DEPARTMENT OF THE INTERIOR
FRANKLIN K. LANE, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

Professional Paper 109

THE CANNING RIVER REGION
NORTHERN ALASKA

BY

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WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

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By Alfred H. Brooks.

Prior to the explorations whose results are set forth in this volume the Canning River region of Arctic Alaska was almost unknown. The adjacent seas had been visited by whalers, and the coast had been hastily traversed by several explorers, but the detailed features of the coast line were unknown and the inland region had been visited by only a few prospectors and fur hunters, so that only its larger geographic features were known. The region as a whole therