly of Devonian age. But in view of the fact that definitely known Devonian rocks crop out still farther north in the Brooks Range, are less metamorphosed, and possess different structural features, this paleontologic determination is not acceptable, and the writers feel constrained to correlate these metamorphic rocks with some part of the Silurian, perhaps the upper Silurian, rather than with the Devonian. Under this interpretation these metamorphic rocks probably overlie conformably the Skajit limestone, and it is almost certain that they underlie unconformably the known Devonian rocks farther north.

In the Chandalar River Valley structural data and fossil collections indicate that Middle Devonian rocks rest at some places unconformably upon the Silurian limestone which is correlated with the Skajit; but on both the Chandalar and the John River, particularly the latter, there are indications that an intermediate formation lies between the Skajit and the Middle Devonian rocks and that this intermediate formation may rest conformably upon the Skajit limestone. This confirmatory evidence, therefore, leads to the belief that Middle and Upper Devonian rocks, here as elsewhere in northern Alaska, rest unconformably upon the rocks of the Silurian system.

The structure of the limestone in the Alatna Valley is too complex to admit any trustworthy estimate of the thickness of the formation until more detailed work has been done. But to the east, where the structure is simpler, a fair guess may be made. Schrader[72] estimated the thickness of the Skajit formation in the John River Valley as at least 4,000 feet, and Mertie[73] estimated a thickness still farther east, in the Chandalar district, of at least 6,000 feet for the Silurian limestone that he correlated with the Skajit limestone. Neither of these two estimates is probably correct in detail, but they check one another in that they are of the same order of magnitude and therefore give an idea of the approximate thickness of the Skajit limestone.

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[72] Schrader, F. C., op. cit., p. 56.
[73] Mertie, J. B., jr., op. cit., p. 231.

AGE AND CORRELATION

No fossils have been found in the Skajit limestone of the Alatna Valley, but in the John River Valley Schrader[74] found a single fossil which was identified by Schuchert as "having the ventral valve of a brachiopod of the order of *Meristina* and *Meristella*, and also resembling a transverse *Seminula*. This kind of shell indicates that the rock can not be older than Upper Silurian and not younger than Lower Carboniferous." From structural considerations, and in view of the age of the overlying Devonian rocks, Schrader elected to assign the Skajit to the oldest epoch that this fossil determination would permit; and therein he agrees with the present determination.

A collection of fossils was made in 1923 from the Silurian limestone of the Chandalar district by Mertie.[75] Although that district is not within the area specifically included in this report, the fossil collection is here recorded because it is the only collection of determinable fossils that has yet been made from rocks that can definitely be correlated with the Skajit limestone. These fossils, which were found in the upper basin of the North Fork of the Chandalar River, came from a very fossiliferous layer a few feet thick, in the massively bedded limestone. Plate 16, *A*, shows a great slab of this fossiliferous limestone, which has fallen into the creek from its near-by bedrock source in the canyon wall and has been washed smooth by the creek, thus exposing clearly the internal structure of the shells contained in it. Edwin Kirk, of the United States Geological Survey, identified these shells as *Conchidium?* sp. He further states that

> This may be the same as the *Conchidium?* sp. from the White Mountains [Fairbanks quadrangle] of the Yukon-Tanana region. The latter seems to have a relatively thin shell, while this species has one of extraordinary thickness. This may, however, be due to difference in preservation. What appears to be the same genus is found in the upper Silurian of southeastern Alaska.

The fossils from the limestone in the White Mountains are regarded by Kirk as highest middle Silurian. The Skajit limestone, therefore, because it is believed to be continuous with the Silurian limestone of the Chandalar district, must be regarded as of upper Silurian or highest middle Silurian age, with a preference perhaps for the former assignment.

The limestone of the Chandalar district, identified by Mertie in 1923 as Silurian, was originally called by Schrader[76] the "Bettles series," but this limestone and the Skajit limestone are now believed

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[74] Schrader, F. C., op. cit., p. 57.

[75] Mertie, J. B., jr., op. cit., p. 232.

[76] Schrader, F. C., Preliminary report on a reconnaissance along Chandalar and Koyukuk Rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 475, 1900.

to be identical, and the formation name Skajit has long been used in place of the system name. In a broad way, the Skajit limestone may be correlated with the buff magnesian limestone that crops out in the lower ramparts of the Porcupine River, below the mouth of the Coleen River, although this limestone was determined by Kindle[77] as middle rather than upper Silurian. Its equivalent is also probably present among some of the undifferentiated limestone in Seward Peninsula, although the fossils so far found in those limestones indicate that they are for the most part of lower Silurian or Upper Ordovician age. South of the Yukon, however, the Skajit limestone is closely correlatable with the Silurian limestone that crops out in the White Mountains (Fairbanks quadrangle) and also on the spur northwest of Tolovana telegraph station. Recent work by Brown[78] also indicates that this or a closely related horizon is also represented in the upper Kuskokwim Basin. In southeastern Alaska the upper Silurian is a well-known stratigraphic unit and is typically developed as a massive crystalline limestone in Glacier Bay.

UNDIFFERENTIATED SILURIAN (?) ROCKS

DISTRIBUTION

The rocks here grouped as undifferentiated Silurian(?) crop out in a belt from 10 to 15 miles wide, which occupies the upper valleys of the Alatna and Noatak Rivers and extends eastward across the valley of the John River. The known east-west extent of this group of rocks is about 160 miles. Farther west these rocks probably continue to crop out in the hills south of the Noatak River for another 120 miles, ultimately extending perhaps under the alluvial deposits of the lower Noatak River into Kotzebue Sound.

These rocks, as will appear later, do not form a definite lithologic or stratigraphic unit and are recognized as a cartographic unit only because their exact relation to the adjoining formations is problematic. This unit includes in reality all the metamorphic rocks that lie north of the Skajit limestone. Subsequent work will probably permit correlation of this group of rocks either with the upper Silurian or with the Devonian.

LITHOLOGY

The lithologic sequence of rocks in this group is known to vary greatly both across and along the strike. Moreover, the lithologic sequence across the strike—that is, from north to south—does not

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[77] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 324–325, 1908.

[78] Brown, J. S., The Nixon Fork district, Alaska: U. S. Geol. Survey Bull. 783, pp. 102–105, 1926.

necessarily correspond to or even approximate the stratigraphic sequence, for the dominant structure of these rocks is known to be cleavage, the bedding being largely obliterated. But the geographic sequence from south to north in the Alatna Valley is fairly well known and will be described as such.

Beginning just north of the Pingaluk River, in the upper Alatna Valley, a belt of metamorphic rocks about 7 miles wide adjoins the Skajit limestone on the north. Adjoining this on the north is a band of crystalline limestone from half a mile to 2 miles wide; and this is followed by another band of metamorphic rocks which extends northward to the known Devonian rocks. No close examination was made of the southern third of this group of rocks, but the upper two-thirds, as exposed in the canyon of the Unakserak River, was examined in some detail.

The rocks immediately south of the middle or limestone member of this sequence consist mainly of a highly crenulated and sheared dark-gray phyllite, grading locally into a true mica schist. This rock is impregnated with opaque white vein quartz, in thin stringers and gash veins, which for the most part follow the cleavage but not uncommonly cut across it. Later faulting has cut both the phyllite and the quartz stringers. Interbedded with the phyllite are numerous thin beds of light bluish-gray finely crystalline thin-cleaving limestone, which grades locally into a calcareous schist. Many of these limestone beds show color banding due to the varying degree of crystallinity rather than bedding planes.

These rocks merge rather gradually into the thick band of limestone that forms the middle member of this group of rocks and is exposed for a distance of about half a mile across the strike in the Unakserak Canyon. This limestone, probably originally massive, is now a thin-cleaving rock, cut by numerous joint planes, which, together with the cleavage, give it at close range a blocky appearance. It also has in places a secondary nodular structure. At other places, particularly toward the northern contact, the cleavage is so perfectly developed that the rock breaks into almost paper-thin slivers. Much of this rock would be better designated calcareous slate or even schist. Yet, with all the cleavage and other secondary structural features, the appearance from a distance is that of a yellow-weathering massive, thick-bedded limestone, and this was probably its original character. Plate 17, *A*, illustrates the appearance of this band of limestone where it crosses the Alatna River above the mouth of the Unakserak River, and Plate 17, *B*, shows a double structure visible in the same limestone on the Noatak River below the mouth of the Ipmiluik River.

At the north edge this limestone gives place gradually to more phyllite and schist, which, though dominantly of argillaceous character, have numerous calcareous and arenaceous layers. These rocks, like those south of the limestone band, are penetrated by many quartz stringers, some of which have been intricately folded along with the country rock. They range in color from black through brown, dark-green, and yellow tones. Here and there, in zones parallel to the cleavage, a canary-yellow sublimate appears on the rocks. At many places the rocks are extremely thin-cleaving, and well-developed schists also occur. The vein quartz in places is sheared into augen, which give to the country rock a superficial resemblance to an augen gneiss. Some of the dark-green sheared rocks resemble somewhat sheared volcanic rocks, but closer examination indicates that the whole sequence is essentially of sedimentary origin. The calcareous schist members of the sequence are in places veined with calcite as well as quartz. Some of the calcareous schist is graphitic. A collection of poorly preserved fossils was found in one of these beds of graphitic calcareous schist in the upper part of the series.

STRUCTURE AND THICKNESS

The structure of these rocks is much the same as that of the Skajit limestone in the Alatna Valley and the schist that directly underlies it. Cleavage is the prominent structural feature, and bedding where observed is either parallel with the cleavage or makes a very low angle with it. The cleavage strikes about N. 60° E. and dips 20° to 30° N. Most of the rocks are sheared, contorted, crenulated, and full of low-lying drag folds, whose axes are more or less parallel with the cleavage. These soft and relatively incompetent rocks have evidently recorded a larger share of the thrusting stresses than the Skajit limestone. In some places the rocks are sheared to a ribbon structure and resemble a pile of thin laminae; in other places limestone, phyllite, calcite, and quartz are ground together into a nondescript mixture of minute fragments.

Much movement has taken place along the cleavage planes, as shown by numerous slickensided surfaces, and probably some thrust faults of considerable magnitude are present, though none were definitely identified. Later faults of the normal type were also recognized but are evidently not all of the same age. One normal fault, striking about east, with the fault plane dipping about 60° N., was noticed in the wall of the upper part of the Unakserak Canyon, and another fault of the same type, striking N. 30° E. and dipping 60° W., was seen somewhat farther upstream.

Along the John River, Schrader[79] observed that the rocks that immediately adjoin the limestone of the Skajit formation along its northern border are more metamorphosed than the known Devonian rocks farther north. He described these more metamorphosed rocks as fine-grained gray or bluish quartz schist, with greenish chloritic schist and slate. He also noted that these rocks carry considerable quartz in small veins and stringers, trending more or less parallel with the schistosity and bedding. These rocks, as shown on Plate 2, are correlated, from their structural similarity, with those in the southwestern part of the Unakserak Valley.

The structural relations of this group of rocks to the underlying Skajit limestone and to the overlying Devonian rocks are not definitely known, but these rocks appear to be more related structurally to the Skajit than to the Devonian. First, the degree of regional metamorphism of these rocks is more nearly comparable with that of the Skajit limestone; second, these rocks have a well-developed northward-dipping flow cleavage, similar to that observed in the schistose rocks closely associated with the Skajit limestone. The overlying Devonian rocks, on the other hand, are much less metamorphosed and have a fracture cleavage dipping south, instead of a flow cleavage dipping north. For this reason the rocks of this group are believed to have suffered a high degree of metamorphism, in which the Devonian rocks did not participate. The presence north of the Skajit of a group of rocks similar to the Skajit and the schist that underlies it might be explained as a result of enormous thrust faulting. But these rocks, including the band of limestone which lies midway in them, have too great a geographic extent along the strike to make this interpretation very convincing. It is believed that they are really younger rocks than the Skajit limestone but partook of the major deformation that the Skajit suffered. In other words, they are believed to antedate the great unconformity that lies at the base of the Middle Devonian in northern Alaska. As such they may lie conformably or unconformably upon the Skajit limestone. Schrader believed that they rested unconformably upon the limestone of the Skajit formation in the John River Valley, but the writers are inclined to favor a conformable relation or perhaps an unconformity without angular discordance.

No trustworthy estimate of the thickness of this group of rocks can be made at present. The only available basis for an estimate is the width across the belt, normal to the strike. It will be seen from Plate 2 that this width is of the same order as that of the Skajit

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[79] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 69, 1904.

limestone; and therefore the best guess is that this group of rocks may be about as thick as the Skajit—that is, not less than 5,000 or 6,000 feet. On the same basis the limestone band in the middle part of the sequence may be 1,000 to 1,500 feet thick.

AGE AND CORRELATION

Fossils were collected from this group of rocks in the canyon of the Unakserak River. The exact location is on the west side of the river, 7¾ miles in an air line from the confluence of the Unakserak and the Alatna. This collection (24AMt8) was examined by Edwin Kirk, of the United States Geological Survey, who reports as follows:

> Alveolites sp.
> Cyathophyllum sp.
> Crinoid stems.
> Crinoid stems probably referable to Melocrinus.
>
> Similar crinoid columnals and corals occur in collection 23AMt38, from the Chandalar district. This lot (23AMt38) was unquestionably Middle Devonian. The preservation of the fossils in the present lot (24AMt8) is so poor as to preclude accurate determination, but Middle Devonian is indicated.

As a result of previous work by Mertie [80] in the Chandalar district and by Kindle [81] along the Porcupine River, a structural unconformity is believed to exist between the upper Silurian and the Middle Devonian rocks of northern Alaska, the Lower Devonian rocks apparently being absent from the stratigraphic sequence. Similarly, on Seward Peninsula Lower Devonian fossils have not been found, although lower and upper Silurian and Middle Devonian fossils have been collected. In fact, Lower Devonian rocks are unknown at present anywhere in Alaska. It does not seem logical, therefore, to assume that a Lower Devonian horizon is represented in the Unakserak and John River Valleys, and the two alternatives remain of correlating this group of rocks with the Middle Devonian sequence, as the fossils suggest, or of correlating them with the upper Silurian sequence, as indicated by the structure and stratigraphy. Unfortunately no Middle Devonian collections have been made in the relatively unmetamorphosed rocks that lie north of this group of rocks on the Unakserak and Killik Rivers, but Upper Devonian fossils have been found in these less metamorphosed rocks about 20 miles to the north, thus giving plenty of room for an intervening Middle Devonian sequence.

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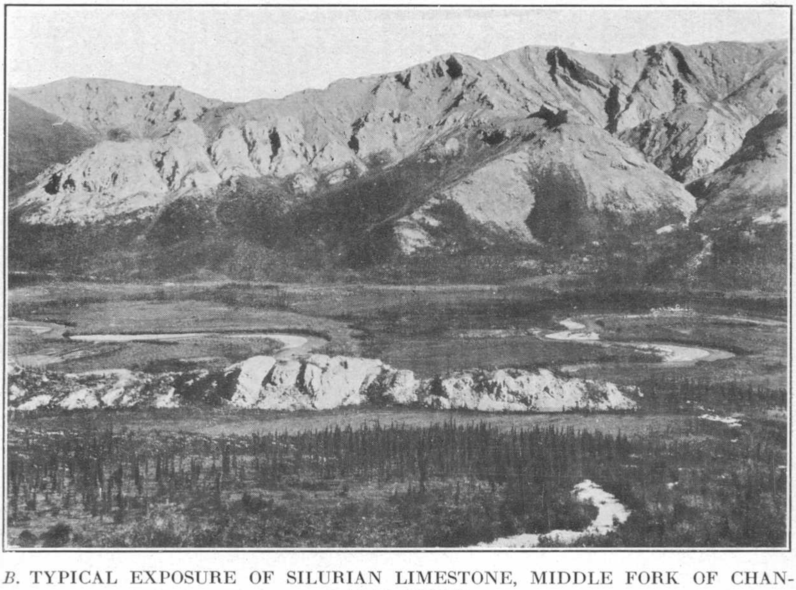
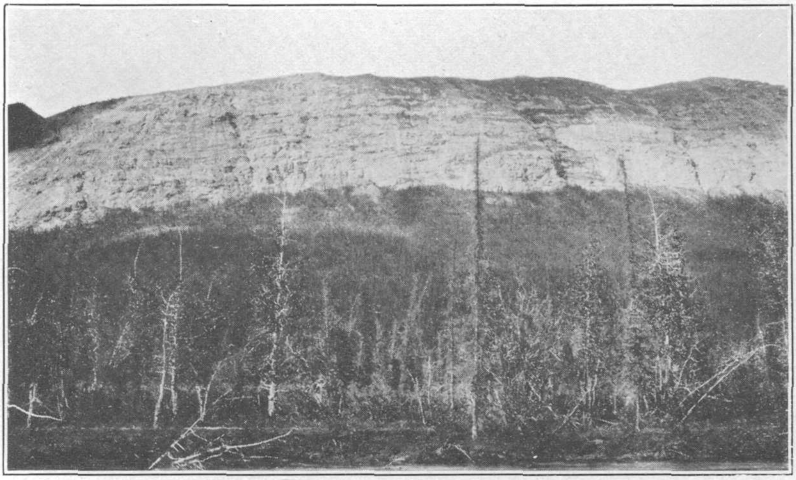
[80] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, p. 234, 1925.

[81] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, p. 327, 1908.

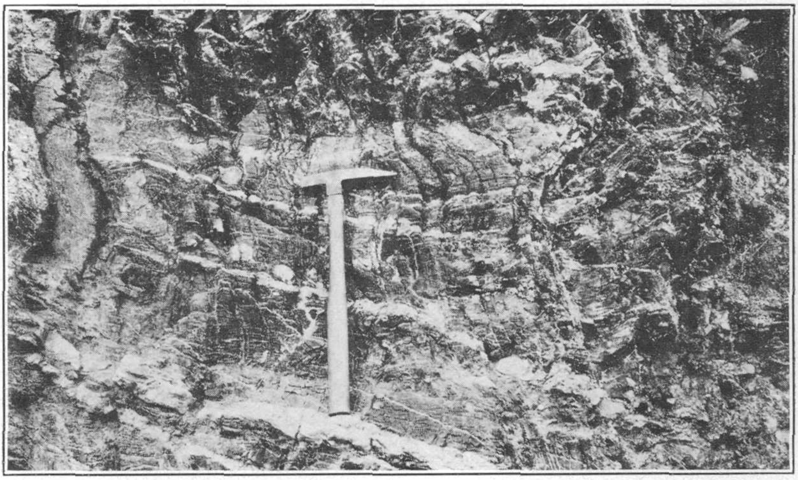
A. CONCHIDIUM? SP., AS SEEN IN A SLAB OF SILURIAN LIMESTONE, FROM NORTH FORK OF CHANDALAR RIVER



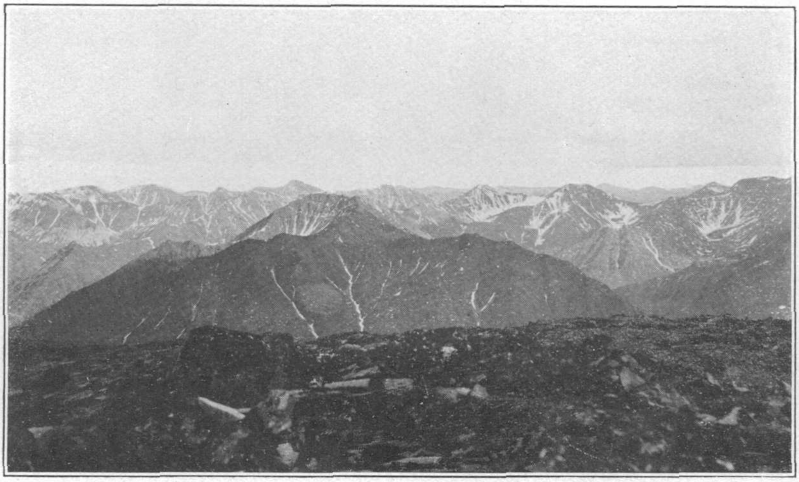
B. TYPICAL EXPOSURE OF SILURIAN LIMESTONE, MIDDLE FORK OF CHANDALAR RIVER



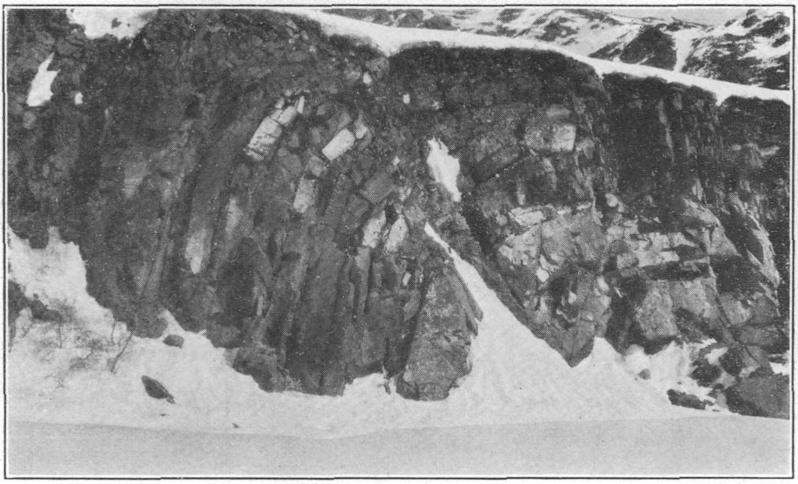
A. LATE SILURIAN LIMESTONE, CROPPING OUT IN ALATNA VALLEY ABOVE MOUTH OF UNAKSERAK RIVER



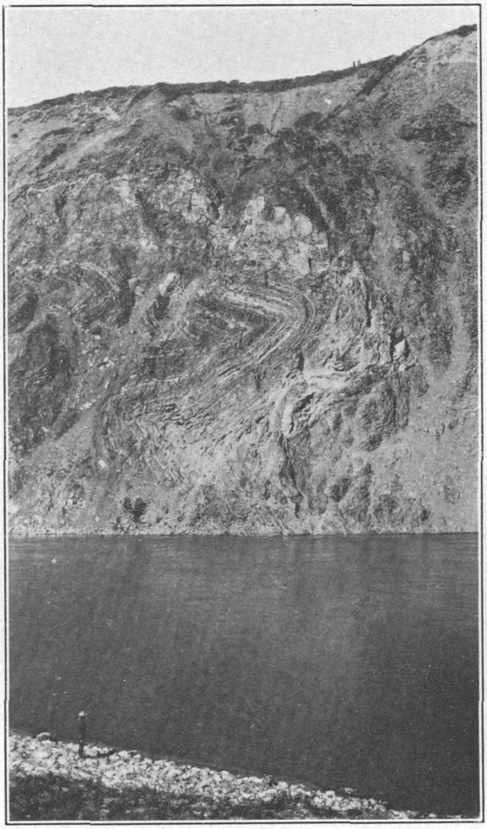
B. DOUBLE STRUCTURE IN LATE SILURIAN LIMESTONE ALONG NOATAK RIVER, BELOW MOUTH OF IPMILUIK RIVER



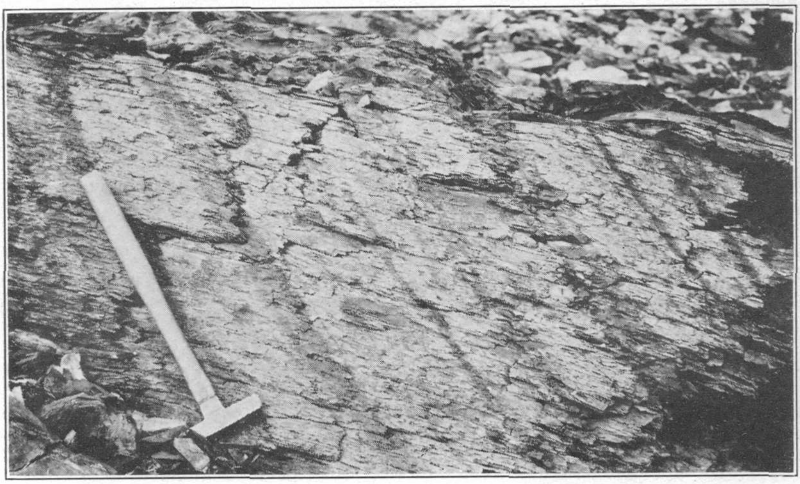
A. CHARACTERISTIC TOPOGRAPHY OF DEVONIAN ROCKS IN AREA SOUTHEAST OF FORK PEAK, NORTHERN PART OF JOHN RIVER VALLEY



B. FOLDED UPPER DEVONIAN ROCKS IN CANYON OF APRIL CREEK, ABOVE HEADQUARTERS WINTER CAMP ON KILLIK RIVER



A. OVERTURNED FOLD IN ROCKS OF NOATAK FORMATION, NOATAK RIVER



B. DOUBLE STRUCTURE IN SLATES OF NOATAK FORMATION, NOATAK RIVER

In the Chandalar district, on the other hand, Middle Devonian fossils were found at one locality in the less metamorphosed rocks relatively close to the upper Silurian rocks, in an area where the structural unconformity between the two groups showed particularly well. It should also be emphasized that not only are the rocks to the north less metamorphosed but the thin fracture cleavage is diametrically opposed in direction to the flow cleavage of this group of rocks. Finally, the regional metamorphism of this group of rocks, together with the character and direction of the flow cleavage, is practically the same as that of the schistose rocks associated with the Silurian Skajit limestone. To summarize, then, the field evidence points to the assignment of these rocks to the late Silurian, but the fossils, so far as they go, favor an assignment to the Middle Devonian. The designation Silurian (?) must therefore be regarded as a necessary compromise for cartographic purposes.

It is of some interest to point out certain stratigraphic interpretations and correlations under each of the hypotheses above outlined. If this group of rocks is correlated with the other Middle Devonian rocks of northern and interior Alaska, some explanation will have to be given of the difference in the character and degree of metamorphism in these two adjoining groups of rocks. Differences in the degree of metamorphism in near-by or adjacent rocks, even in rocks of the same age, is not at all unusual, and numerous examples of such differences in Alaska might be cited. But where the character of the metamorphism in two adjoining groups of rocks differs so materially, as previously described, and where the differences both in character and in degree of metamorphism appear to prevail over large areas, the hypothesis of differential metamorphism seems less convincing. If, on the other hand, these metamorphic differences are interpreted to indicate that the older of these two groups of rocks has been deformed by earth movements to which the younger has not been subjected, it follows that the presence of a major unconformity within the Devonian sequence must be postulated, and that it possibly occurs within the Middle Devonian sequence. This, however, is at variance with what is known of the Devonian rocks elsewhere in interior and northern Alaska.

If these metamorphic rocks, lying between the Skajit limestone and the known Devonian rocks to the north, are regarded as Silurian in age, two conclusions appear reasonably to follow: First, that the Skajit limestone does not represent the top of the Silurian section; second, that the Silurian rocks are separated from the Devonian rocks by a great structural unconformity. Bearing upon the first of these conclusions, the evidence afforded by the fossils so far collected in the Skajit limestone suggests that the rocks in which they occur are highest middle Silurian or upper Silurian. This assignment certainly leaves room for a high upper Silurian horizon, which the metamorphic rocks under discussion may well represent. Moreover, a late upper Silurian horizon is in harmony with geologic conditions observed elsewhere in interior and northern Alaska. In the Yukon-Tanana region, for example, a limestone formation of the same general age as the Skajit limestone is known to be overlain by much-deformed rocks, which in turn are overlain by less metamorphosed Middle Devonian rocks. Fossils so far found in the intermediate group are not critically diagnostic and have been determined usually as Silurian or Devonian; but Edwin Kirk, of the United States Geological Survey, who made these determinations, has come more and more in recent years to regard this doubtful fauna as Silurian rather than Devonian.

With regard to the second conclusion, evidence in adjoining areas is quite as striking. In the valley of the John River the "Fickett series," as originally described by Schrader,[82] has been subdivided, as explained on pages 140, 142, 149, and 155, into three units, the oldest and most southerly of which consists of chloritic schist and phyllite. No fossils have been found in this lowest third of the "Fickett series," but the character and degree of metamorphism serve here, as in the Unakserak Valley, to differentiate this group of rocks on the one hand from the overlying Devonian rocks, and to relate them structurally with the underlying Skajit limestone and associated schistose rocks. Again, Mertie,[83] in mapping the Middle Devonian rocks of the Chandalar district noted that "from the forks of the North Fork of the Chandalar River down the valley to Quartz Creek the slate seems more than ordinarily metamorphosed and shows phyllitic and schistose phases." The rocks thus alluded to lie between the Skajit limestone and the Middle Devonian rocks to the north and therefore border the Middle Devonian on the south. This group or belt of rocks was mapped collectively with the Middle Devonian rocks for want of fossil evidence that would warrant its separation as an additional cartographic unit, but it seems likely now that these rocks may represent the upper Silurian horizon above suggested.

In the Yukon-Tanana region the structural evidence as well as the paleontologic evidence favors the interpretation of a sequence of late Silurian rocks overlain unconformably by Middle Devonian rocks, for here as elsewhere these late Silurian rocks show regionally

[82] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 67–72, 1904.

[83] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, p. 234, 1925.

a greater degree of metamorphism, and at some localities, as on the Yukon, a structure that is different from that of the younger and overlying rocks. In Seward Peninsula regional metamorphism has apparently been more intense than in central and northern Alaska, with the result that rocks as young as Carboniferous have in places been rendered schistose. As a result of this condition, fewer well-preserved fossils have been found in the Silurian and Devonian sequence, and the unconformable relation between Silurian and Devonian beds has not been determined. This possibility, however, has not been disproved, and the lithology and structure, so far as they go, can readily be interpreted to harmonize with this explanation. The Port Clarence limestone of Seward Peninsula seems to range in age through the Ordovician as well as the Silurian, but in its upper part at least it may be correlated with the Skajit limestone. Considerably higher in the geologic column of Seward Peninsula are a group of undifferentiated Devonian and Carboniferous rocks, but between these and the Port Clarence limestone are rocks like the Kugruk schist, described by Collier;[84] the schist of the Fairhaven Precinct, described by Moffit;[85] and the Hurrah slate and Puckmummie schist, described by Smith,[86] which may possibly in part be equivalent to this upper Silurian formation.

DEVONIAN SYSTEM

DISTRIBUTION

The rocks here described under the designation Devonian include representatives of both Middle and Upper Devonian horizons, but because of their relatively uniform lithology and lack of adequate paleontologic data at critical localities they are grouped together as a single unit. As the Lower Devonian is believed to be absent in Alaska, this grouping therefore includes all the known Devonian rocks.

Rocks of known or supposed Devonian age have a great thickness and a widespread distribution in northern Alaska. On the upper Alatna and Killik Rivers they begin at the forks of the Unakserak River and extend northward across their strike to Easter Creek, thus occupying a belt from 20 to 25 miles wide. Along the strike this belt extends westward to the Noatak River, where it is covered by the alluvial deposits of the Noatak, Aniuk, and Cutler Rivers. Some

[84] Collier, A. J.. A reconnaissance in the northwestern part of Seward Peninsula, Alaska: U. S. Geol. Survey Prof. Paper 2, p. 18, 1902.

[85] Moffit, F. H., The Fairhaven gold placers, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 247, pp. 20–24, 1905.

[86] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 433, pp. 59–66, 1910.

corals of possible Devonian age, found by Smith[87] in 1911 in the hills southeast of the Noatak Canyon, suggest that this belt of rock may continue westward from the Aniuk and Cutler Rivers into the hills south of the Noatak, extending, perhaps, to the flats of the lower Noatak River.

Northwest of the lower part of the Noatak Valley, in the hills east of Point Hope, adjacent to the Kukpuk River, is another group of rocks which were assigned provisionally by Collier[88] to the Devonian. These rocks resemble lithologically the Upper Devonian rocks of the Killik River but may nevertheless turn out to be of Mesozoic age. For lack of additional information, however, they are here correlated with and mapped as a part of the Devonian sequence of northern Alaska.

Eastward from the Unakserak and Killik Rivers Devonian rocks crop out on the John River, where they have been mapped by Schrader[89] as a part of his "Fickett series." Still farther east, outside of the limits of the area covered in this report, they crop out again in the Chandalar Valley, flanking Silurian rocks on the north and extending across the strike for an undetermined distance northward. Rocks of Devonian age continue thence still farther east and are known on the Porcupine River and along the international boundary. In general, therefore, it may be said that rocks of Devonian age extend across northern Alaska from the Noatak River, and possibly from Kotzebue Sound, to the international boundary and constitute a prominent and well-recognized unit in the geologic section of the Brooks Range.

LITHOLOGY

The Devonian rocks consist of a rather monotonous sequence of quartzitic sandstone, grit, slate, and shale, with a minor proportion of conglomerate and limestone. In general these rocks are not schistose but have developed a fracture cleavage. Locally, however, they have been more intensely deformed. The outstanding feature of the Devonian rocks is their lack of any well-defined stratigraphic horizons which may easily be traced along the strike and by means of which conclusions regarding the structure and thickness may be drawn from reconnaissance studies. The harder arenaceous beds, to be sure, form hogbacks and ridges, but there are many of these beds, and no one of them can be distinguished from any of the others except by the more refined methods of detailed mapping. The lime-

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[87] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 69, 1913.

[88] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 16–18, 1906.

[89] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 67–72, 1904.

stone beds, moreover, are thin and grade into sandstone and shale along the strike, so that they also can not be used as horizon markers. Below an elevation of 4,000 feet these rocks form rather rounded hills, with a mottled yellow and brown appearance, due principally to the yellow weathering of the argillaceous beds. Above 4,000 feet, owing to the presence of relatively unweathered black talus, they form darker and sharper ridges. Nowhere, however, do these rocks produce the ragged serrate crest lines characteristic of the Silurian limestone. Plate 5, *B*, showing the east wall of the valley of the Killik River opposite camp S April 9, illustrates the type of topography these rocks produce, and Plate 18, *A*, shows the topography of similar rocks near the head of the John River.

The sandstone and grit of the Devonian rocks are generally dark-gray rocks of varying degrees of granularity, which crop out in beds from 6 inches to 4 or 5 feet thick and weather to tones of yellow, brown, and red in surficial oxidation. As a rule more or less recrystallization has taken place in these rocks, so that locally they are quartzitic sandstone and grit. Most of the sandstone is composed essentially of grains of quartz, but some of it, particularly the coarser-grained varieties and the grit, contains a considerable proportion of chert grains. The cherty layers appear to be more characteristic of higher horizons—that is, of the Upper Devonian and Mississippian. Locally much carbonaceous material, chiefly carbonized plant stems, may be seen, both in the sandstone and in the shale.

In the first gulch below camp S April 9, on the southeast side of the Killik River, Upper Devonian fossils were found in thin beds of reddish-weathering gray crystalline limestone and also in reddish-weathering gritty sandstone and fine conglomerate, composed of chert, quartz, and black slate grains evidently cemented by calcite and siderite. One of the curious phases of the lithology at this locality is the relation that exists between adjoining beds of the gray and red calcareous sandstone. In addition to the normal contact, parallel with the bedding, irregular areas of the red sandstone occur within the gray sandstone. The reddish areas are in places rounded and in places very angular, but the border line between red and gray is everywhere sharp and well defined, not unlike that formed by the acidic apophyses in a dioritic country rock. At first sight the red areas suggest a boulder bed or a breccia structure, but in reality they are due to secondary action, which has resulted in the introduction of siderite, probably replacing calcite, in these rocks. The original distribution of lime in the sediments, however, may have been influential in determining the present limitations of the sideritic areas. The sandstone and grit indicate the bedding planes of the Devonian rocks better than the slate and shale, for two reasons. First, they show at many places perfectly developed ripple markings, worm trails, and cross-bedding; second, the formational fracture cleavage is less perfectly developed in the sandstone, being represented in many places by nearly vertical and rather distantly spaced strike joints. (See fig. 5.)

The argillaceous beds constitute a large part of the Devonian sequence—probably, if the sandy shale is included, more than half of the total thickness. They are for the most part dark-gray rocks like the sandstone, with which they are interbedded and into which they commonly grade along the bedding planes. Because of their inferior competency, however, they are more deformed than the sandstone beds and almost universally show a well-developed fracture cleavage, locally accompanied by close or even overturned folds. Moreover, little variation in composition is apparent in successive beds, so that the original bedding is in places obscure, though usually discernible upon close inspection. Cleavage, however, is the most prominent structural feature. Gritty and finely conglomeratic beds are found at many places in the Devonian sequence, but no true conglomerate was noted.

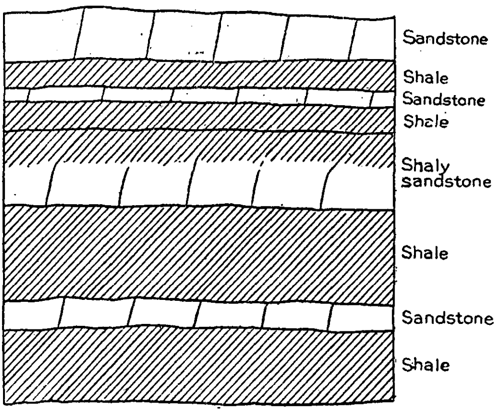

FIGURE 5.—Sketch showing development of cleavage and strike jointing in Upper Devonian slaty shale and sandstone

Along the John River Schrader[90] grouped all the rocks between the Skajit formation and the Lisburne formation into one unit which he called the "Fickett series." This group comprises various formations from upper Silurian(?) to the Mississippian in age. Smith[91] subsequently separated from the "Fickett series" the northern third, which is distinctly less metamorphosed than the southern third of the "series," and correlated it with the Noatak sandstone of Mississippian age, the type locality of which is in the western part of the Noatak Valley. In view of the known occurrence of Devonian as well as Mississippian rocks among the relatively unaltered strata of the "Fickett series," it now seems practicable to subdivide the "series" into three parts, of Silurian(?), Devonian, and Mississip-

[90] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol Survey Prof. Paper 20, pp. 67–72, 1904.

[91] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 71, 1913.

pian age, the Mississippian part being correlated with the Noatak sandstone. The boundary lines between the Devonian and Mississippian rocks on the one hand and between the Devonian and the undifferentiated Silurian(?) rocks on the other hand are inexact and more diagrammatic than real; but this subdivision, indicating as it does the approximate grouping of formations, should be useful in any later work that may be done upon the "Fickett series." Schrader's description of the lithology of the "Fickett series" is more or less generalized, and it is therefore almost impossible to distinguish from his description of this larger group the parts that are particularly pertinent to the lithology of the Devonian rocks as defined in this paper. The rocks along the John River from Hunt Fork to Till Creek, however, are believed by the writers to be probably in large measure Devonian. These rocks, as described by Schrader, consist of gray sandstone, limestone, gray schist, some quartzite schist, slate, and conglomerate. Still farther east in the Chandalar district are Middle Devonian rocks that lie above the Silurian sequence and have been described by Mertie[92] as consisting dominantly of slate with a minor proportion of sandstone and some thin beds of dark-gray limestone. These rocks are literally permeated with discontinuous anastomosing quartz veins, which carry more or less oxidized pyrite. This great amount of quartz veining was noted by Schrader in beds at what is believed to be about the same geologic horizon along the John River. Numerous dikes and sills of altered diabasic rocks are also found in the Devonian rocks of the Chandalar district.

The so-called Devonian rocks of the Cape Lisburne district were examined by Collier,[93] and the following statements are abstracted from his description. These rocks are exposed in the sea cliffs for 15 miles north from Marryat Inlet and also for 10 miles along the Kukpuk River and consist of heavy calcareous sandstone and interbedded calcareous slate. The sandstone beds range in thickness from 1 to 10 feet; the slate beds are usually thinner. Locally some of these rocks contain secondary mica and have developed a schistose texture. Calcite and quartz veins have been formed to a considerable degree along joint planes, but such veins have not yielded any traces of gold or silver.

STRUCTURE AND THICKNESS

The Devonian rocks have been greatly compressed and folded and possess a highly developed fracture cleavage but are not as a rule schistose. On account of this cleavage, together with the lack of

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[92] Mertie, J. B., jr., Geology and gold placers of the Chandalar district: U. S. Geol. Survey Bull. 773, p. 233, 1925.

[93] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 17, 1906.

easily recognizable lithologic key beds, little can be learned of the attitude of the bedding, except by observations at close range, although the structure produced by cleavage is apparent at long distances. Plate 18, *B*, illustrates this fracture cleavage as it appears in the valley of the Killik River when viewed from a distance. Relatively few detailed observations of the attitude of bedding planes have been made, but where the bedding planes have been studied at close range it has been found that the dip of the rocks is reversed within very short distances across the strike. In the canyon of the Killik River above camp April 9, in a distance of about 3 miles the average strike of these rocks is a little south of west, but the dip is reversed at such short intervals that it would be difficult to state with any assurance whether the prevailing dip is to the north or to the south. Along the ridge northeast from camp April 22, on the southeast side of the Killik River, however, in a similar distance the rocks are also greatly disturbed, but the dip is prevailingly northward. But in traverses up several of the creeks tributary to the Killik River, in the same vicinity, many reversals of dip of the bedding planes were noted. In the gulch on the southeast side of the Killik River about 3 miles below camp April 9, where fossil collections were made, the relations of bedding to cleavage are clearly indicated; the bedding dips on the average 20° NW., and the cleavage dips 35° SE. Cleavage is developed in this gulch mainly in the slaty beds, and the interbedded sandstones show for the most part a strike jointing. (See fig. 5.) It is apparent, therefore, that only refined stratigraphic mapping will yield a complete understanding of the folding to which these rocks have been subjected.

The attitude of the cleavage and the dip of the axial planes of the folds, however, yield information of considerable value; and the interpretation of structural relations in the Devonian rocks is based largely on these features, aided by the evidence afforded by fossils. The most striking structural feature is a prevailing though by no means universal southerly dip of the cleavage planes at angles of 30° or more. This is directly opposite to the direction of dip of the cleavage planes in the Silurian and older rocks, and this difference forms one of the criteria used in conjunction with the degree of metamorphism for separating the Devonian from the pre-Devonian rocks. A second criterion is the character of the folding. In the canyon of the Killik River above camp S April 9 small overturned drag folds were seen, one of which was nearly recumbent, and similar folds were seen elsewhere in the same vicinity. (See pl. 18, *B*.) Most of these folds were in the softer or shaly beds, but in one of the folds seen in the canyon of April Creek fairly competent sandstone beds have been thus folded. The axial planes of such folds, where they were seen by the writers, dip south, although in places at a lower angle than the usual pitch of the cleavage planes. These compression folds, therefore, are not a minor feature of the structure confined to incompetent beds, such as may often be seen in relatively mildly folded rocks. Instead, they are believed to be a real index of the type of folding that has affected the Devonian rocks; and considered in conjunction with the cleavage relations, they are believed to indicate that the whole Devonian sequence has been closely folded and probably in part overturned by compressive forces applied from the south.

No large faults were observed, but small faults and fault zones were observed at numerous localities. Some of the fault planes dip southward and some northward, and apparently both normal and reversed faulting have occurred. In the canyon of April Creek above camp S April 9, a well-defined thrust fault dipping about 35° S. and parallel with the cleavage has broken through the axis of one of the overturned folds above mentioned. This indicates that the formation of the cleavage was accompanied by parallel thrust faulting. (See pl. 18, *B*.) In general, however, fault planes are not conspicuous in the Devonian rocks, for much the same reasons that the bedding planes are inconspicuous. It is likely that more detailed work would reveal several systems of faulting, both concomitant with and later than the regional folding.

In the John River section Schrader in his original notes records three structural features in the area from the mouth of Hunt Fork northward to the Lisburne limestone. These are, first, bedding planes that dip prevailingly southward, and this feature he has also indicated on his generalized cross section of the range; second, cleavage planes that from several observations appear to dip rather constantly southward at angles of 30° to 40°; and third, joint planes that are as a rule steeply dipping and parallel with the strike. The cleavage and jointing in this section therefore agree with those seen in the upper valley of the Killik River.

The structural relation of the Devonian rocks to underlying and overlying formations is only partly understood. The Silurian rocks are characterized by a high degree of metamorphism, by appressed folds, whereby the bedding has been either obliterated or rendered nearly parallel to the cleavage, and by a flow cleavage that dips 20° to 30° N. The Devonian rocks are less metamorphosed, have close but not appressed folding, in which the original bedding planes are almost everywhere preserved, and possess only a fracture cleavage. It is confidently believed, therefore, that the Devonian rocks are separated from the underlying Silurian rocks by a great unconformity, but as now traced in the field the actual contact line between the two groups of rocks may be as much the result of faulting as of unconformity.

Both Middle and Upper Devonian rocks are probably represented in this section across the Brooks Range, but on the Killik River fossils were found only in the upper part of the sequence. No structural break, however, is believed to separate the Middle from the Upper Devonian rocks. Similarly, to the north no structural break was found between the Upper Devonian and the Mississippian rocks.

The structure of the Devonian sediments in the Brooks Range as a whole is as yet only imperfectly understood. It seems to be fairly well established that in general the rocks become younger from south to north, and this succession of younger beds toward the north does not stop with the Upper Devonian rocks but continues through two Carboniferous formations and the Mesozoic formations. In a broad way, therefore, the general structure for the Devonian and Carboniferous rocks might be considered that of a northward-dipping monocline. But if the details of the rock structure are considered, it is not so simple. Instead it appears that the whole sequence is thrown into a multitude of close and probably for the most part overturned folds, whose axial planes pitch southward. Some additional evidence bearing on this point is presented in the description of the structure of the Carboniferous rocks. The general picture, then, of this late Paleozoic structure is that of a monocline that has been modified by intense compressive stresses applied from the south, resulting in the development of close and for the most part overturned minor folds and of a southward-dipping cleavage.

As no evidence of an era of marked deformation between the deposition of the Devonian and that of the Carboniferous rocks has been recognized, the geologic and structural history of these two groups of rocks will be considered jointly under the discussion of the Carboniferous. It suffices here to state that the major part of earth movements that deformed the Devonian rocks probably took place during early Jurassic time; but later movements, in Tertiary and Cretaceous time, must have added their quota of deformation.

With this general structure in mind, it is obviously unjustifiable, on the basis of the available reconnaissance data, to venture any close estimate of the thickness of the Devonian rocks. The great distance from north to south across the strike of these rocks suggests at once an enormous thickness of strata, but the evident duplication of beds, due to close folding, shows that their true thickness can not be nearly as great. Even if a moderate estimate is placed on all the factors involved, however, it seems certain that the thickness of this group of rocks is to be measured in thousands of feet.

AGE AND CORRELATION

Most of the fossils found in the area here mapped as Devonian were obtained in the northern and probably the upper half of this group of rocks. A summary of these collections is given below. The paleontologic determinations were made by Edwin Kirk, of the United States Geological Survey.

24AMt17, 24AMt18, and 24AMt19: 3½ miles N. 60° E. from camp S April 9 (winter base camp), on the southeast side of the gulch that flows to the lower end of the lake in the valley of the Killik River:

24AMt17: On weathered surfaces the rock shows brachiopods strongly suggesting pentameroids of the type found in the Silurian of the Fairbanks district and the Chandalar River. It was not possible to work out specimens for satisfactory determination. It is possible that the brachiopods are Spirifers and that the lot is of Upper Devonian age, along with 24AMt18 and 24AMt19.

24AMt18 and 24AMt19:
Spirifer disjunctus Sowerby.
Productella sp.
Camarotoechia sp.
Grammysia sp.
Numerous indeterminable pelecypod and brachiopod fragments.

24AMt36: 15.6 miles S. 21° W. of camp S April 9, in the headwaters of the southwest fork of the Killik River, in gulch on west side creek:
Spirifer disjunctus Sowerby.

24AS16: Doc Creek, 15 miles southeast of camp S April 9:
Spirifer disjunctus Sowerby.
Camarotoechia sp.

24AS17: South branch of the Killik River, above camp S April 9:
Spirifer disjunctus Sowerby.

All these collections that contain *Spirifer disjunctus* are regarded by Kirk as Upper Devonian in age; and collection 24AMt17, which appears paleontologically to be indeterminate, owing to the poor quality of the material, is also of Upper Devonian age, because it was obtained at the same locality as collections 24AMt18 and 24AMt19.

In the valley of the John River Schrader[94] made three collections of fossils between Hunt Fork and Till Creek, in the area mapped by him as part of the "Fickett series," that were definitely determined as Devonian. These fossils were determined originally by Charles Schuchert, and subsequently two of the lots, 460 and 462, were reexamined by Edwin Kirk, who confirmed the earlier determinations of Schuchert. The localities and determinations by Schuchert are as follows:

Schrader 455: Dark, slate-colored limestone, fossiliferous. Locality, John River, camp July 6:
Productella, 2 sp.
Platyostoma sp.
Zaphrentis sp.
Fenestella sp.
Unitrypa sp.

[94] Schrader, F. C., manuscript notes.

Eridotrypa sp. near to or identical with E. barrandei (Nicholson), of the Middle Devonian.

Schrader 460: Dark limestone, pebbly, fossiliferous. Locality, John River, camp July 6:

Spirifer disjunctus.

Schrader 462: Dark limestone or calcareous sandstone. Locality, John River, camp July 9:

Spirifer disjunctus.

Collection 455 has unfortunately been lost and can not be reexamined, and the determination of this lot as Middle Devonian will have to stand, but it seems probable that if it were possible to reexamine this collection in the light of accumulated data regarding Devonian faunas in Alaska, it might also be regarded as Upper Devonian.

P. S. Smith [95] in 1911 made a collection of fossils from the south side of the valley of the Noatak River about 10 miles above the mouth of the Kugururok River. The exact locality and E. M. Kindle's report on the material are as follows:

11AS66: 5 miles southeast of camp August 14. Corals on hill slope with rock exposures. Fossils not absolutely in place but probably within 5 feet of bedrock source.

This material consists entirely of fragmentary corals embedded in dark dolomitic limestone. The best preserved and most abundant of these is a species of *Cladopora* which is comparable with *C. labiosa*. Both the fossils and the rock matrix resemble rather strongly some of the specimens which have been obtained by me and others from Black Mountain, in Seward Peninsula. The evidence is insufficient to make any positive correlation, but I would suggest that the material might be assigned provisionally to the Devonian unless there is some distinctive stratigraphic evidence against such an assignment. The fossils represent in all probability either Devonian or Mississippian but probably the former.

One fossil plant also was collected from the rocks mapped as Devonian at a point 1½ miles east of camp April 9, on the north slope of a gulch tributary to the Killik River. This plant, however, was determined by David White, of the United States Geological Survey, to be of Carboniferous age, and the specific identification and age assignment are therefore given in the discussion of the Carboniferous rocks. This fossil plant is mentioned at this place because its occurrence signifies the presence of infolded or infaulted Carboniferous beds in the Killik Valley, which have not been separated from the Devonian sequence.

The fossils so far collected are, as stated, mainly Upper Devonian, but from previous work done by Mertie [96] in the Chandalar district,

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[95] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 68–69, 1913.

[96] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pp. 234–235, 1925.

to the east, a distinctive Middle Devonian fauna is known to exist among the rocks of the Brooks Range. This Middle Devonian fauna was found a short distance north of the Silurian limestone in that region, whereas the Upper Devonian collections above described were obtained a considerable distance north of the Skajit limestone. On the basis of a northward-dipping monoclinal structure, previously postulated, this is a reasonable distribution of the fossils in the Devonian rocks. It is believed, therefore, that the belt here mapped as Devonian includes both Middle and Upper Devonian rocks.

It seems necessary in this connection to point out a discrepancy that may appear by reference to Schrader's original work. He grouped together all the rocks between the Skajit (Silurian) formation and the Lisburne (Mississippian) formation, applied to them the designation "Fickett series," and deemed them to be of "Lower Carboniferous" age or younger. It is now believed, from comparative geologic studies both east and west of the John River, that this group of rocks includes Silurian, Middle and Upper Devonian, and Mississippian rocks. "Fickett series" therefore has no further usefulness as a group or formational name and will be entirely abandoned in future work. No new group names are proposed in this paper for the Devonian rocks, because two epochs, Middle and Upper Devonian, are involved, and the boundary line between the two has not been determined. One of the geologic problems of future mapping in the Brooks Range will be the separation of the rocks of these two epochs, and a further problem will be the accurate determination of the base and top of the Devonian rocks as a whole.

The correlation of the Devonian rocks of the Brooks Range with similar rocks in other parts of Alaska is difficult, because the Upper Devonian fauna that was collected seems to be restricted to the Brooks Range. On the other hand, the Middle Devonian age of the lower part of this Devonian sequence is only assumed, no fossils of this age having been collected. Only one definite correlation of the Upper Devonian part of the sequence can be made. *Spirifer disjunctus*, which characterizes this fauna, was found by Schrader[97] in 1899 among the boulders of the Chandalar River, and these fossils were believed by him to have come from his West Fork "series," which consisted of "dark-gray quartzite, black flint, calcareous black shale, and impure limestone." Next in closeness of relationship to this Upper Devonian horizon is a group of rocks of late Middle or early Upper Devonian age which crop out along the Yukon above

[97] Schrader, F. C., Preliminary report on a reconnaissance along the Chandalar and Koyukuk Rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 475–476, 1900.

and below the mouth of Woodchopper Creek. These are essentially volcanic rocks with some interbedded limestone and therefore do not correspond lithologically with the Upper Devonian rocks of the Brooks Range. Along the upper Porcupine River is a formation described by Kindle [98] as consisting of 325 feet of brown shale, which he assigned, on stratigraphic grounds alone, to the Upper Devonian. Such a formation can not be correlated well, either in character or in thickness, with the Upper Devonian rocks of the Brooks Range.

On the assumption that the lower part of the Devonian sequence of the Brooks Range is Middle Devonian in age, certain correlations may be made. The nearest correlation geographically and the most acceptable lithologically is the equivalence of these beds with the Middle Devonian slate and sandstone group of rocks in the Chandalar district, described by Mertie.[99] Still farther east the Salmontrout limestone on the Porcupine River, as described by Kindle,[1] is the Middle Devonian counterpart of these rocks.

On the north slopes of the Brooks Range Devonian rocks have not yet been recognized with assurance, but Leffingwell [2] found in the Flaxman formation, of Pleistocene age, a limestone boulder containing the typical Middle Devonian fauna of the Porcupine and Chandalar districts, thus proving that rocks of this age are doubtless present somewhere along the north slopes of the range.

In Seward Peninsula, which is as close to the western extension of these rocks as the Chandalar Valley is to their eastern extension, few correlative data have been found. The only collection of fossils that has been definitely assigned to the Middle Devonian was obtained by Collier at Baldy Mountain, in the Kuzitrin Valley. Several collections of doubtful age, which, however, have been referred either to the "Devonian or Carboniferous" or to the "Silurian or Devonian," suggest strongly that Devonian rocks are developed in Seward Peninsula, though doubtless much more metamorphosed than rocks of the same age in the Brooks Range.

South of the Yukon, in the Mount McKinley region, is a group of rocks of great lithologic variety, known as the Tonzona group, described originally by Brooks,[3] and the name was subsequently extended by Prindle,[4] though with some hesitation, to describe a

[98] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, p. 327, 1908.

[99] Mertie, J. B., jr., Geology and gold placers of the Chandalar district, Alaska: U. S. Geol. Survey Bull. 773, pp. 233–235, 1925.

[1] Kindle, E. M., op. cit., pp. 327–329.

[2] Leffingwell, E. de K., unpublished data in files of U. S. Geological Survey.

[3] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, pp. 73–76, 1911.

[4] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, pp. 44–45, 1913.

group of similar rocks in the Yukon-Tanana region. The Tonzona group is now known to include rocks of Silurian, Devonian, and Carboniferous age, and the name, like Schrader's "Fickett series," will probably not be used in subsequent geologic description. The group probably includes, however, both the typical Middle Devonian rocks, as exemplified by the Salmontrout limestone, and the late Middle Devonian or early Upper Devonian rocks, as exemplified by the volcanic rocks near Woodchopper Creek. It is therefore apparent that a part of the Tonzona group is correlative with the Devonian rocks of the Brooks Range.

Small areas of Middle Devonian limestone were early recognized by Brooks[5] in the Mount McKinley region and subsequently by Capps[6] in the Nutzotin Mountains and the Kantishna district and by Moffit[7] in the Broad Pass district.

A number of fossil collections from Middle Devonian rocks have been obtained in the Minchumina and Ruby districts and thence southwestward in southwestern Alaska; and even more rocks of Devonian age, both Upper and Middle, are known in southeastern Alaska, but such occurrences are so distant from the Brooks Range that separate mention of the individual localities is hardly warranted.

CARBONIFEROUS SYSTEM

The Carboniferous system of northern Alaska includes rocks of Mississippian and Permian age, but within the area covered by this report Permian rocks have not yet been certainly identified. The Mississippian series, however, comprises two lithologically distinct formations, known as the Noatak formation and Lisburne limestone, of which the Lisburne is regarded on stratigraphic grounds as the younger. Sufficient detailed paleontologic work has not yet been done to separate these two formations on paleontologic grounds, and the list of their included invertebrate fossils is therefore given at the end of this description as a single Mississippian fauna.

NOATAK FORMATION

DISTRIBUTION

The type locality of the Noatak formation is in the western part of the Noatak Valley, between the Nimiuktuk and Kugururok Rivers, where it crops out along the strike for a distance of 50 miles. The

[5] Brooks, A. H., op. cit., pp. 77–78.

[6] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, [illegible] 31–33, 1916; The Kantishna region, Alaska: U. S. Geol. Survey Bull. 687, pp. 32–34, [illegible].

[7] Moffit, F. H., The Broad Pass region, Alaska: U. S. Geol. Survey Bull. 608, pp. 24–26, [illegible]

north-south distance across the formation at this locality has not been determined but is known to be at least 10 miles. About 150 miles farther east, on the Killik River, the same rocks were recognized and mapped by the expedition of 1924. There the approximate north and south limits of this formation were recognized and the distance across the formation was found to be about 15 miles. Between the Colville and Noatak Rivers, but closer to the Noatak, the formation was also mapped in the valley of the Aniuk River by the expedition of 1925, thus indicating in all probability the continuity of this belt of rocks between the Nimiuktuk and Killik Rivers. In the valley of the Aniuk the north-south distance across the strike of the Noatak formation is only about 9 miles, but post-Mississippian lavas appear to overlap the southern limits of the formation; and if due weight is given to this fact it seems probable that the width of this belt of rocks is at least as great along the Aniuk River as in the valleys of the Noatak and Killik.

At the easternmost extremity of the area covered by this report, as shown on the accompanying map, the Noatak formation occurs in a belt about 15 miles wide crossing the John River between Till and Contact Creeks. This belt is the northern third of Schrader's "Fickett series," the subdivision of which has been described in the sections discussing the undifferentiated Silurian (?) and the Devonian rocks.

At the western extremity of the area mapped, in the Cape Lisburne district, three small bands of rocks that are intermingled with the Lisburne limestone and the Triassic rocks have also been separated out and correlated, mainly on lithologic grounds, with the Noatak formation. The southernmost of these three bands crops out for about a mile along the coast at Cape Thompson and extends north-northeastward toward the Kukpuk River. A second band, about 5 miles wide, crops out north and south of Cape Dyer and extends southeastward toward the Kukpuk River, possibly joining at the south with the Cape Thompson band. The third and northernmost band crops out for about a mile along the coast north of the mouth of Niak Creek and appears to extend in a general southeasterly direction parallel with the Lisburne Hills.

In summary, then, it may be said that the Noatak formation crops out as a continuous belt of rocks about 15 miles wide for a distance of 250 miles, between the Kugururok and John Rivers, and continues eastward into the Brooks Range for an undetermined distance. It is not known how the Noatak formation on the Kugururok River connects with the rocks of the same age in the Cape Lisburne district, but evidently the broad beltlike distribution fails west of the Kugururok, the formation probably losing its general westerly trend and splitting into several bands whose trend appears to be more nearly south.

LITHOLOGY

The Noatak formation at its type locality in the western part of the Noatak Valley, between the Nimiuktuk and Kugururok Rivers, was originally described in part by Smith[8] in 1913, under the designation Noatak sandstone, but the work of that date did not yield a complete section across the strike. For this reason, and also because other Mississippian rocks have in the present report been assembled and treated collectively with the original Noatak sandstone, it has seemed desirable to create a new and more comprehensive cartographic unit, to be known as the Noatak formation.

Smith's original description of the Noatak sandstone is as follows:

> In the most typical exposures seen from a point near the camp of August 11 [at the mouth of the Nimiuktuk River] to the canyon [of the Noatak River] the rocks are dominantly sandstones, medium fine grained, and rather massive, but containing layers of shale that accentuate the bedding. On exposed surfaces the rocks are usually rusty brown to brownish green, but on fresh fracture they are dark gray or greenish. The component minerals are usually not distinguishable macroscopically with the exception of quartz and flakes of mica. When treated with acid many of the sandstones effervesce slightly, showing the presence of calcite. Under the microscope the sandstone is seen to be composed mainly of quartz and some sericite, with limonitic and carbonaceous material filling the interstices.
>
> Some slightly conglomeratic beds are associated with the sandstones, and certain of these show flattened masses of indurated shale or quartzite which are of pebblelike form but which may represent contemporaneous accumulations of mud. Mica has been developed parallel with the surface of these nodules, but the material within is unsheared. Many of these accumulations closely simulate fossils and can be distinguished from them only by careful examination.
>
> Some thin beds of limestone, few over a foot thick, are interbedded with the sandstones. These limestone beds show considerable variation in color, some being dark gray whereas others have weathered to a light yellow. All the limestones are semicrystalline but exhibit only slight signs of movement. Fossils are fairly numerous in some of these beds and are entirely undeformed. In places the rocks are cut by small local calcite veins and have been intruded by basic intrusive rocks. The limestone beds become more prominent and thicker toward the top of the formation. * * *
>
> Shales and slaty beds are interlaminated with the other members of this formation. Generally they exhibit both bedding and cleavage but not much metamorphism. The slates contain little clayey material but seem to be formed mainly of fine-grained quartz and some calcite. As a rule the rock is too fine grained to permit its component minerals to be distinguished. Under the microscope it is seen to be composed mainly of quartz, kaolin, or sericite, and a greenish, nearly amorphous, finely divided mineral, together with magnetite, some sulphides, and limonitic material.

[8] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 69-75, 1913.

Quartzites are especially common in the exposures in the vicinity of the Noatak Canyon. Most of them are dark, nearly black, but brown and red iron-stained members are not uncommon. The greater induration of the quartzites appears to be due to the pronounced folding to which the rocks have been subjected and also to the igneous intrusions in the vicinity. As a result of the igneous action much of their dark coloring matter has here and there been destroyed, and they weather white, so that at a distance they are difficult to distinguish from certain of the limestones. This contact phase may in places be traced several hundred feet from the igneous rock. The red and brown colors noted above have been produced mainly by the weathering of sulphides that occur in the quartzites.

In the Aniuk River district the Noatak formation is exposed in the hills east and west of the lake in the Etivluk-Aniuk Pass. The rocks of the formation, as observed by the expedition of 1925, consist chiefly of thin-bedded shaly sandstone, shale, and thin beds or lenses of white to bluish-gray limestone. The sandstone is fine grained and weathers to hues of red, brown, and yellow. A freshly broken surface shows rusty grains of sand throughout the mass. The shale beds are from a few feet to 50 feet thick, but all contain thin beds of sandstone. The shale is usually dark and weathers into thin, flat fragments. The Noatak formation as a whole is not so hard as the underlying Devonian rocks, but the contact between these two groups of rocks appears to be a conformable one. Some of the limestone beds are fossiliferous.

Along the Killik River the rocks included in the Noatak formation differ in some respects from the typical exposures in the Noatak Valley. The southern boundary of this group of rocks is drawn tentatively at Easter Creek, not because any discordance in structure or discontinuity in sedimentation is observable at that point but mainly because the rocks between Easter Creek and the Lisburne limestone appear to contain a larger proportion of cherty and argillaceous beds and in general appear to be more carbonaceous and therefore darker in color than the Upper Devonian rocks south of Easter Creek. The most striking difference between these rocks and those of the Noatak formation at its type locality is the presence not only of numerous cherty beds but also of a peculiar chert conglomerate, which occurs along the Killik River. This is an aphanitic siliceous rock composed of angular and subangular chert débris in a siliceous matrix. In other words, all variations may be seen between a chert conglomerate and a sedimentary chert breccia. It is of interest to note that chert conglomerate and sedimentary chert breccia of the same character are also found to the east on the John River and at the head of the Chandalar River in rocks that underlie stratigraphically the Lisburne limestone; and apparently this same chert conglomerate horizon is represented in a more or less continuous zone at the base of the Mississippian rocks of the Yukon-Tanana region.

Along the John River the northern third of Schrader's "Fickett series," which is here correlated with the Noatak formation, is described by Schrader[9] as follows:

Beginning on the south slope of the north axis of the range * * * [these rocks consist of] dark shale, schistose slate, and apparently some dark limestone, which is succeeded by quartzite, grit, and conglomerate. The sediments in the quartzite, and more especially those in the grit and conglomerate, though they are often fine, bear a marked resemblance to the varicolored conglomerate of the Stuver series, from which they seem undoubtedly to have been derived. The quartzite, grit, and conglomerate are hard and flinty, the grains and pebbles being thoroughly united by a siliceous cement.

The Stuver "series" was believed by Schrader[10] to be a formation of pre-Devonian age, and its position within the Lisburne limestone was explained as due to a fault contact along its north flank. The Stuver "series" is believed by the writers to be a part of the northern third of Schrader's "Fickett series" and as such is included in this report with the Noatak formation. No fossils were found in the Stuver "series," and the following description, as given by Schrader, shows rather clearly its lithologic kinship with the rocks above described:

The rocks of this series are principally conglomerates, with interbedded layers of quartzite, which toward the top pass into slate and shale. The pebbles composing the conglomerate are practically all siliceous and consist of black, slate-colored, red, green, and bluish flint and milky-white quartz. They range in size from less than an inch in diameter to cobbles, and in a few instances approach boulderets. The cement is siliceous, usually dense, and often contains grains of cryptocrystalline or aphanitic silica, undoubtedly derived from the same parent rock as the pebbles. Great force is required to break the rock with the hammer, and when broken the fracture plane is almost invariably found to take a direct course, traversing any pebbles, though perfectly sound, that may lie in its path; in fact, the cementation is so firm as to form of the conglomerate, as a whole, a rock substantially as hard as the hardest flint pebbles that are included in it. * * * The interbedded quartzites in the Stuver series are medium grained and exceptionally hard and siliceous and are usually of a gray or sometimes a pinkish or reddish color, while the slate is dark.

One of the most puzzling features of the Noatak formation is the origin of this chert conglomerate, as above described, which occurs in its upper part on the Killik, John, and Anaktuvuk Rivers and thence eastward in the Brooks Range. This conglomerate occurs at several places along the Killik River, below the Lisburne limestone, but in view of the character of the folding in these beds these sundry outcrops may well be repetitions of one well-marked chert conglomerate. Schrader goes to the heart of this problem when he

[9] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 68, 1904.
[10] Idem, pp. 60-62

states, as quoted above, that the matrix of this rock was undoubtedly derived from the same parent rock as the pebbles. So far as known, however, there are no cherty rocks of any extent in the Paleozoic rocks of this vicinity, and certainly no such multicolored chert formation that might act as a source rock for the pebbles in this conglomerate. The Lisburne limestone and the overlying Triassic rocks, to be sure, contain much chert. Yet both in northern Alaska and in the Yukon-Tanana region, according to the independent opinions of several geologists, the chert conglomerate lies apparently below or at the base of the cherty rocks of the Mississippian sequence. Where, then, is the source or parent rock of these chert pebbles?

Cherty rocks are not entirely absent from the early Paleozoic and pre-Paleozoic rocks, however, and the explanation might be suggested that these chert pebbles originated by prolonged residual concentration at the surface of a relatively few weathered cherty beds, just as vein quartz and gold have been concentrated to form almost purely quartzose gold-bearing gravel, such as the white channel gravel of the Klondike district. The weakness of this explanation is that the early Paleozoic and pre-Paleozoic rocks that formed the land mass back of the Mississippian ocean contained much vein quartz, which is as resistant to residual decomposition as chert; and therefore these conglomerates should contain as many pebbles of vein quartz as of chert, if not more. But this, as is well known, is not true.

Perhaps the most significant evidence bearing upon the origin of this conglomerate is the cherty character of its matrix. The chert of the Mississippian rocks in the Yukon-Tanana region has been studied by Mertie,[11] who says:

> The chert is a microcrystalline rock composed of chalcedonic quartz, which under the microscope shows usually only an aggregate polarization. Much of it is brecciated and recemented with silica. It is believed to be of primary origin—that is, to be a rock formed from original siliceous material. Whether the chert is derived from mechanically or chemically precipitated silica has not been determined.

The same description would apply equally well to the chert of the Noatak and Lisburne formations, except that among the Lisburne rocks there has been a pronounced tendency toward recrystallization at certain horizons, resulting in the formation of a certain proportion of fine-grained quartzitic rocks.

In the description above quoted Mertie wished to emphasize the fact that these homogeneous cherts probably originated either from the sedimentation of fine-grained or colloidal siliceous silts, or by a

[11] Mertie, J. B., jr., The gold placers of the Tolovana district, Alaska: U. S. Geol. Survey Bull. 662, pp. 239–244, 1918.

chemical reaction that precipitated silica from oceanic waters. The origin from accumulated deposits of consolidated siliceous organisms, although theoretically possible, was purposely ignored because the examination of many thin sections of the chert failed to reveal any traces of organic remains. It is possible, however, that the cherts may have originated indirectly through the action of algalike organisms that had the power to secrete silica from water, just as certain types of algae have secreted iron from water to form valuable deposits of iron ore.

It is now believed by many geologists that deposits of primary chert have been formed in past geologic time at many places in the world. Some of these deposits, to be sure, are claimed to be of organic origin, but they show no more evidence of direct organic origin than the cherts under present discussion. If we admit, then, the possibility of primary siliceous deposits, it is relatively simple to explain the manner of formation of the chert conglomerates, even if the exact causes and details of the process are not thoroughly understood. Some limestone conglomerates and primary limestone breccias have been proved to form more or less simultaneously with the massive limestone about them by the erosion and sorting action of oceanic currents. Why, then, could not siliceous conglomerates form in the same manner? However, it is not proposed here to limit the formation of chert conglomerate to the one method above outlined. A slight elevation above sea level of siliceous sediments already formed might result in the denudation and sorting of siliceous fragmental débris by atmospheric agencies. The angular character of the chert fragments in the chert breccia, however, indicates that the comminution of these fragments must have taken place after the source rock had attained a considerable degree of cohesive strength; that this comminution took place as a result of subaerial denudation; and that some of these fragments at least suffered little transportation or assortment by moving water. Various explanations might be proposed to fit the conditions thus adduced as necessary to the formation of the chert conglomerate and breccia, but until some further light is thrown upon the mode of formation of primary chert itself the exact mode of origin of these related rocks will have to remain in more or less doubt. The explanation here proposed, however, is that the pebbles and angular fragments in the chert conglomerate and breccia are essentially contemporaneous with the formation of a primary chert matrix; not contemporaneous, perhaps, in the sense of secular time units but in relation to the geologic time units of the Paleozoic era.

One of the peculiar features of the Noatak formation is the lithologic variation observable along the strike. The chert and chert conglomerate of the John and Killik Rivers have not been seen along the Noatak River. Northwest of the lower Noatak Valley, in the Cape Lisburne district, there occurs still another variety of rocks, which must perforce be correlated with the Noatak formation—namely, a coal-bearing and, in part at least, nonmarine group of rocks. These facts suggest strongly that the Noatak formation comprises a great assemblage of rocks, which by more detailed mapping might well be split up into smaller formational units.

The Carboniferous section at Cape Lisburne was described originally by Collier,[12] but subsequently additional work was done by Kindle[13] in the vicinity of Cape Thompson. Collier divided the Carboniferous rocks of this district into three formational units, which for descriptive purposes he called the lower, middle, and upper formations. The middle formation is now known to be of Triassic age. The upper formation constitutes the typical Lisburne limestone. The lower formation comprises the three bands of rock previously enumerated, which in this report are correlated with the Noatak formation.

The so-called lower formation consists, according to Collier, of slate, shale, and limestone, containing several coal beds and, in some of the black shale and clay, Paleozoic fossil plants. Regarding these rocks Collier further states:

> It is therefore essentially a fresh-water deposit. In one instance marine invertebrates have been found in such position as to suggest a possible interbedding of marine sediments with the fresh-water deposits, but as this relation may be due to the infolding of some of the overlying formations it can not be accepted as conclusive evidence. The beds are usually thin and the formation as a whole is softer than the overlying rocks. For this reason it has been more deeply eroded, so that it joins the bedrock of the indented portions of the coast and determines the positions of some of the valleys.

The structure of the rocks in this locality, as elsewhere in the Cape Lisburne district, is so patently complex that it is possible that some of the Mesozoic rocks are infolded in such a manner as to appear to be a part of this "lower" formation. The presence of Paleozoic plants, however, can not be controverted, and it must therefore be accepted that a lower Carboniferous and probably nonmarine group of rocks is here present and is best correlated with the Noatak formation. But inasmuch as such plants do not appear to have been collected directly from the coal-bearing beds a reasonable doubt may exist whether the included coal beds are Carboniferous or Mesozoic in age.

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[12] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 18–27, 1906.

[13] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 520–528, 1909.

STRUCTURE AND THICKNESS

In the type locality, on the Noatak River, Smith[14] noted several structural features that characterize this formation, which in brief are as follows:

1. The degree of regional deformation is not so great as in the older rocks—that is, the rocks of pre-Devonian age; Devonian rocks as such had not been differentiated from the Carboniferous rocks along the Noatak in 1911.
2. The deformation appears to become progressively greater in going westward down the Noatak River.
3. Cleavage but not schistosity is everywhere apparent, except in the massive quartzite beds.
4. The regional strike is east-west, with younger rocks adjoining the Noatak formation on the north.

Along the Killik River much the same structural conditions prevail. In the description of the Devonian rocks of the Killik River was stated the belief that no stratigraphic break separates the Upper Devonian from the Mississippian rocks. It may now be further stated that all available data from the Killik and John River sections indicate more or less continuous deposition of sediments throughout the Mississippian epoch. If any interruption in sedimentation occurred, it is not believed to have been accompanied by any marked diastrophic movements. On the other hand, the pre-Devonian rocks in this region are everywhere not only more highly metamorphosed but deformed by diastrophic proceseses of different character and age. It is therefore apparent that Smith's first generalization, if it is modified to include as a single structural unit both the Devonian and the Carboniferous rocks, holds not only for the rocks of the Noatak and Killik Rivers but, so far as known, elsewhere in northern Alaska.

The second of Smith's generalizations, as above given relates to a structural feature which in the nature of things could be observed only in a series of rock exposures extending over a considerable range east and west. The Killik and John River sections can not therefore confirm this generalization, but if the rock structure in these two sections is compared with that far to the west in the Cape Lisburne district, this impression of progressively greater deformation toward the west is most strikingly confirmed. The structural features of the Noatak formation in the Cape Lisburne district, as given below, will make clear this interpretation.

The omnipresent cleavage developed in the less competent argillaceous beds of the Upper Devonian rocks along the Killik River has

[14] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 71–72, 1913.

previously been commented upon, and it should be stated that the same condition holds true for the argillaceous beds of the Noatak formation along the Killik. Plate 19, *B*, taken from Smith's report, showing the development of a perfect cleavage and the nearly complete obliteration of bedding in the shaly sandstone of the Noatak formation along the Noatak River, is typical of the argillaceous beds of the Upper Devonian and Noatak formation wherever seen in northern Alaska. The quartzitic rocks of the Noatak River were cited as an exception to this condition, the movement having been taken up apparently by stretching and folding of these more competent beds. In addition to such quartzitic beds the Killik and John River sections also have chert and chert conglomerate among the rocks of the Noatak formation, which have behaved under deformational stresses in much the same manner as the quartzitic rocks and have tended to develop into folds fractured by jointing rather than cleavage.

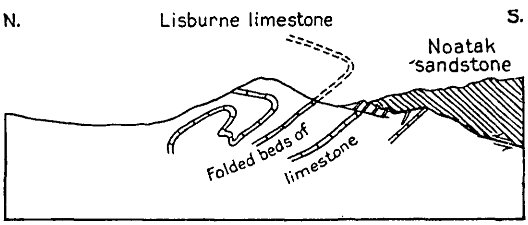

FIGURE 6.—Sketch showing overthrusting of the Noatak formation northward upon the Lisburne limestone, east wall of Killik River Valley at north front of Brooks Range

For the Killik River section, however, an addition must be made to Smith's third generalization regarding folding and cleavage. It has been found that among the rocks of this area the cleavage of the Devonian and Mississippian rocks dips rather uniformly southward at an angle of about 30° or more and that many of the folds in the more competent beds appear to be overturned, with axial planes dipping southward like the cleavage. The sketches in Figures 6 and 7, which represent idealized structural interpretations, the latter taken from Plate 21, *A*, show the southward-dipping cleavage of the Noatak rocks at their northern edge, where they lie in contact with the Lisburne limestone. This additional generalization, however, is not negated by any structural data along the Noatak River, as may be seen by Plate 19, *A*, which shows among the Noatak rocks in the canyon of the Noatak an overturned fold whose axial plane dips southwestward.

The east-west trend of the Noatak formation as observed along the Noatak River also prevails in the Killik and John River sections and in the territory between the Killik and Nimiuktuk Rivers, and nearly everywhere younger rocks lie toward the north. Hence the regional or large-scale dip must be northward, though many reversals of dip occur, the rocks dipping both to the north and to the south, with the prevailing dip southward at certain localities, as, for example, along the Aniuk River, as recorded by W. R. Smith in 1925. The diagrammatic sketch shown in Figure 8 is an attempt to interpret these structural features in terms of an idealized geologic section across the Brooks Range in the longitude of the Killik River. This sketch fits no particular line along the geologic map but shows approximately the geographic north-south extent of the Paleozoic and older Mesozoic formations seen in the range. The structure is interpreted as an assemblage of overturned folds, whose axial planes dip southward, while the regional dip remains northward. The amplitude of these folds is a matter for speculation. Are these folds minor features, such as the small drag folds seen in thin beds of slate, between heavy beds of quartzitic sandstone? Or do they attain to large size, measurable in hundreds of feet, or are they even larger, approximating or even exceeding in size the thickness of the formations involved? The structural data at hand are meager. But it is evident, from certain large overturned folds observed in the field—as, for example, the recumbent fold in the Lisburne limestone at the north front of the mountains, along the Killik River—that this overturning is not confined to small drag folds in incompetent strata. The upper limit of size might roughly be gaged by the degree in which the northward-dipping monoclinal sequence is interrupted. That is, such structure would be sure to result at some places in the infolding of younger rocks, thus breaking the sequence of younger rocks occurring progressively northward. If such infolded rocks are only fragments of their formational units, the conclusion might be justified that the amplitude of the folds is to be measured in hundreds rather than thousands of feet. If all or nearly all of a younger formation were thus infolded, it would probably indicate that the largest of these folds is measurable in thousands of feet. The distribution of certain of the geologic formations in the Brooks Range, particularly in the Nimiuktuk and Kugururok Valleys, suggests that the latter inference is correct, but their distribution may also be explained as due to faulting, and in the absence of more facts than are now available, no decision as to which is the true explanation can be reached.

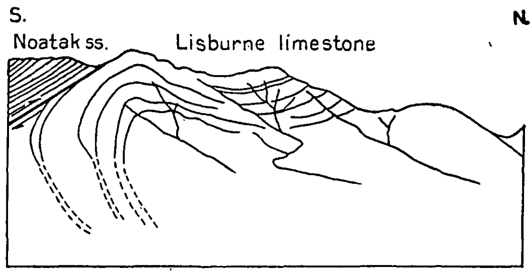

FIGURE 7.—Sketch showing development of cleavage in Noatak formation and close folding in Lisburne limestone, west wall of Killik River Valley at north front of Brooks Range

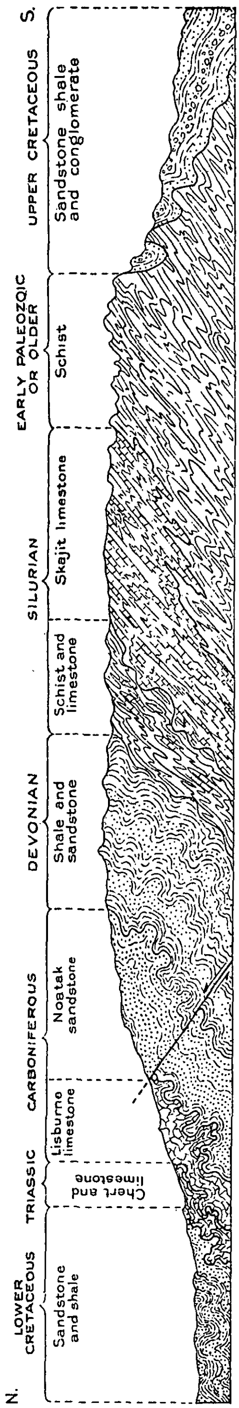

FIGURE 8.—Idealized geologic cross section of the Brooks Range, approximately along the 154th meridian. Approximate horizontal scale, 15 miles to the inch; approximate vertical scale, 8,000 feet to the inch

Faults of several types occur in the Noatak formation, as in the Lisburne and Devonian rocks of northern Alaska, but have not been closely studied. There is much evidence of small-scale faulting of the distributed thrust type as a phase of the development of fracture cleavage in the argillaceous rocks, and similar faults on a somewhat larger scale cut the more competent rocks. At the north front of the Brooks Range is a great thrust-fault zone, which is described in more detail in the discussion of the Lisburne limestone, not because this structure is especially distinctive of the Lisburne, but because that formation is so situated geographically as to have been most affected by this disturbance. As a matter of fact, the chert conglomerate called by Schrader the Stuver "series" and here described as part of the Noatak formation was as much involved in this faulting on the Anaktuvuk River as the Lisburne limestone, the north contact of the Stuver "series" being delimited by this fault zone.

With regard to this faulting, Schrader[15] states:

> To convey a clearer conception of the controlling conditions here, it should be noted that the Stuver series lies in an east-west zone that exhibits the most marked geologic disturbance of the region. Pronounced faulting extends southward into the range for a distance of 15 to 20 miles from its seaward [north] face. * * * The thrust or movement came from the south and apparently produced an overturned fold in the terranes forming the crest of the anticline. The faulting which accompanied this movement broke the beds into several great fault blocks. * * * Toward its northern limits and the crest of the fold the Stuver series dips southward at an angle of 30°. But still nearer its northern limits, practically at the crest of the fold, the beds have been strained, bent downward, and broken, and finally terminate in a well-defined fault scarp. This scarp trends a little south of east and is visibly pronounced for at least

[15] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 61, 62, 1904.

5 or 6 miles. Along this distance, in the higher part of the mountains, the edges of the broken, hard conglomerate beds forming the scarp are distinctly exposed, generally dipping about 30° S., while at a lower elevation along the face of the scarp the broken-off portions of the same strata have dragged behind along the lower face of the scarp and stand nearly on edge, dipping northward at an angle of 80°. These nearly vertical beds of the Stuver series are met at the contact on the north by the limestone of the Lisburne formation, which dips south at an angle of 75° to 80°. The contact of the two formations thus forms a reentrant angle of 25°, opening upward.

The rocks of the Cape Lisburne district that are here included with the Noatak formation belong, it would seem, to a structural province that shows marked divergence from the structure of similar rocks in the Brooks Range. With regard to this structure, Collier [16] says:

> The structure in most cases consists of an intricate system of folding, with faulting along the contact with the underlying and overlying formations. On the south side of Cape Dyer the coal-bearing formation seems to rest conformably on the sandstones which form the cape, while it is overthrust by the same sandstone at the Ears, about 2 miles south of Cape Dyer. Between these two points the formation, which is almost continuously exposed, is closely folded.

Reference to the map that accompanies the above statement shows that the strike of the contact between the rocks now considered members of the Noatak formation and the underlying rocks is about northwest, but the occurrence of similar rocks at Cape Thompson indicates that the regional trend in this district may be more nearly north-northwest. The thrust-fault plane above recorded dips southwestward, and the axial planes of the folds in the Noatak formation dip in the same direction.

Kindle [17] has shown that at Cape Thompson, about 50 miles south and slightly east of Cape Lisburne, the dominant structural feature is a broad syncline whose axis strikes north or northwest. In general the Mesozoic rocks, which occupy the center of this syncline, are relatively little deformed, but the Carboniferous rocks, which form the limbs, are sharply tilted, particularly at the northwest end, and the structure is modified and complicated by local flexures, such as the anticline at Agate Rock, where the less competent rocks are intricately folded. At the northwest end of this syncline occur the rocks correlated with the Noatak formation, comprising 400 feet of shale and sandstone dipping 80°–90° E.

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[16] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 19, 1906.

[17] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 521–522, 1909.

From the structural observations of Collier and Kindle, as given above, it is evident that the regional structure of the Cape Lisburne district does not coincide with that of the eastern part of the Brooks Range, the strike or trend of the rocks being more nearly north than east. One analogy, however, between the two types of structure is noticeable. The fault recorded by Collier and the axial planes of the folds appear to dip southwestward, whereas the general distribution of the Carboniferous and Mesozoic rocks indicates a progressive sequence from older to younger rocks northeastward. Hence, as in the Brooks Range, the dip of the cleavage lies roughly at right angles to the regional dip of the rocks.

The fact has already been mentioned that the deformation of the rocks of the Noatak formation becomes progressively greater westward down the Noatak Valley. If this condition is interpreted in the light of the structural features of Cape Lisburne, the obvious conclusion is that the highly deformed rocks of the Kugururok Valley show the combined effects of both types of deformation. This, to be sure, is a highly speculative surmise but seems to be in harmony at least with the facts observed in the field. No data are available for determining which of the two deformative processes is the older. In general, however, where one structure is superposed upon an older structure, and both are of the same degree of deformational intensity, the later of the two will be more evident. This consideration provides a presumptive basis for the belief that the north-and-south structure of the Cape Lisburne district is later than the east-and-west structure of the Brooks Range, but this can not be accepted as more than a suggestion.

In the type locality along the Noatak River neither the top nor the bottom of the Noatak formation is accurately delimited. In the Aniuk Valley the southern limit of these rocks is masked by later rocks. In the valley of the Killik River the southern limit, or contact between the Noatak formation and the underlying Upper Devonian rocks, is indicated on the accompanying map, but the indication is admittedly more diagrammatic than real. Moreover, these rocks are correlated only on lithologic grounds with the Noatak formation in its type locality. The same holds true in the John River section, the boundary line between Mississippian and Devonian rocks at that locality being less definitely determined than on the Killik River. And in the Cape Lisburne district it appears probable that most of the mapped contact lines are faults, and almost surely only a small part of the stratigraphic thickness of the Noatak formation is there apparent. When this lack of definite boundaries, the intricate structure of this group of rocks, and the lack of detailed work are considered, it is evident that no trustworthy estimate of stratigraphic thickness can be made. The great distance across the strike, approaching 15 miles at its maximum, gives a rough measure of the order of magnitude of the stratigraphic thickness but little more. Probably the true thickness is measurable in thousands of feet of strata.

AGE AND CORRELATION

Both the Noatak and Lisburne formations have been determined from their fauna to be of Mississippian age, but the regional stratigraphy shows clearly that the rocks of the Noatak formation were deposited prior to the deposition of the Lisburne limestone. The Noatak formation therefore includes all the rocks of this region of pre-Lisburne Mississippian age. The invertebrate fossils of these two formations have been assembled as a single Mississippian fauna, which is presented in the ensuing discussion of the Lisburne limestone. Some of these fossils, as, for example, *Leptaena rhomboidalis*, are believed by G. H. Girty to belong distinctively to the lower Mississippian, but insufficient detailed work has yet been done to make two separate faunal lists.

In addition to invertebrates, however, six lots of fossil plants have been collected from the nonmarine Mississippian rocks of the Lisburne district and one from the valley of the Killik River, which are here included with the Noatak formation. All these plants were determined by David White, of the United States Geological Survey. The list follows:

Flora of basal part of Noatak formation

	A	C	4AC25	4AC33	5289	5290	24AMt39
Calamarian fragment (Asterophyllites?)				×			
Annularia? sp			×				
Sphenopteris frigida				×		×	
Fern rachis, fragments			×				
Cardiopteris? sp						×	
Conodophyton sp			×				
Dictyoxylon sp			×				
Lepidodendron cf. L. chemungense		×					
Lepidodendron corrugatum					×		
Lepidodendron heeri			×				
Lepidodendron spetsbergense				×			
Lepidodendron veltheimianum						×	
Lepidodendron veltheimianum var. acuminatum			×				
Lepidodendron sp						×	
Lepidostrobus sp				×			
Lepidophyllum cf. L. fuisseense						×	
Barinophyton sp			×				
Stigmaria verrucosa [a]	×		×	×			×
Samaropsis spetsbergensis?				×			
Problematic impression			×				

[a] The *Stigmaria verrucosa* of collection A was formerly listed as *Stigmaria ficoides*.

A. Corwin mine, 30 miles east of Cape Lisburne. Float along beach. Collector, H. L. Dumars, 1900.

C. Under limestone cliffs 4 miles south of Cape Lisburne. Collector, H. L. Dumars, 1900.

4AC25. (Museum No. 3554). Coal bed 1½ miles south of Cape Lewis. Collector, A. J. Collier, 1904.

4AC33 (Museum No. 3553). Half a mile south of Cape Dyer. Collector, A. J. Collier, 1904.

5289. Lower 140 feet of gray sandstone at base of geologic section at Cape Thompson. Collector, E. M. Kindle, 1908.

5290. From 280 feet of black shale, which overlies the gray sandstone at base of geologic section at Cape Thompson. Collector, E. M. Kindle, 1908.

24AMt39. One and one-half miles east of camp April 22, on the north slope of a gulch tributary to the Killik River. Collector, J. B. Mertie, jr., 1924.

Collection A was found along the beach at the Corwin mine in an area of exclusively Mesozoic rocks. The specimen, however, was not found in place and is believed to have been ice-rafted eastward from Cape Lisburne, where the nearest Carboniferous rocks occur. In addition to the flora above listed, fucoids also form a part of collections 4AW37 and 4AW40. The other fossils of these two collections are invertebrates and are listed among the Mississippian fauna in the table facing page 182.

Collection 24AMt39, which is here included with the flora of the Noatak formation, was found on the Killik River, about 300 miles east of Cape Lisburne, in an area mapped as Devonian. This locality, however, is no great distance south of the belt of Noatak rocks, and the occurrence is believed to signify the presence of infolded or infaulted Noatak rocks in the Upper Devonian sequence.

This fossil flora is believed by David White to be representative of the lower Mississippian, and possibly the basal part of the lower Mississippian. The presence of *Leptaena rhomboidalis* in collection 4AC22, obtained 3 miles southeast of Cape Lewis, in close proximity to these plant-bearing beds, serves to corroborate the assignment of the Noatak rocks of the Cape Lisburne district to the lower Mississippian. The Noatak formation as a whole, however, may and probably does extend upward into higher horizons in the Mississippian, and only more refined stratigraphic and paleontologic work will serve to show its upper limit. The rocks of this group, which occur in the Cape Lisburne district, are regarded as the basal part of the Noatak formation and probably also represent the basal horizons of the Mississippian of northern Alaska.

The nearest counterpart to the Noatak formation elsewhere in northern Alaska is an unnamed group of black shales and slates that underlie the Lisburne limestone in the valleys of Canning and Hulahula Rivers, about 300 miles east of Cape Lisburne. No fossils were found by Leffingwell [18] in this group of rocks, but their position below and in apparent conformity with the Lisburne limestone indicate that they should be correlated with the Noatak formation, and probably with the marine part of the Noatak.

[18] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 105–108, 1919.

The Noatak formation has not been recognized or mapped elsewhere in Alaska as a separate unit, but the geologic section on the Porcupine River, about 600 miles east of the Lisburne district, supports the belief that this geologic horizon may be continuously represented across northern Alaska. Kindle[19] found in 1908, just below the lower ramparts of the Porcupine River, a Carboniferous section which, although stratigraphically incomplete, yielded a number of good collections of invertebrate fossils, largely of upper Mississippian age but showing also distinct lower Mississippian phases. This lower Mississippian aspect was commented upon by G. H. Girty, who identified these fossils, and was believed by Kindle to indicate that the entire Mississippian sequence was probably present at that locality. As additional evidence of this hypothesis Kindle found at the base of the section black shale containing the plants *Sphenotis frigida*, fragments of unidentifiable ferns, *Stigmaria*, and *Lepidostrobus*. Subsequently, in 1911, Maddren[20] collected from these same black shales two species of *Lepidodendron*, namely, *L. veltheimianum* var. *acuminatum* and *L. spetsbergense*. It will be seen from these data that a lower Mississippian group of rocks exists at the base of the Mississippian along the Porcupine River that is comparable and probably to be correlated with the Noatak formation, the plant-bearing shales being equivalent to the shales in the Cape Lisburne district and the lower Mississippian phases of the marine strata being comparable with the marine part of the Noatak formation.

This correlation is in fact the only close correlation that can at the present time be made with the Noatak formation. In the Yukon Basin there is a group of rocks composed essentially of siliceous slate and chert, which, largely on stratigraphic grounds, is believed by Mertie[21] to belong to the Mississippian. This formation, however, to judge from its contained fossils, is apparently entirely marine in origin and is quite different lithologically from the Noatak formation. The lower Mississippian of the Yukon Valley is also characterized by a group of lava flows and interbedded marine sediments, known as the Rampart group, which has no counterpart among the rocks of the Noatak formation. And finally, the Nation River formation of the Yukon Valley, which lithologically resembles to some extent the Noatak formation, particularly in containing coal, is entirely nonmarine and lies stratigraphically between upper Mississippian and Permian rocks. Elsewhere in Alaska no rocks of supposed lower

[19] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 332–336, 1908.

[20] Maddren, A. G., unpublished data in files of U. S. Geological Survey.

[21] Mertie, J. B., jr., The gold placers of the Tolovana district, Alaska: U. S. Geol. Survey Bull. 662, pp. 239–244, 1917.

Mississippian age are known. The present available data, therefore, seem to justify the hypothesis that the Noatak formation is a group of rocks confined essentially to northern Alaska. Other lower Mississippian rocks are doubtless present in Alaska but are likely to be found to differ lithologically and genetically from those of this northern Alaska horizon.

LISBURNE LIMESTONE

DISTRIBUTION

The type locality of the Lisburne limestone is the Lisburne district, in the western extremity of the area covered by this report. In addition to an occurrence at Cape Lisburne, four other bands of this formation are known in the Lisburne district. One of these is seen at Cape Lewis, 13 miles south of Cape Lisburne, and another along the coast about midway between Cape Lisburne and Cape Lewis. The other two bands of this formation occur along the coast at and southeast of Cape Thompson.

In the valleys of the Killik, Chandler, and Anaktuvuk Rivers and at the head of the John River the Lisburne limestone crops out in a belt from 5 to 10 miles wide parallel to and adjoining the Noatak formation on the north. Plate 20, *A*, illustrates the appearance of the topography of this limestone at the head of the John and Anaktuvuk Rivers, near the southern margin of this belt of rocks. About 60 miles west of the Killik River, in the valley of the Etivluk River, this formation appears as a belt 5 miles wide and in the Aniuk Valley as a belt 1 mile wide. These two belts are separated by a horizontal distance of 17 miles in which Mesozoic rocks form the surface exposures. In the valley of the Nimiuktuk, 85 miles west of the Etivluk River, the Lisburne again crops out in a northern band 4 miles wide and a southern band 5 miles wide, separated by a distance of less than 3 miles, in which Mesozoic strata are exposed. Moreover, the southern band in the Nimiuktuk Valley is bounded on the south by Upper Cretaceous rocks instead of the Noatak formation. About 30 miles still farther west the Lisburne limestone forms the principal rocks through a tract of country nearly 25 miles wide along the Kugururok River and continues in a belt almost as wide southwestward into the valley of the Kivalina River and thence presumably westward to the Arctic Ocean. Another small band of the Lisburne limestone, about 1½ miles wide, separated apparently from the limestone of the Kugururok Valley by faulting, is found at the head of the Utukok River, a northward-flowing stream that heads against the Kugururok. The Cape Lisburne or type locality lies about 70 miles northwest of the croppings on the Kivalina River, but as later rocks cover much of the intervening area, the two occurrences do not appear to be connected across country.

In general, therefore, the Lisburne limestone crops out in one or more belts, from 1 to 20 miles in width, extending from the Arctic Ocean in a general easterly direction for 350 miles to the Anaktuvuk River and thence into the Canning River region and eastward to the international boundary. The type locality, at and near Cape Lisburne, is not a part of this great east-west belt but comprises apparently an outlying group of occurrences which have been isolated geographically, possibly by geologic structural processes of a variant character.

LITHOLOGY

The Lisburne limestone, as defined in this report, comprises, as previously stated, what was formerly regarded as the upper of Collier's three formations in the Cape Lisburne district.[22] Collier's statement regarding the lithology of this formation is as follows:

> The formation consists of massive thick-bedded limestones, massive white cherts, and occasional thinner beds of black slate or shale and is distinguished from the underlying Carboniferous [and also from the overlying Upper Triassic] formations by its lithologic character and its fauna, which consists mainly of corals. * * * Fault breccia with interstitial calcite occurs near Cape Lisburne. It resembles coarse-grained porphyry, for which it has probably been mistaken, and perhaps has given rise to the reports of porphyry dikes near Cape Lisburne. On the north side of Cape Lisburne and also at Cape Lewis the limestone weathers into jagged pinnacles.

Plate 21, *B*, shows a typical exposure of the Lisburne limestone a short distance north of Niak Creek, in the Cape Lisburne district.

The Lisburne limestone on the Anaktuvuk River at its easternmost limit, within the area covered by this report, was studied by F. C. Schrader in 1901, three years earlier than the work of Collier in the Cape Lisburne or type locality. Furthermore, Schrader, later in the same season, saw the section at Cape Lisburne and, though unable to do any work there owing to the proximity of winter, nevertheless correlated the limestone of the Anaktuvuk River with the limestone at Cape Lisburne and in his report used the name Lisburne formation for the limestone at the two places. Schrader's statement[23] regarding the lithology of this formation at the head of the Anaktuvuk River is as follows:

> The rocks of the Lisburne formation may be characterized for the most part as medium-bedded semicrystalline limestone of impure white or gray

[22] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 21, 1906.

[23] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 63, 1904.

color. They weather gray, light rusty brown, or chocolate. They form the mountains that rise to a height of 2,500 to 3,000 feet above the floor of the Anaktuvuk Valley. Near the summit occur two beds of intercalated shale, each apparently several hundred feet thick, and containing some thin layers of dark-gray limestone.

Along the Killik River, where seen by the expedition of 1924, the Lisburne formation is prevailingly a group of white rocks, which at a distance would probably be regarded as limestone by a geologist engaged in reconnaissance work. When examined closely, however, these white rocks are seen to consist of innumerable layers of chert and limestone, ranging in thickness from a fraction of an inch up to many feet. The southern and probably the stratigraphically lower part of this formation, along the Killik River, consists of a cream-colored granular crystalline limestone in beds from 10 to 20 feet thick. To the north the rocks consist of an intimate mixture of limestone and chert. This limestone is generally less crystalline than that on the south side, is white to dark brown, and some of it when freshly broken gives a fetid odor of decayed organic material. Both the limestone and the chert are fossiliferous.

On the Chandler River, at the north front of the Brooks Range, essentially the same kinds of rock were seen, with perhaps a somewhat greater lithologic variety. The chert-limestone formation is here at least 4 miles wide, and the two types of rock are intimately interbedded, in part in thin seams and in part as thicker beds. The limestone is for the most part calcitic, not dolomitic, commonly recrystallized, and in places siliceous. A few beds of dense, fine-grained, black noncrystalline limestone were also seen. Much of the limestone, both crystalline and noncrystalline varieties, has a strong organic odor when freshly broken.

The common occurrence of alternating beds of limestone and chert along the Killik and Chandler Rivers has led the writers to believe that the Lisburne formation, as a whole, contains at these two localities almost if not quite as much silica as lime. Collier made no quantitative estimate of the proportion of chert to limestone in the formation at Cape Lisburne, but his lithologic description indicates that the proportion of chert might be considerable. Schrader, strangely enough, does not mention chert as an important part of the Lisburne along the Anaktuvuk River, but his original notes indicate that he was unable to examine this formation at close range and obtained his ideas of lithology and structure from observations at a distance. Under such circumstances the siliceous character of part of the formation would hardly be suspected. One of his photographs, here reproduced as Plate 20, *B*, shows beds of limestone with other beds of a noncalcareous composition, and this occurrence probably constitutes a typical alternating chert-limestone sequence of beds.

With regard to the thin beds of alternating limestone and chert, a considerable amount of silicification was recognized in the field and therefore part of these chert beds may be regarded as due to secondary processes, although the larger beds of chert, of which there are many, are regarded as of primary origin. Microscopic examination of a number of thin sections of siliceous limestone and calcareous chert from this formation, however, has led to the opinion that the dominant secondary process has been calcification rather than silicification. Without precluding the possible influence of silicification in the formation of chert, the data at hand seem to warrant the conclusion that many of the chert beds in this formation are of primary origin and that some of the beds of siliceous limestone are the result of the partial replacement of silica by calcite.

Along the Kugururok River, where the Lisburne formation is so extensively developed, it was reported by the expedition of 1925 to consist of white to dark bluish-gray limestone, with several exposures of black chert and a single outcrop of dark-gray sandstone. The chert occurs within the limestone and is believed to be an integral part of the formation. The sandstone probably underlies the Lisburne formation and is part of the Noatak formation. The greater part of the limestone is massive and weathers into jagged pinnacles on the crests of the mountains, although many of the lower slopes are smooth. Near the summit of a high mountain on the west side of the central Kugururók Valley a massive reddish-brown granular crystalline limestone occurs in several beds which make a total thickness of 60 feet or more. This limestone is brecciated at certain horizons but contains numerous crinoid stems throughout. These beds of red limestone overlie a great thickness of massive chert and are overlain by hard bluish-gray limestone. The exact position of this red brecciated limestone in the stratigraphic section is not definitely known, but it is believed to be closer to the top than to the base of the Lisburne formation. Siliceous limestone is common along the Kugururok River, the siliceous beds occurring usually in large lenses and extending but a short distance along the bedding planes. In general, a large part of the nonsiliceous limestone of the Kugururok Valley is crystalline, but some noncrystalline varieties are also present. In the Utukok Valley, north of the Kugururok Valley, the Lisburne formation is again exposed as a cream-colored semicrystalline limestone but contains a considerable amount of silica. About 1,400 feet of the formation crops out on the steep north slope of a mountain just south of a fault and east of the upper Utukok Valley. This limestone, which is here abundantly fossiliferous, lies in thick massive beds, at the base of which occurs fine-grained massive sandstone that is believed to represent the Noatak formation. The basal part of the section, as here exposed, resembles the base of the Lisburne formation along the Killik River in that the limestone is not markedly siliceous.

In the Nimiuktuk Valley the Lisburne formation occurs in two bands and is much less extensively developed than along the Kugururok River but has the same general lithology, consisting for the most part of crystalline limestone, with a certain proportion of beds of chert and siliceous limestone.

The Lisburne formation as found in the Etivluk Valley forms a range of mountains trending east and consisting entirely of pure-white limestone. No fossils were found in this limestone, but on lithologic and stratigraphic grounds it is correlated with and mapped as a part of the Lisburne formation. The southern band of this formation in this region crops out in the Aniuk Valley just south of the Etivluk-Aniuk divide and consists of only a few hundred feet of massive white limestone. The beds at upper horizons in the section are here covered by alluvium and effusive rocks, so that the total thickness represented by this band is indeterminate. No fossils were obtained from this limestone, but like the limestone of the Etivluk River, and for the same reasons, it is included as part of the Lisburne formation.

The Lisburne limestone is well exposed throughout the lower part of the Kivalina River Valley, forming the country rock on both sides of the river from a point about 7 miles east of the town of Kivalina as far north as camp P April 10. From the higher hills near that camp it can be recognized by its distinctive color, stretching westward until it appears to merge with the exposures near Cape Seppings and eastward until it seems to join with the mapped Lisburne limestone area in the Noatak Valley west of the Kelly River. Its continuity in the Kivalina Valley is interrupted north of camp P April 10 by basic effusive rocks, which extend within 3 miles of camp P April 14, but east of that camp and extending for many miles east of the headward parts of the Kivalina, Kukpuk, and Kukpowruk Rivers these rocks were at some places seen at close range and at many others could be readily recognized in the distance. Plate 6, *A*, shows the characteristic appearance of these rocks in the hills near the extreme head of the Kivalina River.

The Lisburne limestone in the vicinity of the Kivalina River shows a number of different phases. Thus at the more southern localities it is dominantly dark brownish, whereas near camp P April 10 it is principally a light-grayish rock, and in the hills near the Kukpuk-Kukpowruk divide it has a light-bluish color. At many places the recrystallization which the rock has undergone has given it a streaked white color and a coarse crystalline grain. In places where the rock has been shattered by deformation later veins of calcite intersect the rock in all directions and give it a mottled appearance. At several localities fragments of crinoid stems make up so large a proportion of the rock that it appears speckled, the crinoid columns being usually clear white, whereas the rest of the rock is gray or bluish. Organisms of other kinds are also found at many places in these rocks. The most abundant of these fossils are isolated corals which have been more or less silicified and therefore, on weathering, stand out distinctly on the surface. Locally the entire limestone has been more or less silicified, but so far as observed this process has affected individual grains and particles rather than large masses and has not produced rocks that resemble the cherts reported on the Killik River or those that occur in the overlying Triassic formations. In fact, at a short distance from an exposure it would be impossible to recognize that silica formed so much of the rock as it actually does. The calcite veins mentioned above appear to be younger than this silicification. It is of some significance to note that the fossils found do not appear to have been much distorted by the deformation the rocks have undergone. Instead they, as well as the inclosing limestones, seem in most places to have been shattered or even recrystallized with little or no recognizable movement.

STRUCTURE AND THICKNESS

The structure of the Lisburne limestone in the Cape Lisburne region is extremely complex, as has been abundantly demonstrated both by direct observation and by the anomalous position of certain of the fossils that have been collected, whereby certain rocks appear to underlie others that are definitely older. It is therefore not at all strange that some of the interpretations made by earlier workers in this field can not be reconciled with themselves nor with later observations. Much remains to be done before these complex relationships are correctly evaluated, and doubtless some of the following interpretations will require modification after the region shall have been adequately studied.

It has not appeared practicable in this presentation to show in detail the specific contributions of individual workers nor to enumerate the successive steps by which the present understanding of the structure of the Lisburne formation has been attained. Instead, a summary of the structural relationship of these rocks is here presented, based principally upon the fundamental data supplied by Collier and Kindle, with necessary modifications of their interpretations to conform with all information at present available.

First, it appears that no discordance in structure exists between the Lisburne formation and the overlying Upper Triassic rocks. Yet the intervening parts of the geologic column, namely, the Permian and the Lower and Middle Triassic groups of rocks, are absent. In reality, therefore, a great discontinuity in sedimentation or stratigraphic hiatus exists. In this particular field this condition might be interpreted to indicate either, first, that the missing Permian and Triassic strata were eroded prior to the deposition of the Upper Triassic beds or, second, that a great migration of the strand line, involving elevation and subsequent subsidence on a large scale, took place in this interval. The fact that much the same condition has been found in many other districts in Alaska, however, leads to the belief that the second condition prevails here as elsewhere and that the gap in the stratigraphic sequence represents an elevation at the end of Paleozoic time which was of wide extent geographically and constituted a major geologic episode. The structural concordance between the Lisburne and Upper Triassic rocks, however, shows clearly enough that this elevation and the subsidence which followed it prior to the renewal of marine sedimentation in Upper Triassic time resulted in no marked deformation of the Carboniferous rocks and therefore had no part in the development of the folded and faulted structure of the Lisburne formation. Collier's published sketch of the relations between the two formations south of Cape Lewis shows the Lisburne limestone actually lying concordantly upon what are now known to be Upper Triassic beds.

In 1904 these Upper Triassic beds were not recognized as such but were believed to antedate the Lisburne formation; but in the light of present information this relationship indicates that both these formations at Cape Lewis are actually upside down, the Lisburne lying without apparent structural discordance upon the Upper Triassic rocks. Under any dynamic assumption, therefore, a highly intricate type of structure is indicated. If, as Collier's field data appear to indicate, the thrust-fault planes of this area dip southwestward, it is likely that the axial planes of the overturned folds also dip in the same direction, indicating a possible structural interpretation, which is shown in Figure 9. This interpretation, of course, is hypothetical and diagrammatic but is believed to give a rough picture of the type of folding and faulting involved in the Cape Lewis structure.

In general, the formational contacts in the Lisburne district are largely fault contacts, but in his published sketches Collier indicated this faulting only diagrammatically, showing most of the fault planes in a vertical or nearly vertical position. In reality, many of the fault planes are low-lying and dip southwestward, indicating that thrust movement from southwest to northeast took place, and this movement, it is believed, constitutes an important phase in the structural history of this district.

Some open folding has been seen, but it is doubtful if open folding characterizes the structure of this district as a whole. Kindle[24] refers particularly to the open folding which he believed to characterize the synclinal structure at Cape Thompson. But the anticlinal core of this large synclinorium, as seen at Agate Rock, is characterized by close folding and consists of appressed minor folds whose axial planes dip southwestward; and it is probable that if the entire structure were as visible as the portion at Agate Rock, the appressed type of folding might prove to be rather prevalent.

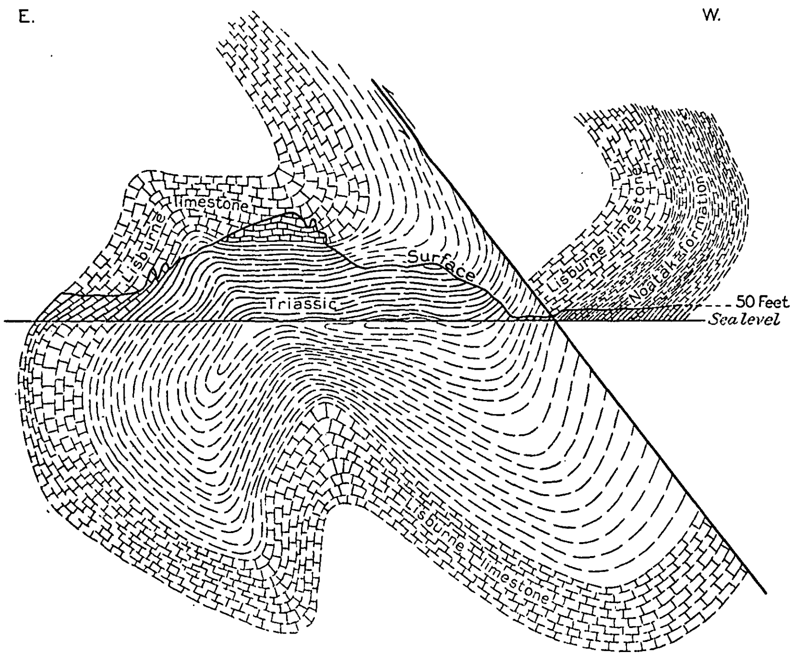


FIGURE 9.—Sketch showing stratigraphic relations of the rocks south of Cape Lewis and a possible structural interpretation of them. (After Collier)

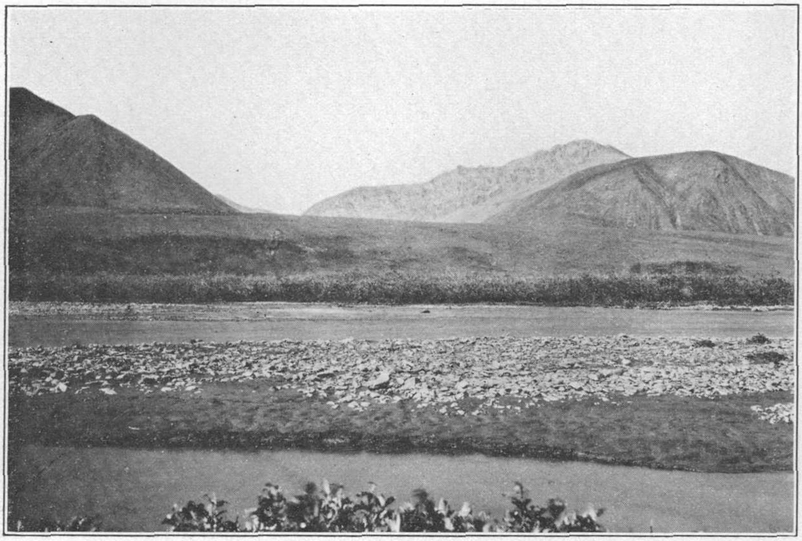
In northern Alaska, particularly in the valleys of the Anaktuvuk, Chandler, Killik, and Etivluk Rivers, the Lisburne limestone appears to have been deformed by the same stresses that affected the adjoining Noatak and Devonian rocks, but the effects have been somewhat different. The axial planes of the folds and the fault planes pitch for the most part southward, but the limestone and chert of the Lisburne formation have not developed a fracture cleavage in the same degree as the underlying slaty rocks. The limestone apparently has taken up small internal stresses by granulation and recrystallization, and the chert beds, particularly the

[24] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 521–522, 1909.

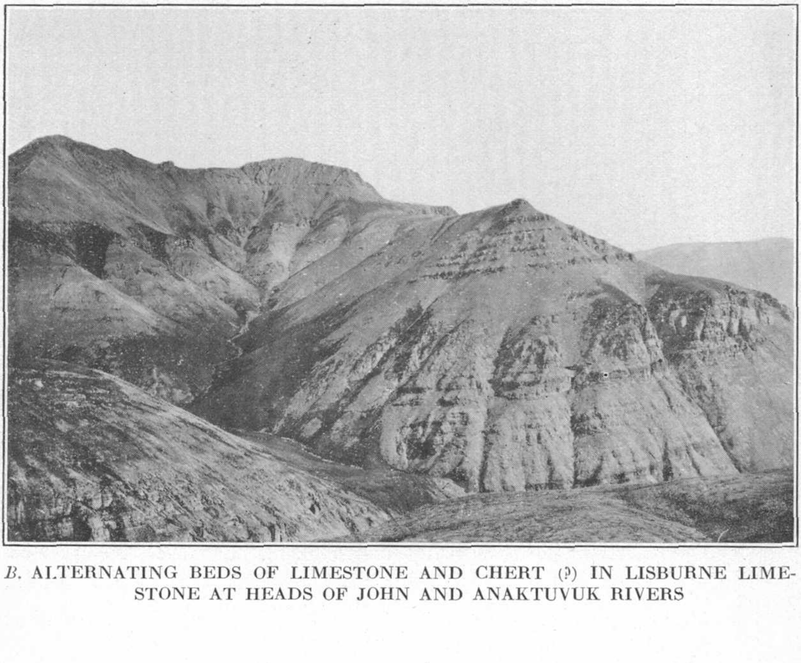
thicker beds, have acted as competent members in much the same way as the quartzites of the Noatak formation.

A striking structural feature of the Brooks Range may be seen along the north front in the valleys of the Anaktuvuk, Chandler, and Killik Rivers, and probably for a long distance westward. This structure, which appears to be a manifestation of pressure applied from the south, is mentioned here, not because it is confined to rocks of Lisburne age but because it has affected the Lisburne limestone more than other formations that could have been affected. It consists of a zone of intensive folding and faulting which extends eastward along the front of the Brooks Range. Along the Killik River a great overthrust fault is indicated, accompanied by overturned folding. The actual fault plane was not seen, but the overturned folding in the Lisburne limestone, the abrupt change in lithology between the Lisburne and Noatak formations, and the well-developed fracture cleavage in the Noatak near the supposed fault contact all point to a great thrust fault. Plate 21, *A*, shows this structure on the west side of the Killik River, and Figure 6, drawn from this plate, and Figure 7 show the nearly recumbent folds in the limestone on both sides of the river and the cleavage of the adjoining Noatak rocks. Several interpretations of this structure might be made, but the favored one is that the rocks of the Noatak formation have been shoved northward over the Lisburne limestone up a great thrust-fault plane of low dip. The dip of the fault plane is therefore presumably southward.

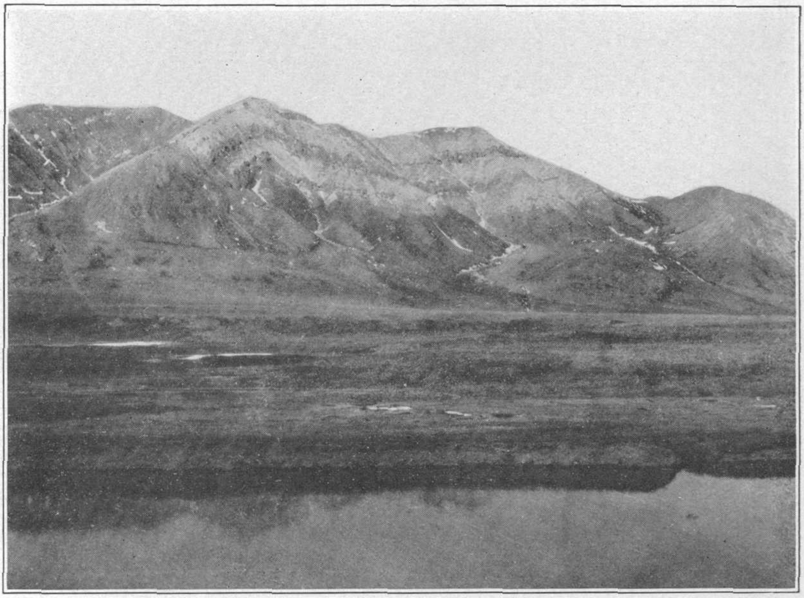
The same deformational feature was seen in the valley of the Chandler River, at the north front of the range. The southernmost point on the Chandler River visited by the Geological Survey party of 1924 was a 3,600-foot knob on the west side of the valley 8.7 miles S. 20° E. of camp June 23. From the top of this knob the contact between the Lisburne limestone and the adjoining rocks to the north may be seen for several miles, both to the east and west. This contact line plainly makes reentrant angles up into the small valleys of streams that issue northward from the range, and on the Chandler River, the largest of such streams in this vicinity, the limestone extends southward up the valley for a distance of 3 or 4 miles from the north front of the range, indicating that the contact plane between the two formations has a relatively low dip, perhaps 20°, southward. As the Lisburne limestone is older than the adjoining rocks to the north, its apparent superposition upon those rocks shows that this contact is either the trace of a low-lying southward-dipping fault plane, or the trace of a bedding plane of an overturned structural feature of enormous dimensions. This contact is believed to be principally a fault contact, but in reality the strata are probably



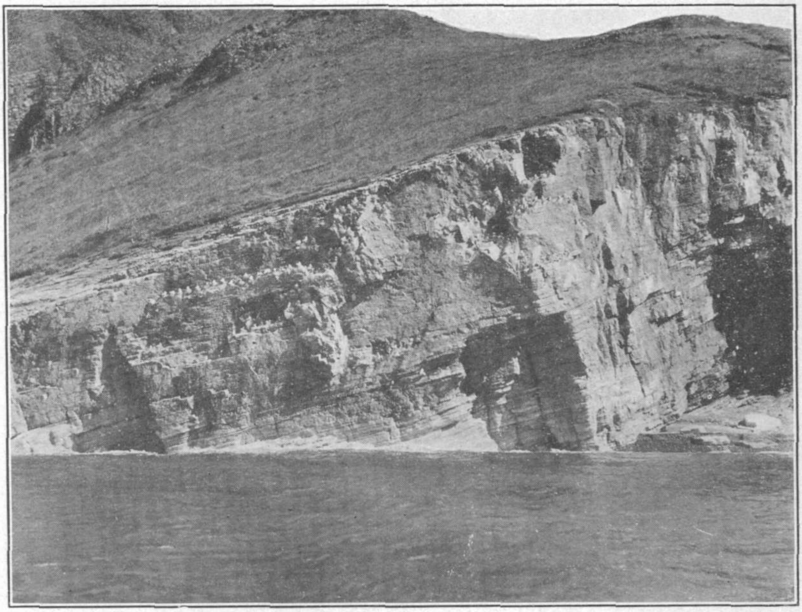
A. SOUTH FLANKS OF LISBURNE LIMESTONE, AS SEEN IN BROOKS RANGE AT THE HEADS OF JOHN AND ANAKTUVUK RIVERS



B. ALTERNATING BEDS OF LIMESTONE AND CHERT (?) IN LISBURNE LIMESTONE AT HEADS OF JOHN AND ANAKTUVUK RIVERS



A. OVERTURNED FOLD IN LISBURNE LIMESTONE, WEST WALL OF KILLIK VALLEY, AT NORTH FRONT OF BROOKS RANGE



B. GENTLY INCLINED BEDS OF LISBURNE LIMESTONE NORTH OF NIAK CREEK, CAPE LISBURNE DISTRICT

Photograph by Merl LaVoy.

also overturned in much the same manner as along the Killik River, as shown in Figures 6 and 7. Still farther west, in the direction of the Killik River, the limestone beds of the Lisburne formation may be seen dipping at an angle of 80° S. Evidently the structure along this north part of the range is highly complex, but it is believed to be explicable in the main in terms of overthrusting from the south.

In the Anaktuvuk Valley, at the north front of the Brooks Range, the same zone of faulting was seen by Schrader [25] and described in his discussion of the Stuver "series," which is here mapped as a part of the Noatak formation, and in his discussion of the Lisburne formation. His structural observations with regard to the Stuver "series" have already been quoted. With regard to the Lisburne formation, he states:

> The entire area of the Lisburne formation here considered is deeply involved in the system of faulting and disturbed blocks referred to under the heading "Stuver series." As viewed from the Anaktuvuk Valley, looking either east or west, the Lisburne series reveals but little of the disturbance it has undergone. On the southwest, however, toward Contact Creek, the rocks have been folded and broken into blocks, which in some instances are highly tilted. The fault on the west side of the Anaktuvuk probably represents the westward extension of the same fault that gave rise to the scarp along the northern edge of the Stuver series, which series, however, has not here been brought to view.

Another interesting feature of this zone of faulting along the north front of Brooks Range is that it has also affected Lower Cretaceous rocks along the divide between the Nimiuktuk and Nuka Rivers. This observation offers corroboration of the hypothesis, previously stated, that although part of the deformation in the post-Silurian rocks of the Brooks Range is later than Triassic and earlier than Lower Cretaceous, additional deformation has also taken place at some later period or periods, perhaps in mid-Cretaceous or Tertiary time, or both.

The structure of the Lisburne formation in the Kugururok Valley merits additional mention, chiefly on account of the unusual geographic extent of the formation at this locality. In this valley many of the limestone beds strike due north and dip west, so that the river is running nearly along the strike. At the head of the valley, however, the trend of the Lisburne formation, as well as of the other formations that adjoin it, is about east, with the dip of the bedding rather indeterminate. The presence of another band of limestone, lying north of the main band, and the manifestly complex structure of the intervening Mesozoic rocks suggest strongly that the east-west fault zone above described may continue as far west as this point.

[25] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 16–64, 1904.

The north-south trend of the limestone in the lower Kugururok Valley shows the influence of the Cape Lisburne type of structure and indicates both a southwestward veer to the formation and the beginning of the north-south structure that lies to the west. The great geographic extent of the limestone in the Kugururok Valley doubtless is a result of this change in trend.

The structure of the Lisburne limestone in the vicinity of the Kivalina River displays many of the features already noted in the outcrops of this formation elsewhere in northern Alaska. As in those other exposures the detailed observations made at widely scattered points do not allow the geologist to reconstruct the complex structure with precision. They do, however, show that here too the Lisburne limestone is part of a large deformed sequence that has undergone intense folding and faulting. In the southern part of the Kivalina Valley the limestone has in general a southerly dip, but this is interpreted as probably resulting from overturning. A short distance north of camp P April 10 the limestone apparently terminates against a fault that trends northeast. In the region east of camp P April 14 and extending thence northeastward the limestone has in general a steep dip to the northwest. This dominant structure is interrupted by numerous faults, which have broken the rocks involved into slices that have a prevailing northeasterly trend. The plane of certain of these faults is steeply inclined, but the movement of the blocks on opposite sides has been laterally in a nearly horizontal direction along the fault plane rather than up or down that plane. The faulting has brought these rocks into contact with rocks of a number of different ages, so that the true stratigraphic sequence is seldom the sequence observed in the field.

Minor structural features which show that the rocks have been somewhat folded and crumpled can be recognized at many outcrops, but the result of smashing and recementation of the fragments by later calcitic material is especially prominent near the western margin of this group of rocks in the hills east of camp P April 16.

Collier estimated the thickness of the Lisburne limestone in the Cape Lisburne district as at least 2,000 feet, and although this figure may be of the right order for the beds exposed in that district, it is not believed to give an adequate idea of the thickness elsewhere in northern Alaska. Either the Lisburne limestone is thicker in the Killik-Anaktuvuk district or the formation is incompletely exposed at Cape Lisburne. Not enough work has yet been done on this formation anywhere in northern Alaska to give an accurate estimate of thickness, but it is believed that the thickness in its maximum development is at least 4,000 feet.

The geologic age of the earth movements that produced the deformation of the Devonian and Carboniferous rocks has not been exactly ascertained, but certain data seem to bear upon this problem and afford the basis for a plausible interpretation. First, those rocks in the Carboniferous and Triassic formations that are similar lithologically to the Devonian rocks show much the same type of structure and degree of metamorphism; second, the field evidence in this region appears to indicate the absence of any period of marked deformation between the Devonian and Carboniferous deposition; third, no major structural unconformity has been found in this region, or elsewhere in Alaska, between the Carboniferous and Upper Triassic rocks, although a great break in sedimentation, accompanied by regional uplift and followed by regional subsidence, is believed to have taken place at the end of Paleozoic time; fourth, the next youngest rocks of this region—the Lower Cretaceous—though considerably deformed where found in or close to the Brooks Range, are on the whole less metamorphosed than the Devonian, Carboniferous, and Triassic sequence. When these data are considered, together with the total absence of Lower and Middle Jurassic formations in northern Alaska, it seems a fair presumption that a major part of the deformation of the Devonian, Carboniferous, and Triassic sequences took place during the Jurassic period. It can not be denied, however, that later earth movements, in Tertiary and Cretaceous times, by means of which the Cretaceous rocks were themselves folded, must have added their quota of deformation to the earlier deformation above indicated.

AGE AND CORRELATION

Numerous collections of invertebrates have been made in northwestern Arctic Alaska from the rocks now known and mapped as the Noatak and Lisburne formations. The first collections by members of the Geological Survey were obtained by Schrader in 1901, and these have been followed successively by later collections, up to and including those made by P. S. Smith in 1926. Plant remains have been found only in the rocks that are here included in the Noatak formation, and these are separately listed on page 165. In addition, 72 collections of invertebrates have been made, of which records are available. The fossils are listed in the accompanying table, and the localities, collectors, and dates of collection are set forth below.

Localities of Mississippian invertebrate collections, northwestern Alaska

Collections by F. C. Schrader, 1901

454. Crystalline limestone. John River, camp July 4, about 3½ miles upstream from Hunt Fork. Float.

461. Gray semicrystalline limestone. John River, midday July 9, about 1 mile downstream from Till Creek. Float.

463 and 464. Black flint. John River, camp July 9, about half a mile downstream from Till Creek. Float.

493. Dark-gray semicrystalline, dense limestone. John River, east fork of Contact Creek. Float.

495. Gray crystalline limestone. John River, east fork of Contact Creek. Float.

497. Silicified coralline limestone. John River, east fork of Contact Creek. Float.

511. Semicrystalline limestone. Base of mountain, west of head of Anaktuvuk River, opposite camp July 21.

513. Dark semicrystalline limestone. Anaktuvuk River, east of Portage Creek, about elevation of 5,000 feet.

518. Dark-gray crystalline limestone. Head of Anaktuvuk River, summit of Browne Mountain (station 14), elevation, 6,250 feet.

519. Dark crystalline limestone. Anaktuvuk River, north contact slope, east of camp July 24, about 4½ miles from source of Anaktuvuk River.

520, 521, 522, and 525. Dull-gray crystalline limestone. Anaktuvuk River, north contact slope, east of camp July 24, about 4½ miles from source of Anaktuvuk River.

529. Dark siliceous limestone. Anaktuvuk River, mountain slope, on west side of valley, station 17V, July 26, about 7 miles from source of Anaktuvuk River.

534. Dark-gray, slightly crystalline, impure limestone. Anaktuvuk River, top of mountain on west side of valley, station 17, about 7 miles from source of Anaktuvuk River.

A. Cape Lisburne district; exact locality unknown.

Collection by H. L. Dumars, 1901

B. Limestone of cliffs 4 miles south of Cape Lisburne, just south of the mouth of a considerable stream [probably Niak Creek].

Collections by A. J. Collier, 1904

4AC14. 3 miles southeast of Cape Lisburne.
4AC16. 2 miles southeast of Wevok.
4AC17. 3 miles southeast of Wevok.
4AC19. 3¼ miles south-southeast of Wevok.
4AC22. 3 miles southeast of Cape Lewis.
4AC27. 2½ miles south of Cape Lewis.
4AC28. 2 miles east of Cape Lewis.
4AC29. 1 mile east of Cape Lewis.

Collections by C. W. Washburne, 1904

4AW27. 4 miles east-southeast of Cape Lisburne.
4AW29. 1 mile southeast of Wevok.
4AW30. Cobble in creek, east of Wevok.
4AW35. 1 mile south of Cape Lewis.
4AW36. South side of Cape Lewis Mountain.
4AW37. 2 miles north of Cape Lewis.
4AW39. 3 miles north of Cape Lewis.
4AW40. 4 miles north of Cape Lewis.
4AW44. 6 miles north of Cape Lewis.
4AW46. Gravel of Kukpuk River.

Collections by E. M. Kindle, 1908

14C. Lowest invertebrate horizon at Cape Thompson.
14D (Mesler). Higher invertebrate horizons at Cape Thompson.
14D (Kindle). Higher invertebrate horizons at Cape Thompson.
14D′. Higher invertebrate horizons at Cape Thompson.
15A. 2 miles southeast of Cape Thompson.

Collections by P. S. Smith, 1911

11AS43. Gravel from first big creek from north, west of camp August 7–8, approximately latitude 68° N., longitude 159° W., 29 miles east of Nimiuktuk River.

11AS45. Gravel from second stream from north below camp August 7–8, 23 miles east of Nimiuktuk River.

11AS46. 2 miles below second stream from north, below camp August 7–8, on south side of Noatak River, 21 miles east of Nimiuktuk River.

11AS51 and 11AS53. 1 mile above camp August 11 (mouth of Nimiuktuk River), in limestone layers interbedded with shale, approximately latitude 68° 10′ N., longitude 160° W.

11AS56. Float on north side of Noatak River, 6 miles below camp August 12, 30 miles east of Kugururok River.

11AS61. Float in Noatak River Canyon, half a mile below camp August 14, approximately latitude 68° N., longitude 161° 50′ W., 8 miles east of Kugururok River.

11AS65. Noatak River Canyon, 5 miles southeast of camp August 14, 5 miles southeast of Kugururok River.

11AS67. Large boulder in Noatak River Canyon, a short distance below camp August 14, 8 miles east of Kugururok River.

11AS73. Float from Noatak River, 3 miles above camp August 19, approximately latitude 67° 55′ N., longitude 162° 45′ W., 5 miles southwest of Kelly River.

11AS77. Float from point west of Noatak River, 3 miles below camp August 25, approximately latitude 67° 12′ N., longitude 162° 30′ W., 7 miles south of Agashashok River.

Collection by W. T. Foran, 1924

24AF6 (5696). Divide between Reynard and Transit Creeks, 41.2 miles N. 4° E. from the confluence of Nimiuktuk and Noatak Rivers.

Collections by J. B. Mertie, jr., 1924

24AMt42. Spur on west side of Killik River, 24 miles N. 22½° E. of confluence of April Creek with Killik River.

24AMt56. Hill on west side of Chandler River, 32 miles S. 14° E. of confluence of Chandler and Killik Rivers.

Collections by Walter R. Smith, 1925

25ASmF1 (5868). 12 miles north of mouth of Kugururok River.
25ASmF2 (5869). South side of mountains near head of Utukok River.
25ASmF4 (5870). North side of mountains near head of Utukok River.
25ASmF10 (5871). West of pass, Aniuk River, Brooks Range.

Collections by P. S. Smith, 1926

26AS2. Kivalina River, camp 1, 11 miles northeast of Kivalina.

26AS3. Hill 1 mile northwest of camp 1, 11 miles northeast of Kivalina, Kivalina River.

26AS4. Kivalina River, between camps 1 and 2, 11 and 18 miles northeast of Kivalina.

26AS5. Near topographic station 6, midway between camps 1 and 2, 11 and 18 miles northeast of Kivalina, Kivalina River.

26AS7. Hills 4 miles east of camp 2, 18 miles northeast of Kivalina, Kivalina River.

26AS9. Hills 4 miles east of camp 2, 18 miles northeast of Kivalina, Kivalina River, 100 yards above 26AS7.

26AS17. 4 miles southeast of camp 4, 38 miles north of Kivalina, Kivalina River.

26AS18. 1½ miles east of camp 4, 38 miles north of Kivalina, Kivalina River.

26AS41. Bar opposite camp 12, 1 mile south of Tingmerkpuk River, Kokolik River.

26AS44. Camp 13, 5 miles north of junction of Tingmerkpuk River, Kokolik River.

26AS50. 3 miles north of camp 13, 5 miles north of junction of Tingmerkpuk River, Kokolik River.

26AS97. 1 mile north of Niak Creek, 6 miles south of Cape Lisburne.

Four of these collections—Schrader 454, 461, 463, and 464—were obtained on the John River between Hunt Fork and Till Creek, in an area mapped as Devonian; but as all these fossils were collected from boulders along the John River, their locations have little significance. These four collections contain nothing more diagnostic than crinoid columns and may be regarded as either Carboniferous or Devonian in age, but as they were assigned originally by Charles Schuchert to the Carboniferous it has seemed best to retain this assignment for them.

These 72 collections, which represent the fauna of both the Noatak and Lisburne formations, contain 101 genera, and if specifically determined would probably be found to contain from 150 to 200 species. The earliest of these collections—those made by Schrader in 1901—were determined by Charles Schuchert, now of Yale University, but all the remainder, representing the bulk of the fauna, have been identified by G. H. Girty, of the United States Geological Survey. These determinations do not represent detailed paleontologic work, but chiefly work of only such degree of detail as was necessary in order to determine the general aspect of the fossils and their age.

The entire fauna is recognized by Girty as Mississippian in age and constitutes the typical Mississippian fauna of northern Alaska. It is not to be regarded, however, as the typical Lisburne fauna, for many of the collections here assembled were obtained from the

	Schrader 454	Schrader 461	Schrader 463	Schrader 464	Schrader 493	Schrader 495	Schrader 497	Schrader 511	Schrader 513	Schrader 518	Schrader 519	Schrader 520	Schrader 521	Schrader 522	Schrader 525	Schrader 529	Schrader 534	Schrader A	Dumars B
Endothyra cf E bowmani																			
Asteractinella sp																			
Corals, small, indeterminate																			
Stromatoporoid coral (?)																			
Zaphrentis sp																		X	X
Triplophyllum sp [a]																			
Campophyllum sp																			
Cyathophyllum sp																			
Cystophyllum sp																			
Endophyllum sp																			X
Diphyphyllum cf D simcoense																			X
Diphyphyllum cf D stramineum																			X
Diphyphyllum sp																		X	
Lithostrotion cf L basaltiforme																			
Lithostrotion irregulare																		X	
Lithostrotion irregulare?																		X	
Lithostrotion junceum																		X	
Lithostrotion portlocki																		X	
Lithostrotion portlocki var																			
Lithostrotion portlocki?																			
Lithostrotion cf L whitneyi																			
Lithostrotion sp					X													X	
Lonsdaleia sp																		X	?
Acervularia sp																			
Favosites sp																			
Leptopora sp																			
Cladopora sp																			
Syringopora cf S multattenuata							X									X			
Syringopora cf S porelegans																			X
Syringopora cf S tabulata																			X
Syringopora sp																		X	
Pentremites sp																			
Crinoid columns	X	X	X	X				X		X	X								
Melonites sp																			
Spirorbis cf S annulata																			
Echinocrinus sp																			
Cyclotrypa cf C barberi [b]																			
Batostomella sp																			
Leioclema sp																			
Stenopora sp																			
Fenestella cf F cestriensis																	X		
Fenestella sp											X			X			X		
Hemitrypa sp																			
Polypora sp																			
Pinnatopora sp																	X		
Rhombopora sp																	X		
Streblotrypa cf S nicklesi																	X		
Streblotrypa sp																			
Cystodictya cf C lineata													X						
Cystodictya sp											?						X		
Bryozoan																			
Lingula sp																			
Rhipidomella cf R pulchella																			
Rhipidomella cf R thiemei																			
Rhipidomella sp																			
Schizophoria cf S swallowi																			
Schizophoria sp																			
Leptaena rhomboidalis																			
Orthotetes sp																			
Derbya sp																			
Schuchertella cf S minuta																			
Schuchertella sp																			
Chonetes cf C burlingtonensis																			
Chonetes cf C choctawensis																			
Chonetes cf C illinoisensis																			
Chonetes sp																			
Productella hirsutiformis?																			
Productella sp																			
Productus cf P altonensis																			
Productus cf P burlingtonensis																			
Productus cf P concentricus																			
Productus giganteus?																			
Productus cf P longispinus																			
Productus cf P ovatus [c]																			
Productus semireticulatus												X							
Productus cf P semireticulatus																			
Productus cf P setiger																			
Productus cf P undatus																			
Productus sp													X						
Pustula cf P indianensis [d]																			
Pustula cf P punctata [e]																			
Pustula scabricula [f]						X			X										
Pustula cf P vittata [g]																			
Pustula sp																			
Diaphragmus cf D elegans [h]																			
Pugnax sp																			
Rhynchopora sp																			
Rhynchonella sp																			
Camarotoechia cf C mutata																			
Camarotoechia sp																			
Dielasma cf D formosum																			
Dielasma sp																			
Girtyella cf G indianensis																			
Girtyella turgida? [i]																			
Spirifer cf S agelaius																			
Spirifer cf S centronatus																			
Spirifer martiniiformis?																			
Spirifer cf S mortonanus																			
Spirifer cf S mosquensis																			
Spirifer cf S paucicostatus																			
Spirifer cf S rockymontanus																			
Spirifer cf S rostellatus																			
Spirifer cf S striatiformis																			
Spirifer striatus						X							X	X	X				
Spirifer cf S striatus																			
Spirifer cf S subcardiiformis																			
Spirifer cf S tenuicostatus																			
Spirifer cf S tenuimarginatus																			
Spirifer sp																			
Spiriferella cf S neglecta? [j]						X													
Brachythyris cf B chouteauensis																			
Reticularia cf R lineata																			
Reticularia cf R setigera																			
Reticularia sp																			
Ambocoelia cf A levicula																			
Ambocoelia sp																			
Martinia cf M glabra																			
Martinia sp																			
Spiriferina cristata															X				
Spiriferina cf S solidirostris																			
Spiriferina cf S subelliptica																			
Spiriferina cf S transversa																			
Eumetria marcyi?																			
Eumetria sp																			
Hustedia cf H multicostata																			
Hustedia sp																			
Athyris sp																			
Cleiothyridina hirsuta?																			
Cleiothyridina cf C hirsuta																			
Cleiothyridina cf C incrassata [k]																			
Cleiothyridina roissyi																			
Cleiothyridina cf C roissyi																			
Cleiothyridina cf C sublamellosa																			
Composita cf C levis																			
Composita cf C lewisensis																			
Composita cf C subtilita																			
Composita sp																			
Sanguinolites sp																			
Sphenotus cf S contractus																			
Sphenotus cf S unioniformis																			
Sphenotus sp																			
Edmondia sp																			
Nucula sp																			
Paleoneilo cf P sera																			
Leda sp																			
Leptodesma cf L spergenense																			
Conocardium sp																			
Schizodus sp																			
Aviculipecten sp																			
Cypricardinia sp																			
Dentalium sp																			
Plagioglypta sp																			
Bellerophon cf B sublevis																			
Bellerophon sp																			
Bucanopsis cf B cancellata																			
Pleurotomaria sp																			
Phanerotrema sp																			
Bembexia sp																			
Murchisonia sp																			
Solenospira sp																			
Euomphalus cf E spergenensis																			
Euomphalus sp																			
Trochus sp																			
Naticopsis cf N carleyana																			
Naticopsis sp																			
Loxonema sp																			
Bulimorpha cf B elongata																			
Bulimorpha sp																			
Zygopleura sp																			
Aclisina sp																			
Platyceras sp																			
Sphaerodoma cf S littonana																			
Sphaerodoma sp																			
Orthoceras sp																			
Eumorphoceras sp																			
Goniatites sp																			
Phillipsia sp																			
Griffithides sp																			
Proetus sp																			
Ostracode																			
Paraparchites sp																			
Primitia sp																			
Bairdia sp																			
Cythereila sp																			
Glyptopleura sp																			

	4AC14	4AC16	4AC17	4AC19	4AC22	4AC27	4AC28	4AC29	4AW27	4AW29	4AW30	4AW35	4AW36	4AW37	4AW39	4AW40	4AW44	4AW46	Kindle 14C	Kindle 14D	Kindle 14D (Mesler)	Kindle 14D′	Kindle 15A
Endothyra cf E bowmani																							
Asteractinella sp																							
Corals, small, indeterminate									X														
Stromatoporoid coral (?)																							
Zaphrentis sp		X			X	X		X	X	X		X					X				X	X	X
Triplophyllum sp [a]																							
Campophyllum sp																							
Cyathophyllum sp																							
Cystophyllum sp						?																	
Endophyllum sp																							
Diphyphyllum cf D simcoense																							
Diphyphyllum cf D stramineum																							
Diphyphyllum sp	X					X		X										X					
Lithostrotion cf L basaltiforme																							
Lithostrotion irregulare							X	X	X			X	X		X			X					
Lithostrotion irregulare?																							
Lithostrotion junceum	X						X			X													
Lithostrotion portlocki	X			X						X													
Lithostrotion portlocki var					X	X								X				X					
Lithostrotion portlocki?									X														
Lithostrotion cf L whitneyi																							
Lithostrotion sp	X			X			X	X	X				X	X		X		X		X		X	
Lonsdaleia sp	?																						
Acervularia sp																							
Favosites sp																							
Leptopora sp																							
Cladopora sp																							
Syringopora cf S multattenuata																							
Syringopora cf S porelegans																							
Syringopora cf S tabulata																							
Syringopora sp	X						?		X	X		X	X	X									
Pentremites sp																						?	
Crinoid columns							X													X			
Melonites sp																							
Spirorbis cf S annulata																							
Echinocrinus sp																							
Cyclotrypa cf C barberi [b]												X											
Batostomella sp																					?		
Leioclema sp																							
Stenopora sp										X		X								X			
Fenestella cf F cestriensis																							
Fenestella sp								X			X	X	X	X				X	X	X	X	X	
Hemitrypa sp																				X		X	
Polypora sp											X											X	
Pinnatopora sp																							
Rhombopora sp														X									
Streblotrypa cf S nicklesi																							
Streblotrypa sp																				?			
Cystodictya cf C lineata																							
Cystodictya sp																			?	?		?	
Bryozoan																							
Lingula sp																							
Rhipidomella cf R pulchella																							
Rhipidomella cf R thiemei																							
Rhipidomella sp																						?	
Schizophoria cf S swallowi																							
Schizophoria sp												X											
Leptaena rhomboidalis					X																		
Orthotetes sp															?								
Derbya sp																			?		?	?	
Schuchertella cf S minuta																							
Schuchertella sp																							
Chonetes cf C burlingtonensis																							
Chonetes cf C choctawensis																							
Chonetes cf C illinoisensis																							
Chonetes sp																		X		X			
Productella hirsutiformis?																							
Productella sp		X	?																				
Productus cf P altonensis																							
Productus cf P burlingtonensis																				X		X	
Productus cf P concentricus																				X			
Productus giganteus?										X													
Productus cf P longispinus																							
Productus cf P ovatus [c]																						X	
Productus semireticulatus																			X	X			
Productus cf P semireticulatus					X				X	X		X											
Productus cf P setiger																						X	
Productus cf P undatus																							
Productus sp			?			X			X			X										X	
Pustula cf P indianensis [d]																							
Pustula cf P punctata [e]						X			X			X						X					
Pustula scabricula [f]																							
Pustula cf P vittata [g]																						X	
Pustula sp																						X	
Diaphragmus cf D elegans [h]																						X	
Pugnax sp																							
Rhynchopora sp																						X	
Rhynchonella sp									X	X								X					
Camarotoechia cf C mutata																							
Camarotoechia sp																						X	
Dielasma cf D formosum																							
Dielasma sp																						?	
Girtyella cf G indianensis																							
Girtyella turgida? [i]																						X	
Spirifer cf S agelaius																					X	X	
Spirifer cf S centronatus																							
Spirifer martiniiformis?																							
Spirifer cf S mortonanus																							
Spirifer cf S mosquensis					X		X	X				X		X									
Spirifer cf S paucicostatus																							
Spirifer cf S rockymontanus																							
Spirifer cf S rostellatus																						X	
Spirifer cf S striatiformis																							
Spirifer striatus																							
Spirifer cf S striatus																				X			X
Spirifer cf S subcardiiformis																						X	
Spirifer cf S tenuicostatus																							
Spirifer cf S tenuimarginatus																							
Spirifer sp																X							
Spiriferella cf S neglecta? [j]																						X	
Brachythyris cf B chouteauensis																							
Reticularia cf R lineata					X																		
Reticularia cf R setigera																							
Reticularia sp		X																	?	?			
Ambocoelia cf A levicula																							
Ambocoelia sp																							
Martinia cf M glabra																							
Martinia sp		X																				?	
Spiriferina cristata																							
Spiriferina cf S solidirostris																							
Spiriferina cf S subelliptica																						X	
Spiriferina cf S transversa																							
Eumetria marcyi?																						X	
Eumetria sp																						?	
Hustedia cf H multicostata																							
Hustedia sp																						?	
Athyris sp																							
Cleiothyridina hirsuta?																					X	X	
Cleiothyridina cf C hirsuta																							
Cleiothyridina cf C incrassata [k]																						X	
Cleiothyridina roissyi																						X	
Cleiothyridina cf C roissyi	X													X	X						X		
Cleiothyridina cf C sublamellosa																							
Composita cf C levis																							
Composita cf C lewisensis																							
Composita cf C subtilita																							
Composita sp																							?
Sanguinolites sp																							
Sphenotus cf S contractus																							
Sphenotus cf S unioniformis																							
Sphenotus sp					?																		
Edmondia sp																							
Nucula sp																							
Paleoneilo cf P sera																							
Leda sp																							
Leptodesma cf L spergenense																							
Conocardium sp																							
Schizodus sp																							
Aviculipecten sp		?								X								X					
Cypricardinia sp					?																		
Dentalium sp			?																				
Plagioglypta sp																							
Bellerophon cf B sublevis																							
Bellerophon sp										?													
Bucanopsis cf B cancellata																							
Pleurotomaria sp														X			X						
Phanerotrema sp																							
Bembexia sp																							
Murchisonia sp																							
Solenospira sp																							
Euomphalus cf E spergenensis																							
Euomphalus sp		X																					
Trochus sp																							
Naticopsis cf N carleyana																							
Naticopsis sp																							
Loxonema sp																							
Bulimorpha cf B elongata																							
Bulimorpha sp																							
Zygopleura sp																							
Aclisina sp																							
Platyceras sp																						X	
Sphaerodoma cf S littonana																							
Sphaerodoma sp																							
Orthoceras sp																							
Eumorphoceras sp																							
Goniatites sp			X																				
Phillipsia sp																							
Griffithides sp																				?		?	
Proetus sp		X																					
Ostracode		X																					
Paraparchites sp																							
Primitia sp																							
Bairdia sp																				?			
Cythereila sp																							
Glyptopleura sp																							

	11AS43	11AS45	11AS46	11AF51	11AS53	11AS56	11AS61	11AS65	11AS67	11AS73	11AS77	24AFC6 (5696)	24AM42	24AM56	25ASmF-1 (5868)	25ASmF-2 (5869)	25ASmF-4 (5870)	25ASmF-10 (5871)	26AS2 (0296)	26AS3 (0295)	26AS4 (0303)	26AS5 (0297)	26AS7 (0292)	26AS17 (0300)	26AS18 (0301)	26AS41 (0299)	26AS44 (0298)	26AS50 (0293)	26AS97 (0302)
Endothyra cf E bowmani																						X							
Asteractinella sp																						X							
Corals, small, indeterminate																													
Stromatoporoid coral (?)	X																												
Zaphrentis sp	X	X		X	?				X																				
Triplophyllum sp [a]			X										X	X	X				X		X	X		X	X				
Campophyllum sp	?																?												
Cyathophyllum sp													X																
Cystophyllum sp																													
Endophyllum sp																													
Diphyphyllum cf D simcoense																													
Diphyphyllum cf D stramineum																													
Diphyphyllum sp																													
Lithostrotion cf L basaltiforme															X														
Lithostrotion irregulare																													
Lithostrotion irregulare?										X																			
Lithostrotion junceum																													
Lithostrotion portlocki																													
Lithostrotion portlocki var																													
Lithostrotion portlocki?							X																						
Lithostrotion cf L whitneyi													X																
Lithostrotion sp																													X
Lonsdaleia sp																													
Acervularia sp																													X
Favosites sp	?																												
Leptopora sp														?															
Cladopora sp	?	?																											
Syringopora cf S multattenuata																													
Syringopora cf S porelegans																													
Syringopora cf S tabulata																													
Syringopora sp														X															
Pentremites sp																													
Crinoid columns	X					X						X		X											X	X	X			
Melonites sp																						?							
Spirorbis cf S annulata																						X							
Echinocrinus sp																						X							
Cyclotrypa cf C barberi [b]																													
Batostomella sp						?																							
Leioclema sp																								X					
Stenopora sp			X																										
Fenestella cf F cestriensis																													
Fenestella sp											X							X				X							
Hemitrypa sp																		X				X							
Polypora sp																													
Pinnatopora sp											X																		
Rhombopora sp												X																	
Streblotrypa cf S nicklesi																													
Streblotrypa sp																													
Cystodictya cf C lineata												X																	
Cystodictya sp											X											X							
Bryozoan								?																					
Lingula sp				?																									
Rhipidomella cf R pulchella											X																		
Rhipidomella cf R thiemei														X															
Rhipidomella sp																													
Schizophoria cf S swallowi				X																									
Schizophoria sp																													
Leptaena rhomboidalis																													
Orthotetes sp																										?			
Derbya sp											X	?																	
Schuchertella cf S minuta																						X							
Schuchertella sp			?																										
Chonetes cf C burlingtonensis																X													
Chonetes cf C choctawensis																												X	
Chonetes cf C illinoisensis			X	X	X						X			X							X								
Chonetes sp														X															
Productella hirsutiformis?			X																										
Productella sp																													
Productus cf P altonensis																		X											
Productus cf P burlingtonensis																													
Productus cf P concentricus																													
Productus giganteus?																													
Productus cf P longispinus			X	X							X																		
Productus cf P ovatus [c]																													
Productus semireticulatus																													
Productus cf P semireticulatus											X																		
Productus cf P setiger																													
Productus cf P undatus			X								X																		
Productus sp			X	X				?			X																		
Pustula cf P indianensis [d]			X	X							X																		
Pustula cf P punctata [e]																													
Pustula scabricula [f]																													
Pustula cf P vittata [g]																													
Pustula sp																				X									
Diaphragmus cf D elegans [h]																													
Pugnax sp				?																									
Rhynchopora sp																		?											
Rhynchonella sp																													
Camarotoechia cf C mutata																	X	X						X					
Camarotoechia sp	?	?	X																		X								
Dielasma cf D formosum				X																									
Dielasma sp											X						X												
Girtyella cf G indianensis																						X							
Girtyella turgida? [i]																													
Spirifer cf S agelaius																													
Spirifer cf S centronatus			X																										
Spirifer martiniiformis?																												X	
Spirifer cf S mortonanus															X														
Spirifer cf S mosquensis																													
Spirifer cf S paucicostatus				X							X																		
Spirifer cf S rockymontanus								X																					
Spirifer cf S rostellatus																X	X												
Spirifer cf S striatiformis																								X					
Spirifer striatus																													
Spirifer cf S striatus			X	X							X																		
Spirifer cf S subcardiiformis																													
Spirifer cf S tenuicostatus														X															
Spirifer cf S tenuimarginatus																		X											
Spirifer sp					X															X	X				X	?			
Spiriferella cf S neglecta? [j]																													
Brachythyris cf B chouteauensis														X															
Reticularia cf R lineata																													
Reticularia cf R setigera																		X											
Reticularia sp											X											X		?					
Ambocoelia cf A levicula				X																									
Ambocoelia sp					X																								
Martinia cf M glabra											X																		
Martinia sp																							?					X	
Spiriferina cristata																													
Spiriferina cf S solidirostris																		X											
Spiriferina cf S subelliptica				X																									
Spiriferina cf S transversa																				X	X								
Eumetria marcyi?																													
Eumetria sp																												?	
Hustedia cf H multicostata																						X							
Hustedia sp																													
Athyris sp				?																									
Cleiothyridina hirsuta?																													
Cleiothyridina cf C hirsuta				X							X									X									
Cleiothyridina cf C incrassata [k]																													
Cleiothyridina roissyi																													
Cleiothyridina cf C roissyi																													
Cleiothyridina cf C sublamellosa			X																		X								
Composita cf C levis																				X									
Composita cf C lewisensis																		X											
Composita cf C subtilita								X																					
Composita sp																												?	
Sanguinolites sp											X																		
Sphenotus cf S contractus											X																		
Sphenotus cf S unioniformis											X																		
Sphenotus sp											X																		
Edmondia sp											X																		
Nucula sp											X											X							
Paleoneilo cf P sera											X																		
Leda sp											X																		
Leptodesma cf L spergenense			X								X																		
Conocardium sp														?															
Schizodus sp											X																		
Aviculipecten sp			X	X							X														?				
Cypricardinia sp											?																		
Dentalium sp																													
Plagioglypta sp																						?							
Bellerophon cf B sublevis																						X							
Bellerophon sp																					X	X							
Bucanopsis cf B cancellata																						X							
Pleurotomaria sp				X							X																		
Phanerotrema sp												?																	
Bembexia sp			?																										
Murchisonia sp				X																									
Solenospira sp																						?							
Euomphalus cf E spergenensis											X																		
Euomphalus sp				X																									
Trochus sp											?																		
Naticopsis cf N carleyana				X																									
Naticopsis sp				X							X																		
Loxonema sp											X											?							
Bulimorpha cf B elongata																						X							
Bulimorpha sp											X																		
Zygopleura sp																						X							
Aclisina sp																			?										
Platyceras sp											X			X								X							
Sphaerodoma cf S littonana											X											X							
Sphaerodoma sp												X																	
Orthoceras sp			X								X	X																	
Eumorphoceras sp											?																		
Goniatites sp																													
Phillipsia sp				X																									
Griffithides sp																													
Proetus sp																													
Ostracode																													
Paraparchites sp			X	X							X								X		X	X							
Primitia sp											X																		
Bairdia sp																						X							
Cythereila sp																					X								
Glyptopleura sp											X											X							

[a] Previously tabulated as *Menophyllum* sp (U S Geol Survey Bull 536, p 73, 1913)
[b] Previously tabulated as *Fistulipora* cf *F barberi* (U S Geol Survey Bull 278, p 24, 1906)
[c] Previously tabulated as *Productus* cf *P pileiformis* (Am Jour Sci, 4th ser, vol 28, p 525, 1909)
[d] Previously tabulated as *Productus* cf *P indianensis* (U S Geol Survey Bull 536, pp 73, 78, 1913)
[e] Previously tabulated as *Productus* cf *P punctatus* (U S Geol Survey Bull 278, pp 23, 24, 1906)
[f] Previously tabulated as *Productus scabriculus* (U S Geol Survey Prof Paper 20, p 70, 1904)
[g] Previously tabulated as *Productus* cf *P villatus* (Am Jour Sci, 4th ser, vol 28, p 525, 1909)
[h] Previously tabulated as *Productus* cf *P cestriensis* (Am Jour Sci, 4th ser, vol 28, p 525, 1909)
[i] Previously tabulated as *Dielasma turgidum?* (Am Jour Sci, 4th ser, vol 28, p 525, 1909)
[j] Previously tabulated as *Spirifer* cf *S neglectus* (U S Geol Survey Prof Paper 20, p 70, 1904, Am Jour Sci, 4th ser, vol 28, p 525, 1909)
[k] Previously tabulated as *Athyris* cf *A incrassata* (Am Jour Sci, 4th ser, vol 28, p 25, 1909)

Noatak formation. Future work will doubtless provide the data necessary for separating this fauna into two paleontologic units, corresponding in age to the Noatak and Lisburne formations. On stratigraphic grounds alone a beginning could even now be made on this separation, by assembling the fauna that has been collected from the Noatak formation into one unit and from the Lisburne limestone into another unit. Such a separation, however, would hardly show distinct faunal differences, unless all the collections were described and identified specifically, and this has not yet been done. Moreover, a complete separation on stratigraphic grounds could not be made at the present time, because the locality descriptions of some of the older collections, especially in the Lisburne district, are not sufficiently exact for this purpose. On paleontologic grounds alone, only collection 4AC22, which contains *Leptaena rhomboidalis*, is distinctively lower Mississippian in age. Obviously, any division should be made from both stratigraphic and paleontologic studies, the stratigraphic data bolstering the paleontologic data in weak places, and vice versa. This remains a task for the future.

The Lisburne limestone has been recognized and mapped by Leffingwell [26] in the Canning River region, about 150 miles east of the Anaktuvuk River, and by Maddren [27] in the valley of the Firth River and contiguous territory along the international boundary. Hence it may be said, so far as northern Alaska is concerned, that the Lisburne limestone constitutes a distinct lithologic unit, which extends from Kotzebue Sound eastward for more than 600 miles to the international boundary and probably for some distance still farther east. It has also been found in Seward Peninsula, where it has been observed and studied by a number of geologists in the York district, particularly near Cape Mountain, east of Cape Prince of Wales.

The Lisburne limestone of northern Alaska is distinctively upper Mississippian in age, and because of the uniformity of its lithology it is also a well-defined lithologic unit. But this dual correlation can not well be carried to other parts of Alaska, for the lithology of the upper Mississippian rocks elsewhere is found to be variable. Hence in correlating with rocks of like age in other parts of Alaska, we are in reality correlating the upper Mississippian rocks of northern Alaska, rather than the Lisburne limestone alone—that is, we are including in the correlation the upper part of the Noatak formation, which is also probably upper Mississippian.

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[26] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 108–113, 1919.

[27] Maddren, A. G., Geologic investigations along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 310–312, 1912.

With this reservation, it may be said that rocks of like age are found at many other localities in Alaska. In the Yukon Basin two standard or type localities should be mentioned. At Calico Bluff, on the Yukon River a short distance below Eagle, is found a group of thin-bedded shale and limestone, which contain an upper Mississippian fauna, even larger perhaps than the Lisburne fauna. Paleontologically the Calico Bluff formation may be correlated with the upper Mississippian rocks of northern Alaska, but lithologically it is dissimilar. The Calico Bluff and the Lisburne-Noatak faunas together, however, may well be regarded as the typical Mississippian fauna of interior and northern Alaska.

The other locality is on the Porcupine River, just above the lower ramparts and also farther upstream just above the mouth of the Coleen River. A typical upper Mississippian fauna has been collected from the Porcupine River localities by Kindle.[28] The Mississippian rocks of the Porcupine region, like those at Calico Bluff, are shale and limestone and therefore are correlated paleontologically rather than lithologically with the upper Mississippian rocks of northern Alaska.

Far to the south, in the headwaters of the White and Nabesna Rivers, Moffit [29] and subsequently Capps [30] recognized and described rocks at this horizon. These rocks, however, are partly sedimentary and partly igneous and include shale, limestone, lava flows, tuff, volcanic breccia, and conglomerate, the last intruded by a variety of doleritic rocks.

A well-defined Mississippian horizon has been recognized by Moffit and Mertie [31] in the Chitina Valley, in the Copper River region. In this district the Mississippian rocks are largely bedded lava and tuff but contain intercalated beds of fossiliferous limestone and shale, as well as beds of chert.

Finally, Mississippian rocks are highly developed in southeastern Alaska, being found at many localities on Prince of Wales, Kuiu, and Chichagof Islands and in the Porcupine placer district. The rocks are largely limestone, and although southeastern Alaska is more remote from northern Alaska than the other localities above mentioned, these rocks may be correlated better lithologically with the Lisburne limestone than those of the other known localities. A

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[28] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 330–333, 1907.

[29] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, pp. 17–27, 1910.

[30] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 33–47, 1916.

[31] Moffit, F. H., and Mertie, J. B., jr., The Kotsina-Kuskulana district, Alaska: U. S. Geol. Survey Bull. 745, pp. 21–28, 1923.

comparative paleontologic study of the Mississippian faunas of northern and southeastern Alaska, however, might possibly reveal important faunal differences.

TRIASSIC SYSTEM

DISTRIBUTION

No rocks representing Lower Triassic age have been recognized anywhere in Alaska, and none of Middle Triassic age have been identified in the part of northwestern Alaska that forms the subject of this report. This does not mean, however, that Middle Triassic rocks may not occur there, for the fossils which best establish the actual age of the rocks that are considered as belonging to the Triassic system are found at a considerable distance above the base of those rocks. More detailed search may therefore result in subdividing the rocks described in these sections or may disclose representatives in groups now otherwise correlated. Upper Triassic rocks, however, have been recognized at a number of places along the north front of the Brooks Range and at a few places within the range in the Noatak Valley.

The tract occupied by these rocks near the northern margin of the Brooks Range extends in a more or less east-west direction for a distance of 300 miles from Cape Lisburne and the Kivalina River to the Chandler River. This tract is from 5 to 15 miles wide. It has not been traced continuously through this entire distance, but it has been crossed at seven different sections, and its continuity can therefore be assumed with a high degree of probability. It is uncertain whether these rocks continue uninterruptedly east of the Chandler River, because 45 miles to the east on the Anaktuvuk River they were not recognized. That they do extend farther east, however, is shown by the explorations of Leffingwell[32] in the Canning River region, where these rocks were definitely recognized. Still farther east, according to Maddren,[33] they occur on the international boundary.

Apparently the first place in northwestern Alaska at which the presence of Triassic rocks was recognized was near Cape Thompson. Although as early as 1896 specimens from this place had been identified as probably Triassic, it remained for Kindle in 1908 to work out some of the details of the structure and to make a new interpretation of the stratigraphy of parts of the Cape Lisburne region, in which he pointed out the Triassic age of certain of the strata

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[32] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, p. 115, 1919.

[33] Maddren, A. G., Geologic investigations along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, p. 312, 1911.

that had hitherto been regarded as Carboniferous. In 1911 Smith found Triassic fossils on the Noatak near the mouth of the Nimiuktuk, and in the same year Maddren found Triassic rocks along the Alaska-Canada boundary. About this time geologic investigations by Leffingwell were in progress in the Canning River region, to the east, although the results of that work bearing on the Triassic were not made available until 1916, in a preliminary article by Martin,[34] and Leffingwell's final report [35] was not published until 1919. Each of the recent Geological Survey expeditions brought back additional data regarding these rocks. The expedition of 1924 found these rocks along the Killik and Chandler Rivers and in the mountains at the heads of the Nimiuktuk and Nuka Rivers and Reynard Creek. The expedition of 1925 found Upper Triassic rocks in the divide at the heads of the Kugururok and Utukok Rivers and in the headward portions of the valley of the Etivluk River. The expedition of 1926 encountered these rocks 30 miles or so northeast of Kivalina, in the valley of the Kukpuk, and near the heads of the Kukpowruk and Kokolik Rivers.

Although these rocks are exposed in the places enumerated, it is certain that in other places they have been covered by some of the younger formations described below. There is therefore every reason to believe that they would be found in drill holes at many places north of the area in which they are indicated on the map as forming the surface rocks. Possibly some infolded or infaulted Triassic rocks also occur in the unexplored areas between the Noatak and the Colville, but their areal extent is probably small, and they doubtless have complex relations to the adjacent rocks.

LITHOLOGY

The section of rocks about 2 miles southeast of Cape Thompson, as described by Kindle, includes at the base about 5,000 feet of limestone, which is correlated with the Carboniferous or Lisburne limestone. Above the limestone there is an abrupt lithologic break, the succeeding 600 feet consisting of argillite, with bands of black, green, and dull-red chert. These rocks are, in turn, overlain by 25 feet of dark chert and thin-bedded cherty limestone, with some greenish bands in which Triassic fossils were found. The upper 7 feet of this unit is composed almost exclusively of shells that have been largely altered to chert. Next above these rocks is 500 feet of soft black shale that may be Triassic or younger.

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[34] Martin, G. C., Triassic rocks of Alaska: Geol. Soc. America Bull., vol. 27, pp. 703–704, 1916.

[35] Leffingwell, E. de K., op. cit.

The determinations by Kindle of the Triassic rocks near Cape Thompson led him to review the notes and specimens collected earlier in the Cape Lisburne region, to the north. As a result of this review, it has been definitely determined that in the Cape Lisburne region similar Triassic rocks also occur. It was not possible to determine from these earlier notes the exact extent of this formation, but it appears to coincide more or less closely with the rocks grouped by Collier as his second or middle subdivision, which he described as made up of "black cherts, slates, shales, and cherty limestones containing corals and bivalve fossils, the most common being several species of *Aviculipecten*" (later determined to be *Pseudomonotis*). This member was distinguished from the near-by Carboniferous rocks by the absence of coal beds and the less abundance of corals. It was supposed to rest conformably on the coal beds and conformably beneath the Carboniferous limestone, but the succession is known to be enormously faulted and folded, and it is now believed to lie unconformably above both the limestone and the coal-bearing member, as has been stated and discussed in more detail in preceding pages.

The Triassic material in the valley of the Noatak was found midway between the Aniuk and the Nimiuktuk and consisted of float which was mainly dark chert within dark thin-bedded limestone. The silicification had apparently occurred after the consolidation of the rock and had replaced much of the original material, which was probably limestone. At the mouth of the Nimiuktuk the exposures on the west side of the river, according to W. R. Smith, consist of slaty material and thin-bedded chert which is greenish and contains numerous large cubes of pyrites.

Excellent exposures of the Triassic rocks were studied in the hills both east and west of the Etivluk River about 30 miles upstream from its junction with the Colville. There chert is the outstanding lithologic constituent of the unit, though sandstone, shale, and limestone are not uncommon. The rocks show a great variation in color. At one horizon the massive chert is in narrow black, blue, white, and gray bands superficially resembling limestone. The hills west of the river below the forks are almost entirely massive white chert. A few miles southeast of this chert a high cliff on an eastern tributary of the Etivluk shows thin-bedded chert, shale, sandstone, and limestone. All the rocks are brilliantly colored, especially the chert, which ranges through purple, blue, green, and orange, each color being characteristic of beds 20 feet or more thick. Spherical bodies of dark crystalline calcite, from 1 to 6 inches in diameter and showing distinct radial structure, are embedded at several horizons in the chert. A few small crystals of pyrites occur with the calcite.

Sandstone and shale make up a considerable portion of the Upper Triassic rocks at the heads of the Utukok and Colville Rivers, but there is also a large amount of chert in beds from 2 to 5 inches thick, in places separated from one another by thin partings of shale. The chert is not banded, but the sides of many of the beds where exposed weather for a depth of one-eighth to one-fourth inch to a light olive-green. The greenish tint is sufficiently characteristic to serve as a means of discriminating this chert from the more massive black chert found in places in the Carboniferous rocks. Some of the sandstone and shale beds appear to underlie the cherty part of the formation, but there are also shale and sandstone above the chert. These beds are well exposed where the Utukok and Colville cut across the trend of the rocks. At this place about 1,000 feet of alternating beds of sandstone and shale are exposed. The sandstone is light gray and occurs in beds 3 to 4 feet thick, but these split up under the influence of the weather into slabs that are usually less than 2 inches thick. The sandstone and shale are ripple marked and show impressions of raindrops and mud cracks, thus indicating that they were deposited in shallow water or perhaps upon mud flats. The uppermost 150 feet of the Triassic rocks exposed at the head of the Utukok are thin-bedded limestone and chert.

In the Kivalina, Kukpuk, and Kukpowruk Valleys the most distinctive feature of the Triassic rocks is the chert, which weathers into fantastic pinnacles that are readily recognized for long distances. In all the places where these rocks were examined in these valleys they have been much deformed and faulted, and in some places the rocks have been completely overturned, so that it is not always certain just where the stratigraphic boundaries should be drawn. In general, the series here appears to consist near the base of varicolored chert with some subordinate beds of sandstone and shale. These rocks are overlain by several feet of shale and sandstone with small concretions and flattened mud lumps. These in turn are overlain by several hundred feet of a light-colored silicified and cherty limestone, which is followed by thin limestone. The limestone is dark chocolate-colored, and on its surface are numerous light-colored trails of worms. Overlying the limestone is about 100 feet of dark thinly splitting tenacious shale that is full of vegetable material and somewhat flexible. Still higher in the section are more beds of shale and sandstone which contain some concretions and a number of pyrites balls. These highest rocks are generally dark colored and where exposed to the weather are considerably iron stained. Opportunity for examining the rocks that probably lie above the highest member of this sequence was not afforded, as a prominent zone of faulting intervenes, which brings Lower Cretaceous rocks into contact with these Triassic rocks.

Another good section of the Triassic rocks was found on a tributary of the Kukpowruk above camp P April 28. At the top of this section is several hundred feet of black shale breaking into small "pencils" and having a yellowish color on weathered surface. The shale is underlain by a considerable thickness of chert with thin shale bands, the chert forming conspicuous rock pinnacles. A hundred yards south of the chert, in a position that would be stratigraphically 100 feet or more below the chert if no fault occurs in the interval, is an abundantly fossiliferous limestone which has been more or less completely replaced by chert. The rock is badly fractured, so that it breaks into angular pieces a few inches in diameter. Underlying the limestone is more shale whose thickness was indeterminate.

The Triassic rocks in the vicinity of the Killik and Chandler Rivers consist dominantly of chert. These rocks form a belt 5 to 8 miles wide which flanks the Lisburne limestone on the north. The best exposures were seen on the 3,265-foot hill about 25 miles in an air line above the mouth of the Chandler River. Here the rocks consist of chert, siliceous thin-bedded limestone, and a siliceous dark-colored but white-weathering argillite. The chert in places is banded, but some of it is pure black. It occurs for the most part in beds a few inches thick and at some places has a highly contorted structure. Near the Killik River the chert formation was also recognized, but the exposures are poor, consisting only of hillside rubble. The lithologic characteristics, however, were the same as those shown at other localities in this region described above.

The Upper Triassic rocks in the Canning River region, which were called by Leffingwell the Shublik formation, are described as consisting of dark limestone, shale, and sandstone. Their maximum possible thickness is 1,350 feet, but Leffingwell thinks that the true thickness is more probably about 500 feet. The lower part of this section is composed dominantly of dark shale and sandstone, which is succeeded by a dark, almost black limestone, which in turn is followed by softer rocks that make poor outcrops and are probably soft shale. These rocks differ lithologically from any of the other Triassic rocks already described in that they apparently contain no chert, and in the Canning River region none of the near-by formations contain chert. The Shublik formation contains a much more varied fossil fauna than the other Triassic rocks in the region that is especially described in this report. (See p. 194.)

STRUCTURE AND THICKNESS

In every place where the Triassic rocks have been examined in good exposures they have been found to be highly deformed and faulted. In fact, the observable structure is so complex and involved that many different interpretations of their real attitude may be made unless checked by extremely detailed studies. Thus, in many outcrops the dip of the beds is vertical or overturned. Small faults can be seen in all parts of the series, and large faults are probably numerous, though the amount of movement is not readily determined. The beds are obviously folded into small wrinkles and probably also into major arches. The accompanying field sketch (fig. 10) of bluffs formed of these rocks that crop out about 4 miles south of camp P April 16, on the Kivalina River, may serve to indicate the complex structure. This sketch, however, fails to show that, in addition to the more obvious structure, many of the folds have a strong pitch, which still further complicates the areal distribution of the rocks. For instance, the crests of the folds shown in the right-hand portion of the sketch have a pitch of about 35° NW. (toward the reader). This feature may also be seen in Plate 22, *A*, where in the extreme left-hand portion of the view, and pitching steeply forward, is part of the westernmost of the small folds shown in the sketch.

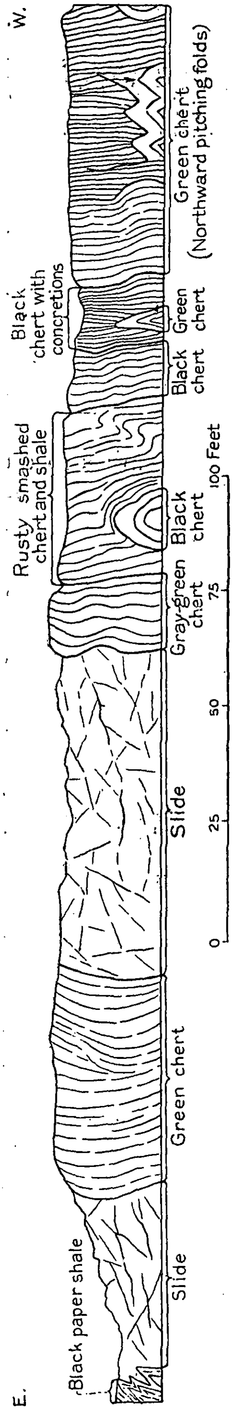

FIGURE 10.—Sketch showing structure in Triassic rocks on Kivalina River

Another locality that illustrates the complexity of structure in the Triassic is at Agate Rock, near Cape Thompson. A sketch made at this place by E. M. Kindle is shown in Figure 11, and a picture of the same anticline is shown in Plate 22, *B*. Obviously the structure in the less crumpled beds in the upper part of the sketch is even more complex than indicated or else the more deformed beds that form the lower central part of the figure represent a different group of rocks. The former interpretation seems more likely to be correct, for all of this unit is described in the field notes as composed of hard black chert and siliceous shale. Overlying these rocks is soft black shale, which has a thickness in this exposure of about 300 feet. This whole fold, however, is only a minor flexure which is part of a large synclinal fold. In other words, the entire structure in the vicinity of Cape Thompson as now interpreted is believed to correspond to that shown in Figure 12. This figure, however, serves only to suggest in diagrammatic manner the major structure, for the details are much more complicated by faults and folds.

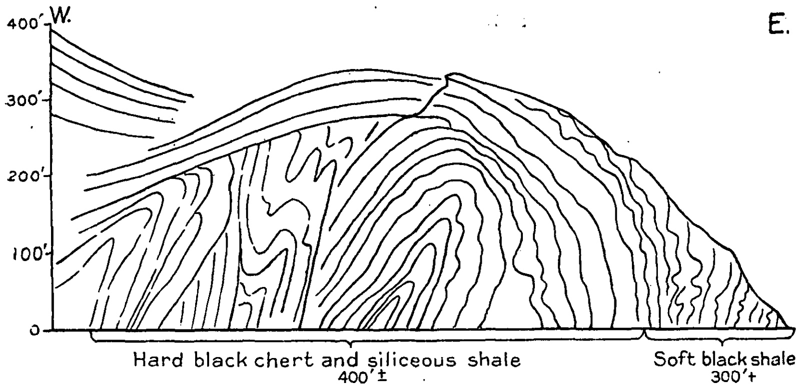

FIGURE 11.—Sketch of Triassic rocks exposed at Agate Rock, near Cape Thompson. (After E. M. Kindle)

Nowhere has the relation of the Triassic rocks to the underlying formations been clearly determined, though in general there seems to have been the impression that these rocks lie without structural discordance on the older rocks. In general they seem to have undergone essentially the same structural movements as the younger of the underlying rocks, but the youngest of these underlying rocks whose age has been well determined are dominantly Mississippian, whereas

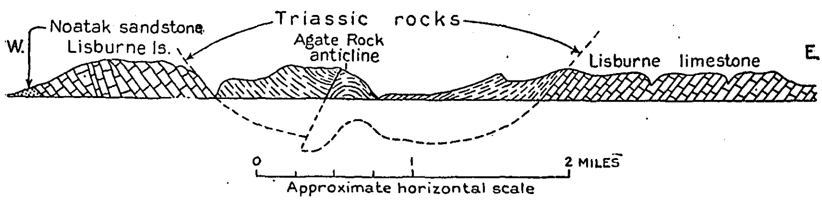

FIGURE 12.—Generalized sketch of structure in vicinity of Cape Thompson. Data principally from Kindle and Collier, modified and simplified by Philip S. Smith.

the Triassic rocks are Upper Triassic. This clearly shows that a long interval elapsed between the two epochs of deposition, so that there is certainly a stratigraphic hiatus, if not an angular unconformity, at the base of the Upper Triassic rocks. In view of the extreme complexity of the known structure of these rocks and the fact that in practically every exposure the complete sequence is interrupted by faults that may have profoundly modified their relations to adjacent formations, it does not seem justifiable to make an unqualified assertion as to the relation of these rocks to the underlying and overlying formations, but they are believed to be unconformable.

Viewed broadly, however, the Triassic rocks have been involved in the same general mountain-building deformations as the Carboniferous rocks, and like them in this region form part of a great northward-dipping structure, so that on the whole the rocks become progressively younger from south to north. This major structural feature, however, has been intersected by faults which trend in general east and west and which here and there have broken the normal sequence into a series of slices. In some places the faulting has entirely cut out the outcrop of this series at the surface, and in other places it has brought these rocks into juxtaposition with rocks belonging at far different horizons in the stratigraphic sequence and may even have resulted in reversing the dip of the dislocated blocks.

It follows from the uncertainties already discussed that any estimate of the total thickness of the Triassic section in this region is too indeterminate to be of much value. However, from the sections that have been measured it is clear that these beds form a stratigraphic sequence of not less than 700 feet and that their total thickness may be several times that amount.

AGE AND CORRELATION

The only definitely identified fossils that have been found in these rocks in northwestern Alaska are considered representative of the Upper Triassic. One imperfectly identified collection was regarded as "probably Triassic."

Concerning the collections made by Kindle in the vicinity of Cape Thompson and by Collier in the Cape Lisburne region Stanton[36] states:

> Lot 15d. Mouth of creek 2 miles southeast of Cape Thompson. This collection consists of limestone fragments with numerous specimens of aviculoid shells referable to *Pseudomonotis subcircularis* (Gabb) or to a closely related species. No other recognizable species are associated with it. This species occurs in an Upper Triassic horizon in California and has been accepted as sufficient evidence for the Triassic age of rocks containing it at Cold Bay and in the Copper River region, Alaska. In my opinion the horizon which yielded it at Cape Thompson is also Upper Triassic.
>
> Among the collections obtained by Mr. Collier in the Cape Lisburne region some years ago there are several small lots consisting mainly of a fauna that seems identical with *Pseudomonotis subcircularis* and probably comes from about the same horizon as the Cape Thompson locality.

[36] Stanton, T. W., in Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 520–528, 1909.

The collections of the Lisburne region referred to were originally listed as follows: Lot 4AC15, 1½ miles southeast of Wevok; 4AC18, 3½ miles southeast of Wevok; 4AC21, 3 miles east-southeast of Wevok; 4AC81, 4 miles southeast of Wevok; 4AW33, 3½ miles southeast of Wevok; 4AW34, 4AW38, 2½ miles north of Cape Lewis. These were described by Collier,[37] and on the basis of the information then available were correlated with the Carboniferous.

The determination of the Triassic float in the central part of the Noatak Basin was based on its identification by Stanton, who states:

7244 (11AS44). Noatak River at first stream from south, west of camp of August 8 (1911), approximately latitude 68° N., longitude 159° W. *Pseudomonotis subcircularis* (Gabb). Upper Triassic. The collection contains only a single species, but it is represented by a number of well-preserved specimens and is a widely distributed and very characteristic form found thus far only in the Upper Triassic.

The collections made by W. R. Smith from the mouth of the Nimiuktuk River, No. 13314, locality 25ASmF11, contained *Pseudomonotis subcircularis* (Gabb), according to Stanton, and he identified it as of Upper Triassic age.

Two collections made by W. R. Smith in the course of the explorations of the expedition of 1925 were examined by Stanton, who reported upon them as follows:

13308 (25ASmF3). 10 miles downstream from the head of Utukok River pass. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

13312 (25ASmF8). 20 miles south from mouth of Etivluk River. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

The fossils collected from these rocks in the Kukpuk, Kukpowruk, and Kokolik regions were likewise identified by Stanton, who reports as follows:

13734 (26AS27). 1 mile north of camp P April 25, Kukpuk River. Small ammonites (2 specimens) not well enough preserved for generic identification. Probably Triassic.

13735 (26AS32). 2 miles east of camp P April 28, Kukpowruk River. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

13736 (26AS33). 3 miles east of camp P April 28, Kukpowruk River. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

13737 (26AS34). 1 mile north of camp P April 28, Kukpowruk River. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

13738 (26AS42). 6 miles southeast of camp P May 10, Kokolik River. *Pseudomonotis subcircularis* (Gabb). Upper Triassic.

In the vicinity of the Killik and Chandler Rivers only one fossil was found in the chert formation. This was identified by G. H. Girty, who reports as follows:

24AMt62. West bank of Chandler River 19½ miles S. 12° E. of confluence of Chandler and Killik Rivers. *Michelina* sp.? The general appearance of

[37] Collier, A. J., op. cit., pp. 23–26.

this fossil is strikingly similar to the genus, but of the structures which would determine such a reference none remain. Even if the genus can be definitely identified as *Michelina*, however, *Michelina* is known in the Devonian, Mississippian, and Pennsylvanian rocks.

Inasmuch as this fossil is therefore of no great diagnostic value, these rocks have been correlated with the Upper Triassic mainly on lithologic and stratigraphic evidence.

Although in northwestern Alaska the Triassic rocks have been identified mainly by a single type of fossil, this condition does not prevail farther east, for both in the Canning River region and near the international boundary a much richer fauna has been found in the rocks that are in general correlated with the Triassic system. In the Canning River region, however, all the collections have been identified only as "Triassic" or "probably Triassic," though many of them contain *Pseudomonotis subcircularis* (Gabb). A complete list of the Triassic fossils collected in the Canning River region is given in Leffingwell's report.[38]

The correlation of these Upper Triassic rocks with those in other parts of Alaska has already been clearly indicated by Martin[39] in his comprehensive analysis of the Mesozoic stratigraphy of Alaska, and detailed discussion may therefore be omitted here. It is perhaps sufficient to point out that Upper Triassic rocks are widely distributed throughout Alaska, including southeastern Alaska, the Copper River region, the Susitna region, the country adjacent to Cook Inlet, and the Yukon Valley. In general, the Upper Triassic rocks of northwestern Alaska correspond in age with the Upper Noric of Europe and with the Brock shale of California and part of the Star Peak formation of Idaho.

JURASSIC SYSTEM

In northwestern Alaska a series of coal-bearing rocks known as the Corwin formation has long been recognized east of Cape Lisburne in the vicinity of Corwin, Cape Sabine, and Cape Beaufort. Various determinations of the age of these rocks have been made, ranging from Middle Jurassic to Upper Cretaceous. The most comprehensive study of the plant remains from these rocks was that made by F. H. Knowlton, who decided that they were of Jurassic age. However, in the course of the recent Geological Survey investigations an essentially similar group of rocks was recognized through the larger part of the area to the east. These rocks were traced areally almost into the type field that yielded the fossils on

[38] Leffingwell, E. de K., op. cit., pp. 117–118.
[39] Martin, G. C., Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, pp. 117–129, 1926.

which Knowlton based his determination, and yet several collections of Upper Cretaceous plants and invertebrates were made in these other rocks, and the types of many of the plants are such that had they not been found with dicotyledons they unquestionably would have been determined as of Jurassic age.

Efforts to reconcile these different observations have not resulted in settling the problem. With the matter standing in that situation it would have been relatively simple to indicate the doubt or the comprehensive character of the group by calling it Jurassic and Cretaceous, or Jurassic or Cretaceous. This method, however, does not appear feasible, because in this region there is a definitely recognized Lower Cretaceous formation, and the rocks in question, elsewhere than in the Corwin region, definitely lie above it, and those in the Corwin region may reasonably be interpreted as lying above Lower Cretaceous rocks. It would, of course, be entirely inconsistent to refer these overlying rocks to a possible Jurassic age and at the same time show them as overlying Lower Cretaceous rocks. Although the question can not be regarded as finally settled until further definite paleontologic proof is obtained from the specific area in which the fossils themselves were collected, it has seemed as if the only practicable method of meeting the requirements of this report is to refer the rocks to the system to which, in the writer's opinion, they most probably belong. Therefore, while admitting the possibility that additional data may necessitate revision of the present correlation, they have thought it best to include all these rocks in the Cretaceous system and the coal-bearing and related rocks in the Upper Cretaceous.

More reluctance to adopt this course would have been felt if similar rocks of Jurassic age were definitely known elsewhere in northern Alaska, but at the only locality where Jurassic invertebrates have been found the rocks are entirely different from those at Corwin. In the Canning River region Leffingwell found black shale, called the Kingak shale, which contains marine fossils of Lower (?) Jurassic age. His other questionably Jurassic formation, the Ignek, has slight significance in solving the present problem because its fossils are so unlike any other Alaskan fauna that they do not permit a close determination of their age. Furthermore, all the definitely determined fossils are marine, whereas the Corwin is definitely of fresh-water deposition, and Leffingwell's suggestion regarding the probable age of the fresh-water part of the Ignek formation is based not on fossils but on its lithologic similarity to the Corwin formation, so that it does not shed any new light on the true age of the rocks near Corwin.

Martin [40] has discussed the general problem and has expressed the following conclusions:

The flora of the Corwin formation does not show a close relationship with any of the undoubted Jurassic floras of southern Alaska. * * * The probability that the Corwin formation is Cretaceous instead of Jurassic is suggested by the above-cited apparent lack of relationship with any of the undoubted Jurassic floras of Alaska, by its closer relationship with the Kennicott formation, which is classified as Lower Cretaceous, by the presence of several species which Lesquereux, Fontaine, and Ward considered Lower Cretaceous, and especially by the presence of dicotyledonous leaves.

The dicotyledons, however, have not been found in the rocks in the areas from which the Corwin was named.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

DISTRIBUTION

Rocks that are now considered Lower Cretaceous were first recognized in northern Alaska by Schrader on the Anaktuvuk River, and hence this section has been regarded as more or less the type with which all other probable occurrences have been compared or contrasted. It would seem therefore most appropriate that when these rocks are defined, the name Anaktuvuk, given to them by Schrader, should be used in a formational rather than a series sense. At present, however, the data are not sufficiently complete to warrant their definition, so that the broader term has been continued in this report. As thus defined, the Lower Cretaceous rocks are exposed at the surface throughout a wide belt north of the Brooks Range that extends from the Anaktuvuk River westward as far as the coast of the Arctic Ocean and may also extend eastward for a long distance, though its continuity in that direction has not been demonstrated. There are strong reasons for believing, however, that certain of the beds in the Canning River region which Leffingwell has included in his Ignek formation may be the same as the proved Lower Cretaceous rocks farther west. It is because of this possible correlation and the fact that at the point where the Lower Cretaceous rocks were crossed by Schrader on the Anaktuvuk River the series had a considerable thickness that a considerable eastward extension of the rocks seems almost certain.

The tract in which these rocks are exposed at the surface is in most places about 15 miles wide, though its width is here and there diminished by faulting that has narrowed the outcrop and is elsewhere increased by duplication through folding or faulting. This condition

[40] Martin, G. C., Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, p. 466, 1926.

was especially marked in the western part of the area and in the eastern part near the Killik and Chandler Rivers.

The Lower Cretaceous rocks probably extend northward a considerable distance beyond their outcrop, but in that direction they are covered by rocks of later age, so that unless they have been brought up locally by folding or faulting it is improbable that they will be found at the surface north of latitude 69.° Undoubtedly, these rocks would be found in drill holes sunk north of that latitude, though, in general, at progressively greater depths.

South of the main belt of Lower Cretaceous rocks and forming more or less isolated areas within the Brooks Range are rocks which are correlated with the Lower Cretaceous. These areas undoubtedly represent infolded and infaulted blocks that have been brought into their present position by mountain-building forces during one of the episodes in the formation of the range. It would not be at all unexpected to find other inset blocks of Lower Cretaceous in some of the unexplored tracts elsewhere in the mountains between the Noatak and the Colville, and it is entirely probable that some may even be found in the unexplored region between the Kobuk and the Noatak. Such areas, however, would probably be small and, although of extreme interest in shedding light on the age and development of the range, would be of relatively no moment in solving the general problems of the economic geology of the region.

Between the proved Lower Cretaceous rocks on the Kokolik River and the supposed Lower Cretaceous rocks near Corwin there is an unexplored area of about 2,000 square miles that, if the interpretation now adopted is correct, is probably largely formed of these Lower Cretaceous rocks. The rocks at the margins of this area, however, have been subjected to great stresses, so that undoubtedly the same stresses have affected the rocks in the unknown area. Consequently it is believed that any Lower Cretaceous rocks that are found there will have been sliced so that their distribution will be more or less discontinuous and they will be interspersed between slices of rocks of different ages.

A very few miles south of the mapped area and only a short distance south of the Lockwood Hills are rocks that for a long time have been correlated with the Lower Cretaceous. As these rocks do not come into the area covered by this report, they may be dismissed here with the statement that they are of special significance in affording a means of comparing events on the south side of the Brooks Range in the Lower Cretaceous and later periods with those on the north side of the range. Unfortunately, however, this area of Lower Cretaceous rocks appears not to be very extensive but is more or less isolated in the midst of later deposits, so that it does not afford as complete information as could be desired.

LITHOLOGY

The lithologic characters of the Lower Cretaceous rocks recognized by Schrader on the Anaktuvuk River were described by him[41] as follows:

> The series consists essentially of impure sandstone or arkose with a little fine conglomerate. The sandstone is usually heavy bedded, beds 6 to 8 feet in thickness being common, and it is generally fine to medium grained but in some localities becomes so coarse as to be almost a grit. In color it ranges from dark or bluish gray to dirty greenish, while the coarser-grained rock often presents a speckled or salt-and-pepper appearance and is seen to be composed of the variously colored flints represented in the Stuver conglomerate. In fact, the color of the rock throughout seems to be determined largely by the relative abundance of the different-colored sediments from the Stuver series.

In the vicinity of the Killik and Chandler Rivers the rocks that have been correlated with the Lower Cretaceous are dominantly sandstone of moderately fine grain. No outcrops of grit or conglomerate were recognized, but the present river gravel contains a number of conglomerate boulders that may have come from this group of rocks. On the whole, exposures of the Lower Cretaceous rocks in the vicinity of these streams are poor, and much of the area in which these rocks occur is covered with outwash glacial material and moss. Therefore only a few outcrops were examined critically. At all of them the rocks were found to be rather thin bedded, soft, and ranging in color from yellow to greenish brown. In the sandstone that crops out near the small creek that joins the Killik River near camp M June 12 there are considerable amounts of sulphides, which on weathering have given the rock a blotchy, rusty appearance. The pyrite appears to have been introduced into the sandstone subsequent to the formation of the rock.

The next area west of the Killik River in which the Lower Cretaceous was examined in some detail was on the Etivluk. In that valley these rocks occur in two separate areas. The northern one is about 12 to 15 miles wide, and its northern margin is about 10 miles south of the junction of the Etivluk and Colville. The southern area is separated from the northern by a belt of Mississippian and Triassic rocks about 15 miles wide and is itself about 6 to 7 miles wide. The older rocks have apparently been brought into their present position by faults of great displacement. The rocks in the southern area are dominantly sandstone, arkose, grit, and fine conglomerate. Most of the sandstone beds are massive, and the coarse-

[41] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 75, 1904.

textured varieties make up the greater part of the unit. The individual beds are from a few inches to 5 feet thick. The rocks are very compact, and the grains are cemented together in large part by siliceous material, though a few examples were seen in which the cementing material is calcareous. The conglomeratic members are interbedded with the coarse sandstone and rarely contain pebbles more than half an inch in diameter. Most of the pebbles are various colored chert, presumably derived from the Lisburne or the Triassic formations. No pebbles of igneous material were recognized. The lowest strata examined in this area consist of about 60 feet of thin-bedded dark-gray carbonaceous shale and shaly sandstone. A few irregular nodular bands of siderite that weather to a bright-red color occur in the shale. Associated with the thin-bedded and fine-grained sandstone which occurs higher in the section are several thin beds of dark shale, some of which are as much as 1 foot thick. The rocks throughout the formation are almost invariably of a dark dull-greenish color, the only exception being a few beds that have a speckled pepper-and-salt appearance. The greenish color of the sandstone may be in part due to the large amount of greenish chert from the Triassic rocks which forms the individual grains.

In the northern area of rocks mapped as Lower Cretaceous on the Etivluk the lowest members occur in the hills near the southern margin of the area. The rocks there are coarse and fine conglomerate, grit, sandstone, and a minor amount of shale. The pebbles of the conglomerate range in size from small fragments to boulders 6 inches in diameter, but in probably the bulk of the conglomerate and gritty phases the pebbles are under 2 inches in diameter. The pebbles represent a great many different kinds of rock, though dark chert predominates. In addition to the chert fragments of gray and black shale that may represent Mississippian shale, limestone that probably came from the Lisburne limestone, and a number of different kinds of volcanic rock were distinguished in different pebbles. No granitic rocks were recognized in the pebbles, but search for them was not thorough enough to give definite proof of their absence. All the pebbles are well rounded and cemented together by a siliceous matrix that forms a considerable part of the rock mass. So firmly cemented together are many of the pebbles that in places the rock fractures indiscriminately across both the pebbles and the matrix. In other specimens, however, the cementation is not so strong and the pebbles break out of the matrix. The sandstone beds show a considerable range in size of grain, but all of them are of a dull greenish or bluish-gray color when seen close at hand, though appearing very dark—nearly black—when seen at a distance. The shale members are dark and thin bedded.

The same general sequence of rocks as was observed in the northern area of Lower Cretaceous on the Etivluk continues westward and was intersected at several places between that stream and the heads of the Utukok and the Colville. The conglomeratic beds are well exposed in the hills 10 miles south of camp G June 30, the hills at the head of Meridian Creek near camp F September 3–7, and the hills at the head of the Utukok just north of camp G April 29. In these places, as on the Etivluk, the pebbles in the conglomerate consist dominantly of chert with a subordinate number of shale, limestone, and a variety of igneous rocks. In addition to the conglomerate beds this group of rocks consists of alternating beds of sandstone and shale. The sandstone forms the greater part of the section and is usually in fairly massive beds. In color it is generally dark gray or greenish brown, appearing dark in the distance.

In the vicinity of the Kivalina, Kukpuk, Kukpowruk, and Kokolik Rivers the Lower Cretaceous rocks are dominantly sandstone, with subordinate amounts of shale. At a point 1½ miles east of camp P April 16 is a small exposure of conglomerate that probably marks the basal member of these rocks in that region. It was found in a region that had suffered considerable faulting, and its continuation could not be traced along the strike for more than a few yards. The pebbles in this conglomerate were of all sizes up to 6 inches in largest diameter and consisted mainly of chert fragments, though many of them were formed of various igneous rocks. Well-rounded pebbles of a conglomerate made up of more or less angular fragments of chert and other rocks were found. These pebbles were light colored and could readily be mistaken for granite. The rock was rather firmly cemented, but the pebbles broke away from the matrix when the rock was fractured. No limestone pebbles were recognized, though limestone crops out not very far away from the conglomerate and stratigraphically below it. Above the conglomerate are fairly heavy sandstone beds separated from one another by subordinate amounts of shale. These rocks are dark greenish brown or gray-brown and produce relatively subdued topography. The sequence of these rocks has been too badly disturbed by folding and faulting to permit a final statement regarding the stratigraphic succession of the several members, but the general impression gained from the many exposures visited in the field was that the proportion of shale to sandstone was small in the lower part of the section but was reversed and became greater in the upper part, so that in that part the shale was dominant.

In almost all these sandstones in the Kivalina-Kukpowruk region flakes of mica that had been derived from the preexisting rocks were readily recognized in the hand specimens. In some of the rocks comminuted fragments of vegetation were also recognized, but they appeared similar to the trash that is frequently seen along modern beaches. Many of the strata show remarkably developed ripple marks, some of them 6 inches or more between successive crests and others only an inch or so. Scour marks and current wash are also common. Many of the surfaces show peculiar blobs of mud whose origin is indeterminate. Some of these resemble the little irregular piles of mud that drip from the melting snow banks or cakes of aufeis of the present day. Trails of bygone animals, raindrop impressions, and other features that give an intimate insight into the conditions that prevailed when these rocks were being deposited are fairly widespread. In some of the sandstone beds are small flattened lumps of what was formerly mud that give the rocks a conglomeratic appearance, and as these usually weather out quickly on exposed surfaces they leave circular pits that strongly resemble molds of fossils.

The rocks in the area which has long been regarded as formed of Lower Cretaceous strata and which stretches inland from the coast between Wevok and Corwin are described by Collier [42] as follows:

> Lithologically this formation consists of sandstones and shales with the former in the ascendant. The sandstone beds range in thickness from a few inches to 20 or more feet. They resemble the sandstones of the Corwin formation but taken as a whole are probably somewhat less gritty and contain no conglomeratic material. The shales which are interbedded with the sandstone are dark-colored and sometimes micaceous, so that they have a silvery sheen on the bedding faces. In a few instances ripple marking was observed on shaly beds.

The Lower Cretaceous rocks on the south side of the Brooks Range in the central part of the Koyukuk region are described by Schrader [43] as consisting of pinkish to reddish limestone, which is associated with igneous amygdaloids and andesitic tuffs, together with some dark shale, slate, and sandstone or arkose. In the Zane Hills, in the same general region, Smith [44] reported the entire absence of limestone in these rocks, which there consisted of agglomerate and arkosic beds associated with basic intrusive and effusive rocks cut by acidic intrusives. These rocks are characteristically dark colored, generally greenish but here and there dark red. Some conglomerate beds were recognized in which the pebbles were mainly of dark igneous rocks. Ferromagnesian minerals are common and appear as

[42] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 30, 1906.

[43] Schrader, F. C., U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 476–477, 1900; U. S. Geol. Survey Prof. Paper 20, p. 77, 1904.

[44] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 80–81, 1913.

glistening crystal faces on freshly broken specimens. Generally, however, the rocks are too fine grained to allow determination of their component minerals by the unaided eye. The rocks are thoroughly compacted, so that usually they break across the grains and pebbles rather than around them.

STRUCTURE AND THICKNESS

Although on the whole the structure of the Lower Cretaceous rocks does not appear to be as complex as that of the other formations already described, it is nevertheless highly involved and has been affected by enormous diastrophic movements and stresses. As a result it is not always possible to determine by direct observation at a single locality the true major structure, because local overturns or reversals through faulting in many places give apparent relations that are exactly the opposite of the true relations. For instance, at many places along the north front of the Brooks Range the dip of these rocks would indicate that these rocks underlie the older rocks, such as the Lisburne limestone or the Triassic chert, but the fossils clearly prove that this is not the real relation. At places along the north front of the range great overthrust faults have reversed the normal stratigraphic sequence. Several large tracts of Lower Cretaceous rocks, separate from the main outcrop of this formation, have been inset among rocks of widely different age, through profound faulting and folding.

Although in detail the structure of these rocks is extremely complex, in a broad way the rocks appear to have a general outward dip from the axis of the main range, so that on the north side of the range, where they are most extensively developed, the general resultant of their various dips is to give the formations as a whole a dominant dip northward. Unfortunately the tract in which these rocks can be well studied in surface exposures is too narrow to allow a very extended analysis of their structure, but the very distinct impression was obtained that the structure is much more complex near the present mountain front and becomes progressively simpler toward the north. In other words, overturned folds are perhaps the dominant characteristic of the Lower Cretaceous rocks near the mountains, whereas some miles northward the folds become more open, nearly symmetrical, and much decreased in height.

The desirability of corroborating this impression is obvious, because one of the criteria that has been more or less relied on to distinguish these rocks from some of the younger rocks has been their greater amount of deformation. Therefore, if greater deformation does not indicate difference in age but is due mainly to position with respect to the abutment against which the rocks were thrust or folded, it is evidently not a safe criterion.

Conclusive data on this point are not easy to obtain, because almost everywhere the possibility that the apparent sequence has been brought about by faulting must be disproved, and this is usually impossible without more detailed work than the time available permits. Furthermore, in this area on the whole the older rocks naturally lie close to the mountains, whereas the younger ones usually lie at more remote distances. One of the clearest examples tending to prove that the Lower Cretaceous rocks are in reality more deformed than the overlying rocks was recorded by W. R. Smith in the upper part of the Colville Valley near camp G June 11. At that place structure similar to that shown in Figure 13 was observed and

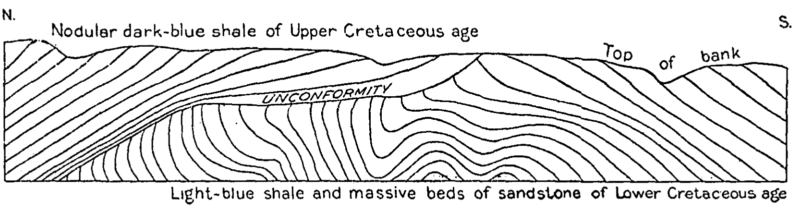

FIGURE 13.—Sketch showing structural relation of Cretaceous rocks on Colville River near Reynard Creek

is interpreted as showing that the rocks at the south, which are correlated with the Lower Cretaceous, are unconformably overlain by less deformed rocks toward the north. W. R. Smith believes that he recognized the same unconformity at several other places in the valley of the Colville.

The complexity of the folding in these beds close to the mountains is illustrated by Plate 23, *A*, which shows the contorted and closely folded sandstone and shale on the Kukpuk River near camp P April 25. This is not only an area of strong general regional folding but also is in close proximity to a thrust fault of profound displacement. Contrasted with this small complex folding and mashing is the large regional folding such as is illustrated in Plate 23, *B*, which shows the rocks in the vicinity of camp G June 18, on the Colville a short distance below the Nuka River. This exposure apparently lies not far from the junction of the Lower Cretaceous series and overlying rocks and is rather remote from the mountain front. Even here, however, there are numerous reversals of dip and some faulting within relatively short distances.

In the general belt of Lower Cretaceous rocks that extends westward from the Etivluk to the Utukok the observed dips range from vertical to about 60° either north or south, the dip on the south flank of an anticline being usually steeper than that on its north flank. Repetition of the same bed by folding was generally not possible to prove, as the individual beds are not readily identifiable for any distance, but it seems probable that some of the observed changes in dip from north to south are due to faults rather than to sharp folds.

Schrader[45] describes the strike of the Lower Cretaceous rocks on the Anaktuvuk as dominantly east. He says:

Broadly considered, the structure seems monoclinal. The rocks in general dip gently northward at varying angles, but subordinate gentle anticlinal and synclinal folds are present, the latter being occasionally open. These were probably caused by the same mountain-building forces that were exerted in the range to the south. This is suggested by the fact that the trend of the more pronounced folds in the plateau is parallel with the main folding of the range, as if all belonged to the same system.

The structure of the supposed Lower Cretaceous rocks in the region east of Cape Lisburne is thus described by Collier:[46]

The structure of the formation, while it consists of simple open folds near its boundary with the Corwin, becomes increasingly complicated as the fault at the contact with the Carboniferous rocks is approached. Overturned folds and minor thrust faults with axes extending in a general way northwest and southeast are typical features.

Collier, however, decided that these rocks overlie the rocks to the north, whereas the present writers consider that they underlie those rocks. The evidence on which Collier based his decision was not conclusive, for he wrote[47]

The exact contact of this formation with the Corwin was not exposed, or if observed its significance was not understood, though the field relations of the two formations are definitely known at a number of localities. Continuous sedimentation and conformity between the formations are indicated, though the possibility of thrust faulting along the contact should not be overlooked.

Inasmuch, therefore, as the possibility was recognized by Collier that the contact was not the actual depositional contact but might be due to faulting and as that alternative seems to fit better with the data now available from a number of relatively near-by localities, it has been accepted for the present report. Under this interpretation the northern boundary between the Lower Cretaceous rocks and the overlying rocks in the Lisburne region is regarded as probably a fault contact, with the beds south of the fault possibly being overturned. Some slight corroborative evidence in support of this interpretation is found in the fact that the southern contact of these rocks against the Triassic is a great overthrust fault, and another fault somewhat farther north is also indicated in the structure section accompanying Collier's report. According to Collier's interpretation the fault be-

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45 Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 75, 1904.

46 Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 31, 1906.

47 Idem, p. 30.

tween the Lower Cretaceous and the Triassic rocks entirely cut out the 15,000 feet or more of the Corwin formation.

The structure of the Lower Cretaceous rocks in the Zane Hills south of the Brooks Range and south of the region specifically described in this report, is said by Smith[48] to be in general anticlinal, with the axis trending northwest. The structure is not simple, however; minor faults have been recognized, and more profound ones have been indicated as probable. The absence of Lower Cretaceous rocks between the Paleozoic rocks on the Kobuk and the overlying Upper Cretaceous rocks, described below, is believed to be due to the masking of the older rocks by the overlap of the later sediments.

The structural relations of the Lower Cretaceous rocks to the older rocks in all exposures that have been studied in northwestern Alaska is believed to be unconformable where the sequence is normal, though, as has already been pointed out, at many places the present relations are highly varied because of faulting and folding subsequent to the deposition of these rocks. Not only is the relation indicated by direct observations of the structure but it is also corroborated by the fragments of the older rocks that are found making up some of the Lower Cretaceous beds. The structural relation of the Lower Cretaceous rocks to the younger rocks in many places is also believed to be unconformable, though data on this point are less conclusive. This relation has already been discussed at some length, and the clearest example of the apparent unconformity between the Upper and Lower Cretaceous rocks is illustrated by Figure 13.

Enough has doubtless been said regarding the complexity of the structure to show that any estimate of the thickness of these rocks can be regarded as at best only a crude approximation. Schrader, who was well aware of the inadequacy of the data for making a guess as to the thickness of this formation on the Anaktuvuk River, considered a thickness of 2,000 feet a minimum. W. R. Smith, from his studies in the Utukok, Colville, and Etivluk Valleys, reached the conclusion that the thickness in that region could not be less than 10,000 feet. Collier also admitted the impossibility of determining accurately the thickness of these rocks in the Lisburne region, but he believed that they could not be less than 5,000 feet nor more than 15,000 feet thick and for the purposes of his report assumed their thickness to be 10,000 feet. P. S. Smith made no estimate of the thickness of the Lower Cretaceous rocks of the Zane Hills. From the various estimates, which admittedly are extremely uncertain, it is none the less apparent that there is a very great thickness of these rocks and that 10,000 feet may be regarded as a crude approxima-

[48] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 81–82, 1913.

tion of their true thickness. So great a thickness of rocks laid down in relatively shallow water and relatively near shore presents many problems that are difficult to explain thoroughly.

AGE AND CORRELATION

The original collections from which the Lower Cretaceous age of certain rocks in northwestern Alaska was recognized were obtained by Schrader in the valley of the Anaktuvuk River. These collections were identified by Stanton as containing the single fossil *Aucella crassicollis* Keyserling. The most southern locality on the Anaktuvuk at which this fossil was found lies about 8 miles north of the southern border of the tract mapped as Lower Cretaceous, so that possibly the fossil comes from a stratigraphic position considerably above the base of the formation.

No Lower Cretaceous fossils were collected on the Killik. The rocks on that stream which are assigned to the Lower Cretaceous are so placed because of their stratigraphic position and general relations to the rocks on the Anaktuvuk River.

In the northern tract of Lower Cretaceous rocks on the Etivluk River, W. R. Smith obtained fossils which were identified by J. B. Reeside, jr., as follows:

13311 (25ASmF7). 8½ miles upstream from mouth of Etivluk River. *Holostephanus* sp. Lower Cretaceous.

Near this same place in 1924 P. S. Smith obtained an indefinite fossil concerning which Reeside stated:

12476 (24AS46). Etivluk River above camp S July 6. Ammonite fragment. Probably Cretaceous but not sufficient for close age determination.

In the southern area of Lower Cretaceous rocks on the Etivluk River W. R. Smith made a collection which was identified by Reeside as follows:

13313 (25ASmF9). 40 miles upstream from mouth of Etivluk River. *Aucella* cf. *A. crassicollis* Keyserling. Lower Cretaceous.

Farther west, in the headwaters of the Utukok River, W. R. Smith collected fossils which were identified by Reeside as follows:

13309 (25ASmF5). 4 miles downstream from head of Utukok River pass. *Aucella crassicollis* Keyserling. Lower Cretaceous.

In the valley of the Kivalina River a short distance above camp P April 16 P. S. Smith made a small collection which was definitely identified by Reeside as follows:

13716 (26AS19). Three-quarters of a mile above camp P April 16, Kivalina River. *Aucella crassicollis* Keyserling. Lower Cretaceous.

No fossils have been found in the rocks immediately east of Cape Lisburne that are correlated with the Lower Cretaceous. Their correlation is based entirely on their areal and stratigraphic relations to the rocks in adjacent areas, and this basis has been fully discussed in preceding portions of this report. Unquestionably there is still room for difference of opinion as to the age, but the interpretation that has been adopted here seems to fit best all the facts that are now known.

The age of the Lower Cretaceous rocks on the Koyukuk River south of the mapped area was determined from fossils collected by Schrader at two localities near Waite Island, about 70 miles southwest of Allakaket. The fossils from both these places were determined by T. W. Stanton as *Aucella crassicollis* Keyserling. In this area the rocks differ somewhat lithologically from the Lower Cretaceous rocks north of the Brooks Range in that they are described as pink impure limestones about 800 feet thick.

Nowhere in the region east of the Colville and north of the Brooks Range have Lower Cretaceous fossils been recognized. It is highly probable, however, that some of the rocks in the Canning River region that were included by Leffingwell in the Ignek formation, of questionable Jurassic age, may be Lower Cretaceous. In the absence of any definite data on this subject there is not justification at this time for regarding this suggestion as more than a surmise.

Lower Cretaceous rocks are widely represented throughout Alaska from the southeastern part to this northern part. They are also known in the Copper River region, the central and eastern Yukon-Tanana region, and the lower Kuskokwim region. The general history of this geologic period has been summarized by Martin [49] as follows:

> In general, it is believed that the Lower Cretaceous deposits were laid down in all the larger geographic provinces, but probably not over the entire area of the Territory. The extent of the Lower Cretaceous seas, so far as known, was not limited along the lines of any of the existing geographic features.

Martin further expresses the belief that the Lower Cretaceous seas were more extensive than those of the Upper Cretaceous. In all the Alaskan localities so far known the Lower Cretaceous rocks were dominantly laid down under marine conditions, and, although some plant remains have been found in these rocks, their presence does not materially modify this conclusion.

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[49] Martin, G. C., Mesozoic stratigraphy of Alaska: U. S. Geol. Survey Bull. 776, p. 287, 1926.

UPPER CRETACEOUS SERIES

DISTRIBUTION

North of the Brooks Range from about latitude 69° northward the hard rocks are dominantly sandstone and shale which are considered to be of Upper Cretaceous age. If the overlying unconsolidated deposits of sand and gravel were stripped off, these rocks would probably form the surface of almost all the country north of that latitude as far as the Arctic Ocean. Areally, therefore, these rocks occupy a far greater tract of country than any of the others so far described. The rocks have been recognized and studied on the Anaktuvuk River and the northern part of the Colville River by Schrader, who described them under the names Nanushuk "series" and Colville "series." They were traversed by the Geological Survey expedition of 1923 along the northwest coast of Alaska, including the Kukpowruk, Utukok, and Meade Rivers, and by the expedition of 1924 on the Killik, Chandler, Colville, Etivluk, and Awuna Rivers, in the drainage basin of the Colville; on the Kigalik and Ikpikpuk Rivers and Maybe Creek, in the basin of the Ikpikpuk; and on the Kuk, Kaolak, and Utukok Rivers. They were critically studied by the expedition of 1925 in the headwaters of the Utukok and Colville Rivers as far downstream as the Etivluk and up that river. They were examined on the Kukpowruk and Kokolik Rivers by the expedition of 1926, which also reexamined certain of the outcrops on the Kuk and extended the surveys into the valley of the Avalik River and Peard Bay and its tributary, the Kukroak River. In the region between Corwin and Cape Beaufort these rocks were among the earliest recognized, and they have been successively described by a number of geologists, the latest of whom, Collier, brought back the most complete and authoritative statements regarding their distribution. No Upper Cretaceous rocks have been recognized in that part of northern Alaska which lies east of the Colville, though it seems probable that they extend into that region.

South of the Brooks Range rocks that are correlated with the Upper Cretaceous were recognized in 1899 by Schrader on the Koyukuk. In 1901 Schrader mapped these rocks on the John River and adjacent parts of the Koyukuk, and in that same year Mendenhall noted them on the Alatna and at several places near the upper part of the Kobuk Valley. In 1909 Smith examined the Upper Cretaceous rocks that form a large part of the country between the Yukon and Seward Peninsula, which, though outside the specific area covered by this report, is useful in giving insight into the general geology of the near-by region. In 1910 Smith examined these rocks in the Lockwood Hills, south of the Kobuk, and in some of the areas already visited by Mendenhall north of this river. In 1911 the Upper Cretaceous rocks on the Alatna River were reexamined by Smith, and the winter expedition of 1924 also traversed this section of the river, though little time was spent on the geology of this part.

On the whole, therefore, it is evident that these rocks have been seen in widely distributed sections by a number of different observers. Although on Plate 2 these rocks have been represented only in those areas where they have been actually examined in some detail, it is obvious that they extend into many of the unsurveyed areas that have been left blank. There is therefore little hesitancy in asserting that probably these rocks form the surface or underlie practically all the unsurveyed areas north of the east-west section of the Colville Valley and much of the unsurveyed area south of the Kobuk in the Selawik Valley.

LITHOLOGY

The Upper Cretaceous rocks north of the Brooks Range are dominantly shale and sandstone. Because of its greater resistance the sandstone is usually more conspicuous than its abundance relative to the shale would warrant, so that usually the traveler takes more note of the sandstone that caps the low hills or forms bluffs along the streams than of the shale, which makes few outcrops or noteworthy features. Near the base of these rocks sandstone probably forms the bulk of the strata. This sandstone is probably marine, though it contains some plant fragments and sticks that were derived from the near-by lands. The middle part of this group of rocks is composed dominantly of shale, with subordinate amount of sandstone. It is in this section that coal beds are most numerous and indicate by their presence that those rocks were formed in swamps and sheltered waters, mainly under land conditions. The upper part of the section of Upper Cretaceous rocks again appears to be composed mainly of marine sediments and includes more sandstone than shale.

Schrader[50] in his description of the Nanushuk "series" on the Anaktuvuk River states:

> The beds range from 3 to 6 inches in thickness and exhibit rapid alternation. They consist of gray and brown sandstone, generally fine grained and sometimes friable, with some gray and impure fossiliferous limestone, dark shale, fine-grained gray quartzite, drab-colored and green chert, and black slate stained reddish along the joints. Coal of good quality is also present.

In no other place, however, has quartzite or chert been found as distinct beds in this formation, and there is some uncertainty as to

[50] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 79, 1904.

whether these rocks were actually seen as beds in this formation or were only particles in the rocks. The latter explanation seems more probable, but if they actually occur as beds it seems likely that they occur in an area where local faulting has brought Triassic or older rocks up to the surface. The typical appearance of the rocks regarded by Schrader as of Upper Cretaceous age is shown by Plate 24, *A*.

The writers have also included in this series the lower of the rocks referred by Schrader to the Colville "series" on the Anaktuvuk River. He described the lithology of the entire sequence of these rocks as follows:[51]

> The series consists principally of heavy bedded silts, soft sandstone, limestone, shale, and lignite. * * * The lower Colville contains the more indurated class of rocks and consists mainly of partly consolidated silts in beds 6 to 8 feet in thickness. They are usually light slate-colored or ash-colored and constitute about one-half of the lower Colville section and are generally much less consolidated toward the top than near the base. The harder rocks, which increase in volume toward the base of the section, include impure dull-gray medium to fine grained sandstone with detrital lignitic plant remains; slate-colored and brownish calcareous shale with disseminated undeterminable vegetable detritus; lignitic coal in layers 1 to 5 feet in thickness; dark slate-colored or brownish chert containing cavities incrusted with chalcedonic silica; rusty brown, very ferruginous sandstone or impure ironstone; and some iron-stained siliceous conglomerate, which also contains lignitic vegetable remains. There are also a few layers of hardened silts, forming a rock of very fine texture resembling soft, smooth honestone.

The lithology of the Upper Cretaceous rocks in the western part of the Colville Valley and at the head of the Utukok was described by W. R. Smith in some unpublished notes from which the following statements are abstracted. Shale is the most abundant rock. It occurs in thin beds making up a section of several hundred feet and also in thin beds alternating with sandstone. It is usually soft and commonly nodular and ranges in color from light bluish gray to black, and certain beds weather light yellow or pink. At the base of the formation as exposed near camp G May 30 and camp G June 19 a dark-blue nodular shale rests unconformably on the Lower Cretaceous rocks. Layers of light-gray fine-grained sandstone or sandy shale from 1 to 4 inches thick are interbedded at irregular intervals with the shale. Ellipsoidal shale nodules give a rather massive appearance to the rock at certain horizons. The nodular beds, which are from 3 to 6 feet thick, are separated by beds of relatively hard thin-bedded shale or sandstone. The nodules weather into conchoidal fragments and do not contain a central nucleus.

Above the shale is a massive sandstone which forms an important horizon marker. This sandstone is about 80 feet thick, is medium

[51] Idem, pp. 82, 83.

grained and cross-bedded, and ranges from light gray to dull greenish. It is the thickest sandstone member noted in this part of the field and forms the uppermost bed on many of the flat-topped hills north of the Colville. The outcrop of this member is generally marked by precipitous cliffs 40 feet or more high, at whose base are steep talus slopes formed of the large slabs broken from the cliffs by frost and other weathering processes. In the central part of the Colville Valley, near the mouth of the Etivluk, this sandstone is much less massive, as it splits up into thinner beds separated by shale partings.

A petrographic examination of the sandstone collected at different points within the Colville Valley shows the presence of subangular grains of quartz, quartzite, chert, feldspar, pyroxene, and a little mica, generally contained in a somewhat calcareous or ferruginous groundmass. Pebbly sandstone and thin irregular lenses of fine conglomerate occur, with a few beds of coarse sandstone, but they are by no means numerous. The pebbles in the conglomerate are chiefly chert of various colors. The coarse beds of sandstone are strongly cross-bedded. The fine-grained beds are notably ripple marked, and many of the beds show an intensely corrugated appearance over the entire exposed surface. The appearance of a typical exposure of these Upper Cretaceous rocks on the Etivluk is shown by Plate 24, *B*.

In the southern part of the valleys of the Kukpowruk and Kokolik Rivers these rocks include a considerable thickness of dark soft shale overlain by alternating beds of sandstone and shale whose layering, as developed by weathering, produces distinctive topographic forms readily identified at long range. Some of the sandstone beds are 20 feet or more thick, and many of them show cross-bedding. At several places a few pebbles are irregularly distributed through the sandstone. These pebbles are not very smooth and are almost exclusively chert. Few of them are more than an inch in diameter, but some 5 inches in diameter were found, especially near the summit of the hill west of camp P June 6. In addition there are numerous layers in which conglomerate of the "mud lump" type was noted. These layers are usually only a few inches thick, but they occur at several different positions in the stratigraphic column.

The rocks have been folded into so many anticlines and synclines that the higher rocks in the sequence do not occupy large areas south of a line near camp P June 12, where the coal-bearing part of the sequence appears. These beds are dominantly shale with subordinate amounts of sandstone and coal beds and lithologically do not differ from those seen farther south. The same sporadic pebbles of chert are found in many of the sandstone beds, and hardened mud lumps with sandstone occur at several horizons. Fragments of vegetation are more common, and in some of the beds there is a good deal of silicified wood, some of which is in pieces 6 inches or more in diameter and several feet long. This is apparently the same part of the series that was found on the Awuna River, where silicified logs are common and stratigraphically are not far from beds of coal.

One of the sandstone beds found near camp P June 12 had a somewhat unusual appearance due to the crystallization of calcareous material, which produced shining crystals that at casual glance gave the rock almost a porphyritic appearance. When examined under the microscope this rock was found to consist of subangular and rounded detrital grains of quartz, slate, chert, and acidic plagioclase feldspar in a groundmass consisting largely of calcite that showed signs of incipient recrystallization. Near this outcrop the sandstone and shale were intersected by numerous seams of calcite in the form of small veins or fracture fillings.

Another unusual phase of the sandstone was found by W. T. Foran in the central part of the Utukok Valley. This is a black rock which weathers to a yellowish brown on exposed surface, is of medium fine grain, and occurs in a bed about 2 feet thick. A chemical and microscopic study of a specimen from this bed shows that the rock is composed of small black spherulites of siderite in a fine greenish-black glauconitic cement. The siderite spherulites give no evidence of having replaced oolitic limestone, as they have none of the concentric structure commonly found in oolite. W. R. Smith has suggested that the water in which this bed was deposited may have been saturated with iron, and that it mixed with carbonate waters brought down by the rivers, and at favorable localities precipitated the iron in the form of ferrous carbonate. It is very difficult to reconstruct the conditions under which this might have taken place without leaving some other evidence of its occurrence, so that the final explanation of this curious deposit must await further data from the field.

Rocks that are now correlated with these Upper Cretaceous beds were studied on the Kukpowruk, lower Utukok, Kuk, and Meade Rivers by the geologists of the expedition of 1923 and were described as follows:[52]

> A thick series of sandstone, shale, thin-bedded limestone, and associated beds of coals extends from Cape Beaufort westward to the Cape Lisburne region. These rocks are believed to extend eastward to and beyond Cape Simpson and inland at least 80 miles south of the coast at Meade River.
>
> The sandstone is gray where fresh, but weathers to a yellow or buff color. It is medium to fine grained, grades in places into shale and rarely into conglomerate, and in general is of normal types that were laid down at the margin

[52] Paige, Sidney, and others, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, p. 12, 1925.

of the sea by rivers and streams that entered it. Cross-bedding and ripple marks are locally abundant.

The shale is gray to yellow, many beds are fine-grained mudrocks, and some beds are darkened by an appreciable amount of carbonaceous débris. In places it grades into sandy shale or sandstone, of which shale is the normal accompaniment in deposition of the type suggested above.

The limestone is gray to brownish and occurs in beds intercalated with the shale, into which it grades. It was noted only in very thin layers or as nodular concretions.

The coal that accompanies these rocks is abundant and occurs in beds of workable thickness. In the regions of strong folding it is bituminous, and in the less-disturbed regions it is of subbituminous rank.

The field appearance of the Upper Cretaceous rocks in the northern part of the region is shown by Plate 25, which gives characteristic views on the coast near Peard Bay and on the Avalik River. Other views which show principally the coals of this formation appear in Plates 30, 32, 33, and 34.

Rather near the top of the section of Upper Cretaceous rocks, as now distinguished, and interstratified with the shale and sandstone are several beds of bentonite. These beds have been recognized on the Kigalik River, a tributary of the Ikpikpuk River, near camp S August 4 and on the main stream at several places farther north. They were also recognized in the central part of the Utukok Valley and at a number of places on the Avalik and Kaolak Rivers. Bentonite is a hydrous aluminum silicate that is extremely plastic and has the property of absorbing enormous quantities of water. It is generally regarded as representing a decomposition product that has been formed by the breaking down of a deposit of volcanic dust. It forms a puttylike substance that is exceedingly sticky and becomes almost untraversable when wet. Specimens of this material were examined petrographically by C. S. Ross, who reported as follows:

I have concentrated and determined the phenocrysts associated with this bentonite specimen [collected on the Kigalik River]. They are predominantly oligoclase-andesine of approximately the composition $Ab_{30}An_{70}$, with smaller proportions of orthoclase and biotite. The material contains little or no quartz. This indicates that the original rock was a latite or sodic andesite, and that there was no mixing with foreign material. Thus the bentonite is the result of the alteration of a clean ash fall and is not reworked or mixed with other detrital material.

Other material from a locality on the Avalik River was later submitted to Mr. Ross, who states:

The bentonitic material from the Avalik River when examined in thin section showed no structures that retained the habit of glassy volcanic ash. This was not due to their destruction when the material was collected but probably to reworking before final deposition. The dominant clay mineral was of the type characteristic of bentonite, but this can not be accepted as definite evidence of volcanic origin. More significant is the presence of a very large proportion of perfectly fresh plagioclase among the mineral grains and an unusually large amount of biotite in very perfect euhedral crystals. Quartz is the most abundant material among the crystal grains after washing out the clay. Quartz and plagioclase are in sharply angular grains which indicate an absence of extensive transportation by water. The fresh plagioclase and especially the euhedral biotite crystals seem to indicate that the clay is derived from volcanic ash, even though there is a lack of evidence through the presence of volcanic glass structures.

A few well-rounded reddish grains of quartz are present, and these appear to be quite different in mode of origin from the more abundant angular quartz. The presence of this rounded quartz of detrital origin also confirms the impression that there has been a certain amount of reworking of the material.

The specimen contained small crystals of a second clay mineral (probably anauxite) that I have long tried to isolate for analysis.

The lithology of the rocks in the vicinity of Corwin and extending along the coast as far east as Cape Beaufort was described by Collier [53] as follows:

Lithologically the formation consists of rather thinly bedded shales, sandstones, conglomerates, and coal beds. Fossil plants occur in the shales wherever they have been closely examined. The shales which comprise the greater part of the formation vary in composition from greenish-brown calcareous to black carbonaceous beds and in texture from mudstone to fine-grained sandy shales. The sandstones which occur at infrequent intervals through the formation in beds less than 10 feet thick are easily traceable over eroded areas, since their outcrops rise in relief above the surrounding shales.

The conglomerates are made up mainly of quartz and chert pebbles from one-half inch to 4 inches in diameter. The most definite bed of this kind, which is about 15 feet in thickness and reaches the coast at Corwin Bluff, forms a prominent ridge from 100 to 200 feet high. * * * This ridge, with the conglomerate of which it is composed, has been traced continuously to the southeast for about 15 miles. Since it extends in a nearly straight line and is not deeply covered by tundra growths, it is the usual route followed by natives in traveling overland from Corwin Bluff to Pitmegea and Kukpowruk Rivers, and it is almost invariably indicated on the maps drawn by them. On account of its persistence and the ease with which it can be traced and identified, this conglomerate bed offers a definite key to the structure of the formation over a large area and indicates the absence of any extensive faults in the portion of the field shown on the map.

The stratigraphic section given by Collier, which clearly indicates the varied lithologic aspect of the rocks exposed in the region near Corwin, is here reproduced as Figure 14.

The recognized Upper Cretaceous rocks south of the Brooks Range are dominantly a series of dark greenish-gray arkosic conglomerate and sandstone. The observations of the geologists who have studied these rocks were summarized by Smith [54] as follows:

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[53] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 27–28, 1906.

[54] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 84–85, 1913.

The base of the section exposed on Alatna River, on the lower part of John River, and on the upper part of the Kobuk is a conglomerate made up of pebbles of the older rocks, namely, schists, limestones, vein quartz, and igneous rocks, such as greenstones and granites. The beds are thoroughly indurated and are usually more resistant than the higher sandstones. As a result they form conspicuous pinnacled ridges. * * * This division corresponds closely in all physical features with the Ungalik conglomerate, of probable Upper Cretaceous age, described in the extreme eastern part of Seward Peninsula and adjacent Norton Bay region.

Toward the top of the lower division sandstones become more numerous, and at its top the group is composed almost entirely of sandstones which are practically indistinguishable from the sandstones of the Shaktolik group of the more southern part of the Koyukuk Basin. The rock is medium fine grained, of rather uniform texture, and generally of a greenish-gray color. It is thoroughly indurated and offers fair resistance to weathering—not so great resistance, however, as the rocks already described. As a result the sandstone portion of the Bergman group generally forms somewhat rounded, coarsely dissected hills of medium elevation.

The rock contains abundant fragments of rather angular ferromagnesian minerals and feldspars, whose glittering faces and partial crystal outline resemble the phenocrysts of an igneous rock. Generally the beds are rather massive, showing no pronounced stratification. At many places, however, beds of dark shale interlaminated with the sandstones serve to bring out the structure. No extensive exposures of the shales were observed by the expeditions of 1910 or 1911, but Mendenhall notes belts of shale many hundred feet thick. He also notes red and green shales in the Kobuk Basin near Lake Nutavukti, but such shales have not been recognized in other parts of the region.

Fragments of what appears to be wood and lignitic beds have been found here and there in the sandstone member. A bed of lignite occurs in the hills immediately east of Pah River, and another near Tramway Bar on the North Fork of the Koyukuk, but both beds are apparently thin and of poor quality.

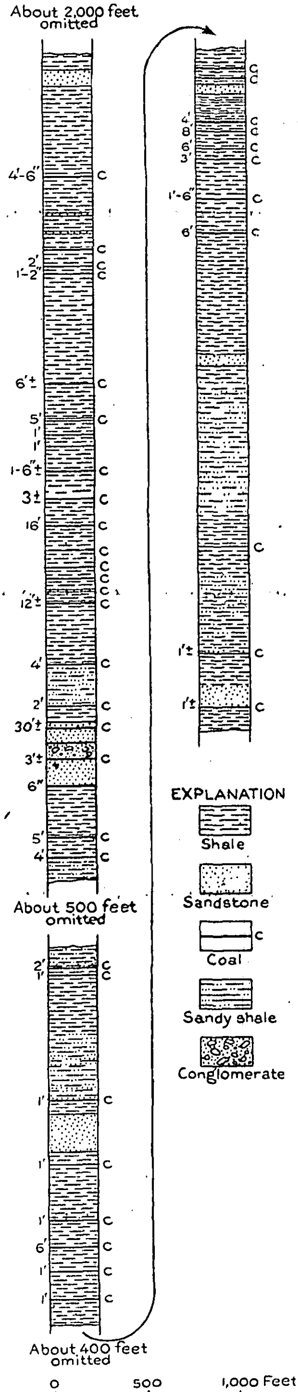


Figure 14.—Columnar section of rocks near Corwin. By A. J. Collier (U. S. Geol. Survey Bull. 278, pl. 9. 1906)

STRUCTURE AND THICKNESS

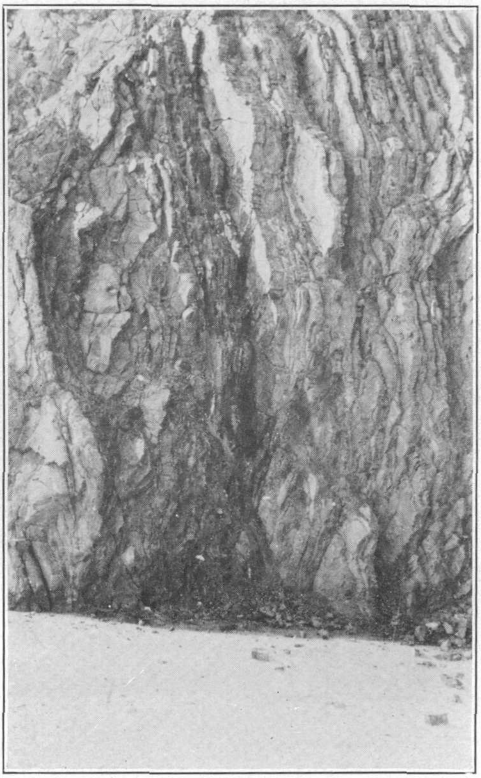
The Upper Cretaceous rocks appear to have been involved in part of the deformation that gave rise to the Brooks Range. As a result they dip in general outward from the flanks of this range at angles that become progressively less away from the range. There are strong reasons, however, for believing that they experienced only the later part of this mountain-building deformation, because, on the whole, they are much less complexly folded than the older rocks. As has already been noted, this conclusion is not yet fully substantiated, because these rocks now lie farther from the center of the range than the older rocks and therefore might well be less deformed. However, the absence of any areas of the Upper Cretaceous rocks well within the range and the fact that there is considerable difference in lithology between these rocks on the northern and southern flanks lend support to the view that the range was already well blocked out before these rocks were laid down and that the northern area was quite separate from the southern area.

Although these rocks are less deformed than the older rocks, they are by no means little affected by folds and faults. At many places the beds stand vertical, and faults, on some of which apparently considerable movement has taken place, have been recognized. The dips appear steeper in the areas near the older rocks, and on the whole they become less in the more remote areas, in many of which the beds appear essentially flat. There are, however, few places where there are not some folds, and this fact is of special significance in considering the structural possibilities of these rocks for trapping oil that may have migrated in them. North of the Colville, in the vicinity of Lookout Ridge, these rocks are warped into broad, gentle anticlines and synclines, the dip of whose limbs in few places exceeds 18°. One of the most noteworthy flexures of this sort is a well-defined anticline that crosses Disappointment Creek some 15 miles north of the Colville and extends in an east-west direction for 30 miles. The crest of the anticline is cut across by Disappointment Creek and the Utukok River. The flanks dip from 5° to 16° and form long ridges plainly recognizable from a distance.

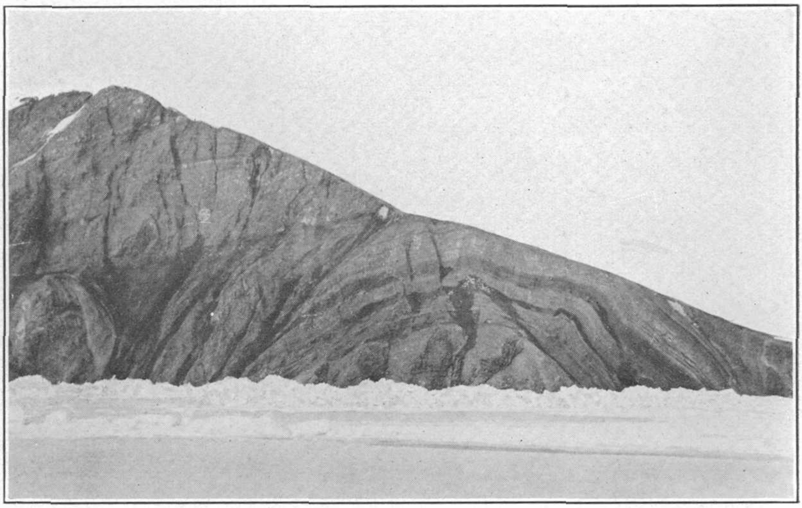
On the Kukpowruk River three anticlinal folds were recognized by the expedition of 1923 in the stretch of country between the coast and a point 36 miles inland. The folds were described as follows:[55]

> The axis of the first is 3 miles from the coast; of the second, 16 miles; and of the third, 23 miles. All these folds are somewhat unsymmetrical. On the northern anticline the dips range from 90° at the crest to 3° at a point 2 miles north. On the south flank of this fold the dips are 35° near the crest and grow progressively less southward to the center of the adjacent syncline.

[55] Paige, Sidney, and others, op. cit., p. 18.

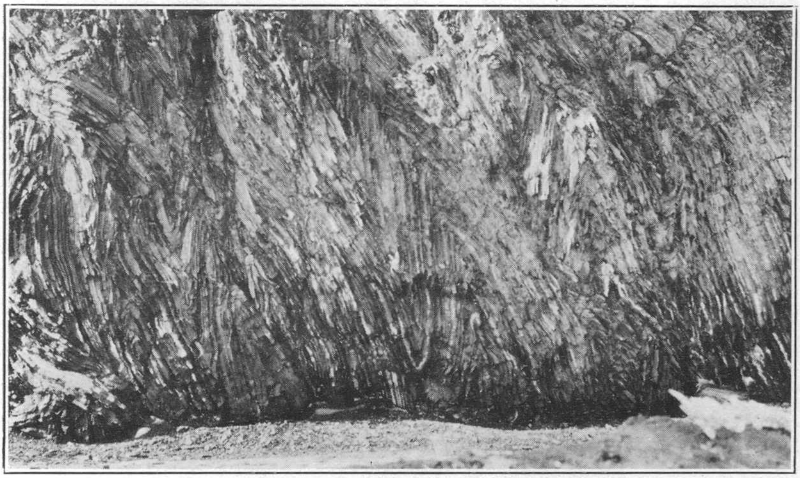


A. TRIASSIC ROCKS ON KIVALINA RIVER

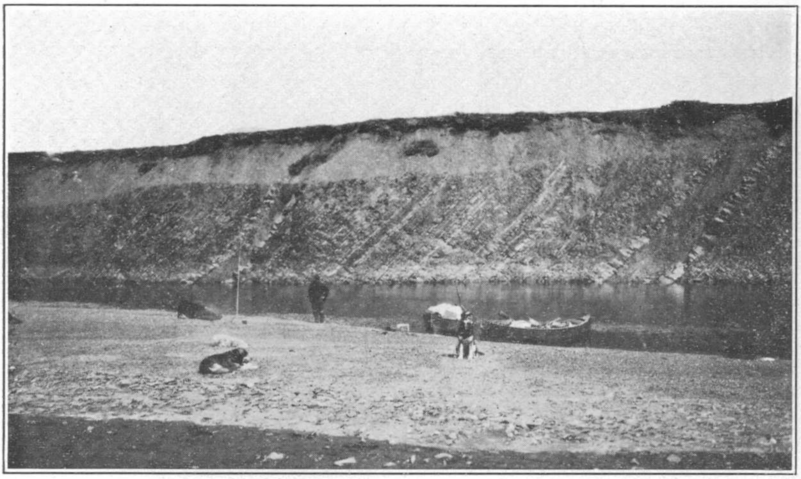


B. TRIASSIC ROCKS AT AGATE ROCK, NEAR CAPE THOMPSON

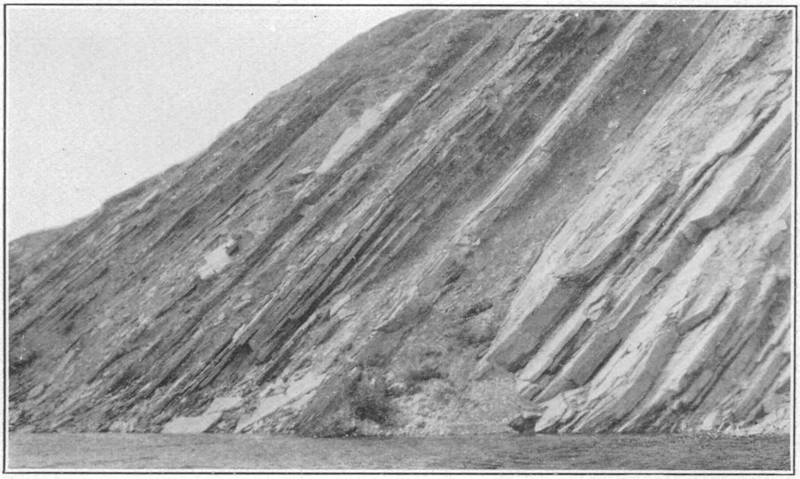
Photograph by Merl LaVoy.



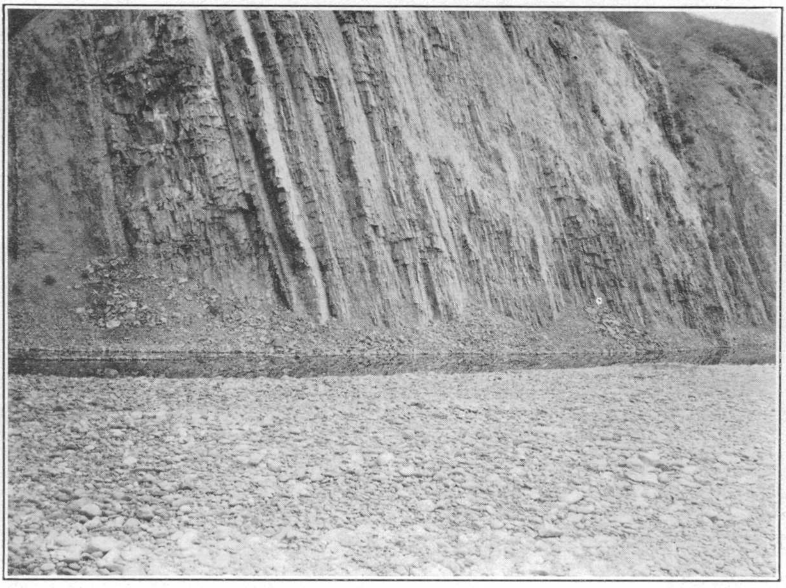
A. LOWER CRETACEOUS ROCKS ON KUKPUK RIVER



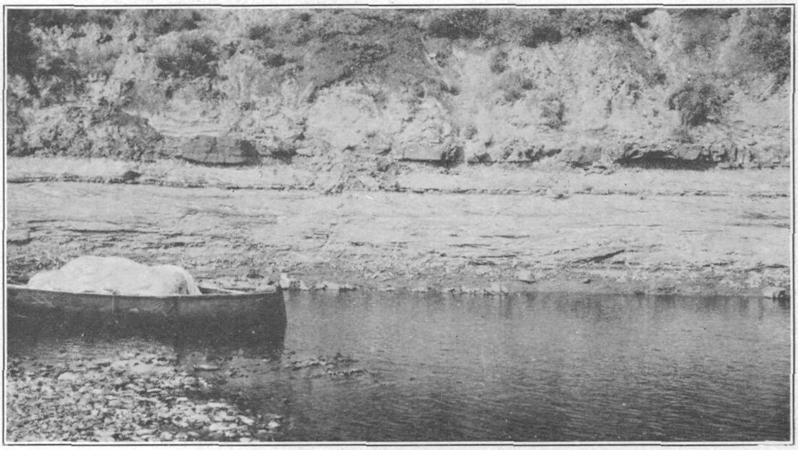
B. LOWER CRETACEOUS ROCKS ON COLVILLE RIVER



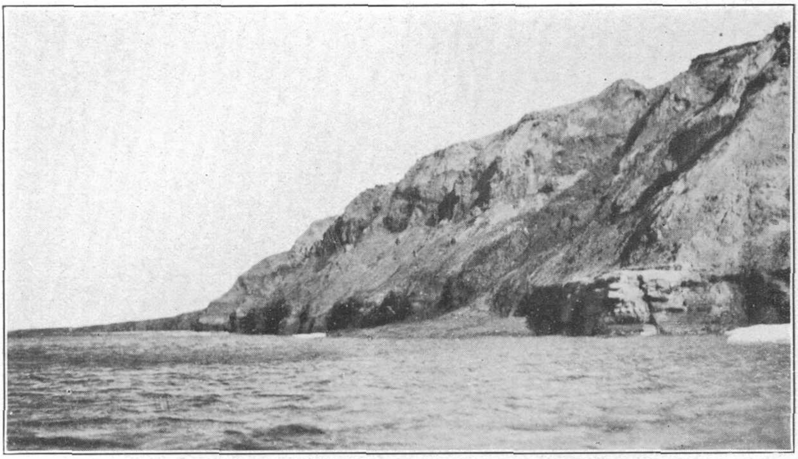
A. UPPER CRETACEOUS ROCKS ON ETIVLUK RIVER



B. UPPER CRETACEOUS ROCKS ON ANAKTUVUK RIVER



A. HARD PEBBLE-BEARING SANDSTONE AND SOFT CROSS-BEDDED SANDSTONE ON AVALIK RIVER



B. FLAT-LYING SANDSTONE OVERLAIN BY UNCONSOLIDATED DEPOSITS EAST OF PEARD BAY

On the central anticline the dips are steeper on the southern flank than on the northern and range from 70° near the crest to 9° at the synclinal axis. On the northern flank the dips are about 47°.

On the southernmost anticline the northern flank carries the steepest dips, from 50° near the crest to 9° in the syncline to the north. On the southern flank the dips range between 12° and 28°.

On the Kokoluk six anticlines and six synclines were recognized between camp P May 10 and the northernmost outcrops that occur a short distance downstream from camp P June 15. In some of these folds the dip of the rocks is as much as 55°, but dips of 15° to 30° are more common. There is no systematic relation of the steepness of the dip on the opposite limbs of the folds, as in some places the northern limb is steeper than the southern, and in the succeeding fold the reverse relation is likely to prevail. Some faults were recognized, but they all indicated only a small amount of displacement, and nowhere, except possibly in the vicinity of the contact of these rocks with the Lower Cretaceous rocks, was there any suggestion that they might be cut by faults of large throw.

The structure of these rocks near Corwin is described by Collier[56] as follows:

> The structure of the Corwin formation in general consists of several broad synclines and anticlines. * * * There is no evidence of faulting other than minor shearing movements parallel with the bedding planes.

It has heretofore been suggested, however, that the contact between these rocks and the lower Cretaceous sandstone and shale may possibly be due to faulting, which has resulted in making the western rocks appear to lie on top of the eastern ones.

The thickness of the Upper Cretaceous rocks north of the Brooks Range can not yet be stated with any degree of precision, but when all the conditions under which the work has been done are considered, there is a surprisingly close agreement in the various estimates that have been made. The geologists of the expedition of 1923[57] expressed in their report the following opinion:

> The bottom of the series was not seen, nor is it possible to estimate from the data in hand how many feet of strata have been removed by erosion. By direct measurement and by estimates from observed dips it is known that the coal-bearing portion of this sedimentary series is not less than 7,000 feet thick and may be considerably more and that a non-coal-bearing portion beneath the coal is at least 2,000 feet thick and in all probability much more. An estimate of the entire thickness of these rocks can not be made at this time, though it may be stated with considerable assurance as more than 15,000 feet.

[56] Collier, A. J., op. cit., p. 28.

[57] Paige, Sidney, and others, op. cit., p. 17.

A somewhat similar figure was arrived at by W. R. Smith, who stated in an unpublished manuscript that the lower non coal-bearing portion in the part of the country visited by him was perhaps 4,000 feet thick, so that probably the total thickness of the Upper Cretaceous rocks was as much as 15,000 feet. The observations of P. S. Smith on the Kokolik, though somewhat less exact than some of the other measurements, seemed to show a thickness of the non coal-bearing portion of the section of at least 5,000 feet, and the coal-bearing portion was estimated at 5,000 feet, though, because the upper part of the coal-bearing portion was not exposed, this estimate represents only a part of the total thickness.

Probably the most exact measurements of these rocks were those made by Collier in the Lisburne region. The results of these measurements are graphically shown in the stratigraphic column given in Figure 14. That section represents in detail 9,500 feet of strata, not including two breaks within the section of 4,000 and 1,500 feet, in which the rocks were evidently poorly exposed, and a thickness estimated at about 2,000 feet that was omitted at the top of the section. Furthermore, in the text that accompanies the section Collier states that probably the base of the section is not shown. Thus, while he states that the section is not less than 15,000 feet thick, it is evident that he practically accounts for 17,000 feet without reaching the actual base of the section.

On the south side of the Brooks Range the Upper Cretaceous rocks as a whole dip away from the range, but these rocks have been thrown into a number of folds, so that even a few miles south of the Kobuk northward dips were observed. This deformation was accompanied by faulting, but, so far as determined, by none of very great movement. No accurate estimate of the thickness of these rocks has been made. Schrader determined that they were at least 2,000 feet thick, and later measurements have shown that they are probably at least 10,000 feet thick, with neither the top nor the bottom of the section exposed.

AGE AND CORRELATION

As indicated in the section of this report which treats of the Jurassic system (pp. 194–196), there is still considerable difference of opinion as to the age of certain rocks which have here been assigned to the Upper Cretaceous. Some of the invertebrate fossils that have been collected represent long-living genera which do not afford an adequate basis for determining the geologic age closely. Others represent species that have not been found in other regions and therefore are of little value in giving a close check on the time when they lived. Among the collections of plants are many types that had a long geologic range, for some of the old ones are found in the same beds that contain much more recent forms. Under such conditions, as expressed in the quotation from Knowlton below, the youngest ones "set the pace," but if by chance the collector was not fortunate enough to find representatives of the younger forms, the only data available are the older forms. It is perhaps significant to note that, on the whole, the determinations based on the invertebrates indicate a somewhat younger age than those based on the plants. In spite of the absence of entire accord in the paleontologic evidence, there seems to be no paleontologic evidence that is in direct conflict with the views here set forth. Furthermore, all the geologists who have had the opportunity of studying these rocks in the field agree that whatever the age may turn out to be, the rocks form a distinct stratigraphic unit. Therefore, because unquestioned Upper Cretaceous fossils have been found in widely separated places within the group of rocks here mapped as Upper Cretaceous, the entire sequence is regarded as of that age.

Before the individual reports on the fossil collections and the age determinations put on them by different paleobotanists are presented, the following excerpts from letters may be of assistance in clarifying the use of certain terms that otherwise would not be fully appreciated. A statement by Knowlton in a letter of May 12, 1925, is as follows:

> When I found [in some of the recent Geological Survey collections from northwestern Alaska] certain cycads that I had formerly supposed were indications of Jurassic age associated with dicotyledons, the dicotyledons set the pace, and I was brought to the conclusion that the age was Cretaceous. This view was further confirmed when I looked over Doctor Hollick's report on the Cretaceous floras of Alaska and found that he had a similar assemblage. I did not, however, intend that this conclusion should apply equally to the age of the Corwin formation. I, of course, admit the possibility that the Corwin may be Cretaceous, but up to the present time, as I understand the conditions, this has not been demonstrated. No dicotyledons have been found in the Corwin section, and the areas (Cape Lisburne-northern Alaska region) are separated by some hundreds of miles of unknown territory.[58] Therefore, I am constrained to hold the Corwin formation in the Jurassic, with the possibility that it may be Cretaceous.

A letter from Arthur Hollick dated February 1, 1927, contains this statement:

> In regard to identification of the Alaskan material recently sent me, I am not sure that I made one point quite clear—namely, wherever I used the term "Jurassic" my intention was to identify it with the Cape Lisburne Corwin flora, which I see no good reason to regard as other than Jurassic in age. If, however, this flora should be proved to be of more recent age, then my use of the term would have to be modified accordingly.

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[58] Written before the results of the field work of 1925 and 1926 were available.

The age of these rocks on the Anaktuvuk is indicated by the fact that they unconformably overlie Lower Cretaceous rocks, are less deformed than the older rocks, and contain Upper Cretaceous fossils. The fossils were collected on the north bank of the Anaktuvuk about 5 miles south of the mouth of the Tuluga and were positively identified by Stanton as of Upper Cretaceous age. The forms identified were as follows:

Inoceramus, a rather large species, fragmentary specimens.
Astarte, small, numerous specimens.
Nucula, numerous specimens.
Avicula.
Pectunculus, several specimens. [The genus is now called Glycimeris.]
Thracia.
Tellina, 2 sp.
Siliqua.
Modiola.
Scaphites.
Haminea.

Stanton stated that all these species are apparently different from those with which he was familiar but that several of them are types known only in the Upper Cretaceous.

The specimens from this locality were later reexamined by W. R. Smith, who, in a report dated March 7, 1924, gives the following data:

3206. Original numbers [Schrader] 565, 504, 606. Upper Cretaceous, Nanushuk "series," from banks of Anaktuvuk River, 5 miles above mouth of Tuluga River:

Nucula, undescribed sp.
Glycimeris, undescribed sp.
Modiolus, undescribed sp.
Tellina, two undescribed sp.
Tellina sp.
Thracia, undescribed sp.
Thracia? sp.
Astarte, undescribed sp.
Inoceramus sp.
Haminea sp.
Undetermined gastropod.
Undetermined pelecypods.

No diagnostic fossils have been found in that part of the sequence of rocks on the Anaktuvuk River which Schrader called the "Colville series" and assigned to a Tertiary age but which in this report has been correlated with the Upper Cretaceous. However, as these rocks appear lithologically, areally, and structurally to be more closely related to the rocks here regarded as Upper Cretaceous, they have been so correlated in this report.

In the central and western parts of the basin of the Colville River and its tributaries and on the Ikpikpuk and its tributaries both invertebrates and plants have been collected. The following collections of invertebrates were identified by W. R. Smith, who prepared the accompanying reports:

12412 (24AMt68). Southeast bank of Colville River, 18½ miles N. 63° E. from confluence of Killik River with main Colville:

Astarte n. sp.
Inoceramus sp. Apparently belongs to a species collected by Schrader on bank of Anaktuvuk River 2 miles below [his] camp of August 4 [1901].
Cretaceous.

12413 (24AMt69). Northwest bank of Colville River 4.3 miles S. 62° W. from confluence of Prince Creek with Colville River:

Tellina sp.
Thracia? sp.
Undetermined pelecypod.
Upper Cretaceous.

12414 (24AMt70). Southeast bank of Colville River 2 miles S. 78° E. from confluence of Prince Creek and Colville River:

Nucula sp.
Tellina, 3 species.
Thracia? large species.
Thracia? small species.
Lucina sp.
Undetermined pelecypod.
Upper Cretaceous.

12477 (24AS50). Etivluk River, second station above camp S July 6:

Inoceramus sp., imprint of small specimen.
Upper Cretaceous.

17478 (24AS64 and 24AS65). Ikpikpuk [Kigalik] River 1½ miles below camp S July 28:

Unio sp. Numerous casts of a small species, not sufficient for age determination but similar to a small Upper Cretaceous species from bank of Yukon River.

17479 (24AS67 and 24AS68). Ikpikpuk [Kigalik] River three-fourths mile below camp S July 30:

Inoceramus sp.
Dentalium sp.
Upper Cretaceous.

17480 (24AS69). Ikpikpuk [Kigalik] River 1½ miles below camp S July 30:

Inoceramus sp.
Pelecypod cast, genus not determined.
Specimens of the *Inoceramus* were collected by Schrader on bank of Anaktuvuk River 5 miles above mouth of Tuluga River, where it occurs with a rather large and characteristic Upper Cretaceous fauna. Upper Cretaceous.

17481 (24AS72 and 24AS73). Ikpikpuk [Kigalik] River one-half mile below camp S July 31:

Lucina? sp.
Not sufficient for age determination.

17482 (24AS84). Ikpikpuk River midway between camp S August 6 and S August 7:

Inoceramus, large species.

Inoceramus sp., small specimens. Probably young of large species.

Upper Cretaceous.

Near the head of Disappointment Creek, a tributary of the Utukok, a collection was made by W. R. Smith, which was examined and reported on by J. B. Reeside, jr., as follows:

13310 (25ASmF6). 2 miles north of Colville River, 8 miles east of big bend from the south. Pelecypod related to *Anisocardium* but probably new species. This species was found by Foran in his collection 12178, 43 miles from the mouth of the Kukpowruk River. I can not say from the fossils alone whether the age is Jurassic or Cretaceous, though if the stratigraphic and structural relations link this lot with those containing Lower Cretaceous fossils that assignment would be acceptable.

W. R. Smith, however, states that the field relations of these rocks clearly place them well above the unconformity he recognized between the Upper and Lower Cretaceous, and they are therefore regarded as of Upper Cretaceous age.

A number of collections of fossil plants have also been obtained in this same general region, and they were examined and identified by F. H. Knowlton, who reported as follows:

24AMt64. Northeast bank of Killik River, 9.8 miles S. 68° E. of confluence of this stream with Colville River:

Ginkgo sp. fragment only.

Podozamites cf. P. lanceolatus or P. latipinnis.

Sequoia cf. S. smidtii Heer.

Sequoia cf. S. angusta Heer.

Pterospermites sp. probably new.

In seeking to determine the age of this material it is necessary to throw out all but the dicotyledon. According to our present knowledge the dicotyledons did not appear until middle or later Cretaceous time. Therefore this is presumably not older than middle Cretaceous, though it might be later in the Cretaceous.

24AMt73 (7759). East bank of Ikpikpuk River 10.1 miles N. 26° W. of confluence of east and west forks of river [Maybe Creek and Kigalik River]. Three small pieces of matrix show the following:

Taxodium sp.?

Podozamites lanceolatus eichwaldii Heer.

Taeniopteris? sp.

The *Podozamites* has been found in the Cape Lisburne Jurassic, and I do not recall that it has been found in later beds. Practically the same may be said of the supposed *Taeniopteris*, but the *Taxodium* seems to be younger. I hesitate to pronounce on the age of this lot without more complete material.

24AS29 (7742). Colville River near camp S June 20:

Cladophlebis sp.?

Podozamites lanceolatus (Lindley and Hutton) Braun.

Cephalotaxopsis sp.

Sequoia fastigiata (Sternberg) Heer.

Sequoia, cone of.

24AS32 (7744). Between camps S June 23 and S June 24 [Colville River]:

Cephalotaxopsis sp.

Tumion sp.

Pterophyllum? sp.

24AS36 and 24AS37 (7745). Above camp S July 1 [Colville River]:

Podozamites lanceolatus (Lindley and Hutton) Braun.

Nilssonia sp.

24AS61 (7747). First station above camp S July 6 [Awuna River]:

Nilssonia sp.

Podozamites lanceolatus (Lindley and Hutton) Braun.

24AS76 (7748). Ikpikpuk [Kigalik] River opposite camp S August 1:

A single large leaf of Credneria or possibly one of Hollick's new genera.

24AS78 (7749). Ikpikpuk [Kigalik] River a short distance below camp S August 2:

Sequoia fastigiata (Sternberg) Heer.

Sequoia sp., fragmentary cone.

Ginkgo digitata (Brongniart) Heer.

Ginkgo sp.

Podozamites lanceolatus (Lindley and Hutton) Braun.

Three small fragments of dicotyledonous leaves with little or no margin. Can not be identified positively, though two genera seem to be represented.

24AS81. Ikpikpuk [Kigalik] River midway between camps S August 3 and S August 4:

A single dicotyledonous leaf. A *Platanus* comparable with *Platanus heerii* Lesquereux.

This material (24AS29 to 24AS81), although insufficient and rather scrappy, proves to be very interesting. As in the case of the material collected by J. B. Mertie, jr. (24AMt64 and 73), from the same general region, the dicotyledons fix the pace. There is little doubt that they indicate Upper Cretaceous age—that is, on the basis of present knowledge they are not older than this. Associated with the dicotyledons, though not on the same pieces of matrix, are certain cycads and conifers, the most abundant being *Ginkgo* and *Podozamites*. There are also several fragments of a *Nilssonia*. The *Ginkgo* and *Podozamites* are very abundant in the Jurassic of Cape Lisburne, but the genus *Nilssonia* has not been found there, although it is well known in the Jurassic elsewhere and has been found in the Cretaceous.

Until recently these forms were supposed to indicate a Jurassic age, but later it has been found that they have a wider vertical range than was supposed. Arthur Hollick has identified no less than nine forms of *Ginkgo*, three or four forms of *Podozamites*, and two new forms of *Nilssonia* in the Upper Cretaceous of Alaska. One of the forms of *Nilssonia* in the present collections is probably the same as one of Hollick's new species, though it is pretty close to a Jurassic form.

Of the true conifers the *Cephalotaxopsis* and *Tumion* are probably identical with Hollick's species; *Sequoia fastigiata* was reported by Lesquereux from the Dakota, and it is also reported by Hollick in his Upper Cretaceous volume.

There is only one fern in these collections, and it is not very well preserved. It is referred to *Cladophlebis*, but it is not the same as any known Cape Lisburne form.

It appears that I have previously attached too much importance to the Jurassic facies of these plants, especially in the light of Hollick's findings, and I am now convinced that they should be referred at least tentatively to the Upper Cretaceous.

As a result of the surveys conducted in 1926 in the Kokolik, Avalik, and Kukroak Valleys several small collections of invertebrate fossils were obtained. These have been examined by J. B. Reeside, jr., who has prepared the accompanying report:

13717 (26AS37). Igloo Mountain 5 miles west of camp P May 7, Kukpowruk River:

Pleuromya? sp.
Mactra? sp.
Cretaceous or Jurassic.

13718 (26AS40). 1 mile east of camp P May 7, Kukpowruk River:

Trails or fucoids, undetermined.

13719 (26AS43). 1 mile north of camp P May 15, Kokolik River:

Inoceramus sp.
Mactra? sp.
The *Inoceramus* in this lot impresses me as being an Upper Cretaceous type, but I would hesitate to attach a specific name.

13720 (26AS45). $1\frac{1}{2}$ miles north of camp P May 15, Kokolik River:

Asteroid? undetermined.

13721 (26AS48). 1 mile north of camp P May 15, Kokolik River:

Ostrea, small simple species.
Entolium? sp.
Anomia? sp.
Pleuromya? sp.
Tellina sp.
Mactra? sp.
Cretaceous or Jurassic.

13723 (26AS49). 2 miles north of camp P May 15, Kokolik River:

Pleuromya? sp.
Mactra? sp.
Cretaceous or Jurassic.

13728 (26AS60). 6 miles below camp P June 6, Kokolik River:

Imprint of part of whorl of ammonite, undeterminable.

13729 (26AS61). 7 miles below camp P June 6, Kokolik River:

Pelecypod, undetermined.

13730 (26AS66). 5 miles below camp P June 12, Kokolik River:

Serpula or Dentalium sp.

13732 (26AS90). Near camp P August 9, Peard Bay and Kukroak River:

Pelecypods?, undetermined.

A collection of invertebrates was also made on the Kukpowruk River in 1923 by Foran, concerning which Reeside states:

12178 (23AF100, 23AF101). Thin conglomerate bed 43 miles above mouth of Kukpowruk River, about 1,000 feet stratigraphically below coal series:

Ostrea sp. Large simple form.
Pecten sp.
Pelecypod related to Anisocardium but probably a new genus.
Thracia sp.
Tellina sp.

I have not been able to identify this fauna with any degree of certainty. The species present are probably all new and might come equally well from the Upper Jurassic, Lower Cretaceous, or Upper Cretaceous. It impresses me as more likely to be Upper Cretaceous than older.

In the Kokolik region a number of collections of plants were also made, and these have been studied and identified by Arthur Hollick. In the following reports by Hollick the term Jurassic is used throughout in the sense referred to in his letter quoted on page 219.

There are certainly two and apparently three distinct geologic horizons represented in these collections, ranging from Jurassic to Tertiary. Identification of the Jurassic was based upon certain well-defined recognized Jurassic species of fossil plants, in connection with which no question could be raised. Identification of the Tertiary horizon was based upon well-preserved coniferous remains that surficially appear to represent undoubted Tertiary species, but it should be recognized that these alone, without other supporting data, may not be absolutely conclusive of the geologic age, inasmuch as certain Cretaceous and Tertiary species resemble one another so closely that unless minor characters are clearly defined it becomes impossible to differentiate satisfactorily between them.

7840 (26AS46). Kokolik River between forks above camp P May 15. Two pieces of matrix. Grayish shaly sandstone with circular pitlike markings that lead to tubular openings, some of which contain columnar casts. These markings and casts may represent worm burrows or rhizomorphs. Nothing definitely identifiable.

7842 (26AS52). Kokolik River between camp P May 15 and camp P June 5. Three pieces of matrix. Black shale filled with fragmentary remains that apparently represent leaves of species of *Ginkgo*. Jurassic (?).

7843 (26AS64). Kokolik River bluff below camp P June 12. Twenty-one pieces of matrix. Black shaly sandstone:

Fragmentary remains of Thyrsopteris?
Pinus nordenskiöldii Heer?
Ginkgo digitata Heer.
Jurassic.

7844 (26AS65). Kokolik River, second bluff above lunch stop June 13. One piece of matrix. Black shale containing fragments of *Baiera* sp.?. Jurassic.

7845 (26AS67). Kokolik River, first bluff above lunch stop June 13. Two pieces of matrix. Grayish ferruginous shale:

Ginkgo digitata Heer.
Podozamites lanceolatus (Lindley and Hutton) Braun.
Phoenicopsis sp.
Jurassic.

7846 (26AS69). Kokolik River, bluff below lunch stop June 13. Four pieces of matrix. Gray shaly sandstone:

Fragmentary remains of a fern.
Thyrsopteris sp.?
Jurassic (?).

7847 (26AS72). Kokolik River, between camps P June 13 and P June 14. Four pieces of matrix. Hard black shale, containing fragmentary remains of cycads and other gymnosperms, but nothing definitely identifiable. Jurassic (?).

7849 (26AS74). Kokolik River between camps P June 13 and P June 14. One piece of matrix. Gray shaly sandstone containing well-defined specimen of *Ginkgo digitata* Heer. Jurassic.

7850 (26AS75). Kokolik River between camps P June 13 and P June 14. Four pieces of matrix. Grayish-brown sandstone containing poorly defined fragmentary remains of a fern (*Onychiopsis* sp.?). Jurassic or possibly Cretaceous.

7852 (26AS77). Kokolik River between camps P June 15 and P June 16. Five pieces of matrix. Gray sandstone containing well-defined leaves of *Podozamites lanceolatus* (Lindley and Hutton) Braun. This species, with its numerous forms and varieties, is common to both the Jurassic and the Cretaceous and hence by itself can not be accepted as an exclusive index fossil for either period. Jurassic or possibly Cretaceous.

In the Kukpowruk Valley, to the west of the Kokolik, and in the Utukok Valley, to the northeast, Foran made a number of collections which were examined and identified by F. H. Knowlton as follows:

7641 (23AF11). Kukpowruk River, 5 miles above mouth, near bottom of coal series. *Phoenicopsis?* sp. *Phoenicopsis* is common in the Cape Lisburne Jurassic.

7644 (23AF14). Shale below 10-foot bed of coal, 5 miles up Kukpowruk River, near base of coal series. Three small pieces of matrix. Shows stems, some grasslike, and fragments that appear to be a *Taeniopteris*. No age determination possible.

7645 (23AF15). Shale 1 foot below coal, 5 miles up Kukpowruk River. Fragments of what appears to be *Phoenicopsis*.

7647 (23AF17). Kukpowruk River, 4½ miles above mouth, near bottom of coal series. *Phoenicopsis?* sp. Same remark as under 23AF11.

7649 (23AF19 to 23AF22). Kukpowruk River 6 miles above mouth, approximately 2,000 feet stratigraphically above 10-feet coal bed. Coniferous wood fairly well preserved, but no sections have been cut.

7650 (23AF23). Kukpowruk River 10 miles above mouth. Syncline axis:

Ginkgo sp.

?Cladophlebis alata Fontaine.

Fragments of two or three dicotyledonous leaves.

This is by all means the most puzzling lot in the whole collection. The *Ginkgo*, although large and well enough preserved, is of little value in fixing the age, as *Ginkgo* has come down to us from the Jurassic to the present with very little change. The fragment of a fern seems to be the same as a form from Cape Lisburne, but the well-defined dicotyledons absolutely preclude a reference to the Jurassic. On the basis of present knowledge it can hardly be older than the middle or upper part of the Lower Cretaceous.

7651 (23AF24). Kukpowruk River 17 miles above mouth at junction of forked stream. Phoenicopsis? sp.

7652 (23AF27). Kukpowruk River 22 miles above mouth, probably near top of coal series. A single small fragment. A conifer and apparently a *Taxites*, but not sufficient for positive identification.

7653 (23AF28). Kukpowruk River 18 miles above mouth, probably near top of coal series:

Ginkgo sp.

?Cladophlebis alata Fontaine.

These forms are similar to forms found in the Cape Lisburne Jurassic, but considering the report on 7650 (23AF23), I hesitate to call it Jurassic. No dicotyledons present.

7666. Station E, Utukok River 17 miles above mouth:
Phoenicopsis speciosa Heer.
?Cladophlebis alata Fontaine.
These forms also occur in the Jurassic at Cape Lisburne.

7668. Station Z, Utukok River 43 miles above mouth. A single small piece of matrix with about six species of plants:
Oleandridium sp.
Onychiopsis sp.
Cladophlebis sp.
Apparently new fern.
Some coniferous leaves.
The age appears to be Lower Cretaceous, in the approximate position of the Kootenai or Wealden.

7665. Station X, Utukok River:
Taxites olriki Heer.
Stems, etc.
Age can not be fixed by this specimen. May be Tertiary.

Collections 7650 (23AF23) and 7668 (station Z, Utukok River) were reexamined by Hollick, who has made the following report:

7650. The collection in addition to less well-defined specimens of a fern (*Cladophlebis* sp.) and a gymnosperm (*Ginkgo* sp.) contains fragmentary remains of leaves of an angiosperm. This precludes the possibility of Jurassic age for the rock in which they occur. The age is Lower Cretaceous and apparently about the equivalent of the Potomac group.

7668. This collection, consisting of a single piece of matrix, contains plant remains, mostly fragments of ferns, among which are specimens of *Oleandridium* sp. and *Cladophlebis* sp. The age appears to be Lower Cretaceous and equivalent to the Kootenai formation.

On the coast at a point described as 7 miles southwest of Wainwright Inlet Schrader made a small collection in 1901, which he states[59] was identified by Fontaine and Ward as *Nageiopsis longifolia* Fontaine, *Podozamites distantinervis* Fontaine (both older Potomac of Virginia; Lower Cretaceous), and *Baiera gracilis* (Bean) Bunbury (oolite of Yorkshire, England; Jurassic).

Several small collections obtained east of the Utukok, in the valley of the Avalik River, were examined by Hollick, who reported as follows:

7853. (26AS79). Avalik River between camps P July 11 and P July 12. One piece of matrix, consisting of a piece of silicified lignite, not identified.

7854 (26AS82). Avalik River below camp P July 13. Fourteen pieces of matrix. Yellowish fine-grained sandstone containing *Dicksonia montanensis* Fontaine (fruiting specimens), *Thyrsopteris* or *Onychiopsis* sp., and fragments of dicotyledonous angiosperm leaves. Cretaceous.

7855 (26AS83). Avalik River, short distance above camp P July 13. Seven pieces of matrix. Three distinct kinds of rock are included in this lot—namely, black shale, fine-grained ferruginous sandstone, and a sandstone-lignite conglomerate. The black shale contains fragments of what is apparently an

[59] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 74, 1904.

Equisetum; the sandstone contains impressions of a coniferous leafy twig that may be tentatively identified as *Cephalotaxopsis* sp.; and the conglomerate contains fragments of twigs and leaves and cones of *Sphenolepidium?* or *Sequoia?*. Cretaceous(?).

7856 (26AS84). Avalik River, between camps P July 14 and P July 15. Twenty-four pieces of matrix. Gray and yellowish-gray fine-grained sandstone (except for one piece, a hard compact ferruginous shale rock). The odd piece of matrix above mentioned contains an impression of a fern more or less satisfactorily identified as *Aspidium meyeri* Heer. The other pieces contain numerous leafy twigs of conifers, among which are well-defined specimens of *Juniperus* (*J. tertiaria* Heer?), many of *Taxodium* (*T. gracile* Heer and *T. tinajorum* Heer), and several of *Thuites ehrenswardii* Heer. If these are correctly identified, they all represent Tertiary species, but identifications of certain coniferous remains without other supporting data can not always be regarded as absolutely conclusive as to the alternative of their Cretaceous or Tertiary age. I am strongly inclined, however, to designate this lot as Tertiary in age.

7557 (26AS85). Avalik River, between camps P July 16 and P July 17. Two pieces of matrix—one brown shaly sandstone, the other a hard compact sandstone. The former contains a fragment of a *Nilssonia* or a *Taeniopteris*. The latter contains remains of *Sequoia*. No specific identifications are possible. Cretaceous.

7558 (26AS86). Avalik River, between camps P July 16 and P July 17. Two pieces of matrix. Yellowish-gray fine-grained sandstone containing fragmentary remains of *Taxodium tinajorum* Heer? or one of the many varietal forms of *Taxodium dubium* (Sternberg) Heer? If these identifications could be definitely verified, the age of the lot would not be questioned, but, as in connection with lot 7856, the age may be designated as possibly Cretaceous but probably Tertiary.

Collections made on the Kukroak River, which enters the head of Peard Bay to the east of Wainwright, have been examined by Hollick, who has submitted the following statement:

7859 (26AS91). Kukroak River 3 miles above camp P August 9. One piece of matrix. Hard ferruginous shale containing well-defined leaves of *Phoenicopsis speciosa* Heer. Jurassic.

7860 (26AS93). Kukroak River 5 miles above camp P August 9. Two pieces of matrix. Fine-grained hard gray sandstone containing a stem or rhizome of a monocotyledonous plant. Not identified. Age doubtful.

Three collections of fossil plants obtained by the expedition of 1923 on the Meade River were examined both by Knowlton and by Hollick. Knowlton's statement regarding them is as follows:

The material is the same as that from Cape Lisburne, Alaska, namely, Upper Jurassic.

No. 1 (7699). Right bank of Meade River about 27 miles above mouth; poor exposure (float?). Stems and coniferous leaves, the latter probably *Pinus*.

No. 2 (7700). Right bank of Meade River 32 miles above mouth; poor exposure:

Phoenicopsis speciosa Heer.
Podozamites lanceolatus eichwaldi (Heer) Seward.
Taeniopteris sp.
Taxites zamioides? (Leckenby) Seward.

No. 3 (7701). Meade River 67 miles above mouth. Horizontal bed in shale, sandstone, and coal series:

Pagiophyllum sp.
Baiera sp.

Hollick's report on the same collections is given below:

7699. Right bank of Meade River 27 miles above mouth. Nine pieces of matrix consisting of gray and brown sandstone and containing leaf fragments apparently of conifers or possibly of cycads but not generically identifiable. Apparently not younger than Lower Cretaceous and probably Jurassic.

7700. Right bank of Meade River about 33 miles above mouth. Twenty pieces of matrix consisting of yellowish-brown sandstone containing fragmentary remains of conifers and cycads, including *Podozamites* sp. and *Phoenicopsis* sp. Jurassic.

7701. Meade River about 67 miles above mouth. Seven pieces of matrix, consisting of yellowish-brown sandstone containing fragmentary remains of gymnosperms, apparently *Pagiophyllum* sp. and *Baiera* sp. Jurassic.

The age of the rocks in the vicinity of Corwin, as given in this report, is based on their lithologic similarity to known Upper Cretaceous rocks and their apparent structural continuity with those rocks. This interpretation is not supported by any direct paleontologic evidence. In fact, the fossil plants that have been collected in that region are considered to be Jurassic. The paleobotanic data were thoroughly summarized by Knowlton in 1904 as follows:

From the time, about 20 years ago, when I handled the first collection of fossil plants from the Cape Lisburne region, I have been greatly interested in this flora and have followed somewhat closely the results of its study. The present collection is in many respects the best thus far obtained, being in general ample and especially rich in fruiting ferns, and thus permits the settlement of some questions of affinity, which was before impossible. The combined previous material has recently passed through Professor Fontaine's hands, and by the courtesy of Professor Ward I have been granted access to his manuscript and the proof plates which are soon to be issued in his [Ward's] second paper on the status of the Mesozoic floras of the United States. I have also had access to the original material, which is now the property of the United States National Museum. Without these collections and the manuscript and plates above mentioned my work on the present material would have been greatly increased, if not made impossible, although I am compelled to dissent from some of Professor Fontaine's conclusions, as will be set forth.

There are 19 localities represented in this collection, all apparently in the vicinity of Corwin Bluff, Cape Lisburne region. Combined they yield the following fossil plants:

Cladophlebis huttoni (Dunker) Fontaine. Abundant.
Dicksonia n. sp.? Most abundant of all; finely fruiting.
Dicksonia borejensis Zalessky. Single specimen.
Taeniopteris parvula Heer. Small fragments.
Equisetum sp. Single stem.
Podozamites lanceolatus latifolius (Schenk) Heer. Many.
Podozamites? sp. A number of large leaflets.
Baiera palmata Heer. Two or three specimens.

Phoenicopsis angustifolia Heer. Several specimens.
Phoenicopsis speciosa Heer. Several specimens.
Pagiophyllum kurrii (Pomel) Schimper. One or two fine specimens.
Stachyotaxus septentrionalis? (Agardh) Nathorst. One small example.
Taxites? subzamioides? Möller. Fragments.
Ginkgo huttoni Fontaine n. var. Large number.

In my opinion these plants indicate a Jurassic age for the beds containing them or at least are not younger than the Wealden. By eliminating the two forms not specifically named and the two species not satisfactorily identified, we have 10 of the 14 forms sufficiently well determined to permit their use in fixing the age. Of these no less than seven are common to the Jurassic of eastern Siberia, not to mention other parts of the world. Of the remaining three, one (*Pagiophyllum kurrii*) is found in the Lias of Bornholm, another (*Cladophlebis huttoni*) in the Wealden of Hanover, and the last is what appears to be a new species of *Dicksonia*. This is the most abundant form, being found at nearly all the localities, and among them are a number of large, fine fruiting specimens which fix definitely its systematic position. It has not been found fruiting before, and sterile portions from the upper part of the frond were identified by Fontaine as *Onychiopsis psilotoides*, while lower portions were called *Cladophlebis alata*. This *Onychiopsis psilotoides* is found in the Wealden of England and elsewhere, and the *Cladophlebis* in the Potomac formation, and as both are abundant in the original collections, they were much relied upon by Fontaine to prove the Jurassic-Cretaceous age of the Cape Lisburne beds. Mr. Collier's fortunate specimens show by the fruit that it is undoubtedly a *Dicksonia*, and further that the two forms of foliage occur on the same frond. The other *Dicksonia*, although a mere fragment, is with little doubt the same as *D. borejensis*, described late in 1904 from Amur. What I here called *Podozamites lanceolatus latifolius* was determined by Professor Fontaine as *P. distantinervis*, a well-known Potomac species. However, I have compared the types of this Potomac species with the specimens in hand and can confidently say that they are not the same and moreover that they are not separable from *P. lanceolatus latifolius*. There are also several other species identified by Professor Fontaine with Potomac species that I have carefully studied and compared and can only conclude that he was in error, but as they are not present in Mr. Collier's collection, it is not necessary to mention them otherwise than to point out that it was undoubtedly upon these and those above enumerated that he based his conclusion as to the relationship between the Potomac of Virginia and the Corwin of Alaska. This relationship does not seem to me to exist in fact. The *Ginkgo* present in these collections is a large-leaved form that Fontaine has separated from *G. huttoni* as a new variety, but I can at the moment see but little warrant for separating them from the widely spread *G. digitata*.

Again I state that at present I can see no valid reason for regarding this flora as other than Jurassic, or in any event as other than identical with the flora from eastern Siberia, the Jurassic age of which is, so far as I know, universally accepted.

Although there is no indication in Mr. Collier's notes that more than one horizon is represented, nor is the thickness of the beds mentioned, I have tried to see if I could detect any difference in position. In this I have not signally succeeded. None of the localities are represented by more than five species, and most of them yield but two or three; so the basis for comparison is slight. However, I should think that localities 4AW5 and 4AW9, and possibly 4AW25, are probably at the base of the section.

Later Doctor Knowlton[60] reexamined the collections made by Collier and prepared a report which he stated "is the first time it [the paleobotanic material] has been adequately described and figured." In this report, which was published in 1914, he gives the following revised list of species in the collections:

Coniopteris hymenophylloides (Brongniart) Seward.
Coniopteris burejensis (Zalessky) Seward.
Cladophlebis huttoni (Dunker) Fontaine.
Cladophlebis? alata Fontaine.
Equisetum collieri, n. sp.
Podozamites lanceolatus eichwaldi (Schimper) Heer.
Podozamites lanceolatus (Lindley and Hutton) Braun.
Otozamites giganteus Thomas.
Zamites megaphyllus (Phillips) Seward.
Phoenicopsis speciosa Heer.
Phoenicopsis angustifolia Heer.
Elatides curvifolia (Dunker) Nathorst.
Pagiophyllum kurrii (Pomel) Schimper.
Pagiophyllum steenstrupi Bartholin.
Pityophyllum nordenskiöldi (Heer) Seward.
Fieldenia nordenskiöldi Nathorst.
Ginkgo digitata (Brongniart) Heer.

He sums up his conclusions as follows:[61]

From the composition and wide distribution of this flora as outlined above, the final conclusion is reached that the Corwin formation of the Cape Lisburne region is undoubtedly Jurassic in age, belonging either in the upper part of the Middle Jurassic or Brown Jura or the extreme lower portion of the Upper Jurassic or White Jura—that is to say, it is probably not older than the Bathonian nor younger than the Oxfordian.

Although the recent work in the region east of Corwin has raised the question as to the correctness of the paleobotanic correlations, as was courteously recognized by Knowlton and expressed in his letter, on page 219, no additional data have been obtained from the Corwin area itself since the collections of Collier, which were made in 1904. There is therefore no tangible basis for altering the paleobotanic opinion there set forth, nor can a change reasonably be expected until more complete collections are available. Under these conditions additional weight has been given to the new stratigraphic and structural data in arriving at a balanced judgment between data from different sources that require reconciliation.

The determination of the age of the rocks south of the Brooks Range which have been mapped as Upper Cretaceous is not based on direct paleontologic evidence but entirely on general stratigraphic

[60] Knowlton, F. H., The Jurassic flora of Cape Lisburne, Alaska: U. S. Geol. Survey Prof. Paper 85, pp. 39–64, 1914.
[61] Idem, p. 43.

and structural relations. Schrader determined that they overlie rocks of Lower Cretaceous age on the Koyukuk and have not been as greatly deformed. Mendenhall, basing his judgment on their greater induration than that of the known Tertiary rocks in the neighborhood, stated that they were probably Mesozoic. Smith in 1911, from all those reasons and the lithologic similarity of these rocks to the known Upper Cretaceous rocks in the lower part of the Koyukuk Valley, regarded their age as in part certainly Upper Cretaceous. He pointed out, however, that it was by no means certain that sedimentation did not proceed uninterruptedly from the Upper Cretaceous into the Tertiary, and he recognized the possibility that the upper part of the series might be of Tertiary age. No recent work has been done on these rocks, and there has been no dissent from the conclusion that in the main these rocks are of Upper Cretaceous age, though as mapped they may include some small areas that are really Tertiary.

TERTIARY SYSTEM

DISTRIBUTION

No extensive deposits that have been definitely identified as of Tertiary age have been recognized in northwestern Alaska. The scanty recognition of representatives of this age is probably due not to the real absence of these rocks but in large measure to the lack of adequate field examination and data. This has doubtless resulted in the inclusion of some beds that may later be distinguished as Tertiary in the upper part of the section now correlated as of Upper Cretaceous age and of others in the unconsolidated deposits of the coastal plain that are now regarded as dominantly of Quaternary age. There is every reason to expect, therefore, that with more complete knowledge of the region the distribution of the Tertiary rocks will be found to be considerably more extensive than is at present indicated on Plate 2. Except in the coastal plain province, however, it seems very doubtful whether any Tertiary deposits that may be found will be very extensive, and even in that province, although they may be extensive, they are likely to be thin and form more or less of a veneer rather than a formation of much volume.

From all the data now available the only places where Tertiary rocks have been definitely recognized are in the valley of the Kobuk and near the mouth of the Colville. Fossils that were identified as "probably Pliocene" were collected by James Gilluly from deposits in the valley of the Topagoruk River, southeast of Barrow, but other collections from similar deposits near these were determined as Pleistocene, and in this report all three collections are regarded as essentially of the same age and more likely to be Pleistocene than Pliocene. They have therefore been described in the Pleistocene section of this report (pp. 240–241). Schrader regarded the rocks that lie north of the junction of the Anaktuvuk and Colville Rivers as of Tertiary (Oligocene) age, but this decision was not based on fossil evidence, and the present writers, from the fossil evidence obtained in the apparent continuation of these rocks farther west, assign the lower part of the " Colville series " to an Upper Cretaceous age. The rocks on the Colville whose age was definitely determined by paleontologic evidence as Tertiary were found by Schrader at a point on the bluffs on the west side of the river 1 mile north of latitude 70°.

The Tertiary rocks in the Kobuk Valley occur in discontinuous patches, which are generally not more than a few square miles in extent. One area of this sort is in the low hills between the Ambler and Kobuk Rivers, and it extends for some distance up the Redstone. Another area occurs somewhat farther downstream on the north side of the Kobuk, near the mouth of the Hunt River. The westernmost area is along the north and west side of the Kobuk River, near the mouth of the Kallarichuk River and between that stream and Trinity Creek.

LITHOLOGY

The lithology of the Tertiary rocks on the Colville which form the upper part of Schrader's " Colville series "[62] is described by him as follows:

> This portion of the section is practically free from indurated rock. It consists of nearly horizontally stratified beds of fine gray, slate-colored, or ash-colored calcareous silts containing faunal remains.

The Tertiary rocks in the Kobuk were most fully described by Mendenhall,[63] and the following notes have been prepared mainly from his report. The Tertiary rocks in the vicinity of the Ambler River consist of conglomerate, soft cross-bedded sandstones, and shale. In many places the shale is carbonaceous and contains obscure remains of plants. Some phases of the conglomerate are made up principally of poorly assorted material derived directly from the underlying and adjacent pre-Silurian schist. Many of the pebbles are white vein quartz, somewhat rounded and embedded in a matrix of muscovite and chlorite scales. The beds usually have a distinct

[62] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 83, 1904.

[63] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska, by way of Dall, Kanuti, Allen, and Kowak Rivers: U. S. Geol. Survey Prof. Paper 10, pp. 41–42, 1902.

brownish color by which they may be distinguished at a distance from the other rocks.

The Tertiary rocks that crop out near the Hunt River are described by Mendenhall as consisting of hard conglomerate made up largely of quartz pebbles and containing numerous coal fragments. Prospectors state that rock of this same type continues for several miles up the Hunt River. Near the mouth of the Kallarichuk there is a succession of conglomerate beds with pebbles of quartz, mica schist, and serpentine embedded in a micaceous matrix. The conglomerate beds are interlaminated with less resistant shale and sandstone. The individual conglomerate beds range in thickness from 10 to 200 feet. The softer beds are described as sandstone, shale, fine clay, and coal.

STRUCTURE AND THICKNESS

The Tertiary rocks on the Colville River, as has already been stated, are practically unconsolidated, and their structure is essentially horizontal. Schrader states that the beds here considered Tertiary are possibly separated by an unconformity from the underlying beds, but he believed the amount of discordance to be rather slight. No estimate of the thickness of these beds that does not include also parts of the underlying rocks is available, but it is more or less obvious from the general descriptions that the formation is thin, perhaps less than 100 feet thick.

The Tertiary rocks in the Kobuk Valley, according to Mendenhall, are everywhere thrown into folds, some of which show dips as steep as 30°. Faults were not recognized, though the areal distribution suggests that some of the blocks may have been dropped into their present position through faulting. The structure is decidedly complex, but the folds are distinctly local in character, and the rather uniform southward dip that generally prevails in the adjacent older rocks is absent. No estimate of the thickness of these rocks was obtained, as the time available to Mendenhall was not sufficient for him to determine the details of the structure. In all the localities these rocks rest unconformably on the early Paleozoic or older rocks. This may be interpreted to mean that the Upper Cretaceous rocks had once been laid down there and subsequently removed during a period of erosion that intervened between the deposition of the last of the older rocks and that of these Tertiary rocks, but it may also mean that the Upper Cretaceous rocks were never deposited in the area now occupied by the Tertiary rocks. No data are available for testing these two alternatives, and therefore decision as to which is correct can not be made, but the writers are inclined to believe that the second explanation is the more likely.

AGE AND CORRELATION

The age of the Tertiary rocks on the Colville has been determined largely by their physical condition, by their stratigraphic relation to other rocks whose age is more or less definitely known, and by paleontologic evidence. The fossil collections from these rocks were examined by W. H. Dall, who reported as follows:[64]

Fossils from upper Colville series in bluff on west side of Colville River 1 mile north of 70th parallel:

Chrysodomus, two species, both undescribed and very interesting; the first Tertiary Arctic shells (not Quaternary) I have ever seen. Perhaps they are Pliocene.
Amauropsis sp., fragments.
Tachyrhynchus polaris Beck.
Macoma frigida Hanley.
Macoma incongrua von Martens.
Astarte semisulcata Leach (possibly Quaternary intrusion).
Saxicava arctica Linnaeus.

Later Dall[65] reexamined this collection, gave its age unreservedly as Pliocene, and described the new species *Chrysodomus leffingwelli* and *Pyrulofusus schraderi*, which evidently are the same as the undescribed species of *Chrysodomus* mentioned in the earlier report.

The age of the Tertiary rocks on the Kobuk was suggested by Dall[66] on the basis of specimens and descriptions furnished by Cantwell in 1886 but without any fossils. Later Mendenhall collected fossils near the mouth of the Kallarichuk (Reed) River, which were reported on by F. H. Knowlton[67] as follows:

This collection consists of five small specimens, the matrix being grayish fine-grained very hard sandstone. The plant remains are not retained with great fidelity, but fortunately all are determinable. Four species are represented, as follows: *Ginkgo* sp., probably *G. adiantoides* (Unger) Heer, *Taxodium distichum miocenum* Heer, *Taxodium tinajorum* Heer, *Populus arctica* Heer. With so few species as a basis for comparison it is not possible to speak very dogmatically as to their probable age, but all things considered, I should incline to refer them to the so-called Arctic Miocene, which is now generally regarded as belonging really to the upper Eocene.

Another small collection was made by L. M. Prindle on the Shungnak River about 25 miles north of the Kobuk. This collection was examined by Arthur Hollick, who stated that it consisted of two pieces of gray sandy shale containing fragmentary remains of angiosperms, which, however, could not be specifically identified.

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[64] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 83, 1904.

[65] Dall, W. H., Pliocene and Pleistocene fossils from the Arctic coast of Alaska and the auriferous beaches of Nome, Norton Sound, Alaska: U. S. Geol. Survey Prof. Paper 125, p. 26, 1921.

[66] Dall, W. H., and Harris, G. D., Correlation papers—Neocene: U. S. Geol. Survey Bull. 84, pp. 248–249, 1892.

[67] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, p. 42, 1902.

There is still considerable question as to whether or not there was a structural break between the Upper Cretaceous and the Tertiary in the Kobuk region. Many bits of evidence suggest that deposition was almost uninterrupted from Cretaceous into Tertiary time. According to this view, the Tertiary beds mark deposits close to the shore or on land at a late stage in the constantly encroaching marine invasion which began in the Upper Cretaceous epoch and ended with mountain building in the Tertiary. In other words, the conglomerate found close to the old land may be an unbroken lithologic unit which ranges in age, in different parts of central Alaska, from the base of the Upper Cretaceous into the Eocene.

QUATERNARY SYSTEM

Naturally the most extensive deposits that are found in northwestern Alaska are those that are now in process of formation or that have been made in the recent past. They occur everywhere and have been formed by a great diversity of processes. Because of limited space it is impossible to record here in detail all the observations that have been made of these deposits, and because of inadequate data it has been impossible to make comprehensive generalizations that would be thoroughly trustworthy. Furthermore, the deposits of different types merge into one another so intricately that a pure type is the exception rather than the rule. In the following pages, therefore, it will be practicable only to discuss some of the major types of these deposits and these only in a more or less general manner. To do this as systematically as possible under these limitations has made it desirable to distinguish the different types on the basis of the main agency involved in their formation. On this basis the deposits may be divided into four principal classes—marine deposits, glacial deposits, river or fluviatile deposits, and wind-made or eolian deposits. No attempt has been made to represent separately these different types on the geologic map, and even in the descriptions it is not feasible to enumerate in detail all the places where deposits of certain types have been recognized, though it will be practicable to state the general types of regions in which certain deposits predominate or have been specially noted.

MARINE DEPOSITS

Deposits of distinctly marine origin are of course in process of formation everywhere along the coast. These range from sand and fine material along much of the coast to coarse boulders and blocks at those places where rocky cliffs lie immediately inland of the strand. Some of the material that is being brought to the sea is mainly of river origin, and so when laid down in the sea preserves some of the characteristics of fluviatile material. In other places the ocean is beating against cliffs of unconsolidated deposits of various origins, and there the deposits now being formed have a mixed aspect. Obviously, the present marine deposits are being laid down principally under water off the coast, so that they can not readily be seen. It is significant, however, that the sea floor off the entire coast is under only a slight cover of water. This may be well seen in Figure 15, which represents by different patterns areas in which

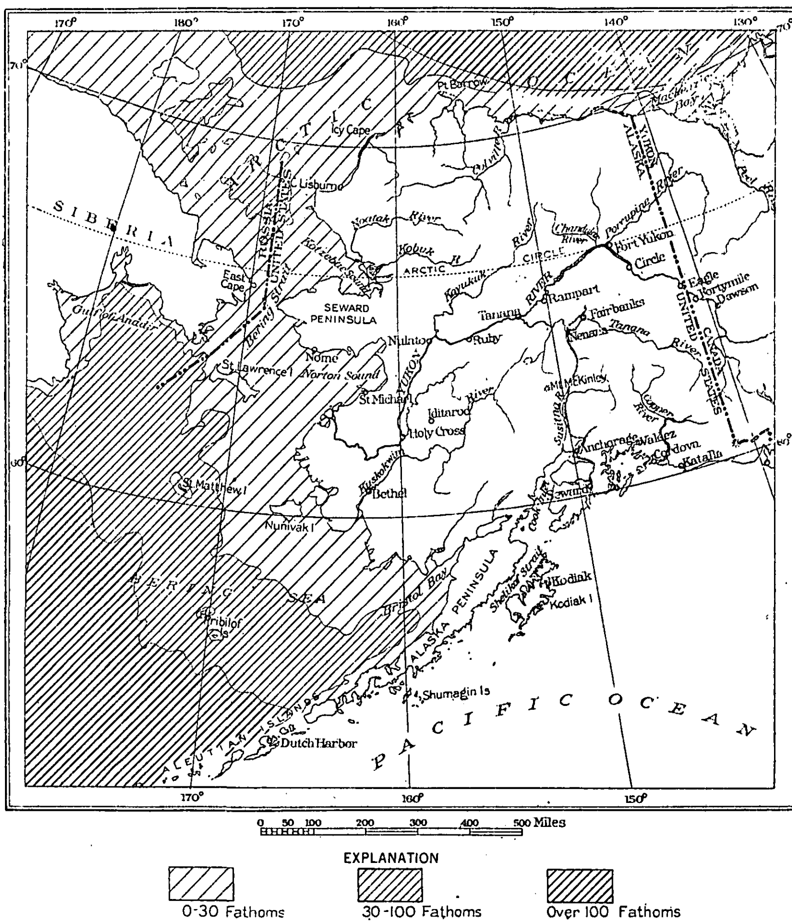

FIGURE 15.—Sketch map showing depths of ocean off north and northwest coast of Alaska

the water is less than 30 fathoms deep, from 30 to 100 fathoms, and more than 100 fathoms. In other words, almost all the present marine deposits near northwestern Alaska are being formed in extremely shallow water.

As will readily be seen from Plate 1, much of the northwestern coast is fringed with narrow sand reefs that lie a longer or shorter distance off the coast and are similar in general mode of formation to the reefs off many parts of the Atlantic coast and other parts of the world. They differ from these other reefs, however, in that one of the processes which in northern Alaska has been largely instrumental in eroding material from the sea floor and heaping it up in the ridges that form the reefs is the sea ice. Each year the young ice that forms on the sea to the depth of 5 feet or less becomes attached to the material of the sea floor where the water is shallow, and the thicker ice of the pack, which may be tens of feet thick, is driven against the material resting on the sea floor. Thus by floating and rasping they bring shoreward considerable quantities of detritus, which serves to renew the seaward faces of the beaches and cover many of them with coarse material entirely dissimilar from the smaller material usually handled by the water currents. Plate 26, *B*, shows a view near Kilimantavi of some of this ice-shoved gravel (at the left), which was brought in during the winter of 1925–26 and laid down on the fine sands of the beach (at the right). The scale of this view is indicated by the notebook, which is about 8 inches long. Some detritus from the land is also blown or washed onto the surface of the ice and then deposited as the ice melts, but the quantity of this material is relatively small and after deposition is not readily distinguishable from material derived from other sources.

Former higher stands of the land as evinced by marine deposits are obviously difficult to recognize, for evidence of them is now hidden by the sea, but evidence of former lower stands which have since been uplifted is now recognizable through the marine deposits then formed, which are seen at many places and clearly indicate relatively recent uplift. The whole coastal plain province thus appears to have been at one time under the sea and later to have been uplifted. The amount of uplift differed in different places but was certainly as much as 300 feet throughout much of the coastal region. The material originally deposited in the sea and later uplifted has subsequently been much more modified by subaerial erosion and fluviatile carving and deposition. In no place were very thick deposits of marine origin laid down, as is shown by the fact that the underlying hard bedrock is exposed at many places where these deposits are trenched by the present streams.

An interesting occurrence of these now uplifted beds near Skull Cliff, about 35 miles southwest of Barrow, was studied by Meek.[68] At this place at the base are indurated rocks which elsewhere in this report are considered of Upper Cretaceous age. Above these, according to Meek,

[68] Meek, C. E., Notes on the stratigraphy and Pleistocene fauna from Peard Bay, Arctic Alaska: California Univ. Dept. Geology Sci. Bull., vol. 14, pp. 409–422, 1923.

is a series approximately 45 feet thick, the lower beds of which consist of alternate layers of friable unconsolidated yellowish sands and black fissile mud shales, while the upper portion is composed of massive beds of yellowish sand poorly stratified, with practically no shale. Chert pebbles are scattered throughout these upper sands. Individually the lower beds seldom exceed 3 or 4 inches in thickness, but one shaly layer about 8 inches thick was noted. The series is undisturbed and in apparent concordance with the lower members in the section.

In tracing the contact of these softer beds with the calcareous sandstone it is apparent that the upper series was deposited upon a gently undulating surface. The marked change in the nature of the beds in the two formations, together with the slight irregularity between the contact, indicates that there must be some lapse of time and a shift in the conditions of deposition between the two. * * *

The upper 25 feet of the overlying formation, however, contains numerous marine shells, though none are observed in the lower beds of shale and sand. The fauna from the upper sands consist of the following species:

Pelecypoda:

Astarte arctica Gray, new subspecies brownii.
Astarte cf. fabula Reeve.
Astarte borealis Schnecker.
Astarte leffingwelli Dall.
Cardium ciliatum Fabricius.
Leda pernula Müller.
Macoma calcarea Gmelin.
Saxicava pholadis Linnaeus.
Serripes grönlandicus Gmelin.
Siliqua patula Dixon.
Yoldia limitula Say.

Gastropoda:

Buccinium normala Dall.
Buccinium glaciale Dall.
Buccinium polare Dall.
Chrysodomus clarki, n. sp.
Lora skullcliffensis n. sp.
Natica clausa Broderip and Sowerby.

The following species were collected from the beds southwest of Cape Smyth by Leffingwell in 1914:

15 miles southwest from Cape Smyth in talus and in place:

Astarte actis Dall.
Astarte leffingwelli Dall.
Balanus rostratus alaskensis Pilsbry.
Chrysodomus fornicatus Dall.
Macoma sabulosa Spengler.
Venericardia crebricostata Krause.

* * * This fauna is of an Arctic type in that most of the forms live only in high latitudes. A number are circumboreal, their presence being noted by Sars[69] in the Arctic fauna occurring along the coast of Norway. Several, however, seem to be restricted in their occurrence to the Arctic region of western America.

Owing to the paucity of extinct forms it has been concluded that the upper formation in which these fossils occur is of Pleistocene age. It seems likely

[69] Sars, G. O., Mollusca regionis arcticae Norwegiae, 1878.

that the entire upper formation belongs to a single period of deposition, marine shells failing to appear in the lower beds only because conditions were unfavorable for their existence in them.

Dall, who originally determined collections from both localities, stated that the fossils collected 15 miles southwest of Barrow were Pleistocene but that those collected from the locality 40 miles from Barrow might be Pliocene, and therefore the formation in which the fossils occurred might be correlated with the Pliocene exposed near the mouth of the Colville River.[70] The more detailed work done by Meek and quoted above seems to indicate that that possibility is remote and that the unconsolidated deposits at both localities are presumably Pleistocene.

In the course of his surveys of the Inaru and Topagoruk Rivers in 1923 James Gilluly made five collections of shells, which were examined and identified by W. H. Dall, who determined three of them as of Pleistocene age and two of them as probably Pliocene. All the collections that were made from deposits in place were determined as of Pleistocene age; the two collections that Dall regarded as probably Pliocene came from material collected on bars in the Topagoruk Valley and therefore may have come from anywhere within an extensive area. Furthermore even the Pliocene age of these two collections is open to serious doubt, as Dall had suggested a Pliocene age for certain fossils that came from a locality which Meek has demonstrated contains fossils of Pleistocene age. In this report, therefore, all five of the collections made by Mr. Gilluly are regarded as having probably come from Pleistocene or Recent deposits. The following description of the localities at which these collections were made has been abstracted from Mr. Gilluly's field notes:

Locality 23AG1A, sandy cut banks near the head of the Inaru River, in the wash from which are found shells so numerous in places that they seem like local concentrations made by some artificial means. Most of the shells are broken, and their concentration in certain localities suggests considerable transportation.

Locality 23AG2A, somewhat farther down the Inaru River; a 15-foot band of yellow-brown sand with considerable coal float and slabs of subangular calcareous yellow-brown sandstone and brown shale. Fossils were intimately intermingled with the float and wash from the cut bank, so that there is no question of their having been in place in the deposits.

Locality 23AG3A, on bars in the lower part of the Topagoruk River, where it is impossible to determine whether they were washed out of near-by banks or have been carried considerable distances downstream.

Locality 23AG4A, farthest collection upstream in the Topagoruk Valley, from chrome-yellow or burnt-umber blocky mucky shale with indistinct hori-

[70] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 149–150, 1919.

zontal bedding which seems to overlie the gray-yellow sands that make up most of the old hill remnants of an earlier erosion cycle.

Locality 23AG5A, intermediate point on the Topagoruk River; not in place but probably washed down from some point farther upstream.

Locality 23AG6A, near the mouth of the Inaru River. The banks there are of muck, yellow-gray sand, and stiff blue clay like those on Wainwright Inlet and are 15 feet above water level. The shales occur about in the middle of this section, associated with fine gravel, and appear to mark an elevated beach.

Doctor Dall's identifications of the fossils in these collections and tentative age determinations are as follows:

23AG1A and 23AG2A. Inaru River:
- Chrysodomus solutus Herrman var. heros Gray.
- Lora laevigata Dall.
- Astarte arctica Gray.
- Venericardia crassidens Broderip and Sowerby.
- Saxicava arctica Linnaeus.
- Serripes grönlandicus Gmelin.

Probably Pleistocene.

23AG3A. Topagoruk River:
- Astarte leffingwelli Dall.
- Astarte actis Dall (young form).
- Venericardia crebricostata Krause.

Probably Pliocene.

23AG4A. Topagoruk River:
- Lymnaea petersi Dall.
- Valvata lewisi Currier.
- Pisidium idahoense Roper.

Probably Pleistocene.

23AG5A. Topagoruk River:
- Lora laevigata Dall.
- Natica sp. (fragment).
- Cardium ciliatum Fabricius.
- Serripes grönlandicus Gmelin.
- Astarte leffingwelli Dall.
- Astarte borealis Schumacher.
- Venericardia crebricostata Krause.

Probably Pliocene.

23AG6A. Inaru River:
- Buccinum cf. B. tenue Gray (fragment).
- Buccinum sp. (fragment).
- Lora laevigata Dall.
- Cardium ciliatum Fabricius.
- Astarte cf. A. compressa Linnaeus.
- Astarte arctica Gray (young form).
- Macoma truncaria Dall.
- Saxicava arctica Linnaeus.

All living species. Probably Recent or late Pleistocene.

In close relation to some of the marine deposits, though also showing characteristics that suggest relations with some other agencies of erosion and deposition, are numerous fragments of rocks of apparently foreign origin. At many places along the beach from Point Lay northward to Barrow and up some of the inlets pieces of red granite, gray granite, red quartzite, and some gneiss or schist were found. Fragments of this sort were particularly abundant in Peard Bay near camp P August 9. Foran notes the presence of large angular blocks of red granite and pink quartz as much as 5 feet in each dimension and many smaller ones as much as 8 inches in diameter at many points along Wainwright Inlet all the way to the head of the Kuk River. Most of the larger ones were found along the beach, but a few were found as high as 30 feet above tide level. These rocks are similar to some of the material noted by Leffingwell on Flaxman Island, where boulders 10 feet or less in length, representing a great variety of different kinds of rock, form a thin deposit usually not more than 3 feet thick. The peculiarity of these boulders on the northwest coast of Alaska is not only their large size and irregular distribution but also their source, for similar rocks from which the boulders could have been derived are not known anywhere in northern Alaska. The explanation that the boulders may possibly have been ice rafted from some remote source seems to fit the known facts more adequately than any other that has been suggested.

GLACIAL DEPOSITS

One of the most interesting of the events in the Quaternary history of northern Alaska has been the growth and almost total disappearance of glaciers. As has already been stated, not more than three or four glaciers have been seen in the course of all the surveys that have been made in the area covered by this report, and none of these was more than 2 or 3 miles long. In the past, however, glaciers were much more extensive, and even in the areas not actually occupied by the glaciers the deposits formed by the streams issuing from them have had a marked effect on the adjacent region. In Figure 16 an attempt has been made to indicate the area that was more or less completely occupied by ice during the maximum period of glaciation. This figure in a measure overemphasizes the area covered by ice, because it includes all of the mountain region, whereas probably many of the ridges were bare and the glaciers principally occupied the valleys. In other words, there was not a continuous sheet of ice within the area outlined but rather a collecting ground that roughly corresponded with the main ridges between the Kobuk and Noatak and between the Noatak and Colville, from which tongues of ice extended outward into the lower country to the north and south of both ridges. The figure, however, does serve to delimit those areas in which typical glacial deposits are likely to be found from those in which there is no evidence of glacial action in the recent past.

It is not always possible to determine the extreme frontal stand of the ice, for in many places the earlier formed deposits have been mantled with later deposits of glaciofluviatile origin, so that they are now hidden. Furthermore, deposits of fluviatile and of pure glacial deposition are so intermingled at the front of a glacier that in many places even the same observer at different times might give different weight to the same evidence, and at one time he might regard

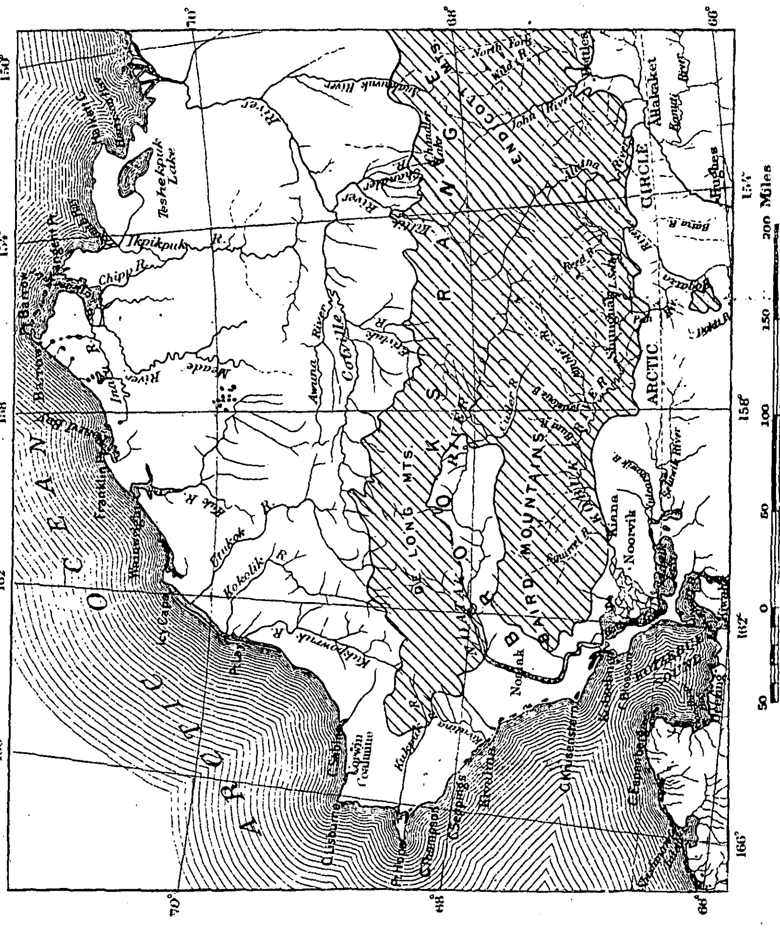

FIGURE 16.—Sketch map showing extent of former glaciation (shaded area) in north-western Alaska

as outwash material that which at another time he might regard as relatively unmodified glacial deposits.

The distinctive glacial deposits are made up of material plucked and eroded by the ice and deposited in a more or less jumbled, unsorted condition as the ice melted. This type of deposit is readily recognized in the sheets of débris found at places in the lower parts of the larger valleys, but its most striking representation is in the ridges or moraines that mark the extreme frontal stand of the ice or various halts in the recession of the glaciers as they gradually disappeared. Moraines of this sort are numerous in almost all the valleys of the larger streams entering the Kobuk, the Koyukuk, and the Colville. In all places they have subsequently been cut across by the present-day streams in rather narrow gorges, whose floors are strewn with great blocks of rock that were in the morainic deposits and were too large to be swept out of the way by the streams that carried off the finer material. Navigation of these trenches through the moraines is therefore difficult and makes these moraines memorable features to travelers on these rivers.

Boulder-strewn rapids of this sort were found on the Killik near camp M June 11, where the summit of the moraine rose several hundred feet above the present level of the stream. The steep south face of the moraine marked the contact of the débris with the old glacier that has now disappeared, and its relatively smooth northward slope showed the form produced by the distribution of material by the streams and other processes beyond the front of that glacier. The moraine mantled the ridges to the east of the Killik, so that only their higher knobs rise above it and appear as islands whose lower parts are submerged in this glacial débris. At different elevations above the present streams are small lakes that occupy depressions in the irregularly deposited morainic material formed at a later stand of the ice.

Similar conditions were reported by Schrader along the Anaktuvuk River as far north as Willow Creek and by the expedition of 1925 in the valley of the Utukok. In the western part of the region, however, the mountains are not so high and apparently glaciation was not so extensive. Thus on the Kokolik no distinct morainal deposits were recognized along the route traversed, and the topographic forms strongly indicate that glaciation there was restricted very closely to the higher hills and did not extend more than a few miles down the valleys draining from them.

In the Noatak Valley the extent of the former glaciers has not been determined with precision, owing to the great mantle of outwash material at many places. It is believed, however, that in that valley the glaciers extended mainly southward from the divide north of the river or northward from the divide south of it. As a result these two sets of glaciers may have coalesced and formed piedmont lobes in the main valley, but it is extremely doubtful if this entire valley was at any time filled with ice. There is evidence that a glacier occupied the upper part of the Noatak Valley at least as far west as a point beyond the mouth of Midas Creek; but there is strong reason to doubt that the ice extended as far west as the narrow part of the valley west of the mouth of the Nimiuktuk. There is also conclusive evidence that a glacier extended southward down the valley of the Kugururok and made many of the features now recognized in the vicinity of the canyon, but there is no evidence that this glacier extended far down the lowland toward Noatak village, and it seems certain that it did not reach the Igichuk Hills.

In connection with the glaciation in the central part of the Noatak Valley, W. R. Smith has suggested that the evidence of glaciation in the Aniuk Valley and in the upper part of the Etivluk is such as to indicate the possibility that the Aniuk Valley was occupied by a lobe of a glacier apparently originating in the mountains south of the Noatak and perhaps following more or less closely the valley of the Cutler River. According to this interpretation the glacier may have surmounted the divide at the head of the Aniuk River, which stands at an elevation of about 2,200 feet, or 500 feet higher than the mouth of the Aniuk, and discharged northward into the Etivluk and Colville Valleys. The available data bearing on the problem are too indefinite to warrant final interpretation. The problem is, however, worthy of further investigation in the field, for its solution might explain the presence of large numbers of great boulders of granite in the glacial deposits at the head of the Etivluk, in a place where no granite is known in the near-by region, though it probably occurs in the hills south of the Kobuk. It is, of course, possible that this deposit may have been formed by a glacier following the upper part of the Noatak Valley and terminating near the head of the Aniuk, for in the hills north of Midas Creek Smith[71] observed outwash gravel deposits which were apparently connected with past glaciation at a height of 850 feet above the Noatak, or over 3,000 feet above the sea, and granite probably occurs at the head of the Noatak in continuation of the areas of granite mapped on the Alatna.

In the Kobuk Valley all the glaciers seem to have originated in the mountains to the north of the river. Recessional moraines have been recognized in almost all the large tributary valleys—in the valleys near the Kobuk-Alatna pass and extending down both Helpmejack Creek and the Kobuk, down the valleys of Walker Lake, the Reed, Beaver, Selby, Mauneluk, Kogoluktuk, and Ambler Rivers, and some of the streams still farther west. Some or all of these glaciers on entering the lowland of the Kobuk undoubtedly coalesced and formed a continuous mass of ice in parts of that valley. It is the writers' general impression, however, that the ice in the main Kobuk Valley was dominantly a stagnant mass, obstructing drainage but not a vigorous moving or eroding agent, and that after the tributary glaciers began to recede its supply of ice diminished rapidly. The

[71] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 92, 1913.

narrowness of the valley below the Kallarichuk suggests that no volume of ice flowed through it, and the size of the delta of the Kobuk—an unusual feature among the rivers north of the Yukon and west of Barrow—suggests that ice did not reach that far. On the other hand, Hershey [72] has interpreted the peculiar peninsula that separates Hotham Inlet and Selawik Lake from Kotzebue Sound as the moraine of an ancient glacier that extended the entire length of the Kobuk, and he reported finding till in the exposures near Cape Blossom.

No signs of glaciation that originated in the hills immediately south of the Kobuk have been recognized, though only part of the Lockwood Hills has been gone over in any detail. Instead, this highland seems to have stood as a buttress against which the ice from the valleys to the north impinged and turned aside downstream. The history of the development of the topography here is obscure, but apparently some of the water from the melting glaciers in the Kobuk Valley found a southward discharge across these hills, using from time to time successively lower gaps as they were disclosed during the melting back of the ice.

So far as known, the glaciers did not reach the main valley of the Koyukuk within the area described in this report, but the evidence is not entirely conclusive, because much of that valley and the lower parts of the valleys of its tributary streams are obscured by later outwash deposits of fluviatile and glaciofluviatile origin. In the Alatna Valley signs of glaciation are abundant everywhere north of camp S March 9, but distinct moraines are relatively rare, apparently because of the constriction of the main valley whereby the deposits were swept downstream rather than allowed to accumulate. The deposits in this valley, however, in many places are distinctly of glacial origin, as shown by their composition and their knob and kettle topography. Some ice reached the Alatna from the hills at the head of the Kobuk by way of Helpmejack Creek.

Just how far south in the valley of the John River the glaciers actually extended, is not entirely clear from Schrader's description, for his use of the term "till" covers outwash deposits that were probably derived from glaciers but were carried to the position in which they are now found principally by fluviatile action. Therefore, although Schrader describes till deposits all the way to the mouth of the John River and even below the mouth of the Alatna, it seems certain that glaciers did not extend that far. Distinct morainic topography, however, on the John River occurs at least as far south as the mouth of Hunt Fork, so that the front must have been some-

[72] Hershey, O. H., The ancient Kobuk Glacier of Alaska: Jour. Geology, vol. 17, pp. 83–91, 1909.

what south of that point. The deposits found near this moraine are described by Schrader as composed of typical boulder clay carrying striated pebbles and boulders, some of which are more than a foot in diameter.

The Wild River and many of the other northern tributaries of the Koyukuk that rise in the higher mountains were also occupied by more or less extensive valley glaciers in the past, and probably most of the mountains were collecting grounds for the accumulation of small bodies of ice.

FLUVIATILE DEPOSITS

By far the greater part of the unconsolidated deposits of Quaternary age in this region show some features of fluviatile origin. Even the characteristic marine deposits merge with those that have been formed under fluviatile conditions, and almost all the glacial deposits have been more or less modified at the time of their formation or later by running water, so that it is practically impossible to recall an example where running water has not had some participation in the deposition. Under these conditions it is neither practicable nor desirable to attempt to describe in detail all the fluviatile deposits. It is perhaps sufficient here to state that near the sea and in the old coastal-plain deposits, formed dominantly under marine conditions, the merging between marine and fluviatile deposits is most pronounced.

The area near the formerly glaciated region shows many interesting aspects of the merging between fluviatile and glacial conditions of deposition. This is especially true of the great outwash deposits that are particularly prominent along the north face of the Brooks Range. In that region, for a score or more of miles beyond the northernmost limit at which true glacial deposits have been recognized, are deposits of glaciofluviatile origin that have been spread unconformably over the older formations. These deposits were recognized almost continuously in favorable localities along the Killik River, and even near the junction of that stream with the Colville a few boulders as much as 6 inches in diameter were found in these deposits. Similar deposits were also recognized as capping the bluffs along almost the entire length of the Etivluk River and in the lower parts of the Kurupa River. They were seen at many places along the headward part of the Colville River and in the section of the Utukok that was visited by the expedition of 1925. Apparently they did not extend northward far beyond the present course of the Colville, for they were not recognized on the divide between the Colville and Ikpikpuk Rivers, nor were they recorded by W. R.

Smith or W. T. Foran on the northern slopes of the hills at the head of Disappointment Creek, in the Utukok Basin.

On the south side of the Brooks Range the fluviatile deposits that are undoubtedly associated with the waning of the glaciers are widespread and form notable features in the Kobuk Valley. There and also in the Noatak Valley they form terraces at different elevations, the highest several hundred feet above the main river. Most of these deposits show good stratification and consist of materials ranging in size from larger boulders to fine mud. These deposits in the Noatak and Kobuk Valleys have been described in some detail by Smith,[73] and somewhat similar deposits in the valleys of the tributaries of the Koyukuk have been described by Schrader,[74] Maddren,[75] and others. All these geologists recognize that the fluviatile deposits in these valleys represent an intensely complex history of deposition. The solution of this history is of great theoretical interest, as it reveals the story of the steps in the development of the region. It is also of much practical value to the seeker for placer deposits, because the accumulation of gold in these deposits differs according to the different agencies involved in their formation, so that the prospector would be much aided in his search if the character, relations, and history of the different deposits were thoroughly understood.

A rather unusual deposit, which presumably is largely of fluviatile origin, occurs on the Kokolik River downstream from a point a short distance above camp P June 12. Near this camp are bluffs that rise about 175 feet to a rather flat-topped bench nearly 700 feet above the sea. The upper part of the bluff is capped by a sheet of gravel 25 feet or more thick. The pebbles in the gravel are made up of a number of different kinds of rock, but those of chert are by far the most numerous. This deposit is more nearly horizontal than the grade of the stream, so that it appears at a constantly greater height above the river as it is traced northward. It could not be recognized far to the north, as the height of the land diminishes in that direction, so that less than 25 miles north of the camp practically all the country lies less than 600 feet above the sea. Possibly the miscellaneous character of the pebbles in this deposit may serve as an explanation of an isolated granite pebble several inches in diameter that was found in the bank of a small stream that joins the Kokolik midway between camps P June 11 and P June 12. Even so, however, the complete story of

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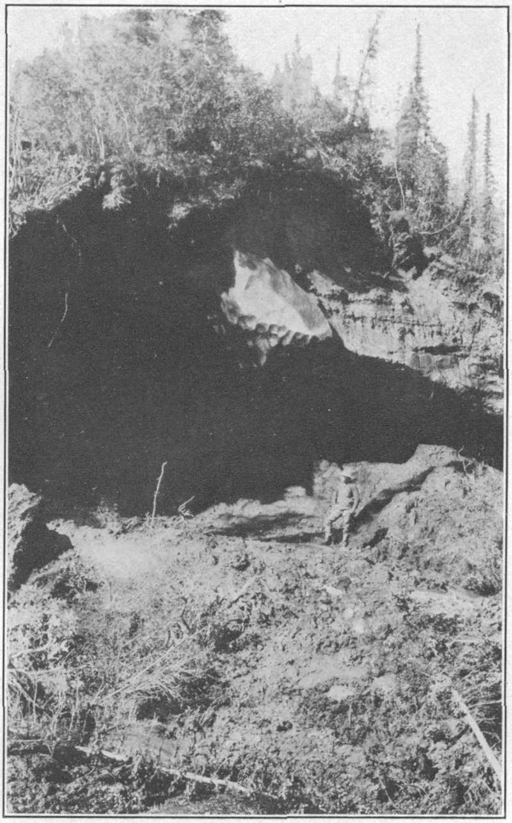
[73] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 104–105, 1913.

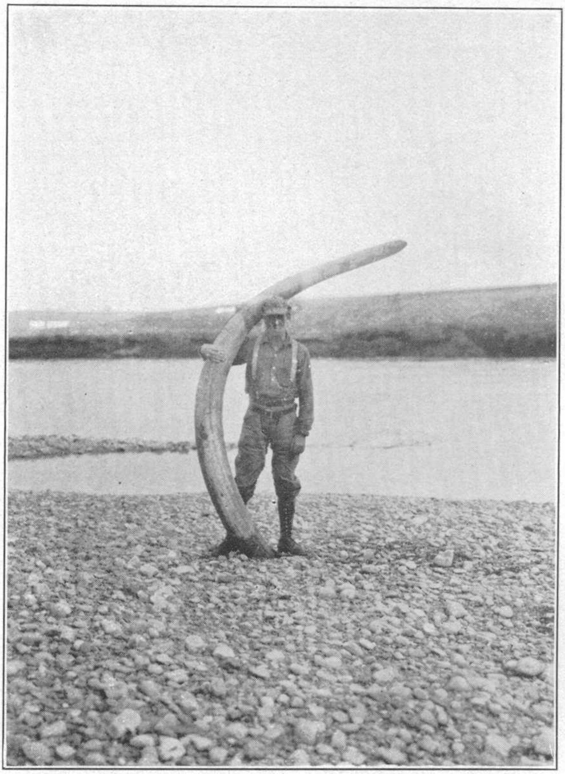
[74] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 94–96, 1904.

[75] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pp. 60–67, 1913.



A. ICE MASSES ON NOATAK RIVER NEAR KUGU-RUROK RIVER

B. ICE-SHOVED MATERIAL ON BEACH NEAR KILIMANTAVI



A. MAMMOTH TUSK ON COLVILLE RIVER NEAR ETIVLUK RIVER

B. ICE WEDGES ON IKPIKPUK RIVER

the source of this granite pebble is not revealed, for no granite in place is known within hundreds of miles of this locality.

EOLIAN DEPOSITS

Although the eolian deposits themselves are of relatively small extent and of little volume, there are many areas, especially in the coastal plain, where wind has a large effect in transporting material derived from other processes and heaping it up in dunes and other forms characteristic of that agency. When the wind blows, which seems to be most of the time, a veritable sheet of sand is sent scudding along the beaches above the high-tide level with stinging velocity until the grains lodge in the lee of some obstruction, such as a log or even a piece of shell. The whole country near the coast northward from Cape Beaufort, and especially on the reef off the coast, has numerous dunes and patches of sand that have been carried thus and laid down by the wind. In the lower parts of the coastal plain, where the relief is so slight that even an owl looms up with startling prominence, almost the only topographic relief is afforded by these eolian deposits. In places along the lower part of the Ikpikpuk the general course of that stream and its tributaries could be recognized at a distance by the dunes 10 to 20 feet high that are formed of the sand and silt swept from the bars and banks by the wind and piled near by on the upland. Many of the dunes show strongly cross-bedded structure and characteristically wind-worn and polished grains. The larger rock fragments lying exposed on the surface show typical wind scour and faceting.

Schrader also noted in the lower part of the Colville dunes and extensive unconsolidated deposits, which form part of what he called the Gubik sand. As described by Schrader,[76]

> The deposit consists of fine sand with apparently an admixture of considerable silt. In some localities it seems to be more sandy toward the base and more earthy toward the top, where it terminates in from one to several feet of dark-brown or black humus clothed at the surface with moss and a little grass. It is ordinarily free from gravel, but in several instances subangular cherty pebbles ranging from mere sand grains to fragments as large as one-fourth inch in diameter were found. These occur very scatteringly and are sometimes roughened, as if wind worn.

Schrader described this material in his field notes as loess, but he indicated in his report that processes other than wind were believed to be mainly instrumental in its formation. The beds lie unconformably on the Tertiary. Certainly the general uniformity

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[76] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 93, 1904.

and extent of the formation as mapped by Schrader indicate that the deposit is not entirely of eolian origin.

ICE

Among the types of Quaternary deposits occurring in this region is one that deserves special mention because ordinarily it is not found in the sections studied by geologists. This is ice. Although unusual in most places, it is a common feature in the unconsolidated deposits of northwestern Alaska. It is perhaps improper to speak of many of these Quaternary deposits as unconsolidated, for in reality many of them are thoroughly consolidated by ice. It is not, however, the interstitial ice that will be discussed here, nor the seasonal bodies of ice that are formed each year on the rivers, lakes, and ocean, but instead the beds and lenses or wedges of nearly pure ice that are found at many places in or cutting the beds of marine, fluviatile, or lacustrine origin.

Masses of ice of this sort have been observed in many of the deposits in sub-Arctic and Arctic regions, both on this continent and in Asia. Their distribution and the facts known about them up to 1918 were comprehensively studied and described by Leffingwell,[77] who came to the conclusion that most of these masses were formed in place underground, though he recognized that occasionally surface snow and ice might be covered by deposits that served to protect them from melting under the conditions that now prevail. Some of these masses are of large size, but others are merely narrow "dikes." Plates 26, *A*, and 27, *B*, show characteristic views of exposures on the Noatak near the mouth of the Kugururok and on the Ikpikpuk near camp S August 10. It is evident from these views that recognition of these masses at the surface is practically impossible except where relatively fresh sections are available. Even in a fresh cut along the bank of a stream the slumping of the turf and overlying débris quickly tends to cover the ice and so protect it from further melting unless the face of the exposure is kept clear of this accumulation.

The famous ice masses at Elephant Point and near-by places in Eschscholtz Bay have been known since Von Kotzebue's voyages in 1816 and have been visited by many scientists. The ice cliffs on the Kobuk were first described by Cantwell, who saw them on his explorations in 1884, and were later described by Mendenhall and others. The masses of ice along the Pitmegea River were described by Stockton[78] in 1890. The ground ice seen at many places along

[77] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 179–241, 1919.

[78] Stockton, C. H., Arctic cruise of the U. S. S. *Thetis* in the summer and autumn of 1889: Nat. Geog. Mag., vol. 2, pp. 178–179, 1890.

the northern coast of Alaska was described by Schrader in his account of his journey in 1901. Smith described some of the localities where he noted ground ice in the Noatak in the course of his traverse of that stream in 1911. The descriptions of almost all these deposits, as well as many others, have been summarized by Leffingwell, who has added many observations of his own, so that the person desiring more detailed descriptions of these areas should consult his report[79] or the original articles.

A number of new localities were found within areas visited by the recent Geological Survey expeditions, and as their descriptions are not available in any other report, they will be mentioned here. Little or no ground ice was recognized in the valley walls of the Killik or any of its tributaries. The first considerable area of ground ice seen in the valley of the Colville above the mouth of the Killik was near camp S June 22, but above that point small masses of ground ice were seen at intervals all the way to the Etivluk. Ground ice was not noticeable on the Colville below the Killik River or on Prince Creek, the tributary from the north. To the north on Maybe Creek, however, ice wedges and masses were observed at many places, and they were also seen to the west on the Kigalik River. A short distance below the junction of these streams many exposures of ground ice were seen in the banks of the Ikpikpuk. At that place there seemed to be a horizontal sheet consisting mainly of dirty silt-bearing ice which was intersected, at intervals of 100 feet or so, by narrow vertical "dikes" or veins of white nearly pure ice. This general condition was noted at several places farther down the Ikpikpuk. In some of the exposures the "dikes" or wedges of ice were nearly 50 feet across. Plate 27, *B*, shows one of the fairly large ice wedges near camp S August 10. The extensive masses of ice exposed along the coast near Cape Simpson, which had already been reported by others, were also seen at close range, as well as many masses of ground ice in the cliffs along the south shore of Elson Lagoon, west of Point Rowand, which do not appear to have been noted, though they must have been seen by many travelers.

ORGANIC REMAINS

Buried in these Quaternary deposits are remains of some of the animals and plants that lived at the time the different deposits were being formed. Along the coast are found the shells or bones of marine animals similar to forms now living in the near-by waters, and the older marine deposits, as, for instance, those near Skull Cliff above described, contain the remains of sea animals, some of

[79] Leffingwell, E. de K., op. cit.

which are not now represented by living types in the region. In another part of the report mention has been made of the land animals and plants that now live in the region, and their remains are found in many of the deposits now being formed. In the past, however, other land animals roamed over the region but died, and their descendants have migrated to other regions. Among the most interesting of these were the elephants or mammoths, which appear to have had a rather widespread distribution in the past. Tusks, teeth, and bones of the mammoth have been found at a great number of places in northwestern Alaska. Just south of the mapped area the historic bluff known as Elephant Point, in Eschscholtz Bay, which was discovered in 1816 and has since been visited by many eminent scientists, has afforded many remains of the mammoth, including pieces of the skin and hair, and many bones have been found in the adjacent region including Choris Peninsula and Cape Blossom. Remains of the horse, bison, musk ox, deer, wolf, and bear and beaver dams have also been found in these same deposits. On the Kobuk Cantwell found many elephant bones near the ice cliffs in the lower part of the river above the delta, and he noted mammoth tusks as much as 8 inches in diameter in the clay near the mouth of the Ambler River. Tusks have been found at many other places on the Kobuk as far upstream as Shungnak. On the Noatak large pieces of mammoth tusk were found in the Recent gravel about 20 miles downstream from the mouth of the Cutler River, and portions of the skull and thigh bones of mammoth were seen midway between the Nimiuktuk and Kugururok Rivers. Natives report finding a good deal of this old ivory on the Noatak, and as it has a commercial value they keep a close lookout for it. Allen recorded the finding of a single bone, the os pubis of a mammoth, about 6 miles above the mouth of the Alatna River embedded in the alluvial deposits. It was in a fair state of preservation and "to all appearances had never undergone any process of petrifaction."

On the Colville a number of large pieces of elephant ivory were found, especially in the area near which there is considerable ground ice. A remarkably well-preserved tusk, estimated to weigh between 200 and 250 pounds, was found on a gravel bar of the Colville a short distance below the Etivluk. Although it had apparently been washed out of the bank it could not have been carried far, for neither the butt nor the tip had been broken or much abraded. Plate 27, *A*, shows a view of this tusk, whose actual length is, however, considerably foreshortened in the picture because of the double curve that it has. A few miles above camp S July 2 a tusk was found on the upland 40 feet above the river level, with its point projecting nearly a foot above the turf. This was an interesting find, as the tusk occurs close to the present surface. The tusk was solidly embedded in ice and frozen deposits, so that although an excavation was made around it to a depth of a foot or more, it could not be dislodged. From the fact that the base of the tusk was downward it is entirely possible that the skull or more of the skeleton might be disclosed if excavations were carried deeper. That part of the tusk which projected above the turf was badly bleached and checked, so that it broke into long, thin scales. Near the junction of the Awuna River and Birthday Creek but especially on the bars in the lower part of the smaller stream fragments of mammoth ivory were fairly common. Several teeth were also found in the gravel of these bars; the largest one measured 10 inches on its grinding surface.

Across the divide from the Colville along the lower course of Maybe Creek and the Kigalik River, which form the southern headwaters of the Ikpikpuk River, fragments of bones and mammoth ivory were seen at a number of places. North of the junction of these streams for some distance this material became even more abundant, and a short way below camp M August 3 a pair of mammoth tusks in an excellent state of preservation were found embedded in sand in a cut bank at a slight elevation above the river. These tusks measured 9 feet along the curve from base to tip, or 4 feet in a straight line. Each had a circumference at the base of about 17 inches and weighed about 100 pounds. Still farther down the Ikpikpuk and midway between camps M August 5 and M August 6, on the east bank of the river, are terraces at low and high levels carrying mammoth remains. At this place a nearly perfect skull and upper jaw of an elephant was found. The skull was about 3 feet in diameter, and the bone appeared practically undecayed or unmineralized and seemed as if it had been shed only a short time.

A great deal of bone and mammoth ivory was found on many of the bars along the Avalik River. Several tusks were found ranging in length from 5 feet to only a few inches and in diameter from more than 6 inches to less than 3 inches. Several small teeth of the mammoth were also found, especially on bars between camps P July 13 and P July 14.

The most interesting of the animal remains found on the Avalik, however, were the skulls of horses. A skull in almost perfect state of preservation was found on the bar between camps P July 14 and P July 15. This was examined by J. W. Gidley, who reports that the specimen is part of a skull of a Pleistocene horse, *Equus* cf. *E. lambei* Hay. Another piece of one side of a skull that seemed to be essentially the same as this one was found a short distance downstream from camp P July 18, and a tooth that was probably a horse tooth was found 3 miles above the camp.

About half a mile below camp P July 11, on the upland north of the Avalik River, a bleached skull of a musk ox was found lying practically unburied on the surface. It appeared to be as little altered or decomposed as bones that have been lying on the surface for only a few years. Musk-ox skulls were also seen on the upland near camp P May 15 on the Kokolik. One of these was found west of the river about half a mile below the camp, and another was found about a mile east of the river and at a considerable elevation above it. The Eskimos say that these skulls are by no means uncommon in that valley. In the parts of the Kokolik Valley traversed by the Geological Survey expedition of 1926 bones or mammoth ivory were very rare. Some weathered bones were noted on the bar near camp P June 14, including a leg bone about 13 inches long and thicker than a man's wrist, which may have belonged to a species of bear.

According to Quackenbush[80] a native is said to have found a boar's tusk near Lake Teshekpuk, but apparently he had not regarded the report as sufficiently well authenticated to include it in his summary list of Pleistocene animals from Alaska.

The interest that attaches to the finding of the remains of the older forms of life in these deposits and the light they throw on the past history are not confined to animal remains, for some of the plant remains are found under conditions that raise a number of problems. For instance, a spruce log, with roots attached, was found on the bar of the Ikpikpuk a short distance below camp S August 9, at an elevation of more than 200 feet above sea level, and other logs, some as much as 8 inches in diameter, were found below camp S August 9 at intervals all the rest of the way down the river. The logs had apparently been buried originally in the coastal-plain deposits and subsequently washed out of them by the stream. They were sound and unmineralized and were in such good condition that they were extensively used for fuel in camp. It is perhaps significant to note that shells that seemed to be of marine character and were probably also washed out of the coastal-plain deposits were noted on the bars a short distance below camp S August 9. The fact that some of the logs were spruce is of special interest, because no spruce is known to live now in any of the valleys draining northward from the Brooks Range.

In his field notes W. R. Smith records the finding of a section of a tree 2 feet in diameter in the gravel of the Aniuk River near the mouth of Fauna Creek. No further details regarding it are given except that it is said to have been petrified.

[80] Quackenbush, L. S., Notes on Alaskan mammoth expedition of 1907 and 1908: Am. Mus. Nat. Hist. Bull., vol. 26, p. 93, 1909.

IGNEOUS ROCKS

Igneous rocks of several types and ages form an essential part of the geologic record in the Brooks Range but constitute a relatively small part of the regional bedrock. On the north slopes of the range and in the bordering country extending to the Arctic Ocean igneous rocks are almost entirely absent, so that the petrologic data given in the following pages may be said to apply practically to the south flanks of the range. This deficiency in igneous rocks in northwestern Arctic Alaska is a discouraging sign with reference to the possible occurrence of metalliferous deposits; on the other hand, the sedimentary rocks in general should be less fractured than in a region of great igneous activity, and this condition favors the possible development of nonmetallic deposits, such as oil and coal.

On the accompanying geologic map (pl. 2) four general groups of igneous rocks are shown. This fourfold division, as will be seen, does not indicate all the varieties of igneous rocks that are known to be present, but it represents the best cartographic grouping that is permitted by the scattered field observations and the scale of the map. The four groups are (1) greenstone and greenstone schist, (2) basic extrusive and intrusive rocks, (3) granitic rocks, (4) lavas and pyroclastic rocks, mainly of basaltic character.

GREENSTONE AND GREENSTONE SCHIST

DISTRIBUTION

The rocks included in the group of greenstone and greenstone schist may be separated broadly into three divisions, which differ from one another in geographic and geologic distribution and in petrographic character. These three subgroups and their distribution are as follows:

1. The undifferentiated greenstone schists and related rocks of igneous origin, which form in reality an integral part of the early Paleozoic or older metamorphic sequence. These are therefore restricted to the area occupied by the undifferentiated metamorphic rocks and are not separately mapped.

2. Certain bodies of greenstone and greenstone schist, which appear to be in part at least of Silurian or later age and have been identified both among the undifferentiated metamorphic rocks and in the Skajit limestone. The largest area of these rocks consists of a narrow belt that crosses the John River about 25 miles in an air line north of Bettles. To the west this belt appears to be represented by several smaller areas in the Alatna Valley above the mouth of Helpmejack Creek; and still farther west by two small areas in the Kobuk Valley north of Shungnak. Three other small areas of

this greenstone have been recognized and mapped in the Alatna Valley below the mouth of the Takahula River, within the Skajit limestone band.

3. Ultrabasic rocks, perhaps of early Devonian or late Silurian age, which occur in the Ambler-Shungnak district of the Kobuk Valley and in the Zane Hills, south of the upper Kobuk Valley. These rocks, like those of the first subgroup, have not been separately mapped.

CHARACTER AND OCCURRENCE

The undifferentiated greenstones of pre-Silurian age are in general greenish sheared rocks, which from their present texture and mineral composition give little indication of their original character. They are completely recrystallized, are sheared and schistose, and are composed of varying proportions of chlorite, quartz, epidote, hornblende, feldspar, and other accessory minerals. These rocks are more typically developed in the more highly metamorphosed areas of schist south and southwest of the area here considered, but they are mentioned here mainly to place on record the fact of igneous activity in early Paleozoic or pre-Paleozoic time. The state of deformation and recrystallization of these greenstones and the schists that contain them precludes any analysis of their original mode of occurrence.

The greenstones of the John, Alatna, and Kobuk Rivers, which have been partly mapped, were apparently derived from much the same types of igneous rocks as the older greenstones but differ in being somewhat less metamorphosed. Some of them, although schistose and partly recrystallized, still retain enough of their original structure to warrant the determination, with some confidence, that they were originally diabase. Others, however, differ little from the older greenstones and are seen under the microscope to consist of varying proportions of chloritic minerals, sodic plagioclase near albite, quartz, green hornblende, orthorhombic and monoclinic epidote, iron oxides and hydroxides, and more or less apatite, calcite, and pyrite. Broadly, all these rocks may be classified as metadiabase and chlorite and hornblende schists.

Although the mode of origin of these rocks is not everywhere clear, nevertheless their geologic interpretation is much more obvious than that of the older greenstones. At a number of localities they have been observed in intrusive relations to adjoining rocks, and evidently a considerable proportion of them are altered intrusives of basic character, which originated as dikes and sills and even as larger intrusive bodies at some localities. On the other hand, the continuous band that crosses the John River suggests in its east-west continuity that it may represent an original surficial phase of these basic rocks.

The greenstone found in the region north and northwest of Shungnak and in the Jade Hills is a compact little-sheared greenish rock, which under the microscope is seen to consist of microcrystalline serpentine, with inclusions of magnetite and in some specimens pyrite. In nearly all the streams draining the Shungnak district is found a certain amount of nephrite, which is associated with and probably related genetically to the serpentine above described. Some of this nephrite, which is locally called jade, is of gem quality, and several attempts to mine it have been made, but so far unsuccessfully, on account of the high cost of mining in this region and the limited market for gem stones of this character and quality.

AGE

No exact geologic age can be assigned to the oldest group of greenstones, first because the age of the rocks which contain them has not been definitely determined, and second because their paragenetic relations to the containing schists are not known. These highly metamorphosed greenstones are found, however, exclusively within the schistose rocks that underlie the Silurian (Skajit) limestone, and therefore if they are extrusive they are of pre-middle Silurian age; and if they are intrusive they are likely, though somewhat less so, to have originated in pre-middle Silurian time. But another geologic fact that bears on the age of these oldest greenstones should be emphasized. The older and more metamorphosed rocks of the undifferentiated schists are probably separated from the less metamorphosed schists and the Skajit limestone by a great structural unconformity. The position of this unconformity in the early geologic column has not been even approximately determined, and it may be of any geologic age from early Silurian to pre-Cambrian. The principal habitat of these highly metamorphosed greenstones is within the more metamorphosed and presumably older group of schistose rocks. Therefore, these oldest greenstones are probably no younger than the approximate age assignment given above, and more detailed work is likely to prove that they originated in earliest Paleozoic time, or perhaps in part in the pre-Cambrian. Certainly the designation pre-Silurian seems warranted.

The greenstones that are shown separately on the accompanying geologic map are for the most part younger than those above considered but are not found in rocks younger than the Silurian sequence. The Lower Devonian sequence is absent in this region. Hence, if these greenstones were exclusively intrusive, they could be as young as Middle Devonian, if the Middle Devonian rocks were not deeply enough buried at that time to be intruded. But as it seems probable that this basic volcanism had both extrusive and intrusive phases, it is hardly possible for these greenstones to be younger than Lower Devonian. As bearing on their maximum age, all that may be said is that they are believed to be later than the postulated ancient unconformity beneath the rocks of middle Silurian age, and their minimum age is believed to be not younger than the lowest of the known Devonian rocks.

The serpentines, which form the third subgroup of greenstones, may have the same range in geologic age as the greenstones of the second subgroup, but as they seem to be mainly of intrusive character, their origin late in this time range seems more likely. Moreover, their different petrographic character indicates that they may belong to a different period of igneous activity, which was essentially deep-seated. Hence it appears best to regard them as Lower Devonian or late Silurian, although no absolute proof of this assignment can be given.

BASIC EXTRUSIVE AND INTRUSIVE ROCKS

DISTRIBUTION

Igneous rocks of several types and ages are assembled under the term basic extrusive and intrusive rocks and are shown on the geologic map by a single cartographic pattern. Neither the petrographic variations nor the age differences are sufficiently well known to merit differentiation in geologic mapping. Several distinguishing characteristics are known, however, which though inadequate for cartographic purposes are well worth recording. For the purpose of description, therefore, this group of rocks has been separated into three subgroups, whose general character and distribution are as follows.

1. Basic lava flows are typically developed in the valleys of the Aniuk and Kivalina Rivers. In the lower part of the Aniuk Valley the lava occurs in a belt trending somewhat north of west but narrowing materially toward the west and finally disappearing. The eastward extension is not known. Similar lavas crop out in the valley of the Kivalina River at the mouth of a large tributary from the east near camp P April 16, but on account of the wide alluvial filling at this point they are not so completely exposed across the strike. Apparently a belt of these rocks from 6 to 8 miles wide, trending about east, crosses the Kivalina here, but both the eastward and westward extensions of this belt are unknown.

2. In the vicinity of the canyon of the Noatak River, above the mouth of the Kugururok River, occurs a group of igneous rocks which, though dominantly intrusive, include some of extrusive origin. These rocks are mainly of basic character and may be younger than

the lavas of the Aniuk and Kivalina Rivers. With these should also be grouped certain dikes at other localities, as for example, a dike which lies at the southern border of the Triassic chert on the Nimiuktuk River.

3. In the Zane Hills, at the head of the Pah River, the country rock is composed mainly of Lower Cretaceous rocks, dominantly of sedimentary origin and known as the Koyukuk group. Associated and apparently very nearly contemporaneous with these sediments are volcanic agglomerates, tuffs, and amygdaloids, which are later than the volcanic rocks of the Noatak Canyon. So intimately are these volcanic rocks intermingled with the sediments of the Koyukuk group that no attempt has been made to show their position on the geologic map. Broadly, however, it may be stated that they have been seen mainly at the northwest end of the area mapped as Koyukuk group, in such a position geologically as to suggest the possibility at least that they may lie at or near the top of this group. With these volcanic rocks are also grouped certain basic dikes that cut the Lower Cretaceous rocks. One of these was seen on the Killik River at camp M June 12, about 11½ miles in an air line downstream from the north edge of the Lisburne limestone. Another was noted on Meridian Creek, one of the southern tributaries of the Colville River, at a point about halfway between the head and mouth of the creek.

CHARACTER AND OCCURRENCE

The lavas of the Kivalina River consist essentially of basalt and diabase, more or less altered but not sufficiently so to merit the designation "greenstone." Probably a more complete suite of specimens would show numerous variations in original fabric and crystallinity and in subsequent chemical alteration. Typically these lavas are dark greenish-gray rocks, ranging in crystallinity from types in which the constituent minerals may be discerned with the naked eye to types that are notably glassy. Under the microscope they are seen to have the normal basaltic composition, consisting of plagioclase feldspar near labradorite, augite, and iron oxides, with a small amount of accessory apatite. Most of these rocks are chloritized to some degree, but this alteration can not be said to have affected predominantly either the feldspar or the pyroxene, for some of the specimens show unaltered pyroxene and altered feldspar, and others show altered pyroxene and little-altered feldspar. Most of these rocks, though fine grained, are holocrystalline, but in one rock the pyroxene appears to be represented by glassy material, which has subsequently been chloritized. Another specimen shows the amygdaloidal habit, and still another the typical ophitic fabric characteristic of the diabasic rocks. Sheared rock was observed at only one locality, but as this is obviously close to a zone of faulting, that condition can not be regarded as a characteristic of these rocks.

The lavas of the Aniuk Valley are on the whole essentially the same as those of the Kivalina Valley, but one of the specimens collected from the Aniuk Valley is rather coarse grained and is probably best classified as a pyroxene diorite. This is a granular rock, consisting of zonally grown plagioclase feldspar ranging in composition from andesine to acidic labradorite, augite, basaltic hornblende derived apparently from the augite, iron oxides, and apatite. The rock also contains considerable secondary chloritic and sericitic material. The iron oxides exist in skeletal patterns, suggesting that they may have originated through the magmatic replacement of earlier-formed magmatic minerals. It seems best to regard this rock as a deep-seated phase of the lavas of the Aniuk Valley comparable with the pyroxene diorite that is so intimately associated with the Carboniferous lavas of the Chitina Valley, south-central Alaska, and that constitutes in reality an integral part of the products of that period of volcanism.

The igneous rocks of the Noatak Canyon (see pl. 28) are similar chemically to the lavas of the Aniuk and Kivalina Valleys but differ in their genesis and in their resulting texture. These rocks are mainly of intrusive character but appear to have been injected at no great distance below the surface in the form of stocklike masses, with dikes and sills radiating outward from them. A few of these peripheral channels connect with the surface, with the result that some lavas were extruded, but this surficial phase seems to have been exceptional rather than characteristic.

Petrographically these rocks are of medium fine grain and weather to a rusty brown color on exposed surfaces. Feldspar and pyroxene are clearly visible in the hand specimens, and under the microscope the rocks are seen to consist of acidic labradorite, augite, a little biotite, commonly chloritized, and magnetite. Sulphides also occur sparingly. Some of these rocks are locally fractured, brecciated, and filled with secondary minerals, but nothing resembling schistosity has been developed. In general, they are best classified as fine-grained gabbro and diabase. The surficial phases of this magmatic material, where observed, are basaltic, and one ellipsoidal basalt occurs at the west end of the Noatak Canyon. An amygdaloidal phase was seen in one of the dikes, obviously close to the surface.

The intrusive rock found on the Nimiuktuk River is also a chloritized gabbro, similar to those seen in the Noatak Canyon; and its position with regard to the adjoining Upper Triassic chert suggests strongly that it may have intruded the chert.

The volcanic rocks associated with the Koyukuk group of the Zane Hills consist of volcanic agglomerate, subaerial and water-laid tuffs, arkosic rocks, and amygdaloidal lavas of basaltic character. The fragmental phases of these rocks also show their basic origin, in their content of dark ferromagnesian minerals, which show as glittering crystal faces on many freshly broken specimens of these well-indurated tuffaceous and arkosic rocks. Some fine-grained basic intrusive rocks have also been recognized in close association with these pyroclastic rocks and lavas.

The intrusive rock seen on the Killik River is a dark-gray medium-grained gabbro which under the microscope is seen to consist of plagioclase feldspar, almost completely chloritized and sericitized, little-altered augite, and iron oxides. Sulphides are visible in this rock, and an old windlass bucket at this locality indicates that some one had noticed this mineralized rock and had attempted to prospect it.

The dike rock of Meridian Creek is a black little-altered porphyritic basalt, with a fine-grained holocrystalline groundmass. The phenocrysts are mainly augite.

AGE

The lavas of the Aniuk Valley adjoin to the north the rocks of the Noatak formation, of Mississippian age, and to the south the undifferentiated Devonian rocks, and they overlie both these groups of rocks. In the Kivalina Valley the lavas are bounded on the south by the Lisburne limestone and on the northwest by Lower Cretaceous sandstone and shale. They dip southwestward, however, and appear to lie with seeming conformity below the Lisburne limestone, to the south, and are faulted against that part of the Lower Cretaceous formation which lies northwest of them. The apparent structure is probably not the true structure, for the relation of the Lisburne limestone to the Triassic rocks in the near-by parts of the Kivalina Valley distinctly indicates that the rocks have been overturned and on the north have terminated against the fault that separates these lavas from the Lower Cretaceous rocks. The structural relations therefore indicate that the lavas overlie rather than underlie the Lisburne limestone. Obviously in an area of such deformed structure the relation between successive formations is not indisputable. It seems from these facts that these lavas can not well be older than Carboniferous and are probably not older than late Mississippian. Their minimum geologic age, however, can not be stated with such assurance. If they are really conformable with the Lisburne limestone, they can not well be younger than Pennsylvanian; but if, as occurs at so many other localities in Alaska, an unconformity without angular discordance separates these lavas from the underlying Mississippian rocks, they may be of Permian or even of Mesozoic age. They are not believed to be as young as Jurassic, because in Jurassic time there were great crustal movements, which would probably have caused any lavas extruded at that time to rest with a pronounced angular unconformity upon the underlying Paleozoic rocks.

The intrusive and extrusive rocks of the Noatak Canyon can not be so definitely assigned in the geologic column. The intrusive rocks invade the Noatak and Lisburne formations and therefore must be regarded as post-Mississippian, but the extrusive rocks do not occur in relation to other rocks of known age in a manner favorable for an age assignment. Therefore, so far as any available structural data are concerned, this group of igneous rocks may be Pennsylvanian, Permian, or Mesozoic. Their degree of chemical alteration makes it improbable that they could be later than the Mesozoic. They have heretofore [81] been assigned tentatively to the Mesozoic and preferentially to the middle rather than the early part of that era—that is, probably to the Jurassic; but this age assignment was based mainly on their correlation with similar eruptive rocks in Seward Peninsula. The presence of pebbles of basic igneous rocks in the Lower Cretaceous conglomerates on the Etivluk and Kivalina Rivers adds further corroborative evidence in support of this view, though it is realized that the identification of these lavas as the actual source of those pebbles has not yet been positively established.

The gabbroic dike of the Nimiuktuk River is believed to have invaded the Upper Triassic rocks; and therefore a more definite basis exists for assigning this dike to the Jurassic than is available for the intrusive rocks of the Noatak Canyon. As a matter of fact, this gabbro is believed, from its field occurrence and petrographic character, to be correlative with the gabbroic rocks of the Noatak Canyon, and if so, the suggestion of a Jurassic age for those rocks is thereby correspondingly strengthened.

Less doubt exists regarding the age of the pyroclastic rocks and lavas associated with the Koyukuk group. This group of sediments is known, from its contained invertebrate fossils, to be of Lower Cretaceous age, and the interbedded igneous rocks can not therefore well be older than Lower Cretaceous. As no fossils were found in close proximity to the volcanic rocks, however, they may be of late Lower Cretaceous age, or may even have originated during a transitional period between the deposition of the typically Lower Cretaceous rocks and that of the typically Upper Cretaceous rocks.

[81] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 111, 1913.

The geographic and geologic position of these volcanic rocks, as previously pointed out, favors their assignment to such a late stage in the Lower Cretaceous epoch.

GRANITIC ROCKS

DISTRIBUTION

The main habitat of the granitic rocks is believed to be the highland area lying between the Noatak and Kobuk Rivers, but similar rocks occur in the Zane Hills, just south of the area shown on the accompanying geologic map. At the east end of the Noatak-Kobuk watershed the granitic rocks have been definitely recognized, and one large area along the southwest side of the Alatna Valley opposite the mouths of the Unakserak and Kutuk Rivers is shown on the geologic map. The general appearance of these granitic rocks and their topographic expression is illustrated by Plate 4, *B*.

In addition to the granitic boulders found along the Noatak and Kobuk Rivers, which are the basis for the presumed occurrence of granitic bodies along the Noatak-Kobuk watershed, boulders of basic rocks were also found in these valleys, notably along the Noatak River below the mouth of the Aniuk River, and in some of the Kobuk tributaries in the vicinity of Shungnak, particularly in Dahl Creek. These rocks have been considered to be basic differentiates from the granito-dioritic magma.

CHARACTER AND OCCURRENCE

The expression granitic rocks is here used to include all those rocks of the granito-dioritic retinue which are likely to occur in connection with the intrusion of granite on a large scale. Many such types, derived from the granitic magma, will doubtless be identified in this region when more detailed geologic work is done. At the present time only the true granites and certain basic differentiates have been recognized.

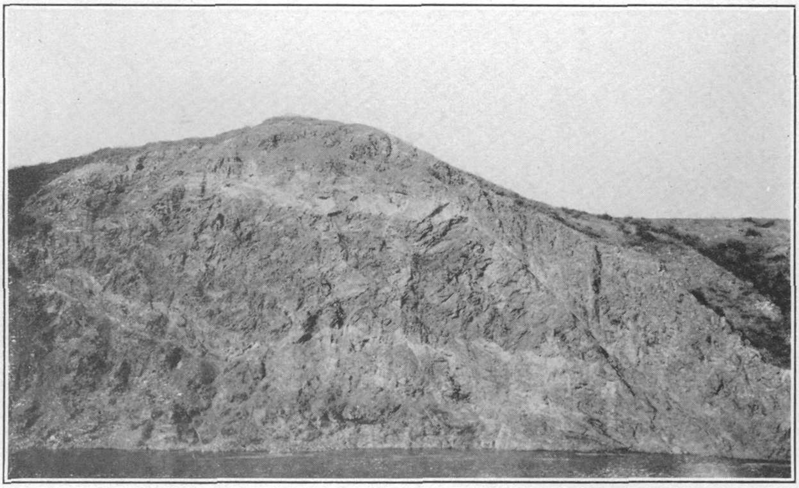
The granite, in the narrower sense of that term, which has been seen in the Alatna Valley and the Zane Hills is typically a light-gray granular rock of medium grain, usually nonporphyritic, and the only large body examined shows little effects of the deformational processes that have taken place since its formation. Under the microscope the constituent minerals are seen to be quartz, orthoclase, and microcline in varying amounts, with occasionally some microperthite, a small percentage of plagioclase feldspar near oligoclase or oligoclase-albite, muscovite and biotite in varying proportions, much of the biotite somewhat chloritized, and in some specimens green hornblende. The accessory minerals include magnetite, titanite, apatite, garnet, and epidote. These rocks seem ordinarily, therefore, to be mica granite, but probably hornblende granite and still other types are also present. Aplitic phases, fine of grain and almost free of mafic minerals, were noted at a number of places. Although neither shearing nor fracturing is a notable feature of these granitic rocks, some of the specimens apparently have a primary gneissoid texture, suggesting the existence of deformational movements during their crystallization.

The basic rocks above referred to indicate considerable differentiation in the granitic magma, if indeed they are derived from this source. The basic rocks found as float in the Noatak Valley below the mouth of the Aniuk are coarsely crystalline hypidiomorphic granular rocks, consisting entirely of bytownite and augite, with small amounts of olivine, and may be called olivine gabbro. The specimens of float from Dahl Creek represent an ultrabasic rock made up mainly of chromite, with subordinate amounts of iron silicates and plagioclase feldspar.

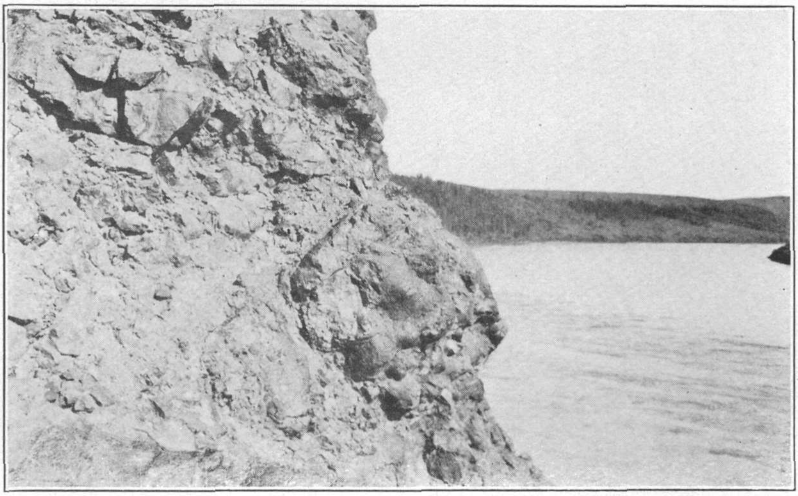
AGE

The age of these batholithic granitic bodies has not been closely determined but is known within certain limits. In Seward Peninsula, where there are similar granitic intrusive rocks, pebbles derived from the granitic rocks have been found in the conglomerate that forms the base of the Upper Cretaceous section; and the same condition is definitely recorded in the Alatna and Etivluk Valleys. It seems safe, therefore, to state that these intrusive masses were in existence before the beginning of Upper Cretaceous time. Their maximum age limit is set by the fact that they invade the Devonian and Carboniferous formations of this region. These constitute the sum total of definite age data, but they suggest strongly that the granite originated during the Mesozoic era, prior to the Upper Cretaceous.

Elsewhere in Alaska the Jurassic has been proved to be one of the great periods of volcanism and particularly of granitic intrusion. Jurassic sediments are regarded as entirely absent in this region, and the presumption is that earth movements of major magnitude took place in Jurassic time, elevating this region above sea level and defining the preexisting rocks. It seems reasonable, therefore, in the absence of any conflicting data, to believe that the granitic intrusions may have been concomitant with these deformational processes, and their Jurassic age is therefore suggested as a most probable interpretation. Evidence exists, however, that similar granitic rocks, usually more monzonitic in type, have elsewhere in Alaska been intruded during the Tertiary period, as for example in the country between the Yukon and the Kuskokwim and thence southwestward



A. IGNEOUS DIKE CUTTING ACROSS PALEOZOIC SEDIMENTS EXPOSED IN UPPER CANYON OF NOATAK RIVER



B. SPHEROIDAL WEATHERING IN BASIC IGNEOUS ROCKS NEAR WEST END OF UPPER CANYON OF NOATAK RIVER into the Kuskokwim Basin.[82] It may therefore be subsequently discovered that some of the granitic rocks of this region have originated in post-Cretaceous time. The basic and ultrabasic rocks above enumerated may or may not be differentiates from the granitic magma and therefore may or may not be of equivalent age. The age of the chromite rock in particular is doubtful. Chromite and picotite have been found in association with the Devonian (?) serpentine of the Yukon-Tanana region by Mertie,[83] but Gill [84] has described other chromite deposits in southern Alaska which more probably are of Mesozoic age. Hence correlation by analogy is equivocal.

LAVAS AND PYROCLASTIC ROCKS

DISTRIBUTION

Basic lavas and associated pyroclastic rocks are known at several localities in the Koyukuk Basin, but only one of these occurrences, at the northwest end of the Zane Hills, comes within the area included in this report. Similar rocks are also known to the southwest, in Seward Peninsula and in the Buckland and Selawik Valleys.

CHARACTER AND OCCURRENCE

These lavas are basalts of normal composition and character, composed essentially of plagioclase feldspar, augite, and magnetite, and show in places amygdaloidal phases. All these rocks are very fine grained but contain little or no glass, and some of them are microporphyritic, with microphenocrysts of plagioclase and augite.

Fragmental deposits of igneous origin have also resulted from the same and other volcanic eruptions, and tuffaceous and agglomeratic deposits are also probably represented in this area. As an example of this may be mentioned a peculiar white clay, found in the Ikpikpuk and Avalik Valleys, as well as elsewhere within Alaska, which by laboratory study has been proved to be derived from an andesitic volcanic ash and is therefore classifiable as bentonite. Further details regarding this material are given on pages 213–214.

AGE

The lavas and pyroclastic rocks here grouped together have been found at different geologic horizons, possibly from the Upper Cretaceous and certainly from the Tertiary to the Recent, and it is

[82] Mertie, J. B., jr., The Ruby-Kuskokwim region, Alaska: U. S. Geol. Survey Bull. 754, p. 71, 1924.

[83] Mertie, J. B., jr., The gold placers of the Tolovana district: U. S. Geol. Survey Bull. 662, pp. 245–248, 1918.

[84] Gill, A. C., Chromite of Kenai Peninsula, Alaska: U. S. Geol. Survey Bull. 742, 1922.

therefore believed that intermittent surficial volcanism has occurred in this region from the end of the Cretaceous period down to relatively recent time.

GEOLOGIC HISTORY

All the significant observations regarding the various rock units that have been recognized in northwestern Alaska have been given in some detail in the preceding pages. Certain general deductions have been made from the structural data, as well as from the stratigraphic relations existing between the several formations, and many others are, of course, obvious to the trained geologist. All the statements, however, have related principally to the individual formations that were being specifically described. It is therefore desirable to attempt to summarize here these more detailed observations, so as to present a sequential and composite outline of the geologic history of the region as a whole. Manifestly it is impossible to present at this time a final analysis of the long and intricate history of the region, because the data supplied by the exploratory and reconnaissance surveys are incomplete and scanty. When, however, the conclusions of the many geologists whose work has contributed to an understanding of this and adjacent parts of Alaska are all assembled, reviewed, and weighed against each other, it is evident that a fair start has been made toward a working knowledge of the geologic history of northwestern Alaska.

The earliest event recognized was the deposition of the sediments which now form the group of metamorphic rocks called in this report the early Paleozoic or older rocks. Where was the land mass from which they were derived? What were the processes that produced them? Were they deposited in the ocean, in estuaries, or on lowlands? These are questions that can not now be answered, because the necessary facts have been obliterated by the subsequent events. The time when the oldest of these rocks were laid down was very long ago, perhaps hundreds of millions of years. A long time was involved in the laying down of the sediments represented by these rocks, and doubtless there were many interruptions in deposition during which the original unconsolidated sediments may have been not only compressed into hard rocks, if not actually changed by metamorphism into rocks that had lost many of their original aspects, but also folded up into mountain chains or plunged deep below the former grade levels. Certain it is that basic igneous rocks now recognized as sheared greenstones in the midst of the other schists in parts of the John, Alatna, and Kobuk Valleys were intruded during part of this time, and in other parts of Alaska there were intrusions of granitic magma that now form gneisses and related rocks. Although not actually recognized in northwestern Alaska, there is little reason to doubt that there is a strongly marked break between the oldest of these rocks and the Paleozoic sediments. This condition is strongly suggested by the apparent differences in degree of deformation and attendant metamorphism in the schists a short distance south of the Skajit limestone on the Alatna and John Rivers and in those farther south. Whether during the whole period represented by this break the region was land or whether deposits were formed during part of that period and have been subsequently removed by erosion is not known. Elsewhere in Alaska not very distant from this region beds have been found which were laid down during at least two epochs of the Cambrian and the three epochs of the Ordovician. The absence of recognized lower Silurian rocks everywhere in central and northern Alaska suggests that during that epoch there was a break in the continuity of sedimentation in northwestern Alaska also. The assumption, therefore, that rocks of some or all of these epochs are represented either in the upper part of the rocks here grouped together as early Paleozoic or older or by formations that have subsequently been removed by erosion is evidently warranted as a working hypothesis.

In the early part of upper Silurian time, if not beginning in the middle Silurian, there was extensive deposition of calcareous mud, which gave rise to the Skajit limestone and related rocks. This deposit shows little variation in the character of its material, and as it is widespread and contains fossils of marine organisms it doubtless was laid down in marine waters rather far from shore or off a land mass that was not furnishing much sand and gravel to the sea. After several thousand feet of calcareous mud had been deposited, but without notable movements within the basin occupied by this limestone, the character of sedimentation changed, so that the deposits became more argillaceous, alternating with occasional beds of limestone. These argillaceous sediments are now represented by the group called in this report the undifferentiated Silurian(?) rocks. Marking the end of the deposition of these rocks was the first definitely recorded period of regional uplift and folding, whereby the rocks were indurated, considerably metamorphosed, and probably subjected to erosion under presumably terrigenous conditions. During this period of deformation some of the oldest greenstones were intruded and also subjected to deformation and shearing. The occurrence of this diastrophism probably accounts for the absence of recognized deposits of Lower Devonian age in this part of Alaska.

This regional uplift was followed in Middle Devonian time by depression of wide extent and the renewal of the deposition of sediments in that part of the sea which covered much of northwestern Alaska. This event is indicated by the shale and sandstone of Devonian age in the Brooks Range, which in places preserve as fossils some of the forms of life that lived in this old ocean. On the whole, these rocks were laid down relatively near the old coast or in a sea that was receiving large amounts of detritus from the old land. Oscillations in the shore line doubtless occurred, as is indicated by the alternations of sediments of different grain and composition. On the whole, however, these oscillations were broad mass movements rather than sharply localized flexures, and their composite result was the development of a geosynclinal basin in which thousands of feet of arenaceous and argillaceous sediments were accumulated. This deposition continued with relatively little interruption from Middle Devonian time until well into the lower part of the Mississippian epoch. On the whole, the deposits were characteristically formed near shore in marine waters. Here and there, however, as shown by certain of the beds in the Noatak formation in the Cape Lisburne region and at one locality in the valley of the Killik River, beds of coal or remains of plants that lived in swamps on the land bear evidence to the existence of the land areas of that remote time.

Later in Mississippian time the character of the sedimentation changed, and instead of sand and clayey mud the deposits became dominantly calcareous. These calcareous sediments were later consolidated and form the rocks called in this report the Lisburne limestone. Although a part of these calcareous deposits were laid down in the sea as sediments, in many places the limestones were formed as great reefs from the skeletons and hard parts of the hordes of corals that flourished in those seas. These ancient coral reefs were doubtless analogous to those that are now forming in many of the warmer oceans, and their presence in this northern region leads the geologist who reconstructs in his mind the conditions that prevailed there then to picture them as similar to those of the genial regions in which similar features are found to-day.

As no representatives of sedimentary deposits laid down in Pennsylvanian, Permian, or Lower and Middle Triassic time are recognized in northwestern Alaska, it is impossible to date accurately the next events that occurred in this region. Possibly some deposits were laid down during these epochs, but if so, they have either not been differentiated from the adjacent rocks or were subsequently removed by erosion. Thus marine sandstone of Permian age has been found in the Canning region, to the northeast, and marine limestone of Permian age has been recognized in the Yukon Valley near the international boundary. In spite of the uncertainty as to the precise age, there is no doubt that at some time in the long period marked by this gap in the sedimentary record there was broad regional uplift of much of the region now forming the Brooks Range province. During at least part of this period of uplift great floods of basic lava were poured out at many places, not only within the area described in this report but also in adjacent parts of Alaska. Within this area these lavas are represented by the igneous rock mapped in the Kivalina Valley, in the hills and valleys of the Noatak near the upper canyon of that stream, and on the divide between the Aniuk and Etivluk Rivers. Outside this area these lavas are especially well developed in the vicinity of Rampart, in the Yukon Valley, and elsewhere in Alaska. Intrusive phases of these same igneous rocks, which form dikes and sills within the preexisting sedimentary rocks, have also been noted at many places.

The uplift that has just been described seems to have been very widespread and to have included almost the entire area occupied by Alaska. This uplift, however, resulted in several peculiar conditions which are not yet well understood. For example, the fact that during part of this long time interval much of this area did not receive any deposits that are now recognizable is the strongest reason for assuming that the area was above sea level and therefore not an area of deposition. But if it were a land area it should have been subjected to erosion, and yet the next overlying deposits, the Upper Triassic beds of marine origin, seem to lie on the Carboniferous rocks with no angular discordance and are fine grained and not like deposits formed off a highland area. However these conditions are to be correctly explained, it seems evident that the broad regional upwarp of the land was followed, prior to Upper Triassic time, by a similar broad but reversed process of downwarping, whereby at least part of the Brooks Range province was again invaded by marine waters in which shale and limestone were deposited.

Another long break in the stratigraphic record occurs, which may represent the whole of Jurassic time, though, as has already been described in detail, some paleobotanic evidence indicates the possibility that certain beds which in this report are considered much younger may have been laid down during that period. Although there is uncertainty as to whether northwestern Alaska was an area of deposition during Jurassic time, there is no question that during part of that period this area, as well as many other parts of Alaska, was undergoing most stupendous mountain-building movements. It was during this period that all the preexisting rocks were subjected to enormous forces that bent and buckled them into folds, some of which were overturned or so sharply appressed that they broke, great thrust faults being thus produced. This was the event which really first clearly blocked out the great mountain unit that has progressively developed into the present Brooks Range. During part of this mountain building and perhaps originating some of the movements was the intrusion of deep-seated masses of acidic igneous rocks, which are now exposed at the surface as granite in the hills west of the central part of the Alatna Valley and at many other places in the areas contiguous to that described in this report. In fact, this batholithic intrusion appears to have been of even greater than continental extent, as it is correlated with the main granitic intrusions of the Alaska Range in south-central Alaska, which in turn are correlated with the batholithic intrusions of the Coast Range in southeastern Alaska and thence through the Coast Ranges of British Columbia, western United States, Mexico, and the cordillera of South America. The same general epoch of mountain building has also been recognized in eastern Siberia. During the period of diastrophism perhaps some of the basic igneous rocks were poured out or intruded.

The land mass which was originated at that time has persisted more or less uninterruptedly throughout the rest of geologic time and has been the nucleus from which most of the later sediments were derived and around which growth of the present land area has taken place. As soon as the growth of the mountains began the processes of erosion were quickened and entered upon the ceaseless task of reducing all parts of the land that rise above grade level. Vast quantities of detritus were thus worn from the growing mountains and carried seaward and deposited off the coast. This part of the history of the region is now represented by the Lower Cretaceous sandstone and shale of marine origin, which form deposits many thousand feet thick. This great thickness of deposits was not dumped into abyssal depths of the ocean, for the character of the sediments and the abundant shallow-water features, such as ripple marks and mud cracks, show that they were deposited close to the shore. It is necessary, therefore, to conclude that sinking of the sea floor continued throughout the accumulation of these sediments, so that, within the area which has been examined, at no time were the marine waters deep.

The accumulation of Lower Cretaceous sediments was apparently terminated by some folding and mountain building whereby these sediments were themselves subjected to uplift above the sea and were eroded. This episode is indicated by the unconformity observed on the Colville River and illustrated by Figure 13. Possibly this incident was also marked by the effusion of basic rocks and associated pyroclastic rocks that have been recorded in the Zane Hills. Compared with several of the earlier mountain-building periods this one appears to have been relatively unimportant and to have given place rather soon to further depression, during which the older of the Upper Cretaceous rocks were laid down in the sea. Marine deposition continued for some time, but after several thousand feet of sand and gravel had been laid down the conditions changed from marine to terrigenous. During this time extensive coastal swamps and estuaries existed in which great quantities of vegetation accumulated, and these areas are now marked by the extensive and numerous coal beds in the Upper Cretaceous sequence. Among the plants recognized in these beds are many of the forerunners of such well-known existing plants as equisetum, sequoia, ginkgo, pine, juniper, and cypress.

After these coal beds had been deposited there was some slight depression, and the sea again covered part of the region and received more sediments. This condition prevailed throughout most of the rest of Upper Cretaceous time and possibly even into the early part of the Tertiary, with little interruption of any significance. Near the top of the sequence here regarded as of Upper Cretaceous age there were some falls of volcanic ash that probably came from remote volcanoes, as the particles are small and had evidently been borne by the wind for long distances. These beds are the bentonitic deposits that seem to be interbedded with the marine sand and gravel in the northern part of the coastal plain.

Bringing to an end the deposition of Upper Cretaceous sediments, or early in Tertiary time, another great period of mountain building ensued. This is an event recognized practically throughout Alaska, but in northern Alaska its intensity seems to have centered in the old nucleus of the Brooks Range. Its effects on the Cretaceous rocks are therefore most pronounced on the flanks of this range and are progressively less striking toward the north or south. As a result the Cretaceous rocks closest to the range are thrown into great folds whose limbs in places stand vertical or even overturned, whereas the presumably equivalent rocks more remote from the center of disturbance lie in gentle arches and still farther away have dips of only a few degrees. Profound faulting accompanied this mountain building and sliced across many of the preexisting rocks, so that intricate and anomalous relations were produced. Doubtless the peaks of the Brooks Range at that time stood higher and their ruggedness was even grander than at present.

Erosion was revivified by this uplift, so that more material was carved from the highland mass and ultimately deposited in the seas that then were rather far from the mountains. Some of these sediments are recognized as the Tertiary deposits near the extreme northern part of the coastal plain province, and others that have not been sufficiently identified to be shown on the map undoubtedly occur in that same general region but have not been separated from the overlying sediments of similar aspect. Some deposits were also formed on the lowlands of that old continent, and representatives of these are now found in the Tertiary areas on the

Kobuk and elsewhere. The character of the material of which they are composed and the coal beds associated with them indicate that they were formed in a region which topographically resembled that in which they are now found but had a much milder climate. These rocks are tilted and folded so that they no longer occur in the position in which they were laid down, and they therefore bear indisputable evidence of having been subjected to mountain-building movements.

Near the end of the Tertiary period and also in places extending into the Quaternary basic lava flows were poured out and mantled over many of the earlier rocks. No rocks representing this event are exposed within the mapped area, but there are extensive exposures at many places near it. The nearest exposures to the area here called northwestern Alaska are in the lower part of the Buckland River and in adjacent parts of Seward Peninsula, in the pass between the Pah and Selawik Rivers south of the Kobuk, in the hills between the South Fork and the Koyukuk River, and in adjacent parts of the valley of the Koyukuk and its tributaries.

The great uplift of the mountains in Tertiary time probably carried many of the peaks into a zone where much of the precipitation that fell on them collected as snow, and with the changes in atmospheric circulation that may have occurred the ultimate result was an accumulation of snow which gradually coalesced to form glaciers. The growth of these glaciers in early Quaternary time gave rise to some of the most interesting and readily discernible of the existing features of northwestern Alaska. In general the maximum growth of these glaciers was probably contemporaneous with that of the great ice sheets in the northern United States, but unlike them the glaciers that originated in the Brooks Range were relatively of slight extent and covered only a small part of the adjacent country, as is indicated by Figure 16. As time went on the glaciers waned until now they have practically disappeared, being represented only by a few shrunken tongues of ice a couple of miles long, though the deposits formed by them still bear witness, on countless hillsides and valleys, to their former presence.

During the period of glaciation in the area outside that occupied by the ice and subsequently everywhere throughout the region most of the same processes have been at work that are operative there now. Thus, near the shore sand and silt were and are being laid down in the ocean, while on the land erosion was and is wearing down the outstanding prominences, and streams and wind were and are transporting the detritus thus produced and laying it down to form new deposits. Nor is the land area as a whole standing quiescent. Broad movements of uplift or depression are probably still going on whereby parts are being carried below sea level and other parts are being elevated. Uplifted benches and other evidence show that these processes have long been going on imperceptibly, except when they have proceeded in one direction long enough to leave significant records of their activity. As each of these late movements has undoubtedly affected to a greater or less extent all the preceding records, it is obvious that many of the minor changes of the past can never be completely determined. The successful unraveling of the many events each of which has had some part in giving northern Alaska the appearance it has to-day unfolds a story replete with variety, which takes on added interest as the separate incidents are correctly fitted into their proper places.

ECONOMIC GEOLOGY

Minerals of value have long been known to occur in northwestern Alaska. Coal was found in the Corwin region as early as 1881 and since that time has been used by some of the old whaling ships and others. In the rush of gold seekers to interior Alaska that commenced late in the nineties some of them overran or settled in the placer fields in the more accessible parts of this region also, and some of the more adventurous even pushed their way across the mountain barrier and sought metals of value in the northernmost part of the region. In the course of these placer-mining ventures in the more southern parts of the region the prospectors discovered lodes of gold, copper, lead, and other minerals. Later came reports of petroleum, and after several years a few oil companies sent their representatives to look over the country, pass on the probabilities of finding oil there, and, if desirable, take up claims. The Government itself took an interest in the possibilities of finding petroleum in this region, and it was that interest expressed in the Executive order of February, 1923, that was principally instrumental in the recent work of the Geological Survey which forms the basis of this report.

In the following pages what is now known regarding the different types of mineral deposits in this region will be stated. It will probably be evident from these statements that deposits of certain kinds are rather closely restricted to rocks of certain definite age or of more or less definite kinds or to areas with certain physical conditions. The descriptions should therefore serve not only to point out the specific places where certain minerals have been found but also should be of even more use in suggesting areas in which further search or prospecting is most likely to be rewarded by success or in acting as a deterrent against wasting effort in a region that seems to hold little promise of containing deposits of the kind sought. A person using the report in this manner should, however, be warned that many of the statements are broad generalizations, some of them only surmises, and consequently may not prove to be correct in detail. Furthermore, it should be remembered that the prediction that an area is unpromising for a certain kind of mineral does not at all forecast that none of that mineral will be found there.

It should also constantly be borne in mind that many economic conditions other than the mere value of the product itself enter into the successful operation of a mine or oil well. Therefore, although many kinds of valuable minerals have been found in the region, it should be remembered that owing to the general geographic conditions the successful commercial development of these resources is heavily handicapped by many factors that do not enter into the problem of developing a deposit of equal mineral content situated in a more accessible region. It is for this reason that many of these factors which influence mining development have been set forth at length in the earlier pages of this report, and while general reference to them will again be made in the succeeding pages, an operator contemplating the development of a deposit in this region should constantly keep in mind the facts already given regarding climate, vegetation, topography, and geology in so far as they apply to the part of the region in which he is interested.

PETROLEUM

LOCATION OF KNOWN OR REPORTED OCCURRENCES

The first published record of the occurrence of petroleum in northwestern Alaska appears in a report of the United States Geological Survey [85] published in 1909 and was based on materials collected and statements made by E. de K. Leffingwell regarding a seepage near Cape Simpson. In 1915 reports of an oil seepage in the vicinity of Wainwright Inlet were noted in the annual progress report of the Geological Survey.[86] In 1919 Leffingwell's report of his work in northern Alaska, which he had been carrying on since 1906, was published.[87] It contained essentially the same data on petroleum near Cape Simpson as had been given in the articles refered to but noted an additional locality at which a petroleum seepage had been reported by natives, between Humphrey Point and the Aichillik River, near the coast of the Arctic Ocean in the extreme northeastern part of Alaska, far beyond the area described in the present report. No further data regarding the presence of oil in the region were obtained by the Government until 1922, when the report and maps of the

[85] Brooks, A. H., The mining industry in 1908: U. S. Geol. Survey Bull. 379, p. 61, 1909.

[86] Brooks, A. H., The Alaskan mining industry in 1915: U. S. Geol. Survey Bull. 642, p. 52, 1916.

[87] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, 251 pp., 1919.

geologists who were sent in 1921 by a private oil company to examine the coastal part of the region were courteously made available for the information of the Geological Survey. It was learned from these reports, however, that A. M. Smith had visited the seepages at Cape Simpson in 1917, and it was said to be largely through his oral description of them that the oil company became sufficiently interested to send the party of geologists referred to above.

Such was the state of information regarding the occurrence of petroleum in the region now forming Naval Petroleum Reserve No. 4 and the adjacent country described in this report when the Geological Survey commenced its more comprehensive examinations of the region in 1923. In spite of the fact that these examinations have covered tens of thousands of square miles in an exploratory or reconnaissance manner, no additional seepages or other direct evidences of petroleum have been found, and several reported seepages have been determined not to show any signs of petroleum. As a result the only seepages that are now actually known are those near Cape Simpson. It is rather amusing, however, that as the area has become better and better surveyed rumors of oil indications in the more remote regions that have not been critically studied constantly crop up. Thus, at the present time it is reported that petroleum residue occurs south of Lake Teshekpuk, and nine permits for prospecting for oil in that region have been granted. Another reported occurrence is in the so-called White Mountains, which are rather vaguely said to lie east of the Colville River. In view of the proved occurrence of oil at Cape Simpson it would be entirely unwarranted to discredit these statements on a priori grounds, but the way in which these rumored finds constantly migrate into the unknown regions induces extreme skepticism as to their occurrence.

In addition to the claims that have been located in the vicinity of the Cape Simpson seepages, oil claims have been staked on the Meade River, and seepages have been reported as occurring at intervals all the way from the mouth of that stream as far south as latitude 70°. Although the maps that were made by the persons who staked these claims were in the possession of the Geological Survey geologists who later surveyed the Meade River, none of the reported seepages proved to be really oil seepages or showed definite indications of petroleum. In all places where seepages had been indicated the signs that had apparently been mistaken for petroleum proved to be films of iron oxide on stagnant pools, for the films when stirred did not readily unite again like oil. Such films were seen at a great number of places not only in the Meade River Valley but also in the valleys of the Colville, Ikpikpuk, Utukok, Avalik, Kokolik, and Kukpowruk Rivers.

Oil claims have also been staked covering almost all the region adjacent to the coast from the vicinity of Cape Smyth to a point east of Peard Bay and the portage to the Inaru River. This tract was also critically examined by Sidney Paige, of the United States Geological Survey, in 1923, but the only indications that might have been mistaken for petroleum in this place were films of iron oxide. The rather high ground in this region suggests that it marks a structural feature which might be favorable for the accumulation of petroleum, and the Geological Survey geologists who have examined it state that the rocks there apparently form a low anticline. In spite of this apparently favorable structure, however, no indications of petroleum were seen, and the natives who traverse much of that part of the region in caring for their herds of reindeer or in hunting and who are especially observant of most natural phenomena do not know of any seepages or other indications of petroleum in that whole region.

Applications for oil prospecting permits have been filed on more than 20 claims, embracing about 80 square miles, along the Kukpowruk River from a point near its mouth to the forks immediately south of the Amatusuk Hills. All of the region adjacent to the river has been carefully gone over by a Geological Survey geologist, but no definite signs of petroleum were seen. Several anticlines, however, that might afford good collecting ground for oil, though they were somewhat broken by faults, were recognized.

On the Kokolik River near its mouth and on the shore of the lagoon a short distance south of the mouth of that river 11 applications for oil prospecting permits have been filed. No development work has been done at either of these places, and, so far as reported, no direct indications of petroleum have been observed. In fact, that part of the Kokolik River Valley is so covered with deposits of Quaternary sand and gravel that no exposures of bedrock were seen there by either of the Geological Survey parties that have traversed that stream.

SEEPAGES AT CAPE SIMPSON

The most complete and authoritative statement regarding the seepages at Cape Simpson is contained in the report by Paige and others,[88] as follows:

The two seepages are on the very margin of the Arctic Ocean and hence of the reserve.

A low moss-covered ridge of irregular shape stretches for 2 miles along the Arctic Ocean, its southeast terminal about a mile northwest of Cape Simpson. Its highest point is about 50 feet above the sea. (See fig. 17.) Seepage No.

[88] Paige, Sidney, and others, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, p. 23, 1925.

1 occurs near the inland base of this ridge, a third of a mile from the ocean and 20 feet above tidewater, from which it is visible. Here in an irregular area several hundred feet in diameter the moss is soaked with petroleum, which also slowly seeps from the gentle slope. (See pl. 29, *A*, *B*.)

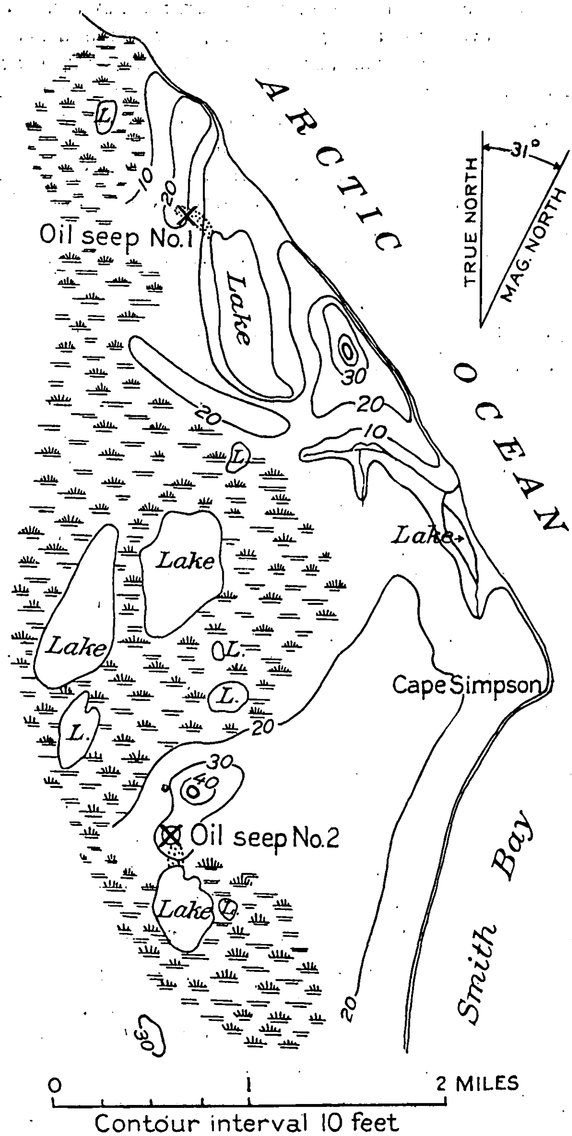


Figure 17.—Map showing location of oil seepages at Cape Simpson

Seepage No. 2 is on the southern top, 40 feet high, of a small double knob 3 miles almost due south of seepage No. 1 and 1¼ miles west of Smith Bay. Here the residue from the seepage covers several acres. (See pl. 29, *C*.)

The main petroleum flow moves southward down the slope for 600 or 700 feet to a lake. This active channel is 6 to 10 feet wide, though the area covered by residue is several hundred square feet and indicates that a considerable flow is coming from this seepage. The ridge at these two seepages is covered with moss and muck, and there are no surface indications that it is made up of hard rock. In surface form the ridges are not different from others elsewhere that appear to consist of Pleistocene alluvium, but shallow excavations at these localities reveal an aggregate of angular shale débris and clearly prove that hard rock is near the surface and that the ridges are the result of the erosion of bedrock and not of alluvium. This suggests that significant geologic facts might be obtained by piercing some of the other mounds or ridges in the coastal plain. Leffingwell [89] has described mounds in the Canning River region. He does not regard them as being made up of bedrock, but he reports on the authority of natives that petroleum occurs at one of them.

The material exposed in shallow pits is sandy and calcareous shale, whose structure can not be definitely determined, but it appears to be practically horizontal.

There is some doubt as to the correctness of the interpretation that the fragments of rock found in the shallow excavations near the seepages are really almost in place and flat-lying. H. A. Campbell, one of the geologists of the oil company that staked claims at this place, says that exposures were so poor that it was practically impossible to determine their structure, but he recorded his observations as indicating a dip of 80°, though he specifically states that the rock may not be in place. P. S. Smith, who, however, spent only a little time in the Cape Simpson region and did not see the excavation referred to, regarded the occurrence of bedrock at the surface as extremely doubtful, as all the material he saw appeared to be unconsolidated coastal-plain deposits.

There is, however, no difference between any of the geologists who have visited this region in their opinion that the bedrock that underlies this part of the coastal plain and may, of course, be exposed anywhere at the surface if the mantle of overlying coastal-plain sand and gravel is removed is in general the same as that described in this report as of Upper Cretaceous age, which crops out on the Meade River 40 miles or more southwest of Cape Simpson; in the cliffs south of Barrow, 60 miles west of Cape Simpson; and at many other points.

Samples of oil from the Cape Simpson seepages were collected by Paige and submitted to the Bureau of Mines for laboratory tests. As the samples were taken from weathered oil at the surface the tests can not be regarded as thoroughly indicative of the true character of the fresh oil as it occurs underground. The analyses of these samples are as follows:

[89] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 150–155, 1919.

Results of tests of oil sample No. 28510, from Naval Petroleum Reserve No. 4, Alaska

[Seepage at surface collected by United States Geological Survey; analyzed by United States Bureau of Mines, August, 1923. Specific gravity, 0.943; A. P. I. gravity, 18.6°. Sulphur, 0.36 per cent; water, 7.5 per cent. Saybolt Universal viscosity at 70° F., 5,160 seconds; at 100° F., 1,370 seconds. Pour point, below 5° F. Cloud test, below 5° F.]

Distillation by Bureau of Mines Hempel method

[Vacuum distillation at 40 millimeters]

Temperature		Cut (per cent)	Sum (per cent)	Gravity		Viscosity at 100° F. (seconds)
° C.	° F.			Specific	A. P. I. (°)	
Up to 200	Up to 392	13.6	13.6	0.894	26.8	34
200–225	392–437	10.2	23.8	.920	22.3	68
225–250	437–482	9.0	32.8	.923	21.8	116
250–275	482–527	10.5	43.3	.931	20.5	240
275–300	527–572	10.7	54.0	.936	19.7	([a])

Carbon residue of residuum, 4.9 per cent.
[a] Over 400.

Approximate summary

	Per cent	Gravity		Viscosity (seconds)
		Specific	A. P. I. (°)	
Gas oil	12.5	0.892	27.1	
Nonviscous lubricating distillate	12.7	0.906–.922	24.7–22.0	50–100
Medium lubricating distillate	9.7	.922–.928	22.0–21.0	100–200
Viscous lubricating distillate	19.1	.928–.939	21.0–39.2	([a])

[a] Above 200.

Results of test of petroleum residue from Alaska, sample No. 23508

[Extraction with benzene]

	Oil (per cent)	Sulphur (per cent)	Specific gravity
Sample marked "dried"	44.5	0.55	1.014
Sample marked "undried"	62.0	.47	.971

In commenting on the results of these tests Paige[90] states:

As a qualitative test by the Holde-Mueller method showed that only a comparatively small part of the oil was precipitated as asphalt with excess of petroleum ether, it would appear that the unusually high viscosity of the sample is not due to an appreciable extent to the presence of asphalt. Although no chemical study of the oil has been made, it seems probable that the high viscosity may be due to the presence of a large proportion of naphthalene hydrocarbons, a view supported by the general appearance of the sample, its low sulphur content, and the small percentage of carbon residue of the residuum.

The tests indicate lubricant values in the weathered oil, which in fact appears comparable in Baumé gravity, sulphur content, viscosity, and distillation tests to the oil obtained from shallow wells in the Pliocene rocks of the Blue Ridge field, in Texas.

[90] Paige, Sidney, and others, op. cit., p. 25.

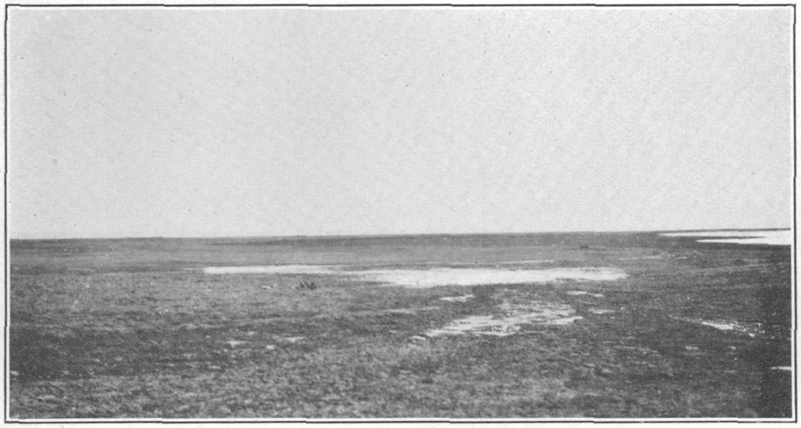
Beyond doubt light hydrocarbons have escaped from the surface seepage, though evaporation in the Arctic climate may not have been so rapid and may not have taken place at so high a temperature as in the better-known regions in lower latitudes. It is to be remembered, however, that the climate of this region is dry. On the whole, therefore, while it is difficult on the basis of the above tests to predict the composition of the unweathered oil, it is practically certain that the oil contains some of the lighter hydrocarbons. It will be seen that 13.6 per cent of the sample was distilled off under 200° C. at a pressure of 40 millimeters.

INFERENCES AS TO PETROLEUM IN THE UPPER CRETACEOUS ROCKS

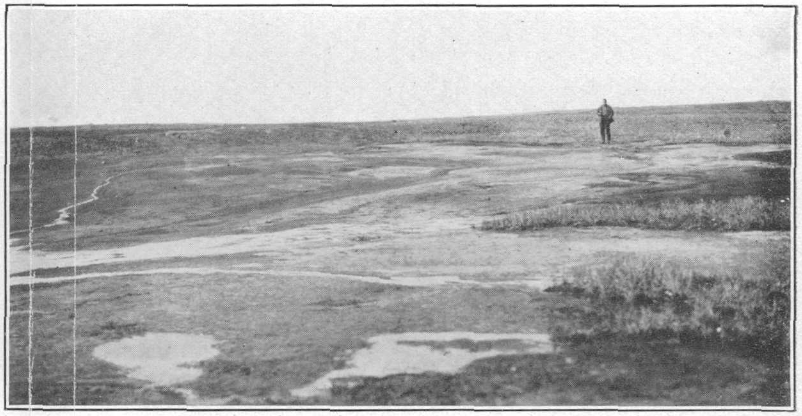
From the very meager data that are available regarding the occurrence of petroleum in the region, it is not justifiable to attempt to state general conclusions as to the geologic conditions that prevail in the area where the oil seepages occur. It is obviously even more unwarrantable to attempt predictions as to the extent of possible oil-bearing areas. In spite, however, of the admitted inadequacy of the necessary data and the many uncertainties surrounding the interpretation of the few facts that are available to serve as a basis for judgment, it has seemed desirable to make certain suggestions as to the probable extent and development of petroleum in the region, even though many of these suggestions are little better than thoughtful guesses or surmises.

It is believed by all the geologists that the bedrock near the known seepages consists of the sandstone and shale that are now mapped as Upper Cretaceous. This belief of course does not necessarily indicate that the oil occurs in these rocks, and much less that it originated in them, but for the sake of simplifying the discussion it is desirable to analyze first the consequences that might follow if the local bedrock is actually the source and the retainer of the oil. On this assumption the area in which oil pools might be sought with some expectation of success would be limited to the area shown on Plate 2 as occupied by the Upper Cretaceous rocks. But not all of that area would be potential oil territory, because the thickness of that series of rocks is estimated as probably 10,000 to 15,000 feet. Therefore, in a large part of the area much of the Upper Cretaceous section would probably be below the limits of practicable drilling, even though some of that great thickness had been removed by subsequent erosion. The areas in which any oil-bearing beds in these rocks lie at depths within practicable reach of the drill can not be indicated closely in the absence of data as to the position within the section at which the oil may occur.

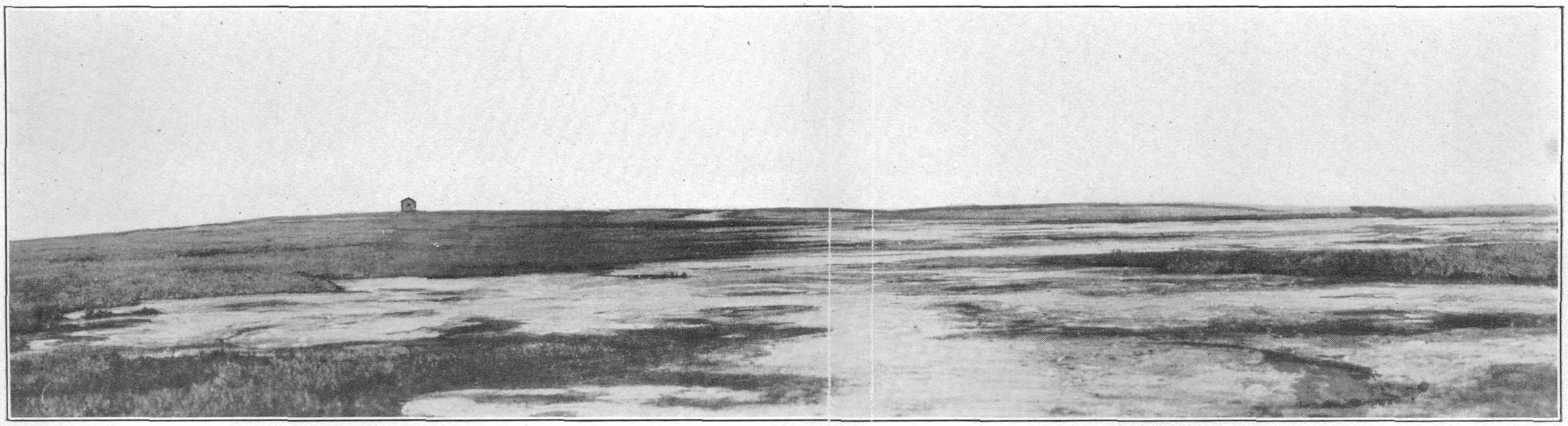
It may be stated, however, that the structure of the Upper Cretaceous on the whole shows folding which, though in many places irregular and trending in different directions, results in giving the



A. OIL SEEPAGE NO. 1, NEAR CAPE SIMPSON



B. OIL SEEPAGE NO. 1, LOOKING SOUTH UP SEEPAGE



C. OIL SEEPAGE NO. 2, NEAR CAPE SIMPSON beds a dominant northward dip. In other words, the base of the Upper Cretaceous lies, in general, at progressively greater depths toward the north. At Cape Simpson, therefore, the first hard rocks encountered below the surface are likely to be high in the formation, far above the base. In fact, there is some question as to whether there may not be some Tertiary deposits between the Quaternary surface deposits and the Upper Cretaceous. If, therefore, the Cape Simpson seepages come from rocks within a few thousand feet of the surface at that place, more than half the area mapped as Upper Cretaceous could be eliminated from consideration as possible oil territory, except where local synclines have brought down the higher rocks below the level which the dip, if uniform, would have given them. But synclinal structure, as is well known, is not favorable for the accumulation of petroleum, so that these synclines would not be promising places to prospect. Furthermore, the upper part of the Upper Cretaceous section in the areas where the rocks are well exposed seems to be composed mainly of materials containing relatively little organic matter that would be likely to yield petroleum. Therefore, if the petroleum originated in this part of the section, it probably came from irregularly distributed masses of organic matter, and in that case the resulting oil pools are likely to be small and sporadically distributed, so that search for them would probably be unduly expensive and uncertain.

If, however, the source of the oil at the seepages near Cape Simpson was far down in the Upper Cretaceous section, the area in which possibly productive pools might be found would be correspondingly increased, though subject to the restriction that the oil sands should not lie too far below the surface to be within reasonable drilling depth. These conditions obviously would be fulfilled best either toward the southern part of the area occupied by these rocks or farther north in areas where anticlines have brought the lower beds relatively near the surface.

An assumption that the oil originated in the lower part of the Upper Cretaceous series is open to some of the same objections that have been noted in discussing the assumption that the oil horizon is high in the series. The lower part of the Upper Cretaceous section consists principally of sandstone and shale, which were laid down mainly under shallow-water marine conditions. Nowhere in the lower part of the series have any indications of extensive deposits of organic material been recognized. Even isolated fossils are rare, so that, as a whole, the rocks do not appear to be promising sources of petroleum. Above the marine part of the section are beds that appear to have been laid down mainly in swamps and quiet water on the land or close to it. In these beds are large accumulations of plants that now form beds of coal, some of which are 20 feet or more thick. Deposits of the composition represented by this part of the section, which has a measured thickness on the Kukpowruk River of 7,000 feet, are usually not regarded as favorable for the accumulation of petroleum. On the whole, therefore, acceptance of the assumption of a source in the lower part of the Upper Cretaceous section would lead to the conclusion that oil pools resulting from that source would probably be small and rather few. Fortunately, however, the lower part of the section, or that part near the mountains in many portions of the area, is folded into rather pronounced anticlines—features which are in general structurally favorable for trapping any oil that has migrated from the near-by rocks. Areas of favorable structure are therefore common and may be found with little search in almost all parts of the region occupied by the Upper Cretaceous rocks but more particularly in the southern part. Some of these anticlines are 10 to 30 miles long and have a structural closure of several hundred feet. It is strange, however, that if oil is present in this part of the region where favorable structure is common, no signs of it have been seen near any of these anticlines. This is a bit of negative evidence that should be taken as a warning to investigate fully before entering into any project of oil development in this region that will require larger expenditures than can be comfortably risked.

INFERENCES AS TO PETROLEUM IN THE LOWER CRETACEOUS AND RELATED ROCKS

Because of the apparent great thickness of the Upper Cretaceous rocks it is with some hesitancy that the possibility that the oil near Cape Simpson was derived from still older rocks is suggested. The next underlying series is the Lower Cretaceous, which is estimated to be itself 10,000 to 15,000 feet thick. The top of this series everywhere north of its contact with the Upper Cretaceous lies under a thick cover, which at Cape Simpson must amount to many thousand feet, and its base in all areas north of the Colville River is presumably far beyond the reach of the drill. On the whole, its lithologic character is also not such as to indicate that it is a promising source of petroleum, as it, too, appears to be a marine deposit that was laid down in relatively shallow water, with normally little organic material. However, there are some indications that near the base of this series or in the underlying formation oil shale occurs that might furnish an adequate source for the petroleum. The field data regarding the occurrence of the oil shale are extremely scanty, as much of the material was found only as float, so that the exact stratigraphic position of the ledges from which it came is unknown. The only locality where a specimen was obtained from rocks in place is in an area of pronounced faulting and folding, so that the relations are obscure and not clearly determinable.

One of the float specimens of oil shale was found on the Etivluk River on the bar a short distance upstream from Camp S July 8, which, as will be noted from the geologic map (pl. 2) is only a few miles downstream from the base of the Lower Cretaceous in the northern area of those rocks on that river. The structure at this place is rather complex, as the beds have been partly overturned and perhaps profoundly faulted, but there seems to be small reason to doubt that the oil shale came from strata near the base of the Lower Cretaceous rocks or from sedimentary rocks farther upstream, all of which are at least as old as the Lower Cretaceous. That there is probably a good deal of material of this sort near this place and consequently that it has not been transported far is indicated by the fact that W. L. Howard, of the Stoney expedition, on his trip down the Etivluk in 1886, found near this place material which he described as "a substance called wood by the natives. It was hard, brittle, light brown in color, very light in weight, and burned readily, giving out quantities of gas. This material was scattered about in all shapes and sizes and quantities."[91] Dall[92] some time ago suggested that the material described by Howard was probably a petroleum residue, and this interpretation has been accepted by later writers. However, the close similarity of Howard's material as described to the material collected by the Geological Survey, which has definitely proved to be an oil shale, seems to make that suggestion untenable.

A microscopic examination of the specimen collected in 1924 (24AS51) was made by David White, who wrote regarding it as follows:

> Examination of thin sections of this specimen under the microscope shows that the rock is made up very largely of the flattened exines of a single type of large megaspore. These exines appear as collapsed or entirely flattened thick golden-yellow bands. The specimen is so remarkably similar to tasmanite that no violence would be done in calling it by that name, though the megaspores may have been produced by a different plant and the chemical composition may differ somewhat from that of the material from Tasmania described under the above name. Rough test-tube tests of the material, which is readily combustible, indicate rather copious condensation of hydrocarbon gases in the form of viscous distillate.

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[91] Stoney, G. H., Naval explorations in Alaska, p. 69, Annapolis, 1900.

[92] Martin, G. C., Preliminary report on petroleum in Alaska: U. S. Geol. Survey Bull. 719, pp. 69–70, 1921.

The locality at which oil shale was found in place was on the Kivalina River about 4 miles south of camp P April 19, near the east end of the section shown in Figure 10. Here the shale (26AS15) is separated from the rest of the exposures of Triassic chert by 25 to 30 feet of broken rock and slide, so that the relations are not determinable, and there is considerable doubt as to whether the shale is part of the Triassic section or part of the infaulted Lower Cretaceous rocks that occur in close proximity to the Triassic both to the east and to the west. In this report, however, the shale has been considered probably Lower Cretaceous.

Two other pieces of oil-shale float have been received through the courtesy of C. D. Brower, of Barrow. One of these (26AS94) is a nearly black fine-grained rock of light weight somewhat resembling cannel coal that is said to have been picked up by natives near the head of the Meade River. The other (26AS95) is a rounded pebble of practically the same appearance that was found on the beach near the mouth of the Meade River. The surface of the entire region tributary to the Meade River is regarded as underlain by rocks of Upper Cretaceous or younger age, so that, if these float fragments came from ledges within that valley, they are presumably not older than Upper Cretaceous. There is, however, a possibility that they may have been brought into the Meade Valley by outwash from the Lower Cretaceous or older areas to the south in relatively late geologic time, or they may have been derived from those areas and built into the Upper Cretaceous rocks as pebbles, which have subsequently been freed from their matrix by later erosion and weathering. The possibility that one or the other of these explanations may be correct is indicated by the abundant chert and other fragments of Triassic age recognized both in the Upper Cretaceous rocks and in the unconsolidated deposits. The source of this material is therefore extremely indefinite and consequently of little significance in determining the probable source of the petroleum or the extent of these shales. In spite of the absence of adequate basis for formulating even a guess as to the source of this material P. S. Smith hazards the opinion that, as it is so unlike any material known in the Upper Cretaceous sequence, it is more likely to have come from some lower formation, and consequently it is noted in this section of the report.

Material that appears similar to the compact oil-shale float from the upper Meade River is by no means unique, as is shown by the fact that a few labrets formerly worn by the Eskimos, apparently made of similar material, have been seen, and one was collected at Point Hope. These labrets had apparently been cherished because of the relative rarity of the material, as well as because of its lightness and the ease with which it could be shaped.

If oil shale similar to that which has been found really forms part of the Lower Cretaceous sequence, it might possibly afford a source for oil in the overlying beds. Some of the samples indicate an oil content of over 50 gallons to the ton of rocks, so that as a horizontal bed of shale 1 foot thick contains about a million tons of rock for each square mile of its extent, it is evident that any considerable volume of these rocks would be a potential source of much oil. There are many difficulties in the way of accepting this shale as of Lower Cretaceous age and considering it the source of the petroleum, especially of the petroleum at Cape Simpson. The principal difficulty is that the lower part of the Lower Cretaceous series is there likely to be 20,000 feet below the surface and that petroleum rising from that depth would doubtless find many sands in which it would be trapped before it reached the surface, and consequently signs of it should be fairly widespread. Therefore, if this shale is the source of the petroleum, it would seem inevitable that petroleum should be apparent as seepages in some of the areas farther south, where the structure is favorable and the shale less deeply buried, but no such seepages were seen. On the other hand, if there is an oil shale near the base of the Lower Cretaceous, oil pools might be found in any place where the structure is favorable in the area to the north, and commercial pools might be found where the accumulation had taken place near enough to the present surface to be within the reach of the drill. In this connection, it will be important to determine the underground extent of the Lower Cretaceous rocks, for there are indications that near their northern margin they are unconformably overlain by the Upper Cretaceous rocks, so that they may not underlie the entire area whose surface is made of the younger rocks. There is, of course, no way in which these facts can be adequately determined except by the use of the drill.

Furthermore, data should be obtained to test the assumption that there is oil shale in the stratigraphic position suggested and, if so, to determine its thickness and its lateral extent. This test could be made by means of relatively shallow drill holes or excavations, but of course it would not prove the occurrence of commercial oil pools, for there are many intervening steps between finding a possible source of petroleum and determining that it yields petroleum and, if so, the probable location of the pools. It seems probable, however, that the mountain-building forces, which are known to have affected both Upper and Lower Cretaceous rocks, were adequate to have formed petroleum if oil shale formed any considerable part of either series.

The foregoing suggestions apply exclusively to the more or less continuous areas of Upper and Lower Cretaceous rocks north of the Brooks Range. They are not applicable to the infolded and infaulted areas that may be found within the range, because these areas are relatively small and usually represent synclines or grabens, which are structurally not conducive to the collection and storage of oil.

INFERENCES AS TO PETROLEUM IN THE MISSISSIPPIAN OR OLDER ROCKS

The oil shales noted heretofore, either as float or in place, are believed to be younger than Paleozoic because of their general composition and because of the lesser amount of deformation they have undergone. There are, however, many limestones in the Paleozoic section in this region, and limestone is believed to be a source of petroleum in many oil-producing regions elsewhere. No signs of petroleum seepages, however, have been noticed in the vicinity of any of the Paleozoic rocks in northwestern Alaska or elsewhere in Alaska where these Mississippian beds are well exposed. It is true that in places the Lisburne limestone has a slightly petroliferous odor on fresh fracture, but, as is well known, practically every limestone that has not been intensely metamorphosed and recrystallized is likely to have that odor, which therefore has no special significance. It is almost inconceivable that the petroleum in the Cape Simpson region came from these rocks, unless there are great structural discordances, for they must be buried there under thousands and possibly tens of thousands of feet of later strata. This same condition probably also exists in much of the region south of the seepages nearly to the northern front of the Brooks Range, so that this formation lies generally far beyond the reach of the drill. The Lisburne limestone is itself apparently intensely deformed, broken, and dislocated, so that, even if it were the source of the petroleum, its structure is not favorable for retaining any notable amount of the oil. In that case any oil that may have originated in the rocks before they were buried under deposits of later sediments would in all probability have long since been dissipated or, if it were formed after these rocks were buried, the oil would doubtless have escaped into the overlying rocks, such as those of the Cretaceous system, and would have accumulated in them in places where the structure is favorable. In distribution and extent oil pools formed under these conditions would therefore closely correspond to those that might have been formed from a source within the Cretaceous rocks themselves—a condition that has been rather fully discussed in the preceding pages.

Although there are several other limestones in the geologic column below the Mississippian, none of them have shown any indications of petroleum, and all of them doubtless lie too deeply buried to be even considered as a possible source of the petroleum in the seepages near Cape Simpson. Furthermore, all the rocks older than the Mississippian are as highly deformed, broken, and metamorphosed as those rocks, or even more highly, so that the chance of their retaining oil that may have originated in them is as bad or worse, and many of them are of such lithologic character that they could not be regarded as promising for the production of oil. It seems, therefore, that in the absence of any direct evidence to the contrary the conclusion is practically justified that the chances of finding commercial pools within the area occupied solely by Paleozoic or older rocks are extremely poor. This conclusion applies not only to those areas where the Paleozoic rocks form the country rock at the surface but equally to the underground extensions of these rocks under the cover of Mesozoic rocks. In other words, if in test drilling in areas of the Cretaceous rock the younger rocks are penetrated and Paleozoic rocks are encountered, it would be unwise to continue drilling deeper unless definite evidence of petroleum is observed.

SUMMARY OF GEOLOGIC CONCLUSIONS RELATING TO OIL ACCUMULATION

The rather indefinite suggestions made in the foregoing remarks may be summed up as follows:

Sources of oil in the Paleozoic rocks are extremely problematic, and the structure of those rocks is such as to make the probability of oil pools in them extremely doubtful.

A strongly indicated source of oil is the oil shale, whose position, though uncertain, is tentatively placed near the base of the Lower Cretaceous series. This shale is likely to be widespread and therefore is likely to have supplied extensive pools in widely distributed favorable structural features in the overlying rocks, many of which should be found at depths within reach of the drill.

No widespread promising sources of oil are recognized in the Upper Cretaceous rocks or in most of the Lower Cretaceous rocks, so that if oil pools have originated from sporadic deposits within these rocks they are likely to be small and of extremely sparse distribution, though structural features favorable for retaining petroleum are widespread.

GEOGRAPHIC FACTORS CONCERNED IN OIL DEVELOPMENT IN THE REGION

The consideration of various geographic factors is perhaps of equal or even greater importance than that of the geologic factors for anyone investigating the possibility of developing oil pools in this region. Certain geographic factors that will have an important bearing on any developments undertaken in northwestern Alaska are transportation, labor, supplies, and working conditions.

There are no regular lines of transportation to or from or within the region, which is accessible now only by long, arduous overland journeys or by occasional trading vessels in the short open season. There are no harbors within several hundred miles for ocean-going vessels, and frequent storms, fog from the ice pack, and the pack itself make navigation dangerous at all times. The sea is closed to navigation for fully ten months a year, and even during the two other months there is no certainty that the ice pack may not be driven in against the coast. The ocean is so shallow that vessels must lie a mile or more off the coast in the open roadstead and send goods ashore in small boats that can land directly on the beach, as wharves or loading devices can not be maintained because of the ice. The rivers are shallow and swift, so that they can be utilized for transportation only by small boats. There are no roads or even trails that are marked on the ground. Horses can not subsist on local forage, even during the summer. The use of wheeled vehicles or tractors across country in the summer is attended with serious difficulty, because of the soft surface of the ground and the spongy mat of vegetation.

Outside of wild meat and reindeer the region produces no food supplies that would be required in oil development. No foodstuffs can be grown outdoors in the area included within the naval petroleum reserve. The nearest trees that could be used for construction, even of shelters, grow nearly 300 miles south of Barrow. Coal could probably be obtained at many places of sufficiently good quality to meet all demands that might be made for local supplies of fuel or for such power as is needed in operating drill rigs. Even water for the operation of boilers may be difficult to obtain except during the short open season or by melting ice. Stores in Alaska at which machinery, tools, and less ordinary supplies can be obtained or repairs made are a long distance from the reserve, and many necessary things could probably be obtained only from the States, which, in terms of time for a round trip, are a year or more distant. Large stocks of spare parts must therefore be maintained at all times and wants anticipated for a year or more, thus adding materially to the cost of operation.

There is practically no near-by supply of labor of any kind. Probably less than a hundred whites and a few thousand natives live within several hundred miles of the area that may be oil bearing. The natives as a rule are not accustomed to regular routine types of work, and probably only a few could be counted on to remain steadily at work, even if they were induced to start. The inaccessibility and remoteness of the region, lack of relaxing interests, and the rigorous climate, with its long winter of darkness and cold, would deter people from accepting employment there unless unusual attractions in the way of pay or accommodations were offered as inducements, and these would doubtless increase operating costs. Doubtless some of the adverse climatic conditions of the region are overemphasized in the minds of many people, because it is believed that with proper preparation and precautions much work could be carried on effectively and with reasonable comfort throughout the year except during periods of storm; but the climate at best is not such as to attract people, though unquestionably it is far healthier than that of many regions where people live and work.

RECOMMENDATIONS REGARDING FURTHER INVESTIGATIONS

The foregoing analysis of the data available regarding the possibilities of finding and developing petroleum in northwestern Alaska is obviously incomplete and inconclusive in many respects. There are still large tracts that have not been examined at all, and even in those tracts that have been traversed the work was necessarily done so hurriedly that sufficient time could not be spared to work out in detail many of the facts of geologic significance. Obviously further information bearing on any of the unsettled problems will be useful, and evidence bearing directly on the occurrence of petroleum in the region would be of inestimable value. Some doubt is felt, however, whether at this time further general scouting or reconnaissance through the region is the best method of obtaining significant data, though later it would unquestionably be essential. Instead, the writers believe that the next move that should be taken in the search for oil in this region is to determine certain details of structure and other geologic data by means of drill tests in the vicinity of the seepages near Cape Simpson. Such tests could probably be made rather inexpensively with a light drill rig, which could be moved rather readily from place to place and drill holes a few hundred feet deep. In such drilling no idea of bringing in a productive well should be entertained; the sole object should be to acquire accurate data on the geology of the area adjacent to these seepages. Consequently it would be essential that a competent geologist should keep in close touch with the drilling operations, carefully collecting samples at frequent intervals, constructing an accurate log of the formations penetrated, correlating the logs of different test holes, determining the areas to be tested, and planning the general campaign.

After enough data have been obtained from this source to indicate the general mode of occurrence or source of the petroleum further scouting in the areas that appear likely to possess similar characteristics should be prosecuted vigorously by both reconnaissance and detail surface methods of geologic investigation, and where necessary it should be followed up by drill tests or such other methods as are indicated.

The plan outlined above involves considerable expense. In fact the estimate originally made for adequate geologic investigations alone by the Government in the reserve amounted to $500,000, of which less than $150,000 has been made available. It must be borne in mind, however, that the returns from the discovery of a successful field would be many times these amounts. An oil field in this region that would yield only a few million barrels of oil might for all practical purposes be regarded as of no present economic importance. Unless, therefore, a very large potential field is indicated, development is not justified, so that the relatively large sums that will necessarily be required to find out the real situation will be only an insignificant part of the investment that will eventually be needed. Consequently, a search for oil in this region should not be undertaken by any organization that is not able and willing to finance adequately the necessary preliminary work, even though that work should prove that the field is not capable of commercial development. Moreover, the handicaps are in general so much greater in northern Alaska than in California, Oklahoma, or many of the other fields that to be compelled to operate under the laws relating to leases of the public lands which may be appropriate to those localities would work a hardship on pioneers in the search for petroleum in northern Alaska and would serve more as a deterrent rather than an incentive for undertaking the necessary financial risks. Prospecting for oil in this region at the present time is wildcatting of a most speculative kind. For a person or company that can afford to enter the field with all these conditions clearly in mind and with a very large money backing, it does hold some attractions. Some oil occurs in that region. How much and where it is are questions that still challenge the resourcefulness of geologists, petroleum engineers, and leaders of business enterprise.

COAL

The coal resources of the region are very great, and though at present they are practically untouched, they constitute an asset whose value will be manifest whenever extensive developments of any of the resources of near-by areas are undertaken. Three main types of coal deposits may be distinguished on the basis of geologic age. These are the Mississippian coals, in the Lisburne region; the Upper Cretaceous coals, occurring principally throughout a broad tract north of the Brooks Range; and the Tertiary coals, which are usually in more or less isolated tracts and are known principally in the valley of the Kobuk. Each of these types will be described in some detail in the following pages.

Before passing to the detailed description of the coals themselves it is desirable to note some of the general facts bearing on the possible development of coal resources in the region at the present time. According to the latest data available the entire Territory of Alaska consumed during 1926 less than 160,000 tons of coal, of which about 87,000 tons was produced from mines located near the Alaska Railroad, and a large part was used in the operation of that railroad; practically all the rest was produced from mines located outside of Alaska. It is not possible to determine the extent of the market that would be open to these northern Alaska coals in competition with the high-grade coals along the Alaska Railroad and the imported coals from Washington and other Western States and British Columbia and other countries bordering on the Pacific. The following figures showing the amount of coal imported to Nome, which is the largest town in northwestern Alaska and the port of entry that serves most of the region to the north and which is 300 to 500 miles or more from these coal fields, are significant: 1925, 5,760 tons; 1926, 2,599 tons; 1927, 3,421 tons.[93] It is a liberal estimate to place the amount of coal consumed in the territory lying within 500 miles of these coal fields as measured along the lines of ordinary routes of transportation at 10,000 tons a year, and because of the dangers and difficulties of navigation these coals can not advantageously be moved far by ships. It is evident that under the present conditions, with so small a local market, there is little probability of developing these fields commercially in the near future. Costs are bound to be high because of the remoteness of the region, which involves all the factors already discussed in the consideration of the possible development of its oil resources.

The foregoing statements are not intended to indicate that a large market may not eventually be developed but relate simply to current conditions. Brooks[94] in his analysis of the possible market for Alaska coal on the Pacific seaboard estimated that under the conditions that prevailed in 1909 there were markets for approximately 120,000 tons of Alaska coal practically without competition with coals from other fields, for 350,000 tons under competitive conditions but with competition favoring Alaskan coals, or for 1,000,000 tons under competitive conditions about even. These conclusions were based mainly on analyses of the situation relating to the coals from the Matanuska and Bering River fields, in south-central Alaska. It

[93] Reed, R. W. J., memorandum copy of reports of deputy collector, Customs Service, at Nome, Alaska.

[94] Brooks, A. H., Alaska coal and its utilization: U. S. Geol. Survey Bull. 442, p. 94, 1910.

is evident from the small amount of coal now produced in Alaska that these possible markets have by no means been fully preempted by coals from these much more favorably situated fields. The coals from the northern fields, however, obviously could not enter nearly so large a market. How large a market is open to them is not determinable from the facts in hand. It would therefore seem that the task of finding and proving an available market for a specified tonnage would be the first thing to be done by anyone considering the development of coal deposits in this region.

The same handicaps regarding transportation, supplies, labor, and living conditions that were discussed in connection with oil developments in the region apply with at least equal force to coal developments. In fact, the problem of transportation of the coal is perhaps even more difficult, because the mobility of oil might allow it to be piped where coal would have to be transported by railroad or ship. Furthermore, probably a larger force of workmen would be required to mine coal, and the variety and amount of machinery and equipment that would be required would also be greater.

PALEOZOIC COAL FIELDS

Coals of Paleozoic age are known only in the vicinity of Cape Lisburne, and these are considered to be of Carboniferous age. Several claims have been recorded on these coals, but no mining is in progress and no appreciable amount of coal has been produced. The coal localities have been rather fully described by Collier[95] as follows:

EXTENT

The coal-bearing member is apparently near the bottom of the series. Owing to the complicated structure of the rocks of the Lower Carboniferous series, the coal-bearing formation outcrops in limited areas, whose inland extensions and outlines can be determined only by more detailed work than the time allowed this expedition.

The coal-bearing member outcrops in several small areas near the coast south of Cape Lisburne, on Kukpuk River about 15 miles from the coast, and on the coast at Cape Thompson. The coal beds were not reported by any of the early explorers, and they have not been worked to any extent by whalemen. They were first recognized as distinct from the Mesozoic coals by A. G. Maddren, who visited one of the localities in 1900.[96] Small amounts of the coal have been tested in galley stoves, and a few tons have been mined for use at the Point Hope whaling station, but there have been no large amounts mined, nor have analyses been made previous to 1904.

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[95] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 43–45, 1906.

[96] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 113, 1904.

It is said to give a more intense fire than Nanaimo coal, but engineers of the revenue cutter *Corwin* regarded it as too hard to burn in furnaces not provided with forced draft.

LOCALITIES IN DETAIL

NIAK

Four miles[97] south of Cape Lisburne black coal-bearing shales outcrop for about half a mile in a cliff about 50 feet high back of a narrow beach. The locality, a famous camping place of the natives, is called Niak and is near the mouth of a large creek from which vessels have occasionally taken water. On the south side the shales are in contact with the massive limestones which are faulted over them. The outcrop of the formation extends inland in a southeast direction, but its limits have not been determined. The shales are very much crumpled, and the inclosed coal beds are often sheared so that no continuous bed remains, but the coal occurs in lenticular masses along fault planes. Maddren reports seeing a 4 or 5 foot bed of coal whose outcrop extended across from the coast to the creek and which dipped north at an angle of 60°. Small amounts have been mined from the lenses noted above, and Mr. Washburne reports that he saw a pile of coal which was mined and sacked previous to 1904. A sample taken from these sacks was analyzed by W. T. Schaller with the following result:

Analysis of coal from Niak, 4 miles south of Cape Lisburne, Alaska

	Per cent
Fixed carbon	77.65
Volatile hydrocarbon	15.64
Moisture	3.77
Ash	2.94
	100.00
Coke	None.
Color of ash	Light gray.
Fuel ratio	4.97

CAPE LEWIS

About 1 mile south of Cape Lewis, which is a promontory nearly 1,000 feet high 11 miles south of Cape Lisburne, there is a second exposure of coal-bearing shales which outcrop for half a mile in a low cliff back of the beach. These shales carry in addition to the coal abundant fossil plants of Paleozoic type. Beyond the short cliff no outcrops of coal have been observed, though there are occasional outcrops of black shale for 3 miles to Cape Dyer. The coal-bearing shales are overlain by thinly bedded limestones and black cherts and slates, which are in turn overlain by the massive limestones of Cape Lewis, and they appear to rest conformably on the massive sandstone of which Cape Dyer is composed.

The coal beds at this point have not been developed and have yielded no coal. Though only one bed of sufficient thickness to mine has been discovered it is probable that a small amount of development would uncover several beds,

[97] This description is based on the work of C. Washburne. The locality was not visited by the writer [Collier].

some of which may be of sufficient size to work. Since the structure does not seem greatly complicated, the beds may be found to contain a considerable quantity of workable coal.

The outcrops which were examined are at a point about 1½ miles south of Cape Lewis. They are usually covered by talus from the cliff, but the locality can be easily recognized, since it is the first rock exposure south of a creek about 1 mile south of the cape.

The upper bed of coal strikes N. 75° E. and dips north at an angle of 40°. It is 4 feet thick but is considerably crushed, and only fine material can be obtained from the croppings. The seam has one small indistinct parting near the middle. It could not be traced back from the coast on account of a heavy covering of chert and limestone débris. The roof of the coal bed is hard gray fire clay, and the underlying beds are hard black fire clays or slates containing fossil plant remains. Two smaller beds, which could not be measured, outcrop south of this at intervals of about 50 yards. Their overlying and underlying beds are similar to those of the bed described above. A sample was taken by the writer across the whole face of the 4-foot coal bed, which, when analyzed by W. T. Schaller, gave the following result:

Analysis of coal from beds 1 mile south of Cape Lewis, Alaska

	Per cent
Fixed carbon	70.33
Volatile hydrocarbon	21.16
Moisture	5.51
Ash	3.00
	100.00
Sulphur	.96
Coke	None.
Color of ash	Brown.

CAPE DYER

A third area of these coal-bearing rocks reaches the coast south of Cape Dyer, and the coal beds are exposed in a low cliff, which is nearly continuous from Cape Dyer to the high bluff called "The Ears," a distance of about a mile and a half. An abandoned native settlement here bears the name Capaloa,[93] and the name is applied by the writer to the creek near which the old houses stand.

Cape Dyer is about 16 miles south of Cape Lisburne. Seen from the north it appears as an isolated butte standing out in the sea, the land back of it being much lower. The coal-bearing formation probably connects back of the high point with the above-mentioned area south of Cape Lewis.

The coal-bearing rocks consist of black shales and slates interbedded with limestone or hard, light-colored fire clay. At the north end of this exposure they overlie the massive sandstones of Cape Dyer with apparent conformity. At the south end the sandstones overlie the shales, the contact relation being a well-defined thrust fault. Where exposed in the cliff, the shales and interbedded limestones are very much crumpled and often faulted. S. J. Marsh reports that in 1900 a schooner on which he was a passenger obtained about a ton of coal here for use in the galley stove. There has been no development, and there are no indications that the coals have been worked; moreover,

[93] According to Dr. John B. Driggs, missionary at Point Hope, Capaloa is the native name for Cape Dyer as well as for the old village.

development will be difficult and mining expensive on account of the disturbed condition of the beds. Coal beds outcrop at several places, but it is impossible to determine their number, since some of them may be repeated. The largest bed seen measured 40 inches and dips to the south at an angle of 50°. The coal is more or less crushed, and from the croppings only small pieces can be obtained. Only one of the other beds presented a measurable exposure; this is a bed 1 foot thick and three-fourths mile south of Cape Dyer. The coal from this bed was obtained in large pieces. A sample taken by the writer across the large bed gave the following analysis:

Analysis of coal collected 1 mile south of Cape Dyer, Alaska

	Per cent
Fixed carbon	79.86
Volatile hydrocarbon	15.62
Moisture	1.71
Ash	2.81
	100.00
Coke	None.
Color of ash	Light brown.
Fuel ratio	5.55

KUKPUK RIVER

Coal beds probably of this formation outcrop on Kukpuk River about 15 miles from its mouth. These have not been examined by the writer, though the occurrence here of the coal-bearing formation was observed. Specimens of cannel coal of good quality are found on the beach at the mouth of the river, which may have been washed down, though their source in the bedrock has not been found, and they may have come from either the Mesozoic or Paleozoic formations. If coal should be developed on this river, Marryat Inlet could be used as a shipping point for small cargoes.

CAPE THOMPSON

Similar coals have been reported from Cape Thompson, about 40 miles south of Cape Lisburne. The Carboniferous rocks are known to extend to Cape Thompson, and the cliffs when seen from a distance appear to contain shales similar to those of the coal formation, but the locality has not been examined by the writer.

SUMMARY

It is evident from Collier's description that the coals have high fuel ratios, but many of the beds are crushed and broken, and the largest beds are about 4 feet thick. According to the empirical formula used by Collier he estimated that these coals had an average heating value of 7,715 calories, or 13,887 British thermal units. Apparently these coal beds do not extend over any considerable area, and because of their complicated structure they will be more difficult and expensive to mine than the Mesozoic coals. Collier[99] summarized his views on these coals as follows:

> It is therefore safe to say that the Paleozoic coals of the Lisburne region warrant investigation, and it is not unreasonable to expect that in the future their exploitation will contribute an appreciable addition to the value of the mineral output of Alaska.

This conclusion appears to be somewhat stronger than the present writers would be willing to express, if it is considered to apply to the relatively near future and if it is regarded as warrant for encouraging small operators to enter into the development of that field now.

MESOZOIC COAL FIELDS

DISTRIBUTION

The uncertainty as to the age of the rocks in the vicinity of Corwin and elsewhere and their assignment in this report to the Upper Cretaceous is fully discussed on pages 194 to 196. As these rocks contain numerous coal beds, the same uncertainty exists and the same conclusion and treatment have been adopted in describing the coals. Thus the Corwin formation, which may be Jurassic, and certain coal beds in the Colville Valley that were originally described by Schrader as Tertiary have been grouped together because of their general areal and stratigraphic relations. As thus grouped these coal beds extend through a large tract of country from the Arctic coast at Corwin to the Colville River. They probably also extend farther east, as natives report coal on the Sagavanirktok and Shaviovik Rivers, and Leffingwell[1] observed in the upper part of the Ignek formation certain red beds which he interpreted as marking the location of former coal beds that have burned.

Within this area coal beds have been recognized at many different points. Near Corwin the coals have been seen at short intervals from the low hill immediately south of the mouth of the Pitmegea River westward to a point 1 mile beyond Corwin Bluff and inland for 3 to 5 miles from the coast. The area actually occupied by coal beds as mapped by Collier was about 100 square miles. About 10 miles east of Cape Sabine Collier also noted coal beds, and about 17 miles beyond that point in the hills back of Cape Beaufort are other beds that had previously been noted by Collie,[2] Schrader, and others.

On the Kukpowruk River coal beds were found all the way from a point near the mouth to a point about 25 miles in an air line above

[99] Collier, A. J., op. cit., p. 50.
[1] Leffingwell, E. de K., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, p. 178, 1919.
[2] Collie, Alex., Zoology of Captain Beechey's voyage, p. 173, London, H. G. Bohn, 1839.

the mouth. On the Kokolik River the southernmost beds of coal were seen near camp P June 12. Downstream from that point coal beds were exposed at intervals as far north as any hard rocks were observed—namely, midway between camps P June 15 and P June 16. On the Utukok River these coal seams were first noted about 20 miles in an air line above the mouth, and other beds were found at intervals as far upstream as the surveys of 1923 were carried, which was about 30 miles in an air line above the mouth. Above that point for a distance of about 20 miles the river was not traversed, so that details of the coal exposures in that part are not known, but at the point where the Foran party of the expedition of 1924 first came to the Utukok there were similar coal beds. and these were found upstream nearly as far as Carbon Creek.

Along the coast between the Utukok and Kuk Rivers coal is exposed in the bluffs southwest of Kilimantavi. Numerous coal beds were seen at intervals along the Kuk River and its tributaries, the Kaolak and Avalik Rivers. Several beds of coal were recognized on the Kukroak River and at near-by points on Peard Bay between Wainwright and Barrow. Coal beds were also recognized at a number of places on the Meade River as far upstream as was reached by the Paige party in 1923. On the Ikpikpuk River coal beds were seen at many places upstream from the Price River and also up its tributary, the Kigalik River, and coal float was found on the bars on Maybe Creek in such quantity as to suggest that coal beds probably occur in that valley also.

From Schrader's description of the lower part of the Colville River and the Anaktuvuk River it appears that coal beds were exposed at intervals from a point about 90 miles south of the mouth of the Colville southward to a point about 5 miles above the mouth of the Tuluga River—a distance of at least 40 miles. Lower down the Colville coal float occurs abundantly and may have been derived from near-by beds now poorly exposed or may have been brought from the beds higher upstream. On the Colville west of its junction with the Anaktuvuk coal beds were noted at a number of places, especially near the mouth of the Killik River and between that point and the Awuna River. Coal was also seen up the Killik River as far south as a point a few miles above the mouth of the Chandler River. Although coal beds were seen on the Colville River near the mouth of the Etivluk River, none was recognized southward up the Etivluk Valley, nor was their presence on the main Colville westward and above the Etivluk recorded in the notes of W. R. Smith, so that in that part they are probably absent or insignificant.

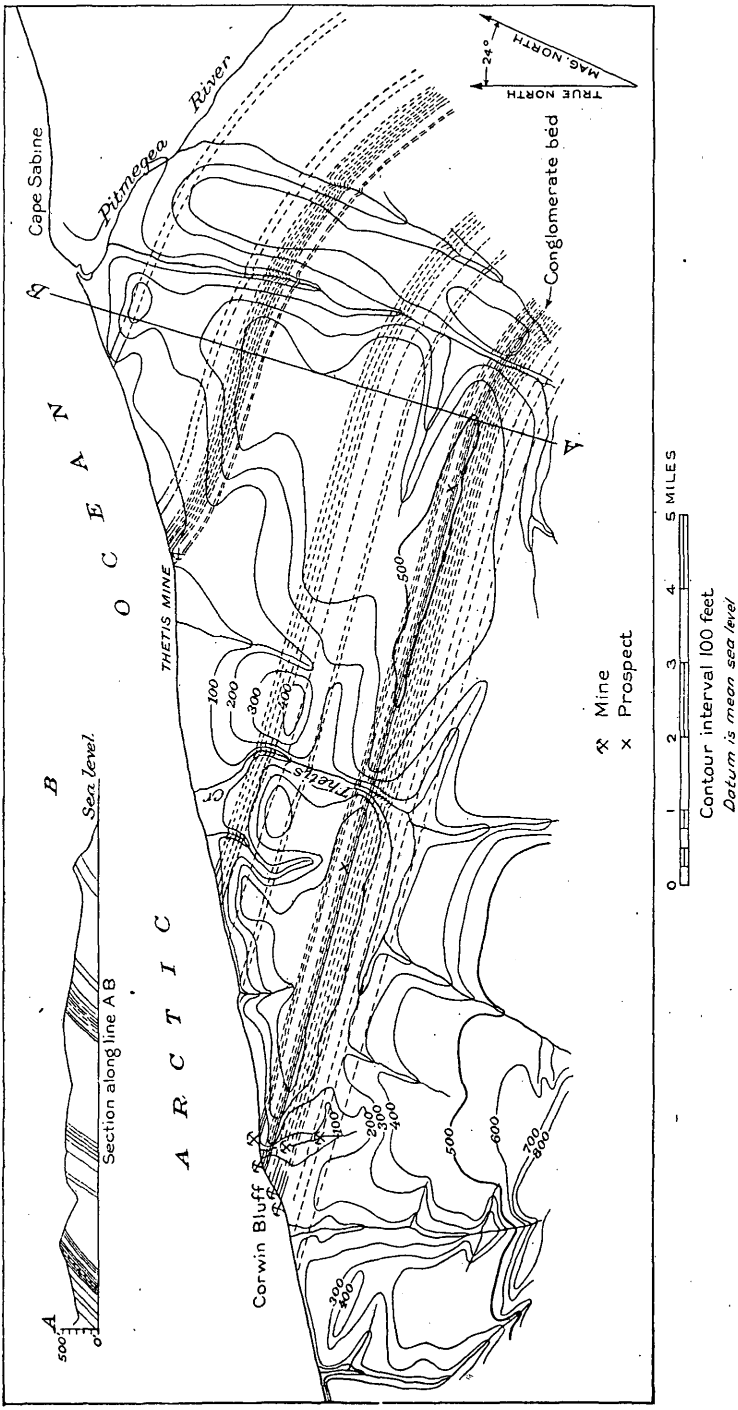


FIGURE 18.—Map of part of the Corwin coal field, showing position of coal outcrops (indicated by dashed lines) and relation of topography to bedrock structure. (By A. J. Collier)

LOCALITIES IN DETAIL

CORWIN REGION

The coals in the Corwin region were divided by Collier into two more or less distinct groups, which he designated the Corwin and Thetis groups. These were most completely studied and described by Collier in 1904, and no late comprehensive data are available regarding them. The distribution of the coal beds and their relation to the structure and topography are shown by Figure 18. Collier's description of those deposits[8] is as follows:

Corwin group.—The coal beds of the Corwin group outcrop in the sea cliffs east and west of Corwin Bluff, which is a cliff 200 feet high about 28 miles east of Cape Lisburne. The bluff itself rises sheer from the water, but about half a mile west of it there are narrow rocky beaches along the foot of the cliff, and a few hundred yards east there is a short sand beach at the mouth of a small creek. The bedding strikes N. 75° W. and dips about 40° SE.

The highest coal seam noted in the series outcrops in the sea cliff 1⅜ miles west of Corwin Bluff. It is exposed by a recent rock slide from the cliff and contains 4½ feet of coal without partings. The roof and floor are soft shales or shaly sandstones.

A sample of this coal taken by Washburne, numbered 4AW7, was assayed by W. T. Schaller with the following result:

Analysis of coal from sea cliff 1⅜ miles west of Corwin Bluff, Alaska

	Per cent
Fixed carbon	40.80
Volatile hydrocarbon	41.30
Moisture	13.55
Ash	4.33
Sulphur	.40
	100.38
Coke	None.
Color of ash	Gray.
Fuel ratio	0.96

A second seam which has yielded some coal is about 1,000 feet lower stratigraphically, the intervening beds being shales which contain several coal seams either too small or too impure to be of value. This bed outcrops in the sea cliff three-fourths of a mile west of Corwin Bluff and is developed by a tunnel about 40 feet long driven without timbers. The photograph (pl. 30), which is probably of this bed, is taken from Schrader's report and shows the nature of the development work done in 1901.

The seam is 5 feet thick and has two thin clay partings, one 1 foot from the floor, the other about the middle. The roof is shaly sandstone, which stands well without timbers. The floor is hard clay or clay shale and contains a smaller seam several feet below the one that has been developed.

[8] Collier, A. J., U. S. Geol. Survey Bull. 278, pp. 37–40, 1904.

A sample of this coal taken by the writer across the bed as exposed in the face of the tunnel, excluding the two partings, was assayed by W. T. Schaller with the following result:

Analysis of coal from sea cliff three-fourths mile west of Corwin Bluff, Alaska

	Per cent
Fixed carbon	42.06
Volatile hydrocarbon	37.72
Moisture	11.18
Ash	9.04
	100.00
Coke	None.
Color of ash	Light gray.
Fuel ratio	1.11

The coal in the face of the tunnel is solid and though frozen does not break up greatly on exposure to the air. A sample exposed to the air for several months in the office is still solid except for some cracks, which may be due to other causes than evaporation, but a sample which had been thoroughly air-dried in the office for several months slacked to fine grains when again put in water. When finely powdered the coal loses moisture rapidly, so that an assay made from a portion of a sample which had been ground in an agate mortar showed only 4.66 per cent moisture as compared with the 11.18 per cent obtained from coarsely ground material. The specific gravity of a sample of the air-dried coal was roughly determined to be 1.39.

The next bed of importance is about 500 feet lower stratigraphically, the intervening beds being shales which contain four or five small unimportant coal seams. This is probably the original Corwin vein and has yielded a considerable amount of coal. It has been developed by a tunnel from the cliff face and an air shaft from the level surface above the cliff, which is about 75 feet above the sea. In the summer of 1904 the entrance to the tunnel was closed by a great mass of ice, the remnant of snowdrifts formed the winter before, and the air shaft was filled with water, so that the workings were inaccessible and the coal bed could not be measured. It is reported to have a total thickness of 16 feet, of which 7 feet is clear coal with no partings, while the remainder contains several partings and is without value.

Two samples were taken by the writer from sacks of coal mined the year before, which were found frozen in the ice at the foot of the cliff. One of these (No. 4AC4) is a fair sample of the material found in the coal sacks and represents the coal as it has actually been mined and shipped. The other sample was taken from the same sacks but was washed before sampling. It probably represents approximately the quality of coal that could be obtained from this bed by careful mining. The analyses by W. T. Schaller are as follows:

Analysis of coal taken from sea cliff west of Corwin Bluff, Alaska

	No. 4AC4 Per cent	No. 4AC5 Per cent
Fixed carbon	41.67	47.49
Volatile hydrocarbon	37.49	39.08
Moisture	9.45	9.49
Ash	11.39	3.49
Sulphur	.30	
	100.30	99.55
Coke	None.	None.
Color of ash	Gray.	Light gray.
Fuel ratio	1.11	1.21

The coal from this bed which was examined was mined about a year before and since then had been subjected to alternate freezing and thawing. Most of it, though not all, was in small pieces. The samples which were brought to the office have not broken up perceptibly. A finely pulverized sample, when assayed,

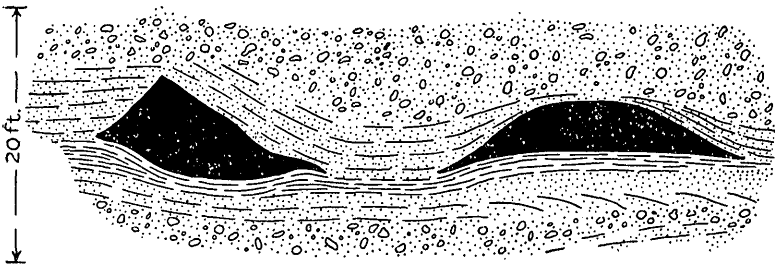


FIGURE 19.—Section of irregular coal bed underlying conglomerate at Corwin Bluff (By A. J. Collier)

contained only 4.49 per cent moisture, as compared with 9.49 per cent in the coarsely ground material. Below this bed there are shales for about 1,000 feet between it and the conglomerate bed which forms Corwin Bluff. In this shale there are eight beds of coal, indicated by croppings, which could not be examined in detail, since their exposures in the cliffs were inaccessible. Three of these beds seemed to be over 4 feet thick. One, which immediately overlies the conglomerate, appears from the sea to be about 30 feet thick and of impure coal. Another about 12 feet thick and a third 4 feet thick are reported to be clean coal of good quality. The conglomerate bed at Corwin Bluff is from 10 to 20 feet thick.

Immediately below the conglomerate, and lying between it and a massive sandstone, there is an irregular coal bed from which it is reported 500 tons of coal were taken in one season. This bed has been affected by shearing movements of the adjacent strata, and the coal is brecciated and polished, though it can be obtained in large pieces. In other parts of the series the adjacent shales are soft beds which have yielded equally to shearing strains, so that the coal beds have remained comparatively unaltered. But in this case, the conglomerate and sandstone beds being rigid, the whole effect of such forces has been felt by the coal bed which lies between them. In the face of the bluff the coal appears in a series of isolated masses, as shown in the sketch (fig. 19), which is parallel with the strike of the bedding.

Since this bed was partially mined out the face of the bluff has fallen down, making the coal inaccessible, and the samples for analysis were taken from large pieces which had fallen down and may not be fully representative. The result of the analysis by Schaller is as follows:

Analysis of coal from Corwin Bluff, Alaska

	Per cent
Fixed carbon	57.49
Volatile hydrocarbon	34.59
Moisture	4.49
Ash	5.43
Sulphur	.30
	100.39
Coke	None.
Color of ash	Gray.
Fuel ratio	1.63

Specimens of this coal which were found on the talus at the foot of the cliff and had probably been long exposed to the weather seemed to be entirely unaffected. The specific gravity of a sample which had been exposed to the air for several months was roughly determined to be 1.30. While the analysis indicates that this is the best coal sampled from the Corwin formation, the irregular nature of the bed makes it doubtful if it can ever be profitably worked.

The next bed of importance in the series outcrops in the sea cliff about 1,000 feet east of Corwin Bluff and is stratigraphically 400 feet below the conglomerate bed, the intervening strata being sandstones and shales containing many plant remains and one small coal bed below the irregular one noted above. The section of the coal bed from the top down is as follows: Clean coal, 1 foot; black shale, 1 foot; clean coal, 4 feet. The coal from the upper and lower benches is about alike.

The roof of this bed is black shale 1½ feet thick, above which is shaly sandstone. The floor of the bed is black shale 2 feet thick, below which there is 1 foot of impure limestone.

The bed has been partially opened at the top of the cliff, which is about 100 feet high, and has yielded for whaling ships some coal said to be of good quality. The face of the cliff up to 75 feet above the sea was covered in July and August, 1904, with snow and ice, the remnant of snowdrifts accumulated the winter before.

A sample across the bed was taken by the writer, excluding the shale parting noted above. The result of its analysis by Schaller is as follows:

Analysis of coal from sea cliff east of Corwin Bluff, Alaska

	Per cent
Fixed carbon	48.47
Volatile hydrocarbon	33.40
Moisture	12.45
Ash	5.68
	100.00
Coke	None.
Color of ash	Light gray.
Fuel ratio	1.45

The sample was taken from the croppings of the bed, where it was considerably broken up by weathering.

About 50 feet below this bed there is an undeveloped bed which appears from the croppings to be about 2 feet thick. Below this for about 8,000 feet no coal beds above 1 foot in thickness were observed by the writer, though thin beds have been noted at several places.

Thetis group.—The coal beds of the Thetis group outcrop on the coast 6 miles east of Corwin Bluff and are stratigraphically about 8,000 feet below the lowest bed of the Corwin group.

The outcrop along the coast is near a sandstone cliff about 30 feet high, the seaward end of a low ridge which extends inland in a southeast direction. It is about 4½ miles west of Cape Sabine and 2 miles east of the mouth of Thetis Creek. The coal here is reported to have been worked first by a whaleman who found all the beds accessible at Corwin Bluff already occupied by the crews of other ships and was directed to this place by natives. The United States revenue cutter *Thetis* coaled here in 1888. It is reported that when the bed was discovered its outcrop extended across the beach, standing above the sand, and a large amount was easily obtained. In 1904 extensive snowdrifts covered the beaches and the cliff face, so that no outcrop was seen. The bedding strikes N. 60° W. and dips southwest at an angle of about 20°.

The vein which was worked in 1888 is probably one that overlies the massive sandstone which forms the cliff noted. Croppings on the level ground above the bluff indicate two coal beds of considerable thickness with 15 or 20 feet of shale between. Reports of the workings indicate that the vein has a thickness not less than 6 feet. In about 700 feet of dark shales underlying the sandstone bed 10 coal beds were noted, only 2 of which are of possible economic value. The first of these is about 250 feet below the Thetis bed and outcrops about 100 feet east of the high sandstone cliff. It contains 4 feet of clean coal without partings, and has for roof and floor black shales which contain several small coal seams. A sample across this bed where it was exposed by the undercutting of the surf on the cliff was taken by Mr. Washburne and was assayed by W. T. Schaller with the following result:

Analysis of coal from Thetis mine, Alaska

	Per cent
Fixed carbon	46.27
Volatile hydrocarbon	35.60
Moisture	13.61
Ash	4.52
	100.00
Coke	None.
Color of ash	Light brown.
Fuel ratio	1.30

As is noted above, the sample was taken from a natural exposure which was frequently drenched by the waves, and the quality of the coal may have been slightly affected. The coal in the croppings is broken up into small pieces.

A second seam which appears to be of workable size is about 200 feet lower in the column and outcrops about 600 feet farther east. It contains 3 feet of clean coal without partings, below the same thickness of bony coal, which is probably worthless. No analysis was made of the sample from this bed.

Below the beds of the Thetis group there are about 3,000 feet of shales and sandstones, outcropping between Thetis mine and Cape Sabine, in which several coal beds have been noted, but none are of commercial value. East of Cape Sabine the structure changes, so that the outcrops of the beds described above are probably repeated, but the work has not been sufficiently detailed to identify them. The coal-bearing formation is not exposed in sea cliffs, and the croppings in the interior are not well defined.

KUKPOWRUK RIVER REGION

The coal beds on the Kukpowruk River were examined by W. T. Foran,[4] and the following statements regarding them are taken from his report:

The general course of Kukpowruk River is northward, nearly at right angles to the folding of the region. Along the river two major anticlines and the corresponding synclinal basins are thus disclosed. In the two synclinal basins much coal is exposed, and there is every reason to believe that the area between the northern anticlinal axis and the sea also carries much coal.

A 3-foot bed of coal is exposed near the mouth of the river. Thence inland for 5 or 6 miles, to the crest of the first anticline, there are no exposures, but the general structure of the rocks and the fact that coal is present on the southern limb of this anticline support the belief that much coal underlies this lower part of the river and would be revealed by excavation.

At the crest of the first anticline, on its north side, two beds of coal crop out, the northern one (stratigraphically the higher) 10 feet thick and beneath it a 3-foot bed. These beds are numbered 12 and 13 in the columnar section (see pl. 31), on which is shown the stratigraphy of the southern limb of this anticline. In other words, these beds appear on both sides of the crest of the fold and are the lowest stratigraphically in this section.

Upstream from the crest of this anticline 13 minable beds of coal, 3 feet or more in thickness, and 18 thinner beds are exposed within a distance of about 1½ miles. Their relative stratigraphic position is shown in the columnar section of the south limb of the northern anticline (pl. 31).

The thickest beds are described in the following table:

Principal coal beds on south limb of northern anticline, Kukpowruk River

No. of bed[a]	Thickness (feet)	Partings	Strike	Dip	Roof	Floor
3	6	None	N. 80° E.	35° S.	Shale	Shale.
5	5	do	do	36° S.	Shaly sandstone	Laminated sandstone.
8	7	do	do	42° S.	Fine-grained sandstone.	Carbonaceous shale.
9	9	One 4-inch, one ½-inch	do	55° S.	Sandy shale	Sandy shale.
13	10	One-half inch wood parting 5 inches from floor.	N. 65° E.	25° N.	Hard nodular shale.	Gray sandy shale

[a] Numbers correspond to numbers in columnar section (pl. 31).

As shown in the columnar section (pl. 31), there are seven other beds with a thickness of 3 to 4 feet and numerous still thinner beds.

[4] Paige, Sidney, Foran, W. T., and Gilluly, James, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, pp. 26–28, 1925.

Much coal is exposed on the south side of the syncline in which occur the beds just described. The outcrops are found throughout a distance of 3 to 4 miles in an air line along the river. * * * The exposures are not continuous, and there are three breaks in the stratigraphic measurements of 1,100, 1,800, and 420 feet, in order upstream. Twelve beds from 4 to 10 feet thick occur in this section and as many more from 1 to 3 feet thick. (See pl. 32, *B*.) The general strike is nearly east; the dip 12°–45° N. It was not found possible, in such rapid work as was necessary, to correlate any of these beds with those on the north side of this basin.

The next group of coals occupy the southern synclinal basin, the center of which lies inland 24 miles in an air line from the sea. Beds crop out on both sides of the synclinal axis, but no bed has been recognized on both sides of the basin. North of the synclinal axis there are four beds more than 6 feet in thickness. Three of these, however, 7, 6, and 9 feet thick, contain much bone and are not valuable. The fourth bed, which occurs stratigraphically near the top of the coal group in this syncline, contains 9 feet of clear coal. Above it, stratigraphically, are two more beds, each 3 feet thick. (See pl. 31.) The 9-foot bed carries a ½-inch parting of petrified wood near the middle of the bed. This parting resembles a similar parting that occurs 6 inches above the base of bed No. 12, near the crest of the anticline 16 miles to the north. Possibly the two beds are the same. South of the axis of this southern syncline there are five beds up to 3½ feet thick, two 4 feet thick, and one 20 feet thick. The 20-foot bed is stratigraphically the lowest. Beneath it no beds of pure coal were observed. This bed strikes east and dips 18° N.

Samples of coal collected from two beds on the Kukpowruk at places 5 and 25 miles upstream from the mouth were analyzed by the Bureau of Mines, with the following results:

Analyses of coal samples from the Kukpowruk coal fields, Alaska

[Made at the Pittsburgh laboratory of the Bureau of Mines; H. M. Cooper, chief chemist]

Laboratory No.	Air-drying loss	Form of analysis [a]	Proximate analysis					Heating value	
			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Calories	British thermal units
96820	3.3	A	9.9	31.5	56.1	2.5	0.4	6,617	11,910
		B	6.8	32.5	58.1	2.6	.4	6,844	12,320
		C		34.9	62.3	2.8	.5	7,339	13,210
		D		35.9	64.1		.5	7,556	13,600
96821	1.0	A	3.9	38.6	55.5	2.0	.2	7,661	13,790
		B	2.8	38.6	56.4	2.2	.2	7,860	14,640
		C		40.0	57.7	2.3	.2	7,978	14,360
		D		41.0	59.0		.2	8,140	14,660

[a] A, As received; B, air dried; C, moisture free; D, moisture and ash free.

KOKOLIK RIVER REGION

The southernmost definite coal beds on the Kokolik River were recognized a short distance downstream from camp P June 12, though small amounts of coaly material were seen at a number of places farther upstream. From that point as far downstream as bedrock is exposed—namely, midway between camps P June 15 and P June 16—coal beds were seen at short intervals, and coal float formed a considerable part of the material on the river bars. The character of the exposures is usually not such as to permit detailed examination of the beds without considerable excavation, but at least three anticlines with intervening synclines were recognized between camps P June 12 and P June 16, so that the same beds are probably repeated more than once in that distance. A short distance below camp P June 13, a 6-foot bed of coal containing very little bone or shale is overlain by some shale and sandstone and another coal bed about 3 feet thick, which in turn is overlain by another coal bed that was not completely exposed but appeared to be nearly 3 feet thick. Below camp P June 14 a coal bed was partly exposed which showed a foot of clean coal but may probably be thicker, as neither the top nor the bottom was shown. This is underlain farther downstream by a bed of coal 4 feet thick, and still farther downstream coal débris could be found in the river banks for several miles. Still farther downstream, a short distance below camp P June 15, a coal bed at least 3 feet thick is exposed a short distance north of some old igloos. The coal is underlain and overlain by sandstone, and on top of the upper sandstone is more coal. The coal had been used locally at the igloos by the Eskimos.

Data are not available for making a close estimate of the total thickness of the coal beds that occur along the Kokolik. From what has been seen it is known that at least half a dozen beds, each over 3 feet thick, occur there, and probably at least as many more might be found if excavations were made at suitable places where the caved banks conceal the bedrock. The coal is usually of good quality, is glossy black, and does not disintegrate badly under the weather. It has none of the general appearance of lignite, but when pieces are whittled they have a somewhat brownish color rather than the jet-black of typical bituminous coal. The coal is therefore probably subbituminous and of approximately the same character as the coals on the Kukpowruk, only 20 to 30 miles distant, that have been analyzed. The coals on the Kokolik are not quite so advantageously situated for commercial development as those on the Kukpowruk or in some of the other areas below, because they are farther upstream, and the river is said to be so shallow during much of the open season that it is navigable only by small boats with light loads. Very likely, however, coals similar to those on the Kukpowruk and Utukok may occur in the lower stretches of the Kokolik, where they are now buried under the later coastal-plain deposits.

UTUKOK RIVER REGION

The coal beds in the lower part of the Utukok River valley were described by Foran [5] as follows:

The first outcrop of coal on Utukok River is 20 miles inland in a direct line. (See pl. 2.) Here, on the north flank of a gentle anticline, a 6-inch seam strikes east and dips 5° N. About 6 miles by air line upstream, on the north side of the low anticline, thin seams of coal, a few inches thick, are interbedded with shale. At 5½ miles farther upstream, on the north flank of a second anticline, a 2½-foot bed of coal containing two 2-inch shale partings crops out. This bed strikes S. 70° E. and dips 10° NE. A short distance farther upstream, 1,000 feet downstream from the crest of the anticline, there is a 5-foot bed containing two thin partings of shale. This bed strikes S. 70° E. and dips 10° NE. Nearly 3 miles farther upstream, on the north limb of the anticline, a bed of coal 11 feet 8 inches thick without partings is exposed.

The coal beds in the Utukok Valley above the portage to the Kaolak River were also examined by Foran, but no detailed description of them was prepared. The following statements have been compiled from his field notes and other records. On the whole the coal-bearing section forms a general syncline whose southern limit is between Elusive Creek and camp F August 20. The beds are, however, considerably folded, so that subordinate anticlines and synclines, whose axes trend about east, interrupt the major synclinal structure. Not many thick coal beds were seen, but thin ones are common, and the large amount of coal débris on the bars indicates that there is in the banks considerable coal which is not well exposed. The thickest bed of coal recorded was 3 feet 6 inches thick.

As a whole, the coal appeared to be of better quality than was seen farther south and was believed to be of bituminous rank. In fact, some float was found that was said to approach anthracite in quality. The higher fuel ratio of these coals was interpreted as due to the greater amount of deformation the rocks have undergone toward the front of the mountains. The coals are compact, are glossy black, and disintegrate little on exposure to the weather. The structure of the vegetable material from which the coal was derived is now entirely obliterated, so that in the coal it can not be recognized in the hand specimens. No samples of the coal were collected for analysis, but Foran's personal familiarity with coals in general and especially with the coal on the Kukpowruk and lower Utukok give weight to his judgment that the coals on the upper Utukok are of equal or better quality than those he had seen elsewhere in north-

[5] Paige, Sidney, Foran, W. T., and Gilluly, James, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, p. 28, 1925.

western Alaska. A few sulphur balls were noted in these coals, but they were not abundant enough to affect the sulphur content of the coal materially nor to interfere seriously with mining and handling the coal.

WAINWRIGHT REGION

Coal beds in the vicinity of Wainwright[6] are said to have been known to the whites in 1889, and since that time they have been mined in a small way and in primitive fashion to supply local needs. The

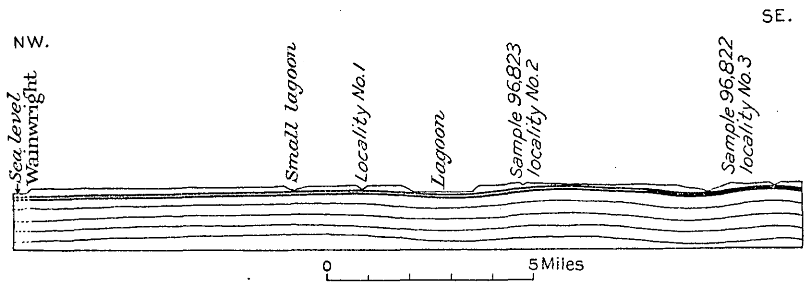


FIGURE 20.—Structural cross section on Wainwright Inlet and Kuk River. (By W. T. Foran)

coal beds are more or less continuous from a locality a short distance southeast of Karmuk Point throughout the valleys of the Kuk River and its tributaries the Avalik and Kaolak Rivers. The thickest and most accessible beds seen, however, crop out along the east side of the Kuk River between points 8 miles and 20 miles south of Wainwright. The coal lies practically horizontal with very gentle warp-

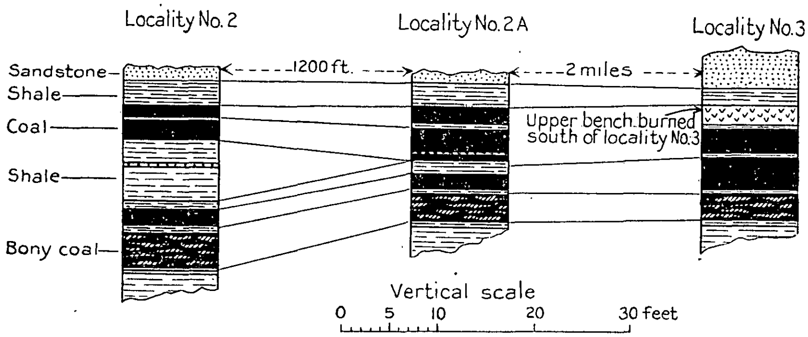


FIGURE 21.—Columnar sections of coal beds on Kuk River. (By W. T. Foran)

ings, so that apparently it is everywhere under a relatively thin cover. Openings to get out the coal have been made at three places in the shore bluffs. The general appearance of the coal beds as exposed at mine No. 3—the southernmost locality—is shown in Plate 33, *A*. The structure of the beds throughout this part of the Kuk Valley and

[6] Report on population and resources of Alaska: Eleventh Census, 1890, p. 133, 1893.

an attempt to correlate the partings at the southern localities are shown in Figures 20 and 21, respectively, which are reproduced from Foran's report. It will be seen from Figure 21 that several partings and thin layers of shale or bone are closely interleaved with the coal, so that at most places not more than 3 feet of clean coal can be obtained. Analyses of coal from the second and third mines were made by the Bureau of Mines, with the following results:

Analyses of coal samples from the Wainwright coal field, Alaska

[Made at the Pittsburgh laboratory of the Bureau of Mines; H. M. Cooper, chief chemist. For source of samples see fig. 20]

Laboratory No.	Air-drying loss	Form of analysis [a]	Proximate analysis					Heating value	
			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Calories	British thermal units
96823	8.7	A	22.3	30.6	44.5	2.6	0.3	5,500	9,900
		B	14.9	33.6	48.7	2.8	.4	6,017	10,830
		C	--------	39.4	57.3	3.3	.4	7,072	12,730
		D	--------	40.8	59.2	--------	.4	7,317	13,170
96822	9.2	A	21.8	29.3	43.7	5.2	.4	5,256	9,460
		B	13.9	32.3	48.1	5.7	.4	5,789	10,420
		C	--------	37.5	55.8	6.7	.5	6,772	12,100
		D	--------	40.2	59.8	--------	.5	7,206	12,970

[a] A, As received; B, air dried; C, moisture free; D, moisture and ash free.

The coal is evidently of subbituminous rank and of less heating value than the other coals so far described. This lower quality is believed to be due to the lesser folding that the beds have undergone and not to an original difference in the beds themselves.

A few hundred tons of coal has been taken from these beds on the Kuk and used locally. The coal that has been taken is, of course, of the poorest quality, as it is more or less weathered and mixed with surface débris. No real mining has been practiced. The natives simply gopher out from the surface the coal within reach of their picks and shovels, so that nowhere are the excavations more than 4 or 5 feet underground. The roof is a fairly heavy sandstone, which disintegrates rather rapidly on exposed surface but probably is firmer underground. No timber is used, and the roof is strengthened by leaving a considerable thickness of coal next to the sandstone. The coal is sacked in bags containing 90 to 100 pounds of coal and is brought to Wainwright by the natives in their skin boats during the summer or by dog team in the winter. A general view of the way in which this coal is handled by the natives is shown by Plate 33, *B*. The current price paid by the traders for this coal at Wainwright is about 75 cents a sack, but even at that price it does not supplant imported coal, which sells for more than twice as much.

Farther south, toward the headwaters of the tributaries of the Kuk, no thick beds of coal were recognized. On the Kaolak River Foran found only thin beds exposed, though the presence of considerable amounts of coal on the bars suggested that there were probably other beds which were concealed by the slumped banks or moss-covered stretches. On the Avalik River three small coal beds were seen a short distance above Kungik. Of these the lower two were less than 1 foot thick, but the upper one, which, however, was only poorly exposed, was at least 3 feet thick. Still farther up that stream other coal beds were recognized at a number of places, practically as far east as the stream was traversed, but none of them seemed to be of great enough thickness to be mined, and it was the geologist's impression that in the eastern part of the valley practically none of the beds was more than 1 foot thick.

PEARD BAY REGION

In the vicinity of Peard Bay coal beds have been seen in place only along parts of the Kukroak River, but at several places along the beach coal float is so abundant that it seems probable that coal beds are not far distant and have probably been buried under the later beach and river deposits. On the south side of the reef near the inlet about 5½ miles north of Atanik coal float in large pieces was especially abundant. The most northern exposure of coal on the Kukroak River is about 1 mile north of camp P August 9. The bed at this place was poorly exposed, as the banks had slumped badly, but the coal bed was at least 2 feet thick, with neither the top nor the bottom exposed.

The coal had disintegrated badly but seemed to be similar in general appearance and composition to the coals on the Kuk River, which are about 25 miles distant. Southeast of camp P August 9, on the east side of the Kukroak, are poor exposures of sandstone overlying a coal bed that can be traced upstream more or less continuously for more than 2 miles. The exposures are poor, so that the coal could not be examined in detail, but it appeared to be at least 5 feet thick, though some bone or shale may be included in that measurement. Half a mile south of the igloos at the head of the estuarine portion of the river heavy coal float was seen in the river deposits, but the bed from which it came is not exposed, though it probably is present and concealed by slide material from the valley walls. The beds throughout this tract are practically flat or gently warped, so that unless removed by erosion the coal everywhere lies near the surface under a relatively thin cover of coastal-plain deposits. Some of the coal has been used locally by the natives, but no excavations that are now recognizable were seen.

MEADE RIVER REGION

The character of the coal beds on the Meade River was examined by Paige [7] and described as follows:

Coal is exposed at a number of places on Meade River, and as the strata are only gently warped or nearly horizontal it is probable that areas of many square miles in this region are underlain by workable coal beds. Weathered outcrops of coal were seen on the right bank of the river about 30 miles inland. The exposure was poor but indicated a thin bed lying nearly horizontal, overlain by blue clay shale.

In a low bluff on the left bank above Atkasuk weathered outcrops of coal were exposed for 500 feet or more. The indications are that a bed of coal about 3 feet thick lies nearly horizontal. It is underlain by clay shale and sandstone. Where the bluff is absent on this portion of the river the coal bed has been removed by erosion. Outcrops of sandstone are found from place to place upstream from this coal for 3 or 4 miles.

Indications of a bed of coal possibly 3 to 4 feet thick are found on the left bank of the river about 20 miles in an air line above Atkasuk. Here a bluff 50 feet high borders the river. The sandstone, shale, and coal occupy the lower 15 or 20 feet of the bank. Such exposures as were seen suggest that the beds are nearly horizontal.

Still higher up the river, on the right bank above Pisiksagiakvik River, coal is exposed underlain by sandstone. There is an apparent dip of 10° upstream, but this may be due to slumping, for coal was observed farther upstream 25 feet above the water, though, on the other hand, this may represent a higher bed.

At the end of the traverse on the left bank débris of coal was found in such relation as to suggest a near-by horizontal bed.

The weathered coal débris at all these places resembles the weathered outcrops of coal on Wainwright Inlet that proved on analysis to be of subbituminous rank.

IKPIKPUK RIVER REGION

The northern part of the Ikpikpuk Valley is so deeply buried in late deposits of coastal-plain or fluviatile origin that the underlying bedrocks are not exposed north of the Price River. South of that point, however, coal or indications of coal are found at short intervals all the way to the head of the valley. On the whole, the exposures are not good because of the slumping of the bank, so that accurate measurements could be obtained only at a few places. The coal beds are relatively less resistant to disintegration than the outcropping rocks with which they are associated, so that they are generally masked by the slide rock. In spite of this condition several beds more than 3 feet thick were recognized, and between camps S July 30 and S July 31 there were indications of a coal bed possibly 20 feet thick. Most of the coal beds near the northern limit of exposures seem to show less compact and poorer coal than the beds

[7] Paige, Sidney, and others, A reconnaissance of the Point Barrow region, Alaska: U. S. Geol. Survey Bull. 772, p. 30, 1925.

farther south, and the coal crumbles and checks more under the influence of the weather.

The dip of the rocks is everywhere rather slight, generally not exceeding 10°, though near camp M August 7 a small anticline was noted whose limbs dip 45°. There are some gentle flexures, however, and the coals are especially common in the synclinal basins. Weathering also seems to have caused greater disintegration and softening in all the rocks in the Ikpikpuk Basin than in those farther south. Coal float on the bars is extremely common, and the pieces seem harder and more lustrous than the coal in the banks probably because of the sorting that has been effected by the streams.

Samples were taken from a thin bed between camps M August 6 and M August 7 and from a thicker bed at camp S August 1. The section measured at the northern of these localities (24AMt77) showed shale above 6 inches of coal, underlain by 2 feet of shale, which in turn is underlain by 1¼ feet of coal underlain by thin-bedded sandstone. Only the lower coal bed was sampled. At the other locality (24AS77) the top of the section consists of coal and slide material underlain by 2.1 feet of coal, below which is three-fourths inch of bone, 2.1 feet of coal, and 1 foot of shale and intermixed coaly material. The general conditions at this place are shown in Plate 32, *A*. The two coal beds and the intervening bone were included in the samples analyzed. These specimens were submitted to the Bureau of Mines for analysis with the following results:

Analysis of coal samples from Ikpikpuk region, Alaska

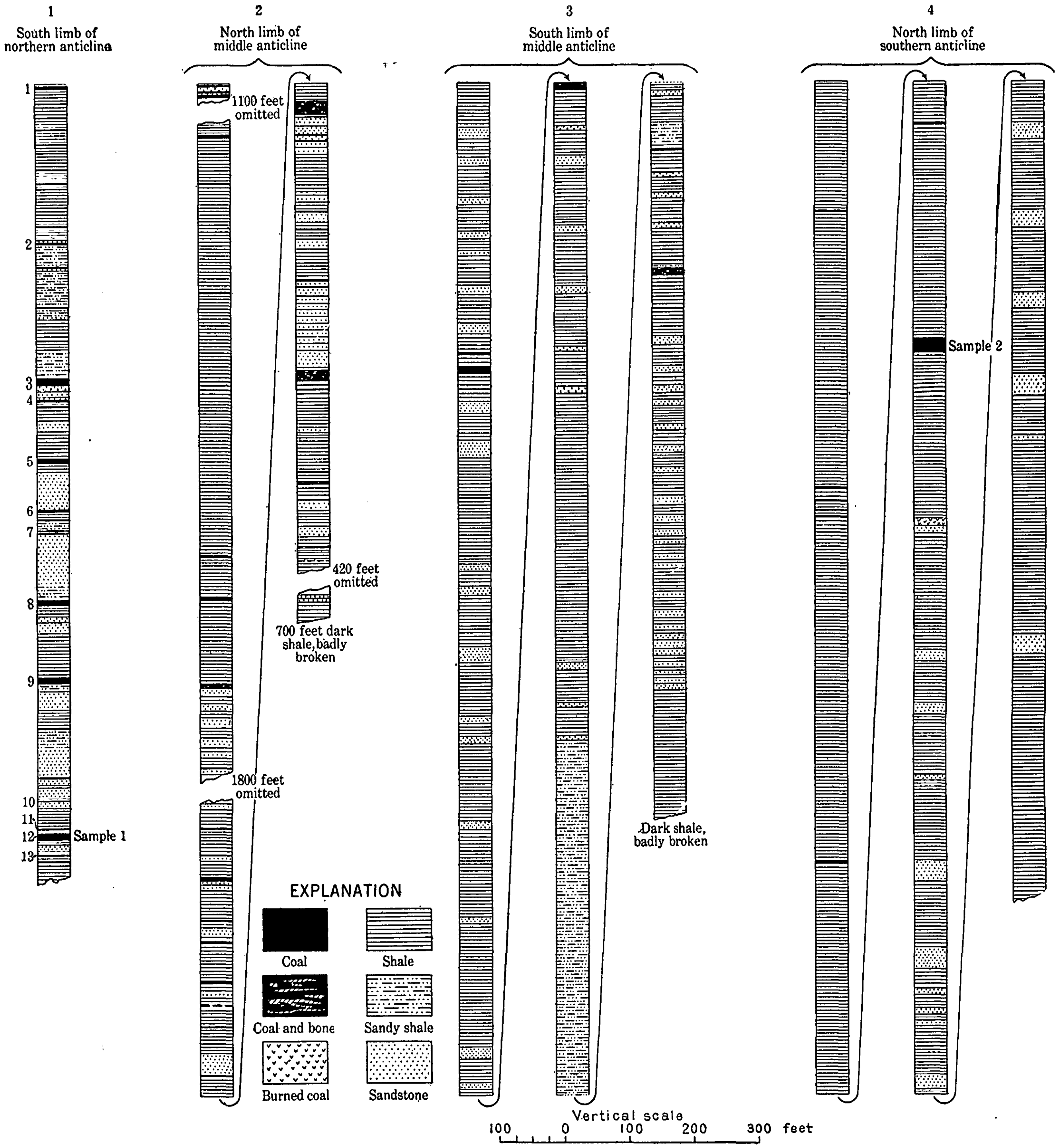
[Made at the Pittsburgh laboratory of the Bureau of Mines; H. M. Cooper, chief chemist]

Laboratory No.	Air-drying loss	Form of analysis [a]	Proximate analysis					Heating value	
			Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Calories	British thermal units
A6849 (24AMt77)	----------	B	8.4	31.2	54.1	6.3	0.6	6,333	11,400
		C	--------	34.0	59.1	6.9	.7	6,911	12,440
		D	--------	36.5	63.5	--------	.7	7,417	13,350
A6847 (24AS77)	11.6	A	3.9	29.4	46.6	20.1	.3	5,328	9,590
		B	15.0	26.0	41.3	17.7	.3	4,706	8,470
		C	--------	30.6	48.5	20.9	.3	5,539	9,970
		D	--------	38.7	61.3	--------	.4	7,000	12,600

[a] A, Air dried; B, as received; C, moisture free; D, moisture and ash free.

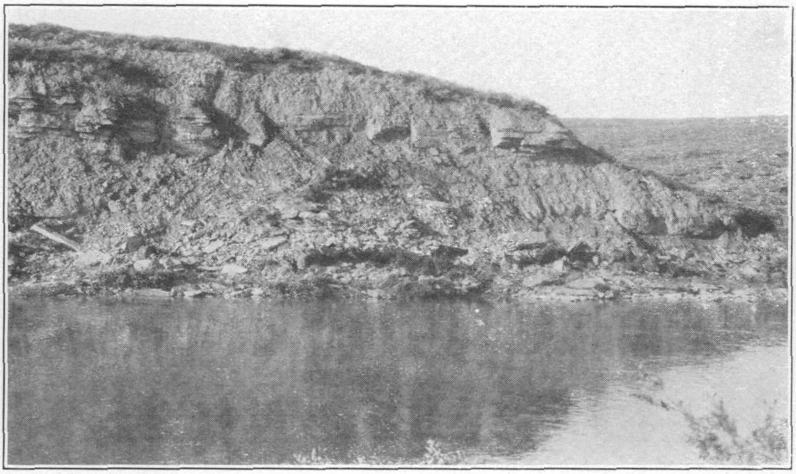
These coals therefore appear to be of lower grade than some of the others so far described but are rather closely similar to the coals from the Wainwright region. Attention, however, should be called to the fact that sample A6847 (24AS77) was collected in the rain with only slight protection, included an obvious bony streak, and was taken from a cut only 10 inches back from the exposed surface, so

COAL BED AT CORWIN

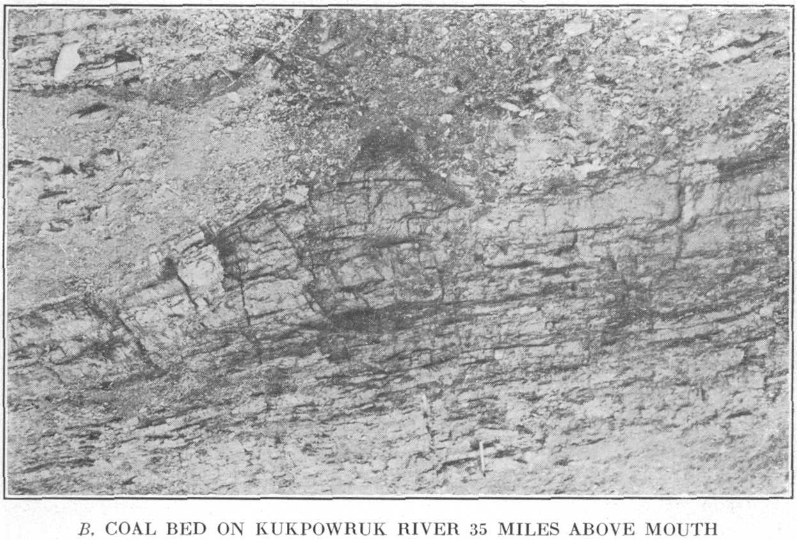


COLUMNAR SECTION OF PART OF COAL-BEARING SERIES ON KUKPOWRUK RIVER

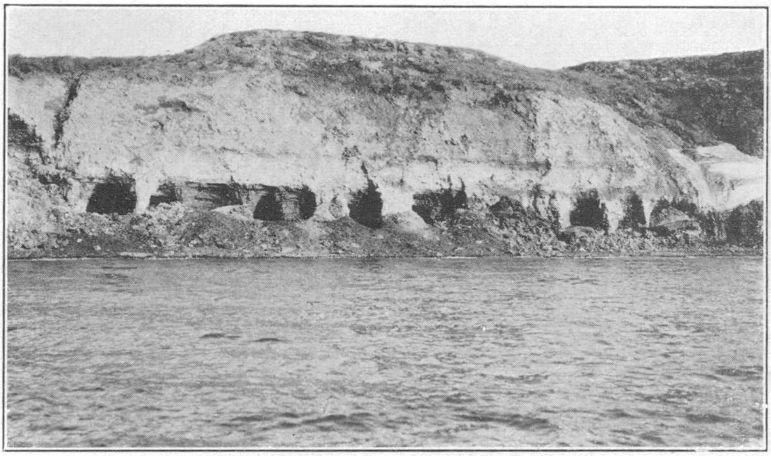
After Foran.



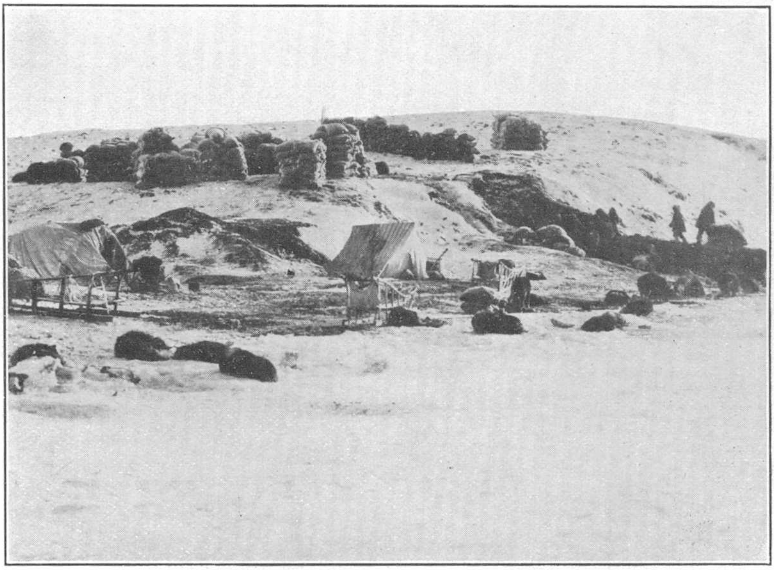
A. COAL BED ON KIGALIK RIVER, A TRIBUTARY OF THE IKPIKPUK



B. COAL BED ON KUKPOWRUK RIVER 35 MILES ABOVE MOUTH

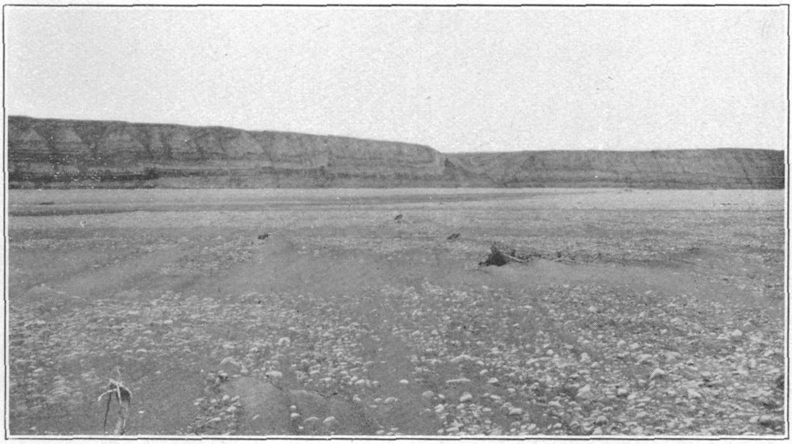


A. COAL BED ON KUK RIVER SOUTH OF WAINWRIGHT

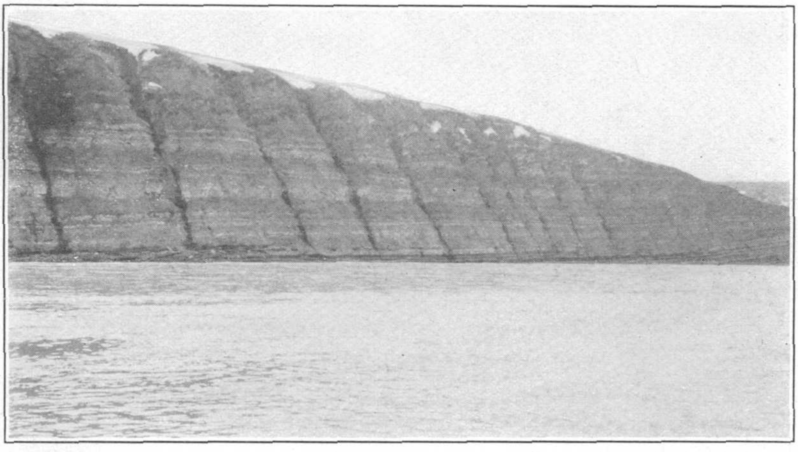


B. NATIVES MINING AND SACKING COAL ON KUK RIVER IN SEPTEMBER

Photograph by E. C. Andrews, United States Office of Education.



A. COAL-BEARING ROCKS ON LOWER PART OF COLVILLE RIVER



B. COAL-BEARING ROCKS ON COLVILLE RIVER ABOVE KILLIK RIVER that it was not really representative of fresh coal collected under more advantageous conditions. As these coals lie in a region of relatively little deformation, it is to be expected that they would show lower heating value than coals which have been subjected to greater dynamic metamorphism.

COLVILLE RIVER REGION

The coals in the eastern part of the Colville Basin were described by Schrader,[8] from whose report the following summary statements have been abstracted. About 30 miles north of the Tuluga River and 100 miles from the coast lignitic coal is abundant in the lower part of the bluffs. More than half a dozen beds from 1 to 3 feet or more thick occur there and are recognizable in Plate 34, *A*, as the darker bands associated with shale and sandstone. The coal has a dull black appearance and is in more or less discontinuous beds and thin layers of highly metamorphosed material which is blacker and has a somewhat anthracitic luster. It burns readily and apparently does not break up badly under the influence of the weather, as it is described as forming boulders a foot or more in diameter on the talus piles. The coal on the Anaktuvuk was seen as far south as 5 miles upstream from the mouth of the Tuluga River. The bedding of the rocks in that region stands at angles of 80° or more. The coal is conformable with the sandstone and shale and occurs in several beds, each a foot or more thick. It is laminated parallel with the bedding, and though in the weathered condition it has the appearance of lignite it is really of subbituminous rank.

Samples of the coals from these two localties were analyzed by George Steiger, with the following results:

Analyses of coal from Anaktuvuk and Colville Rivers

Locality	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	P_2O_5	Coke	Fuel ratio
607. Anaktuvuk River	6.85	36.39	43.38	13.38	0.54	Tr.	None.	1.20
620. Colville River	11.50	30.33	30.27	27.90	.62	Tr.	None.	1.00

The samples probably fail to represent as good quality of coal as might be obtained from these beds, for they were both considerably weathered and seem to have an abnormally high ash content, which may represent the mixture of some dirt and mud not typical of the beds themselves.

[8] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, pp. 107–109, 1904.

In the Colville Valley west of the junction of the Anaktuvuk to a point near the mouth of the Killik River coal was seen at a number of localities, but the beds that were exposed all appeared to be thin, the thickest being only about 2 feet thick. Coal float was also abundant on some of the bars of Prince Creek, but no beds in place were seen in that valley. Near the mouth of the Killik and extending for some distance up that stream as well as up and down the Colville coal was especially conspicuous. The southernmost locality at which coal float was recognized on the Killik River is a few miles upstream from the junction of that stream and the Chandler River. At the mouth of the Killik are several beds of coal whose upper part has been burned, so that their true thickness could not be measured, but to judge from the amount of slumped material they may be at least 3 feet thick.

A sample of the coal was collected about 10 miles upstream from the mouth of the Killik (24AMt65) and submitted to the Bureau of Mines for analysis. The coal bed from which the sample was taken is about 2 feet thick and was both underlain and overlain by shale. The results of the analysis were as follows:

Analysis of coal from Killik River

[Laboratory No. A6848 (24AMt65). Made at Pittsburgh laboratory of the Bureau of Mines; H. M. Cooper, chemist]

	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Heating value	
						Calories	British thermal units
As received	16.4	29.4	41.9	11.8	0.3	4,694	8,450
Air-dried	7.1	33.2	46.6	13.1	.3	5,217	9,390
Moisture-free	([a])	35.7	50.2	14.1	.3	5,617	10,110
Ash and moisture free		41.6	58.4		.3	6,539	11,770

[a] Air-drying loss, 10.0.

On the west side of the river shallow trenches along the outcrop of one of the beds seemed to indicate that some coal had been dug there for local use. On the Colville 3 to 5 miles above the mouth of the Killik River were excellent exposures of coal in the bluffs on the south side of the river, and 11 beds were recognized, several of which measured over 3 feet thick. A view of the bluffs at this place is shown in Plate 34, *B*. The beds occupy a general synclinal basin and on the whole have low dips, though locally in this bluff the dip steepens to 10° to 15°, and farther upstream dips of 45° were recorded. At camp S June 21 considerable coal is exposed interbedded with strongly ripple-marked sandstone. The coal was used in an ordinary Yukon camp stove with good results. Midway between camps S June 21 and S June 22 a 3½-foot bed of clean coal with a small amount of bone above is exposed in the bluffs south of the river. Underlying this coal is a fairly heavy sandstone with sparsely distributed rather angular pebbles, mostly of quartz. Overlying the coal is a massive sandstone which forms a good roof and makes a noticeable escarpment on the hillside. In this sandstone are a few large trunklike stems lying prostrate. West of this point indications of coal are rather scanty until a point a short distance above camp S June 24 is reached. Here there is only a small amount of coal, but near camp S June 26, opposite the mouth of Kurupa River, there is a 2½-foot coal bed lying nearly flat, underlain by thinly laminated sandstone and overlain by a heavy sandstone bed. The coal does not disintegrate rapidly. Many of the fragments on the talus piles were 2 to 3 feet in length, weighed 100 pounds or more, were hard and blocky, and did not soil the hands. Several hundred pounds of this coal was used in the camp stove with excellent results, as it does not clinker or coke and burns to a light ash. Farther upstream coal beds lying nearly flat were recognized at intervals all the way to camp S July 1. At that camp a 4-foot bed of coal is exposed in the bluff. The coal is badly slumped, and there were signs that part of the bed had been burned. This coal is underlain by greenish-gray sandstone. The coal splits into layers rather than into blocks, as most of the other coals do, and this gives it more of a lignitic appearance, but its color is black, and there is little reason to doubt that it represents the same series of coals, especially as Upper Cretaceous fossils were collected in the underlying sandstones.

Indications of coal are evident at many places between camps S July 1 and S July 3, but they do not seem to have come from beds of any great thickness except within a few miles of the latter camp. At that place a remarkably well developed syncline appears, in the lower part of which are several coal beds that reach more than 3 feet in thickness. Coal float is so abundant on the river bars and banks in this stretch that without taking special thought one could probably tread on an egg-sized piece of coal float every step for more than half a mile. The westernmost coal bed seen by the central party of 1924 in the Colville Basin was near camp S July 4, where a good bed of coal is exposed underneath a fairly heavy light-gray sandstone and some shale, all of which dip southward at a low angle.

On the Awuna River, the tributary of the Colville that joins the stream a short distance below camp S July 1, coal was found all the way upstream as far as the river was traversed by the expedition of 1924—that is, to Birthday Creek. The best exposures were seen between camps S July 12 and S July 13. About half a mile above the eastern camp is a bed of coal at least 3 feet thick, but it had slumped considerably, so that its true thickness was not determined, and it may be considerably thicker. West of this bed and somewhat above it stratigraphically is another bed 3 feet 8 inches thick overlain by brownish sandstones showing some cross-bedding, the beds dipping gently northwest. It was in this stretch of river that silicified logs in the sandstone series were especially abundant. These logs were considerably flattened, so that in many of them one diameter was three times the other. Pieces several feet long and 8 inches or more in diameter were common. A layer of coal a quarter of an inch or so thick coated the outer surface of many of the logs. A short distance east of camp S July 14 there is a great deal of coal float, and in a slide on the hillside is a bed of coal that appears to be about 3½ feet thick. Farther west, although coal float is abundant here and there, no beds in place were recognized. It was apparent, however, that at many localities, as, for instance, near camp S July 16, the float was nearly in place, so that a little removal of turf or slide material would undoubtedly disclose the bed from which the float came. Throughout this part of the region the dips are in general low but in both directions, forming gentle anticlinal or synclinal flexures.

REGION SOUTH OF BROOKS RANGE

Some coal has been found in the area south of the Brooks Range which has been mapped as occupied dominantly by Upper Cretaceous rocks. The coal beds, however, do not appear to be nearly as thick or as extensive as those on the north side of the range, though possibly this is due to less extensive surveys, for farther south, in the vicinity of Nulato, where rocks of this age have been more carefully studied, there are a number of coal beds at different places that have been locally developed in the past. Within the area specifically described in this report none of the coal beds in rocks of Upper Cretaceous age have been commercially developed. The nearest place at which some coal has been dug for local use is at Tramway Bar, on the South Fork of the Koyukuk about 30 miles northeast of the town of Bettles. At this place Schrader[9] reported a bed of coal nearly 12 feet thick. The central 9 to 10 feet of this bed is said to be nearly pure coal. An analysis of this coal made by George Steiger (laboratory No. 187) showed the following results: Moisture, 4.47 per cent; volatile matter, 34.32; fixed carbon, 48.26; ash, 12.95; fuel ratio,

[9] Schrader, F. C., Preliminary report on a reconnaissance along the Chandalar and Koyukuk Rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 485, 1900.

1.40. The ash content appears excessively high, but otherwise this coal resembles fairly closely the coals from the Wainwright region.

Schrader[10] also noted the occurrence of considerable coal float on the lower part of the John River. He says:

> Coal detritus in considerable quantity and of a character to suggest the probable occurrence of coal of economic value somewhere in the region north of this locality was seen in the John River gravels near the base of the Endicott Mountains. This coal may apparently with safety be called a good grade of bituminous. It breaks with a conchoidal fracture and has a bright shiny or glossy black surface.

Obviously there is no certainty of the source of this float, but as no other rocks that are coal bearing are known on the John River it seems probable that the float came from the Upper Cretaceous, though the possibility that it came from unrecognized Mississippian beds on that river similar to those that are known to be coal bearing in the Cape Lisburne region should not be dismissed without further investigation.

Some coal of lignitic appearance was observed in the sandstone of the Lockwood Hills near the Pah River, and coal float has also been reported on the lower part of the Ambler and on the Kogoluktuk. The coal in the Lockwood Hills almost certainly came from the rocks mapped as Upper Cretaceous. The coal float on the Ambler may have come from either the supposed Tertiary rocks that are mapped in the valley of that stream some distance north of the Kobuk or from the rocks mapped as Upper Cretaceous that crop out south of the Kobuk. No coal-bearing rocks have been mapped as occurring on the Kogoluktuk, but possibly the Tertiary coal-bearing series may extend eastward from the upper locality on the Ambler along this lowland north of the Cosmos Hills as far as the Kogoluktuk. Whatever may be the source of this float it seems certain that no extensive coal beds occur in any of these places, and though it is entirely possible that beds of coal may be discovered the coal will be of relatively little use except to supply local needs.

SUMMARY

From the foregoing statements it is evident that the rocks that are mapped as Upper Cretaceous contain numerous widely distributed coal beds, most of which are of at least subbituminous quality. Too little is yet known about the coal beds in these rocks south of the Brooks Range to permit statements as to their commercial possibilities. In the two regions north of the Brooks Range where these coals have been measured most accurately—near Corwin and on the Kukpowruk—a tremendous amount of coal is indicated. In

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[10] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 107, 1904.

the measured sections near Corwin are 34 coal beds that represent an aggregate thickness of more than 135 feet of coal, and 15 of these beds, each 3 feet or more thick and the largest 30 feet thick, represent 115 feet of coal. In the Kukpowruk-Utukok section 69 beds were measured each of which is at least 3 feet thick and the largest 20 feet thick. After eliminating duplication these beds represent a total of 187 feet of coal. Although not nearly as great thicknesses were recognized in other parts of the field, this was probably due in large part not to the absence of the coals but rather to the lack of good exposures and of time in which to examine carefully all the available field evidence. There is, therefore, a more or less rectangular tract of country north of the Brooks Range, at least 300 miles long east and west and having in places a width of as much as 120 miles, in which coal can be found almost anywhere at or within a short distance of the surface. In the northern part of this tract the structure is rather simple, consisting of broad gentle warping, but farther south the beds are more closely folded and dips as steep as 90° have been observed. The coals in the different parts of the region have been affected by the different amounts of folding, and their quality and heating value seem to bear a more or less close relationship to these conditions. Thus, in the slightly folded parts of the region the coals seem less compacted, their fuel ratio is lower, and their heating value is less than in the more closely folded areas.

Doubtless in the areas of strong folding the coal beds may show squeezing and some breaking, but so far as could be judged from the meager surface exposures, the coals as a whole have not been badly broken, and faults of considerable throw appear to be rare. The physical conditions for mining therefore seem to be favorable, and relatively little difficulty and expense should be incurred in tracing the beds and planning the methods of development. The actual expense of mining, however, will necessarily be high compared with that in more accessible regions with more inviting climates, where supplies and equipment are more readily at hand.

Unfortunately, throughout most of northwestern Alaska the higher grades of these coals are in the least accessible localities, so that they will be especially expensive to develop, and whether their quality is enough better to offset the extra cost can not be determined until more data are available. Fortunately, some of the better coals are exposed close to the seacoast in the western part of the field, so that as relatively inexpensive transportation by vessel is available to them, doubtless they will be among the first to be developed. Even there, however, as has already been pointed out, costs will be high, and until a suitable market demand exists sound economic policy does not appear to justify any extensive development of these coals in the near future except to supply purely local needs.

TERTIARY COAL DEPOSITS

Tertiary coal deposits have been recognized in northwestern Alaska only in the Kobuk Valley, though some of the beds that are here correlated with the Upper Cretaceous have been considered Tertiary by others and perhaps if fuller information were available might prove to be of that age. The only place where definitely recognized Tertiary coal has been mined is on the Kobuk a short distance below the Kallarichuk River. This is apparently the place concerning which Stoney [11] wrote:

On my second trip to the Putnam [Kobuk] I discovered a vein of bituminous coal outcropping on the north side of the river about 90 miles from the mouth. I tried a lot of it in the furnace of the steam launch, with very satisfactory results, though it had long been exposed to the weather. The vein was between 2 and 3 feet thick and dipped at an angle of 30° from the river.

This same coal was apparently also recognized by Cantwell, but his conclusions regarding its use did not confirm Stoney's, as he found that it was not satisfactory for use on his launch.

This locality was examined by Mendenhall in 1901, and his description of the occurrence [12] is as follows:

The coals occur in low bluffs along the river, interbedded with conglomerates and fire clays. Those sufficiently well exposed for examination are of poor quality and burn slowly, yielding abundant ash and the disagreeable gases which are characteristic of impure lignites. So far as determined none of the coals outcropping here are more than 2 to 3 feet in thickness, and the majority of the seams are much thinner. Half a dozen with a thickness of 6 to 8 inches were examined during the reconnaissance.

A sample of coal from this locality was submitted to the Bureau of Mines for analysis with the following results:

Analysis of coal from Kobuk River

[No. 793; laboratory No. 11097, Nov. 3, 1910. A. C. Fieldner, chemist. Air-drying loss, 2.40]

	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Heating value	
						Calories	British thermal units
As received	10.50	28.95	52.94	7.61	0.41	5,852	10,534
Air-dried	8.30	29.66	54.24	7.80	.42	5,996	10,792
Moisture-free		32.35	59.15	8.50	.46	6,538	11,534
Moisture and ash free		35.36	64.64		.50	7,145	12,861

It is evident from these analyses that this coal compares favorably in heating value with certain of the Upper Cretaceous coals above described—for instance, those in the vicinity of Wainwright—and is

[11] Stoney, G. M., Naval explorations in Alaska, p. 80, 1900.

[12] Mendenhall, W. C., Reconnaissance from Fort Hamlin to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, p. 49, 1902.

not much inferior to several of the coals from the vicinity of Corwin that have been analyzed, though it is poorer than some of the better beds from the Corwin locality or than certain of the beds in the Kukpowruk region.

The coal on the Kobuk near the Kallarichuk is rather fortunately placed for local use, as it lies over a low divide and only a short distance from some of the placer-mining operations that were active in the Squirrel River region. Consequently, for a time a small amount of the coal was mined and carried to these plants. In fact, a few sacks of it have even been carried up the Kobuk as far as Shungnak, as it is said to be especially good for blacksmithing. The extent of this field is probably so small and the cost of mining and transporting the coal so great that except for favorable markets in the immediate neighborhood of the coal beds the coal has little commercial value.

GOLD PLACERS

GENERAL DISTRIBUTION

All the investigations by the recent expeditions of the Geological Survey in northwestern Alaska have been directed primarily toward the study of the oil resources of that region. Inasmuch as the areas in which oil is likely to occur are dissimilar from those in which most metallic mineral deposits of value are likely to occur, few new data regarding these deposits were obtained. However, in going to and from the region and in the previous expeditions that had traversed parts of northwestern Alaska data have been obtained relating to some of the places where other kinds of mineral deposits have been mined and the general conditions under which they occur. For the sake of making this report complete it has seemed desirable to include in it notes of the other known mineral resources, even though little new information is available and some of the data are taken from reports prepared many years ago and therefore do not adequately represent current conditions of mining.

Placer gold was the mineral resource of first importance in bringing about the exploitation and settlement of parts of the Kobuk and Koyukuk Valleys, and it is still the only mineral of value that is being produced in most of the region described in this report. Even before the great gold rush to Alaska began gold had been known in the Kobuk Valley, for Stoney[13] states that on his second trip to that region in 1885 an old prospector went with him on some of his trips and "he invariably found traces of the precious metal, more in some places than in others, and would show me the 'color,' as he called it, which consisted of specks of fine gold."

[13] Stoney, G. M., op. cit., p. 80.

The first rush of gold seekers in 1898 brought thousands of men into the Kobuk and Koyukuk Valleys. Grinnell[14] notes that in 1898 12 steamers were running on the Kobuk, and he estimates that in that year 800 men were living in various parts of the valley. He lists 28 distinct named camps between the mouth of the Kobuk and the Pah River. Many of the placers then discovered still continue to be mined and to yield gold. In recent years, however, gold mining has decreased so much that, so far as known, the only places where any productive mining is being carried on within the area covered by this report are in the Kobuk Valley, though there are extensive gold deposits still being mined in the Koyukuk Valley both east and south of the region here described. Within this region gold has been found in many places in the Kobuk Valley, in the included portions of the Koyukuk Valley and its tributaries, and on the Noatak.

KOBUK VALLEY

SHUNGNAK REGION

In the Kobuk Valley there are two main areas where gold placers have been mined. These are in the general vicinity of Shungnak, in the central or eastern part of the valley, and in the vicinity of Squirrel River, in the western part. No accurate statistics as to the amount of gold that has been produced from this region are available, but it seems likely that the production for the entire period that mining has been in progress has not exceeded $200,000.

In the Shungnak region the principal development work has been done a few miles north of the main river in the valleys of some of the tributaries, such as the Shungnak River and Dahl Creek, and on Riley and California Creeks, which are tributaries of the Kogoluktuk River, especially in those parts of their courses where the streams are flowing in or across the Cosmos Hills. The placers on the streams near Shungnak were described by Smith[15] in 1913 as follows:

SHUNGNAK RIVER

Placer mining on Shungnak River has been carried on for a mile or so below the narrow canyon by which this stream traverses the Cosmos Hills. Work has been in progress here during the open season almost uninterruptedly since 1898. Only two or three parties of three or four men each have attempted mining during any year, and in 1910 only one placer camp of one white man and two or three natives was in operation. The use of native labor is an interesting experiment, and, although it is reported that white men can do more work, the wages paid the natives (about $4 a day and board) are so much lower that the difference in efficiency is compensated for.

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[14] Grinnell, Joseph, Gold hunting in Alaska, pp. 31–32, Chicago, D. C. Cook Publishing Co., 1901.

[15] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 126–132, 1913.

Bedrock in the productive part of the river is mainly black slate and schist, but other sedimentary and igneous rocks occur at no considerable distance from the placers. Limestones occur near the head or northern end of the canyon but are not closely associated with the deposits of auriferous alluvium. The igneous rocks near the placer mines are composed mainly of serpentine with scattered particles of magnetite and are of a dark-green color. These rocks have been sometimes mistaken for jade, and it is probably owing to this error that the whites have reported the name "Shungnak" to mean "jade" in the native language.

Most of the mining has been done near the southern face of the Cosmos Hills, where small flats permit turning the stream aside by wing dams. The gravels mined are usually shallow. The upper 2 feet or so is stripped off, and the lower part only is put through the sluice boxes. The overburden is made up of typical river gravels with some large boulders irregularly distributed throughout. It is not known whether the valley of Shungnak River through the Cosmos Hills was at one time occupied by ice, but it is certain that glacially eroded and transported boulders have been brought in by glaciofluviatile action and form part of the reworked material of the unconsolidated deposits.

The pay gravels are rather irregularly distributed, and mining therefore has been in the nature of pocket hunting in those places where the water could be handled. The gravels are unfrozen, and in a measure this is a disadvantage, as much water seeps into the pits. During high water the miners are sometimes driven out of the workings. The gold is found in the lower part of the unconsolidated deposits and in the crevices of bedrock, especially where it is black slate.

Most of the gold found in the placers of the Shungnak is in small pieces worth from one-half cent to 3 cents, but nuggets worth up to about $40 have been found, although they are by no means numerous. The gold is reddish, and although not rusty is not bright and shiny but has a dead luster. Its assay value is reported to be $16.70 an ounce. The form of the gold is very characteristic and is distinct from that of the gold from any other part of the Shungnak region. The little pieces look like shot that have been flattened under the hammer, and this form is sometimes spoken of by the prospectors as "pumpkin seed" gold.

Magnetite is by far the most abundant mineral among the concentrates collected with the gold and is probably derived from the basic intrusive dikes which cut the metamorphic rocks. Garnet, or so-called "ruby," is almost entirely absent from the gravels. Small nuggets of copper and also of silver are sometimes found in the sluice boxes. Some of the silver nuggets are nearly an inch in diameter and contain but very small amounts of other metals as impurities. No clue as to the origin of the silver was obtained, but the copper nuggets were probably derived from the copper sulphide impregnated zone near the limestone-schist contact.

DAHL CREEK

Dahl Creek is a stream 8 miles long, the lower 3 miles or so of its course being through the Kobuk lowland, the middle 2 to 3 miles in a narrow rocky gorge, and the upper mile or two in a rather open valley. The placers that have been worked are located near the southern face of the Cosmos Hills and in the central part of the valley, where the junction of three small streams with Dahl Creek has made a small flat. * * *

The bedrock under the unconsolidated deposits here is black slate and schist with numerous small veins of quartz and in places some sulphide mineralization. The bedrock breaks into rectangular blocks of small size, and the joint faces are commonly iron-stained. The dominant strike is across the creek, and thus the rocks make good riffles for catching the gold. The slope of the bedrock surface is rather low, so that some difficulty is experienced in disposing of the tailings from mining. Near the lower group of claims schistose conglomerate outcrops but does not form bedrock under the productive placers. Limestone occurs near the placer ground in the middle part of Dahl Creek, but although float from this rock is found in the gravels it does not come down as far as the creek and does not form any of the surface on which gravel accumulation took place. Igneous rocks of a dense texture and greenish, glassy color were noted upstream from the placers, but though these rocks have furnished many of the boulders in the placers, they do not seem to have been connected with the mineralization and did not contribute valuable minerals to the placers.

Only the creek gravels have been mined on Dahl Creek. These average about 4 feet thick. In some places their thickness is only a foot or so, but in others it is as much as 8 feet. Holes sunk on some of the low benches on either side of the stream have shown unconsolidated deposits 15 feet thick. Practically none of the stream gravels are permanently frozen, but some of the low benches that have been prospected are reported to be in that condition.

The gravels in the productive placers are of the normal creek type, consisting of well-rounded pebbles with only a small amount of muck. Large, somewhat angular boulders, most of which are of local derivation, are numerous in the gravels and cause a good deal of trouble in the mining operations. One of these large boulders a short distance below the placers, near the southern face of the Cosmos Hills, measured 14 feet in length. It was made of the sheared conglomerate and had not been transported far. Many smaller boulders occur directly in the pay gravels, however, and it has been necessary to blast them out of the way.

The pay gravels differ in no essential respect from the overburden. They are usually from 1 to 2 feet in thickness, and practically all the gold lies in and on the bedrock. The distribution of the auriferous gravels is very irregular, and it has been impossible to successfully trace any continuous pay streak. The gold occurs in pockets, which, when exhausted, give no clue as to their relation to other rich spots. Such a distribution seems to indicate that valuable minerals were either laid down more or less evenly and then dispersed by a change in the discharge of the creek or else that the gold was originally deposited by a stream having strong variations in transporting ability.

Owing to the irregular distribution of the gold the value per cubic yard is of almost no significance. When a rich spot is found several hundred dollars may be taken out in a few days, but at other times only a dollar or so a day can be made. * * *

The gold examined from the upstream group of placers was reddish to brass-yellow in color. The pieces were small, and some were distinctly spongy and had fairly sharp outlines, as though they had not been transported far from their place of origin. Some wire gold was also seen but was notably rare. Nuggets of considerable size have also been found in this part of Dahl Creek. One of these was seen that had a gold content worth about $65. It was a fairly well-worn piece and had a considerable amount of greasy-looking milky quartz attached. In 1911 a large flat piece of gold worth over $600 was found near this place. Assays are reported to have shown the gold to be worth about $16.20 an ounce.

Among the concentrates from Dahl Creek placers magnetite is the most abundant mineral. There is also a small amount of chromite, some of the pieces being a foot or so in diameter. Garnets are almost entirely absent. The occurrence of native silver in the concentrates has been reported, and pieces nearly an inch in diameter have been examined. The silver seems to be particularly free from admixture with other metallic minerals, such as copper or lead; a small amount of cadmium, however, was recognized by blowpipe examination. No evidence was secured as to the source from which the silver was derived.

Mining is carried on by pick-and-shovel methods, and the gold is won by passing the gravels through sluice boxes of whipsawed lumber. * * *

From the physical features of the gold and the distribution and other characters of the auriferous alluvium it seems probable that the gold has been derived from places within the Dahl Creek Basin, especially from the areas occupied by the black slates and schists. It is believed that the source of the mineralization is the quartz veins, which are so abundant in this formation.

Some prospect holes have been sunk near Dahl Creek close to the southern front of the Cosmos Hills or the northern margin of the Kobuk lowland. The returns have, however, been insufficient to warrant development, and the holes have been allowed to cave, so that it was impossible to examine a section of the gravels. It was reported by prospectors that the bedrock surface slopes southward at a high angle below the lower cabins, so that shafts even 40 feet deep failed to reach bedrock. In this lower part of Dahl Creek the stream flows through the unconsolidated deposits of the Kobuk lowland. The absence of any shallow placers in this part of its course seems to indicate that the upper part of the gravels of the lowland area does not contain sufficient gold to form economic deposits where subjected to the sorting of such streams as Dahl Creek.

KOGOLUKTUK RIVER

Sparsely disseminated colors of gold have been reported from many parts of the Kogoluktuk Basin, but the only stream on which placers have been mined is Riley Creek. This is a tributary from the west, heading against the Dahl Creek divide, and flowing first north, then east, to join the Kogoluktuk.

The placers occur in a region of black slates, limestones, and a few intrusive igneous rocks. The bedrock is similar to that of the placers on Dahl Creek, except that limestones are much more numerous. Evidences of deformation and dislocation are pronounced, and the stratigraphic succession of the rocks has not been determined. Quartz veins in the black slates that form the bedrock under the ground that has been worked are particularly numerous and are believed to be closely associated w.th the formation of the productive placers.

In the placers typical stream gravels are practically absent. Sections show angular slide and slightly worn unconsolidated deposits of local origin in which are irregularly distributed boulders from outside basins. Most of these foreign boulders are of large size and are mainly of igneous rocks belonging to the greenstones and associated types. They are usually well worn and probably have been brought into their present position by the combined action of ice and water during the closing stages of the glaciation of the lowland north of the Cosmos Hills. Although these greenstone boulders are found in the placers, they are in no way connected with the origin of the gold, and their distribution, except as marking former glaciofluviatile conditions, is of no economic signficance.

The gold occurs mainly in the crevices of the bedrock and in the angular unconsolidated material lying on top of the bedrock. In the part of the deposit that is mined large boulders are less numerous than in the upper 2 or 3 feet, but there are many boulders even in the pay streak. The whole character of the material in which the gold is found is more like that of residual placers than of ordinary creek placers.

The slight amount of transportation that the auriferous material has undergone is also indicated by the shape and quality of the gold. Practically all the pieces examined were sharp and angular, and many had small particles of quartz attached. No large nuggets have been reported from these claims. Pieces worth up to 50 cents were seen, and a few worth as much as $2 and $3 were reported. The gold was bright, and in an average sample the pieces were worth from one-tenth cent to 2 cents each. The individual particles are spongy and consequently appear to one used to the usual run of placer gold to be worth much more than is actually the case. The precise assay value of the gold was not learned, but it was understood to be about $16.25 an ounce.

The Riley Creek placers that have been worked seem to derive their gold content from the rocks exposed in the immediate vicinity. They are so situated that they have no adequate water supply, and boulders are so numerous that the placer can be developed only at great expense. Farther downstream, where the water supply might more nearly meet the demands, the presence of thicker overlying deposits and large boulders is to be expected. The absence of especially effective sorting in this part of the basin suggests that placers will be of distinctly local importance. The whole Kogoluktuk Basin, so far as indicated by the conditions on Riley Creek, seems to promise only localized placers of irregular distribution, workable as pockets rather than as extensive deposits.

Within the last few years the only new placer-mining activity of significance in the Shungnak region has been the hydraulicking of ground on California Creek, a tributary of the Kogoluktuk. At this place a ditch several miles long has been constructed and more than 1,000 feet of pipe laid to conduct the water to the ground to be mined. The operators are considerably hampered by the abundance of large boulders, which are found in the deposits all the way from the surface to bedrock and are presumably of glacial origin. The character and distribution of the gold, however, are such as to encourage continuation of mining, though the costs are high.

OTHER LOCALITIES

Mendenhall[16] notes that natives report a little gold on a small stream entering the valley of Lake Selby from the east. As the geology of this region appears to be similar to that in the better-known Shungnak region, there is every reason to believe that gold occurs there, as well as in other parts of the valley.

SQUIRREL RIVER REGION

The placer developments in the vicinity of the Squirrel River have been even less extensive than those near Shungnak. It is understood, however, that within the last few years a project has been under way to prospect this region thoroughly with a drill in order to determine whether more extensive operations would be profitable. The placers

[16] Mendenhall, W. C., manuscript notes.

in the Squirrel River Valley were not exploited to any notable extent until about 1908, and by 1911 the rush occasioned by their reported promise had subsided so much that little productive work was in

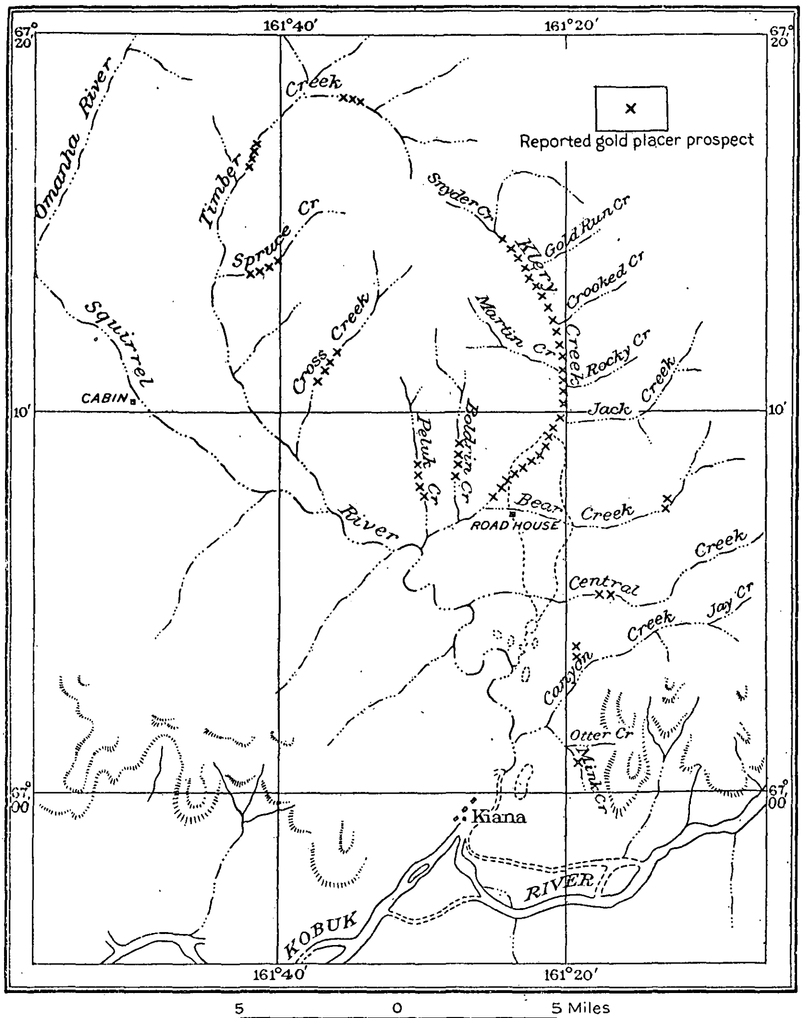

FIGURE 22.—Sketch map of placers in southeastern part of Squirrel River Valley

progress. A sketch map that has been compiled largely from the reports of prospectors and may be considerably in error as regards scale and details is shown in Figure 22.

The general facts and inferences regarding these placers were stated by Smith [17] in 1913 as follows:

The developments in the Squirrel River region have been small, and although gold prospects are said to have been found on eight to ten tributaries, when

[17] Smith, P. S., op. cit., pp. 133–139.

the region was visited in 1910 mining was in progress on only one of the streams, namely, Klery Creek. That this is the only place where productive placer exists is improbable, for conditions analogous to those on Klery Creek are reported at several other places in the Squirrel River Basin. With further prospecting other valuable placers will undoubtedly be found. * * *

CREEK PLACERS

The most active work [on Klery Creek] was in progress near the mouth of a small tributary, Jack Creek, a short distance above the Discovery claim. At this place there is a rock-cut gorge with a gravel-covered floor about 150 yards wide. On this floor the stream formerly followed the eastern side, but in order to allow mining the stream was turned to the other side by a roughly constructed dam. Owing to the exceptionally rainy season of 1910 the stream was abnormally high, and three times during the summer the dams were completely washed away by the floods, some of the sluice boxes with the gold in them being recovered only with difficulty. The upper 12 to 18 inches of gravel in the bed where the stream has been turned aside is removed by shoveling, and the larger boulders are either rolled behind the miners onto worked-out ground or are pulled out of the way by a team of horses. This stripping is done rapidly and is carried down to a point where the gravels show some "sediment" or fine mud that coats the well water-rounded pebbles and fills the interstices. None of this surface material is put through the sluice boxes, as repeated experiment has shown that it contains practically no gold. Between the upper foot or foot and a half of gravel that is stripped off and bedrock is a foot to a foot and a half of gravel in which gold is obtained. These gravels are typical river wash but have been less recently handled by the stream than those above them. The lower gravels, together with the upper 6 inches to 1 foot of disintegrated bedrock, are put through the sluice boxes, and it is from them that the gold is won.

Bedrock on this claim is mostly schist, but on the lower end of the claim and continuing downstream on the next adjacent claim is a massive, much fractured, and contorted bluish-white limestone standing at a high angle and cutting the creek transversely. The schist shows many different phases on the working claim. In part it is a dark graphitic slaty schist with numerous small veins and stringers of quartz. The bands of this schist are not more than a few feet in thickness and are interlaminated with somewhat calcareous and quartzose schists, some of which are rusty yellow in color owing to the decomposition of some of their constituents. The iron mineral from which this limonite had been derived could not be determined, but it was probably in part pyrite. In at least one place on the claim a narrow band of limestone interlaminated with the schist was seen. From this description of the bedrock it is evident that lithologically the rocks are similar to those in the richer parts of the Nome region, in the Iron Creek Basin, in the Kougarok, on Ophir and Melsing Creeks near Council, in the Solomon and Casadepaga regions, and near Bluff. This resemblance is further strengthened by the relation of the schists to the heavy bluish-white limestones at all these places.

Several hundred ounces of gold from this claim were examined, and the coarseness of the pieces was remarkable. Practically no fine gold was found, and few if any pieces of the gold recovered were worth less than one-half cent. Several nuggets worth $25 to $50 have been found, and while the writer was on the ground one nugget weighing nearly 7 ounces and worth about $125 was picked up in the gravel. In form the gold from this claim is chunky or in nuggets, but a little wire gold was also seen, though no flaky or scaly gold was observed. The gold is dark but almost never black and shows few signs of recent movement. Although some of the corners have been rounded, it does not in general appear to have traveled far. In fact, many pieces are sharp and angular as though but recently unlocked from the parent ledge. Some of the nuggets have pieces of the country rock still adhering to them. The most abundant mineral attached to the gold is quartz of the same physical aspect as the quartz in the strings and lenses in the schist. Black graphitic slaty schist is also attached to the gold in some of the specimens, and the way in which the gold forms filaments in this rock shows indisputably that some of the placer gold has been derived from this kind of country rock.

Estimates of the productiveness of this ground are of small value, for the nuggety character of the gold makes the tenor range between wide limits. It is reported that over 190 ounces were cleaned up from about six box lengths shortly before the visit by the Survey geologist. At the time of the writer's visit a clean-up of 120 ounces was made from about 4½ box lengths. This is equal to a bedrock surface of about 500 square feet, so the production from this cut was nearly $4.50 per square foot of bedrock. * * *

The width of the pay streak is not known, for when the claim was visited all the work had been done only on the eastern side, and the western margin of the productive ground had not been reached.

Water for sluicing is obtained from Klery Creek by running a hydraulic hose, several hundred feet upstream and bringing down the water thus obtained on as flat a grade as can be maintained. This supply, however, does not furnish an adequate head, so that some other method will have to be tried. But slight difficulty should be experienced in obtaining a satisfactory supply, as the volume is ample for the present demands. No accurate measurements of the volume of Klery Creek were made, but the fact that a crossing, even on a riffle, could not be made in less than 2½ feet of water. in a current of such speed that care had to be taken in keeping one's feet, shows that several thousand miner's inches are probably available during a season such as 1910. It should be noted, however, that that year was abnormally wet, and estimates based on observations during that time are undoubtedly above the average.

Few assays have been made of gold from this claim, but on a sample submitted to the assayer of the Nome Bank & Trust Co. a fineness of 0.888½ was determined. This would give a value of $18.37 an ounce.

In the concentrates collected with the gold in the sluice boxes magnetite is the most abundant mineral. This forms a much larger proportion of the concentrates than it does around Nome. Together with the magnetite is also some ilmenite and a little pyrite and limonite. These iron minerals are probably derived mainly from the greenstones and greenstone schists, although the pyrite and its accompanying limonite may have come from veins in the schists or from the vicinity of the limestone-schist contact, a place commonly mineralized in other regions. Garnet or so-called ruby, common in the concentrates from Seward Peninsula, is relatively rare and forms but a small proportion of the black sand. This mineral is absent in the adjacent schists derived from igneous and sedimentary rocks. None of the rare heavy minerals so far have been recognized in the concentrates.

About 1¼ miles upstream from this claim is another claim where gold similar in physical character has been found. Work on this ground has been carried on by a crew of only four men and consisted mainly in dam building and bringing up a bedrock drain, so that only a small production had been made, and the opportunity of examining a large amount of gold was not afforded. It seems certain, however, that the gold from this claim is of the same chunky character as on the lower claim, although the proportion of fine gold is larger, and the nuggets, as a rule, weigh less. From the shape of the gold it is believed that it has been derived from near-by sources and has not traveled far.

Midway between these two claims the gold is of an entirely different character, although the general geology shows no marked change, except that the limestone is more remote, and the canyon character of the valley is more pronounced. The gold from this claim is practically all in fine bright scales. No nuggets worth more than a few cents each have been recovered, though several hundred dollars' worth of gold has been won. The scales are all more or less of the same size, no flour gold being seen. All of the flakes are of a bright gold color with no tarnished nor black coating. No pieces with quartz or other foreign material attached were seen. This gold was of the type locally known to the miners as "bar" gold and showed by its physical characters that it has traveled much farther from the ledge from which it was derived than that found either upstream or downstream from this place.

Gold similar to this "bar" gold has also been found downstream from the first-described claim. It is identical in all essential respects with the one just described and has probably had a similar history. The fact that this gold has traveled farther from its parent ledge is indicated by its higher assay value. It is not possible to give the precise assay value, for the sample that was tested was mixed with nugget gold taken from one of the claims farther upstream. This mixed sample, however, showed a higher gold tenor than the nugget gold previously quoted as worth $18.37 an ounce, so the difference is probably to be assigned to the greater fineness of the "bar" gold.

The distribution of the gold and the difference in the physical characters presented by this mineral from the several claims in this stretch of about 2 miles present problems of economic importance. It is believed that the coarse nuggety gold on the two claims has been derived from near-by areas of bedrock and has not traveled far from its source of formation. Possibly concentration had been effected in earlier stages of the valley development, and the gold was subsequently reconcentrated in the present streams, but the movement by this process must have been relatively slight. On the other hand, the fine flaky gold found downstream from the areas of coarse gold seems to represent the smaller, lighter particles which, because of their size, have been carried farther from their source. Such an interpretation is analogous to the well-known distribution of gold in a sluice box, where the larger, heavier particles are found toward the head end of the box and the smaller, lighter pieces near the foot or discharge end. According to this explanation there are several localities of mineralization cut by Klery Creek, each being more or less close to the areas of heavy gold, whereas in the intermediate regions the stream has not been so close to regions of as great mineralization and the gold has been derived from the areas upstream.

Too little is known about the region to determine beyond question whether the mineralization is confined to a single zone or whether there are a great number of these mineralized zones, but from the number of places where gold has been reported in the Squirrel River Basin it seems probable that there are at least several and possibly many zones of mineralization. Further study of this important question is necessary, for it affects the future of the region. Not only is it important in determining the probable area in which gold placers may be expected, but the information is also valuable in determining the trends of the placer ground. From the experience in Seward Peninsula it is believed that the contact of the heavy limestone and the graphitic or quartzose schists is one of the most favorable localities for searching for placer deposits in this group of rocks. This experience seems to be borne out in part by the work on Squirrel River, for the richest claim so far discovered has been near this contact. That there are other places where mineralization has been pronounced can not be doubted, and the prospector should therefore not place undue emphasis on the above suggestion.

BENCH AND DEEP GRAVELS

So far only the shallow creek gravels in the stream beds have been exploited. There are, however, bench and high-level gravels in this region, as well as the broad fillings of the main stream valleys, which are possible sources of mineral wealth. None of these older gravels have been prospected as yet, and therefore suggestions as to their probable value or character are tentative and subject to revision when more information is obtained. The lower benches already noted as occurring at several different elevations above the tributary streams, such as Klery Creek, seem to have had essentially the same method of formation as the known auriferous creek gravels. It is therefore believed that in the neighborhood of bedrock mineralization these benches will be productive of placer gold. Most of the benches of this character on Klery Creek had but small length or breadth, so that only discontinuous deposits resulted. Such benches, however, may afford rich pockets of auriferous gravel which would well repay exploitation. Many of the benches seem to be covered with muck and turf, which fact suggests that the gravels will be frozen and require thawing apparatus.

The higher gravels, which are of wide extent and cover not only the lower slopes of the Squirrel River Basin but also extend both up and down the stream along the Kobuk, present problems that are much more difficult to interpret. The origin of these gravels can be solved only by a general survey of a large area in the lower part of the Kobuk Valley, supplemented by numerous good sections of the deposits by means of prospect shafts. The character and distribution of these high-level gravels strongly suggest that they have not been formed by normal fluviatile action. There is a possibility that they may mark marine deposition, but it seems more probable that they are the outwash deposits from ancient glaciers which at one time occupied the more eastern part of the Kobuk Valley. If this interpretation is correct, there is small probability that economically profitable placers will be found in these gravels. Although outwash deposits may contain gold, it is believed that normally the valuable minerals are so disseminated that, except under conditions of subsequent concentration, the valuable minerals can not be profitably extracted. These high-gravel plain deposits consist largely of rolled quartz pebbles. No striated fragments or other marks of direct glaciation were observed. The condition of these gravels with respect to frost is not known. As a rule, gravel deposits at any considerable elevation above the adjacent streams are so well drained that they are not permanently frozen. At several places where these gravels are exposed in the valley walls of the tributary streams there are indications that they are not frozen. These places, however, are not conclusive as to the conditions of the gravels in the intermediate area between two streams, where the gravels are not exposed to the light and air and where the ground-water level rises so that the gravels are not as well drained. From the character of the surface in some of these less well-drained areas it seems certain that permanently frozen ground will be encountered.

No prospecting of the deeper gravels that form part of the flood plain of the main Squirrel River has been done, so that no definite information as to the presence of placer ground is available. It is understood that prospectors have found colors of gold on many of the bars and in shallow holes which did not reach bedrock. The ground was frozen, and the necessary machinery for exploring the deposits was not at hand, so that the deep ground was abandoned for the more easily worked shallow creek diggings. From the experience on Seward Peninsula it seems questionable whether important placer gold deposits will be discovered in these flats. It should be reiterated, however, that the data for basing a decision are inadequate, and the above suggestion is little better than a guess, warranted only by the desire to prevent the reckless expenditure of time and money on ill-considered projects.

NOATAK VALLEY

During the gold rush of 1898 some prospectors overflowed into the headwaters of the Noatak Valley, and others attempted to ascend the river from its mouth. A little gold was obtained, and stories of fabulous finds whose locations have been mysteriously forgotten are still occasionally heard, but no mining work has been in progress in this valley for more than a score of years. In 1911 a party of three prospectors were looking over the headwater region in the hope of finding sufficiently promising ground to warrant further work, but the results were apparently unsatisfactory, for no work was undertaken. There are two principal areas where placer gold has been reported. These are in the vicinity of Lucky Six Creek, near the head of the valley, and on Midas Creek, farther downstream. The general conditions on Lucky Six Creek were described by Smith [18] in 1913 as follows:

LUCKY SIX REGION

Gold was discovered in this stream [Lucky Six Creek] in 1898, and from time to time since then small parties of prospectors have visited the region. This place is so inaccessible, however, that the miners have spent only a few days there. Not only is the region inaccessible, but it is also difficult to prospect for lack of timber. It is reported that the planks used for making sluice boxes were whipsawed by hand on Reed River, of the Kobuk Basin, nearly 30 miles away, and were hauled by dogs and men to Lucky Six.

The Lucky Six Basin was not surveyed, but the general geology was learned from a study of the stream to the north. This creek, known as Twelvemile Creek, is not more than 10 or 12 miles long. For half a mile or so above the mouth the stream meanders on the outwash gravel plain of the main Noatak. Farther up the stream enters the hills and the river lies in a narrow, precipitous gorge incised in bedrock and early glacial deposits. In this part the creek is not more than 50 feet wide, even during times of high water, but it is a roaring torrent with its bed full of huge boulders that make crossing diffi-

[18] Smith, P. S., op. cit., pp. 140–141.

cult. Still farther up the gradient of the valley decreases, but in the head-water regions the slope again increases.

Geologically the Lucky Six region presents many problems. Various kinds of rocks occur in intricate relations. The larger part of the bedrock appears to have originally been a sediment that was subsequently metamorphosed. No masses of the granite were seen in place, though dikes were reported by prospectors and may exist in the more remote parts of the valley that were not explored. Limestones form a considerable part of the divide north of Twelve-mile Creek and appear to have a general east-west trend. The direction of the structure in the schists, however, is not constant, though it, too, appears to strike east and west and to dip north.

Gravel and partly rounded morainic material extend to an elevation of 1,200 feet above the creek, or 3,600 feet above the sea, but it is not in this material that the gold values are reported to have been found. Instead, the gold is said to occur only in the cracks and crevices of the bedrock in the creek or in the very shallow present-day creek gravels. All the gold is said to be notable for its coarse size and the absence of fine flaky pieces. It is described as shaped like "pumpkin seeds," has a reddish color, and assays about $19.20 an ounce.[19]

MIDAS CREEK REGION

Near Midas Creek some gold was found by prospectors in 1904. The gold was reported to have been found in small particles, all of which were rather well worn. The occurrence at this place was described by Smith [20] as follows:

> It seems that much disseminated gold in fine particles was found in the creek and ancient gravels of the Noatak, both north and south of the river but that the gravels of the tributaries of Midas Creek that are derived entirely from the hills north of the camp of August 2 are not auriferous. From the geologic study of the rocks forming these hills it is believed that they are younger than the metamorphic schists and belong to the group called in this report the Noatak sandstone. The older rocks that are more likely to be mineralized apparently form the bedrock to the south and underlie those forming the hills in which Midas Creek rises. It is therefore believed that the gold reported to have come from Midas Creek was derived either from the older rocks forming the southern part of the basin or else that it may have come from the outwash gravels which have been transported for long distances. These ancient gravels have been recognized up to an elevation of 850 feet above the mouth of Midas Creek, and they are believed to have been mainly of glaciofluviatile origin.
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> Some prospecting has also been done south of the Noatak opposite Midas Creek. Although it is reported that small colors of gold were found at many places, the abundance of large boulders in the streams makes prospecting difficult without numerous appliances not easily procurable in this remote region. The bedrock south of the Noatak at this place appears to be similar to that generally present in the better-known placer regions of the Seward Peninsula. Where the undifferentiated limestones form the hills, however, the probability of finding productive placers seems slight.

[19] Lloyd, L., unpublished letter.
[20] Smith, P. S., op. cit., p. 142.

KOYUKUK VALLEY

WILD RIVER

The principal placer region in the Koyukuk River Basin, from which between $2,500,000 and $3,000,000 in gold has been produced, lies east of the area described in this report, but many of the same geologic conditions which prevail there seem to continue into the mapped area. Gold has indeed been found on several of the tributary streams of the Koyukuk within this region, but no mining has been in progress recently on any of them except on the Wild and John Rivers. In the past some gold was also recovered from placers on the Alatna River and from some of the bars on the Koyukuk itself, and a little gold has been produced in the Hogatza Basin, a short distance south of the mapped area.

The occurrence of placer gold on the Wild River was described by Maddren[21] as follows:

> Wild River enters the Koyukuk from the north about 13 miles below the mouth of North Fork. Its valley lies between that of North Fork on the east and John River on the west, but it is not so long or large as either of these streams. It is probably not over 50 miles long in a direct north-south direction, but the main stream is very winding. The upper part of the valley crosses the gold-bearing schist belt from 30 to 40 miles north of Koyukuk River, and small amounts of gold have been mined from three creeks lying in the schist belt. The first one of these creeks in upstream order is Birch Creek, an east-side tributary from which about $10,000 worth of gold was mined during 1905-6. About 10 miles above Birch Creek the river flows from a lake, and on two small creeks that flow into this lake from the east some gold has been mined. The southern of these streams is called Lake Creek. In 1903-4 gold to the amount of $2,000 was taken from a claim on one of the headwater gulches. The gold was coarse, some of the nuggets ranging in value from $90 to $150. Spring Creek is the next stream above on the same side of the lake. The claim that has been mined is located about 1 mile from the lake. It yielded about $5,000 in 1907, but the summer of 1908 was so dry that there was not enough water available for advantageous work.

Some mining has been carried on in later years on this stream, and later discoveries on J Creek and elsewhere have been reported, but no late data of general significance have been obtained. It may be of interest, however, to note that samples of the concentrates from Lake Creek showed considerable scheelite among the more common mineral constituents, such as hematite, pyrite, and a little magnetite. It seems fairly certain that the gold in these placers was derived from quartz veins in the near-by schists, but no proof of the origin of the quartz veins has been obtained, and it is understood that no areas of igneous rock of the granitic type have been recognized in the vicinity of this valley. Considerable difficulty is reported in handling the large boulders that occur in or above the gold-bearing gravel.

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[21] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pp. 109-110, 1913.

JOHN RIVER

On the John River very little prospecting has been done, though it is currently reported that in 1924 there was renewed activity in prospecting on that stream, and a considerable hydraulic outfit was taken to claims in the lower part. Schrader[22] noted that "colors were obtained from gravels in the mouth of a small creek near the northern edge of the Totsen series" (the undifferentiated early Paleozoic or older rocks of this report), and Maddren[23] states that no gold-bearing deposits have been found north of that belt of rocks. He further states:

> Crevice Creek, which lies in these rocks on the east side of the river, and Fool Creek and its tributaries, on the west side, are the only streams on which encouraging prospects have been found up to this time (1913). About $1,800 worth of gold was mined on Crevice Creek in 1904, and good prospects were found on Midas Creek, a tributary of Fool Creek, in 1905, but these discoveries have not led to further development.

There is little reason to doubt that gold occurs in the central part of the valley of the John River. The physiographic history of the development of the valley and the physical conditions of its unconsolidated deposits, however, suggest that the gold is probably distinctly localized or spotted and rather difficult to develop economically without a considerable outlay of work and money.

ALATNA RIVER

The greatest activity in prospecting for placers on the Alatna River was shown during 1898 and shortly after that year, when the country-wide gold rush was at its height. Small amounts of gold were found in many places, and several boom camps, the largest of which were Beaver and Rapid City, sprang up, but they were soon abandoned, and by 1901 only a few prospectors remained in the valley. This condition prevailed in 1911, when Smith traversed the region, and in 1924 no miners were living in the valley. It is understood that now the valley is practically deserted except for a few natives. The area in which the most promising indications of gold were found lies between the mouth of Helpmejack Creek and a point 8 to 10 miles south of the Takahula River. In this tract the bedrock consists principally of schist cut by numerous quartz stringers. On Mecklenberg Creek, a small tributary of the Malamute River, which in turn is a tributary of the Alatna River, a prospector reported having found fine colors in the creek gravel lying on a schist bedrock. The prospect was not visited, and little

[22] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 101, 1904.

[23] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, p. 110, 1913.

except the general character of the occurrence was learned, but it was evident that no deposit of a size or richness to warrant any considerable expenditure for development had been found. The gold from this place is in very small pieces of reddish color, some of which are flaky. No black or rusty gold was found. Magnetite is everywhere common in the concentrates, but garnet or "ruby" is almost entirely absent.

A little prospecting had also been done farther up the Alatna near the mouth of the Kutuk in the belt here mapped as undifferentiated Silurian (?) rocks. Work there had been desultory and had attempted to test only the shallow creek gravel. Some gold was found, but so little that it did not offer much inducement to continue development. It is believed that the gold that occurs here in the gravel originated in the quartz veins which are fairly numerous in the slate. Magnetite is a common mineral in the concentrates, but none of the other heavy minerals were recognized.

MISCELLANEOUS LOCALITIES

No indications of any placers that appear at all promising for their gold content have been recognized in any of the streams flowing northward from the Brooks Range, and the general character of the bedrock is not such as to hold any inducement to prospect in those areas formed dominantly of sedimentary rocks of Mesozoic age. A few small colors of gold were found in pans taken by the Geological Survey party on a bar near camp F May 28, in the upper Colville Valley, but these were insignificant in amount and probably had been derived from the Paleozoic rocks to the south. Repeated tests elsewhere along the upper part of the Colville failed to show gold, and several pans taken on the tributary of the Etivluk that enters that stream near camp F July 25 also failed to show any gold. Schrader [24] notes that a party of prospectors who apparently traversed part of the Killik and adjacent portions of the Colville reported to him that they failed to find any trace of gold in the sandstone and shale that are the dominant formations in that region.

Although it is possible that some gold-bearing rocks may crop out in the areas formed dominantly of Paleozoic rocks, in the headwaters of the Colville and other northward-flowing streams, the physical conditions that prevail in those regions are such as to indicate small likelihood of any extensive productive placer concentrations having taken place there. On the whole, therefore, except where special conditions prevail, such as in the neighborhood of intrusive igneous rocks, which may occur there but none of which are now

[24] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20, p. 31, 1904.

known in the basin of the Colville River, the probability of finding gold placers that can be profitably worked north of the Brooks Range is so slight that prospectors are not justified in spending time in seeking for them there while so many more promising areas in more accessible districts still remain.

The Quaternary deposits of the northern coastal plain have not been extensively tested to determine their gold content, but as they were probably derived mainly from the Mesozoic rocks to the south, which presumably contain no gold, there seems to be small likelihood that the later deposits are gold-bearing either. Schrader panned some of the material at Pitt Point, between Smith Bay and Harrison Bay, on the Arctic coast, and although he reports that he found considerable black sand, gold was absent.

GOLD LODES

Indications of gold mineralization are confined almost entirely to the areas occupied by the rocks older than the Devonian or to the vicinity of the igneous intrusive rocks. Even in those areas, however, no lode mining is in progress, and what prospecting has been done was carried on more in conformity with the nominal requirements of the land laws than in a real effort to investigate the geologic conditions and the nature of the veins. Practically the only place where an attempt has been made to prospect the veins was in the Cosmos Hills, north of Shungnak. In these hills near the divide between Dahl and Riley Creeks numerous veins intricately intersect the black slate and schist. Most of these veins are small, but some lenses 18 to 24 inches wide were seen. A prospect pit had been dug on one of these veins, and the broken quartz had been panned and yielded numerous small particles of gold. On the north slope of this ridge and extending as far down the hillside as the placers on Riley Creek heavy quartz float covers the surface. In many of the pieces of quartz gold was readily recognized by the unaided eye, and in some pieces several dollars' worth of gold is reported to have been found. The gold-bearing quartz at this place has a dense texture and a greasy white color. Sulphides are practically absent. In places the quartz is stained with iron, but the amount of discoloration from this source differs greatly in different places and seems to have no relation to the gold tenor. Some of the quartz shows indications of comb structure and does not seem to have been badly smashed. For this reason it appears probable that the veins were formed later than the great period of dynamic metamorphism, and this conclusion seems to be supported by the greater continuity of these veins as compared with those in the oldest schists. Apparently the local placers on Riley Creek are intimately connected with these quartz veins and owe their gold content largely to them.

Conditions similar to those at the head of Dahl Creek, described above, are believed to be likely to occur at other points within the Kobuk Basin, but the general inaccessibility of the region and the probable need for extensive plants and equipment make search for them at this time scarcely worth while. From what has been seen of the mode of occurrence of these veins it seems probable that to recover the gold would necessitate handling and milling a large amount of the country rock in addition to the vein material, and this would necessarily reduce the gold tenor. The question, therefore, whether these veins can be worked at a profit can be answered only by careful and extensive sampling of all the material that must be mined and milled on a commercial scale. It is evident that picked specimens are of absolutely no value and that even well-taken samples of the vein filling are misleading unless the vein is so wide that it can be mined without necessitating removal of country rock with it.

Gold quartz veins have been reported at several places in the valley of the Alatna River. A number of claims are said to have been staked in the central part of the valley, but when that region was visited in 1911 practically all trace of work had disappeared, and only a few small iron-stained stringers of quartz were recognized. Schrader [25] noted that a number of quartz veins had been found in the divide between the Alatna and the Noatak, but their location was so indefinite that it could not be recognized by the Geological Survey geologists when the region was visited in 1911 The fact that the highest gold content of the samples from this place examined by the Geological Survey chemists was less than $2 a ton indicates that the value of these veins as lodes is practically negligible. Schrader's description is as follows:

> The country rock is described as quartzite, slate, and schist. * * * The Alatna ore deposits are reported to consist of six or more veins, or ledges, known as the Copper King, Copper Queen, Lucky Six, Mammoth, Iowa, Gray Eagle, Silver King, and Ground Hog. They are on an average about 1 mile apart and are accordingly included in a belt about 6 or 7 miles in width. They lie nearly parallel and trend in a northeast-southwesterly direction and, so far as prospected, are in general nearly vertical or dip about 75° NW. About half of the veins are reported to have a width of approximately 75 feet, while the minimum width of the smallest is given as 10 feet. Some of the veins have been traced by croppings for distances varying from several thousand feet to 2 miles.
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> Through the courtesy of Mr. Prindle the writer has received for study six of these Alatna ore specimens, brought out by the miners in the fall of 1903. In these specimens the ore consists essentially of iron pyrites and quartz, with also chalcopyrite (copper pyrites), which is conspicuous in two specimens. W th the chalcopyrite is associated a little bornite and a trace of malachite.

[25] Schrader, F. C., A reconnaissance in northern Alaska: U. S. Geol. Survey Prof. Paper 20. pp. 102–104. 1904.

Another specimen is composed essentially of stibnite, or sulphide of antimony, and epidote. One specimen contains feldspar as a gangue mineral in addition to quartz and is locally stained reddish brown by hematite or iron oxide, which is seemingly an alteration product of the pyrites.

The quartz is largely of the finely granular sugary type and often remains as a porous honeycombed or corallinelike mass where the metallic contents of the ore have been leached out of the more exposed croppings. This "skeletonized" mass is occasionally traversed by small discontinuous stringers of firmer, greasy-lustered, and evidently younger quartz, producing a semibanded appearance, which, considered in connection with slickensiding and planes of weakness exhibited by other specimens, shows that ore deposition was followed by rock movement and consequent crushing, which produced fractures, into which the barren stringers were subsequently deposited by silica-charged solutions.

The specimens at hand contain both white and yellow iron pyrites, which is mostly fine grained and normally occurs massive with the quartz, but in a few cases an imperfect parallelism, or banding, apparently representing depositional layers of quartz and pyrites in varying amounts, is perceptible.

The value of the ore rests in its auriferous content. At least three of the larger veins are reported, from assays made for the owners in San Francisco, to carry from $40 to $90 per ton in gold. The Survey has just completed the assay of four of the above-described ore specimens, with the following results, in ounces per ton: Specimen B, gold, 0.05; silver, none. Specimens C and D, gold, trace; silver, trace. Specimen F, gold, 0.10; silver, 0.08. These results are not promising. The gold seems to be contained, very finely disseminated, in the pyrites, for so far as known no free gold is visible. None was seen in the specimens examined by the writer.

In his earlier report on the Noatak region Smith noted that gold had been reported to have been found in the vicinity of "Mount Kelley." At that time this mountain was supposed to be somewhere on the Noatak divide and was indicated on some early maps as about 40 miles north of the mouth of what Smith called the Kelley River. Subsequent surveys, however, have cast considerable doubt on this position of this mountain, and it is now believed to lie entirely outside the Noatak Basin. A prominent hill that makes a striking landmark and stands on the divide between the Kukpowruk. Kukpuk, and Pitmegea Rivers seems to be the most likely point to which the name should be given, and this position has been adopted on the accompanying map. The location is of special geologic interest, because if it is accepted it indicates that the country rock there belongs to the Cretaceous unless there has been local intrusion or faulting, and these Cretaceous rocks nowhere else in this region have shown any indications of being cut by veins containing valuable minerals. Whether or not the correct identification of the point originally called Mount Kelley has been made, the report by the prospector Kelley, as given by Stockton,[26] leaves no

[26] Stockton, C. H. Arctic cruise of the U. S. S. *Thetis* in the summer and autumn of 1889: Nat. Geog. Mag., Vol. 2, p. 180, 1900.

room to doubt that the area prospected by Kelley was in the Pitmegea Valley. This report is as follows:

Gold has been found near the Pitmegea at the head of the same creek [Ikuk Creek, a southerly tributary of the Pitmegea] and tributary, it being contained in sulphurets of iron which exist in large quantities in that vicinity, there being from \$3.50 to \$8.00 worth of gold in a ton. The country is all but impassable, however, and this, together with the shortness of the season, would prevent any mining with profit.

Another occurrence of vein quartz whose precise location is extremely indefinite was recorded by Smith on the report of a prospector who went into the hills at the head of the Squirrel River that form the divide between the Kobuk and Noatak. No details of this trip were obtained, but the prospector is said to have returned with numerous specimens of quartz which showed considerable free gold that he had evidently found in that region.

Some metallic sulphides were noted in the sandstone near camp M June 13 on the Killik River, at a point not far from the dike of gabbro already described. The character of this deposit, however, was not such as to indicate that it was of economic significance, even if it occurred in a much more accessible region. Disseminated sulphides were noted in the igneous rocks on the Kivalina River near camp P April 10, but their amount was insignificant and not such as to suggest that they might give rise to ore bodies or commercial deposits.

COPPER

Copper minerals have been recognized in the Kobuk, Noatak, Alatna, and John Valleys. Of these the only one on which any considerable amount of prospecting has been done is in the Kobuk Valley near Shungnak. These were described by Smith [27] as follows:

At two places attempts have been made to prospect copper lodes, but at neither have the explorations been sufficient to determine the extent or the geologic relations of the ore. One of these prospects is located on the west side of Ruby Creek about 5 miles from the junction of that stream with Shungnak River. The other lies west of the left fork of Ruby Creek, near the head of Cosmos Creek. A low limestone hill, locally known as Aurora Mountain, is the center around which the claims at the latter locality are grouped, and this name will therefore be used to designate that locality.

Copper-bearing leads on Ruby Creek have been known for many years and were critically examined in 1906 by experts in private employ to determine their commercial value. Conditions at that time prevented the purchase of the properties, and only a small amount of work has been done recently. Owing to the length of time that has elapsed since active work was in progress, many of the pits and open cuts have caved and filled to such an extent that they

[27] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 147–150, 1913.

afford poor opportunity for examining the deposits and adjacent rocks. In this part of the Ruby Creek Valley on the lower slopes there is a heavy covering of talus and vegetation, so that without pits and other sections many important facts are indeterminable.

Mineralization on Ruby Creek appears to be confined to a brecciated zone or zones in the limestones. Sulphides have been deposited in the open spaces thus formed, and the ore-bearing solutions have penetrated the limestone along many cracks and crevices and have in part replaced it. There is some brecciated dolomite at the mine, and this also has been replaced and intersected by sulphides. The sulphides of economic importance are mainly bornite and chalcopyrite, but galena and iron pyrite were also noted. In the surficial part of the deposit both the blue and the green copper carbonates are common. Limonite, derived from the weathering of the pyrite, in several places forms a gossan, or "iron hat," several feet thick over the sulphide-impregnated limestone. It is reported that the weathered material when panned yields colors of gold. Average pans of the gossan from an open cut above the main workings are said to give from 1 to 3 cents in gold. Assays are reported to have yielded as much as 11 per cent of copper, but no details were obtained as to the manner in which the samples were taken.

The main developments on the northernmost property consist of an adit and two open cuts. The mouth of the adit is only a few feet above the high-water level of the creek. The tunnel has been driven about 40 feet through a much slickensided and fractured limestone, in places showing mineralization. Two short drifts, totaling only about 30 feet in length, followed especially strong indications of mineralization but evidently soon passed out of rich ore. The walls stand fairly well, but caving of the surface has so blocked the mouth of the adit that 12 to 18 inches of water stands on the track. A boiler was brought in from the Kobuk by way of the low pass at the head of Wesley Creek by a team of 70 dogs. When work was started, a home-made mine car was used to tram the broken rock away from the working face, but a new automatic dumping car has since been installed. Wooden rails are, however, still in use. Natives have been employed as muckers and for the simpler mining operations are said to have given satisfaction.

On the hill at an elevation of about 150 feet above the adit an open cut about 30 feet long and 10 feet or more wide had stripped the surface and had cut into the bedrock to a depth of 5 to 7 feet. Most of this pit was covered with caved surficial material, so that little could be seen. The mineralization seemed to be essentially the same as that exposed in the adit. Although the bedrock in the open cut is limestone it differs in some respects from that exposed in the tunnel, for none of the dolomitic phase was recognized, and in places it seemed to be darker and suggested correlation with a higher horizon. However, there has been so much dislocation that the structure was not determinable, and in the absence of fossils the above suggestion is to be regarded as little better than a guess.

At about the same elevation above Ruby Creek as the adit already described, and 200 to 300 yards southeast of the open cut on the hill, another open cut about 30 feet long has uncovered a zone of mineralization. The mode of occurrence is essentially the same as that at the two other places, but only the upper weathered portion has been exposed. Copper minerals are less abundant here, but there is more limonite. Sulphides were but sparingly seen; the iron occurred mainly as oxide and the copper mainly as carbonate. It is reported that samples of the ore from this cut have a higher accessory gold content than that from either of the other two places.

At a locality in Aurora Mountain, about 3 miles west of the Ruby Creek copper leads, the geologic structure is essentially synclinal; brecciated and deformed limestone forming the top of the hill lies above a series of dark slates and schists that form the lower slopes. Near the contact between the two rocks, but occurring almost invariably within the limestone, are indications of sulphide mineralization. The surface of the hill is so covered with frost-riven talus of limestone that except in artificial cuts the rocks are not exposed in place. Here and there copper carbonate float is found in considerable abundance.

Developments on Aurora Mountain consist mainly of holes dug through the overlying mantle of detritus in places where the copper float is particularly abundant. The only prospecting of this sort that has been carried to any considerable extent is on the northeastern slope of the hill about 300 feet above the contact of the limestone and schists. Exploration at this place at first consisted in sinking a shaft on the uphill side of a particularly conspicuous area of carbonate float. At the time this place was visited in 1910 the shaft was partly filled with water and its walls were so covered with ice that they could not be examined. It was reported that the shaft was about 22 feet deep and intersected a fairly promising copper lead about midway between the surface and the bottom. The bottom of the shaft is also said to have shown some good ore. Samples from the lower part of the shaft show bornite and chalcopyrite as well as carbonates.

Owing to the difficulty of mining the shaft was abandoned and a crosscut at about 250 feet lower elevation was commenced to connect with the deepened shaft. This adit was about 30 feet long, and it will be necessary to extend it over 250 feet to reach a point directly underneath the shaft. Throughout its length the adit is in barren brecciated limestone, in few places showing any mineralization. Slickensiding is evident at many places, but although the amount of throw was not determined it probably was not very great, as different rocks were not brought into juxtaposition. In spite of the brecciation and faulting the rock stands well, and it has been necessary to timber only the entrance to the adit, where it passes through the surface detritus.

Analyses by Thomas Price & Co.[28] of picked specimens of the bornite are reported to show 0.04 ounce of gold per ton, worth about 82 cents, and 1.4 ounces of silver per ton, worth about 91 cents, in addition to the copper content. Assays by the same analysts of chalcopyrite from Aurora Mountain yielded 0.01 ounce of gold per ton, worth about 20 cents, and a trace of silver in addition to the copper. Neither at Ruby Creek nor at Aurora Mountain, however, does the sulphide mineralization seem to have produced auriferous placers. In Ruby Creek colors of gold have been found, but at Aurora Mountain no placer gold has been reported in the stream gravels.

Although the Ruby Creek and Aurora Mountain localities are the only ones where prospecting has been carried on, there is probably similar mineralization at many other places. In fact, mineralization near the contact of certain of the limestones and schists has been recognized all the way from Seward Peninsula to this region. So far prospecting has failed to show that any of these deposits either in Seward Peninsula or in the Kobuk region are workable.

Until the mode of origin and the general characters of ore bodies of this type are fully understood it seems unwise to do much dead work, such as running long crosscuts to intersect a possible ore body in depth. Even after a considerable body of ore has been disclosed a careful scrutiny of the costs of mining in this remote and rather inaccessible region should be made before

[28] Lloyd, L., unpublished letter.

expensive permanent mining machinery is installed. Although these facts should not discourage intelligent prospecting, they should serve as a warning that the search is likely to be expensive, as the cost of preliminary investigation will be high.

Copper and silver-bearing veins have been reported on the Noatak side of the divide between that stream and the Kobuk. The following statements were abstracted from the description furnished by the prospector who discovered the veins.[29]

The silver ore is said to occur on the north side of the Kobuk-Noatak divide, between the Reed and Mauneluk River portages. No description of the geology nor mode of occurrence was learned. The same prospector [30] reports that farther west, on the Noatak side of the pass from Kogoluktuk River, there is a considerable deposit of copper ore, and float of native copper is found in some of the streams. This place is probably in the headwaters of Ipmiluik River, a tributary of the Noatak near the camp of August 1. Assays are stated by Mr. Lloyd to have shown 9.81 per cent copper and 27.73 per cent lead; the samples, however, were not representative but selected specimens. This ore is said to carry also some gold and silver. An assay of ore from what is supposed to be a continuation of this same vein on the Kobuk side of the divide is reported to have yielded gold and silver to the value of $1.24 a ton. No work has been done at this place, and in fact it was only discovered and a few samples taken during a hurried trip from the Kobuk to Lucky Six Creek.

The gold-bearing veins at the head of the Alatna, which have already been described, are reported to contain some copper minerals also. The extent of the mineralization is so slight, however, that these deposits do not appear to have value even for their combined content of gold and copper and certainly are of no present importance for either alone.

The only known indications of copper in the John River Valley were those reported by Schrader,[31] who states that

the principal specimens [of copper-bearing rock] seen by the writer during the recent work consisted of waterworn fragments found in the John River gravels and derived apparently from the quartz veins. They contained copper pyrites and a little bornite. * * * What is supposed to be a vein of considerable size containing iron and apparently copper pyrites was observed in a steep limestone cliff of the Skajit formation overlooking the river, where no examination or collection could be made.

LEAD

As already noted, lead occurs in close association with some of the sulphide ores whose principal metallic content is copper. Thus small quantities of lead have been found in association with the copper sulphides on Aurora Mountain and on Ruby Creek near

[29] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 150, 1913.
[30] Lloyd, L., unpublished letter.
[31] Schrader, F. C., op. cit., p. 104.

Shungnak, and considerable lead was found associated with the copper ore at the head of the Kogoluktuk. A small amount of vein quartz and some brecciated and recrystallized dolomite, which carried small amounts of galena, was recognized on the high hill west of Wesley Creek, in the Shungnak region. A prospect pit had been sunk on this stringer to a shallow depth, but the exposures in it were not encouraging enough to tempt further exploration.

Schrader also reported the occurrence of galena on the Wild River and stated that there it is associated with or partly incloses quartz crystals five-eighths of an inch in diameter and an inch or more in length but that in another place the associated quartz seems to be chalcedonic. The ledge is reported to crop out on Michigan Creek, whose exact location is uncertain but which joins the Wild River from the east at about latitude 67° 20′. The bedrock of the part of the valley where the galena is found is said to be the Skajit limestone. The ledge is said to be of considerable size and to carry gold and silver in addition to the lead.

IRON

In the hills north of Shungnak masses of magnetite, some of which weigh as much as 100 pounds, are found at a number of places as surface float, especially near the contacts of the limestone and schist. These were examined by Smith[32] in 1911, and the opinions then expressed, which do not require modification from any later data, are as follows:

> Float of this sort is particularly abundant on the slopes of the sharp conical hill locally known as Iron Mountain, east of the pass between Cosmos Creek and the left fork of Ruby Creek. Specimens from this place show a nearly pure magnetite with here and there drusy cavities lined with small octahedral crystals of this mineral. As the magnetite has not been seen in place, speculation as to its origin is hardly warranted. There are no near-by igneous rocks, so it seems improbable that these bodies are due to contact-metamorphic effects. Owing to the occurrence of limonite and hematite bodies in similar limestones in the Solomon region of Seward Peninsula, a tentative suggestion is that the magnetite of the Shungnak region may have been formed by the metamorphism of similar iron oxides which were laid down either contemporaneously with the inclosing limestones or earlier than the great period of dynamic metamorphism. The magnetite shows no signs of having been sheared, so it must have been either entirely recrystallized or deposited subsequent to the period of regional deformation.
>
> Whatever theory of origin of these ores proves to be the true explanation probably matters little, for the deposits so far as known have but slight economic value. The high operating costs, coupled with the absence of large ore bodies, will necessarily deter capital from undertaking their development.

[32] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 153–154, 1913.

OIL SHALE

In the section of this report in which the possibilities of finding oil in the region are discussed rather fully (pp. 283–285) the fact that oil shale has been found in the region north of the Brooks Range is noted and all the available data are given. Smith[33] reported in 1911 material analogous to oil shale near the mouth of the Noatak. This was described as follows:

> Near the mouth of the Noatak, not far from the camp of August 25 [about 5 miles south of the mouth of the Agashashok River] a prospector reported finding a recent deposit of material that he has used as fuel. Specimens from this place show a dark-brown compact material that burns readily in the flame of a match and gives out considerable smoke and oil but leaves practically no ash. David White, who examined the material, reports that the specimen is composed entirely of large fern spores and resembles the so-called "bogheads." This deposit was not seen in place, and no facts as to its extent or relations were learned.

Although the occurrence of this material is of great significance as a possible source of natural deposits of oil, it can of itself hardly be regarded as a resource of immediate value. However, if the region should become less inaccessible through development and when methods of extracting oil from shale are more fully perfected on a commercial scale, the fact that there is some rich oil shale in this region will doubtless justify more thorough investigation of the oil shale as a potential asset. That time, however, is remote, so that, as with certain of the northern Alaska coal deposits, it would seem to be sound public policy to retain them in public ownership until there is an actual demand for the product and a soundly engineered and adequately financed plan is presented for their active development by a producing company, rather than permit them to be taken up as parts of a development scheme whose main hope of financial success is based on holding or selling land titles or permits.

ASBESTOS

Asbestos has been found in the vicinity of Shungnak and in the Jade Hills, and several attemps have been made in a small way to develop it. The asbestos near Shungnak occurs as small veins in close association with greenstone and serpentine. The greatest amount of this material that was seen occurred on the east side of Dahl Creek, but probably it may be found at other places where the greenstone intrusives have been sheared. Most of the veins are small, but specimens having fibers several inches long have been found. Some of the long-fiber specimens have been submitted to manufacturers, but they report that although the color is good the

[33] Smith, P. S., op. cit., p. 153.

tensile strength of the fibers is small, so that the material is not suitable for the manufacture of the higher grades of asbestos articles and that consequently its value is small. For ordinary purposes this asbestos is apparently entirely suitable, but as the price paid for this grade is only a few dollars a ton it would not repay the cost of mining and transportation from so remote a region.

It is understood that in 1925 and 1926 interest was revived in the asbestos deposits of the Jade Hills and that one of the traders at Kotzebue financed some new prospecting work in that region. No reports of the results of that work have been divulged, but it seems probable that the material and the geologic conditions there are essentially similar to those near Shungnak that have been examined by Federal geologists.

JADE

Since the earliest explorations of the Kobuk Valley, in the early eighties, a jadelike material has been known to occur in the central part of the valley. In fact, the name Shungnak is said to be the Eskimo term for this material. Some of the material collected by Stoney, but without specific data as to the precise locality from which it came, though its general locality was given as the Jade Hills, west of the Ambler River, was submitted to F. W. Clarke and G. P. Merrill for examination. Their report shows that all the material is nephrite—that is, one of the minerals belonging to the amphiboles—rather than jadeite, which is a mineral belonging to the group of pyroxenes. This is rather a refined mineralogic distinction, for the term jade is applied ordinarily to either of these minerals and also to others having a composition analogous to that of serpentine or of saussurite.

The material collected by Stoney was described by Clarke and Merrill[34] as follows:

Analysis of jade from Kobuk Basin

[Analyst, F. W. Clarke]

	A	B	C	D
Ignition	1.78	1.38	1.76	1.73
Silica	58.11	55.87	56.85	57.38
Alumina	.24	2.07	.88	.19
Ferric oxide	5.44	5.79	4.33	4.43
Ferrous oxide	.38	.38	1.45	1.25
Manganous oxide	Trace.	Trace.	Trace.	Trace.
Lime	12.01	12.43	13.09	12.14
Magnesia	21.97	21.62	21.56	22.71
	99.93	99.54	99.92	99.83

[34] Clarke, F. W., and Merrill, G. P., On nephrite and jadeite: U. S. Nat. Mus. Proc., vol. 11, pp. 115–130, 1888.

A. Greenish gray, splintery, lamellar in structure. This sample as seen in the slide and by ordinary light presents a uniformly colorless field of a homogeneous nonpleochroic mineral and is traversed by fine wavy rifts running all in the same direction. The inclosures are very minute; some are mere dustlike particles; others are distinctly recognizable as limonite. Between crossed nicols the entire field is covered with very indefinitely outlined areas, which are alternately light and dark as the stage is revolved. With a power of 230 diameters these areas are seen to be composed of wavy and uneven scales and bundles of fibers so interwoven and confused that no trustworthy measurements of extinction angles are obtainable. Many of the bundles seem to extinguish in directions approximately parallel with their length; but others show wide angles. * * *

B. Like A, but more granular. This specimen in thin section and by ordinary light is also almost colorless, or very faintly greenish and without pleochroism. It shows only a few yellowish and opaque inclusions, which are evidently of a ferruginous nature. Between crossed nicols it exhibits the well-known nephritic structure—a dense aggregate of short fibers and scales, the fibers arranged in clusters, or radiating tuftlike bundles without definite boundaries, which merge into one another as the stage is revolved. In cases where these bundles are composed of fibers lying approximately parallel, angles of extinction were measured varying from 0° to 15°.

C. Paler, nearly white, closer grained.

D. Brownish, highly foliate.

The Jade Hills have not been examined in detail by any of the Geological Survey parties, but almost all the streams north of Shungnak contain pebbles and boulders of hard green, slightly translucent rock that might well be described as jade if that term is used in its general and not its restricted mineralogic sense. These specimens consist of various rocks, some of which are serpentine, others green quartzite, and still others nephrite. None of the pieces examined seemed to be of gem quality. The imperfections are due to cleavage, which causes the rock to split into layers, and to inclusions of other minerals, most commonly magnetite, which spoil the translucency and give the specimens a spotted appearance. Several desultory attempts to develop jade in this region have been unsuccessful, and there is little probability that in the near future any great quantity will be produced. The raw material is of relatively low value, so that the inaccessibility of the region, the great preponderance of material of inferior quality, and the small and relatively well-controlled market for jade serve as deterrents to commercial exploitation of this resource.

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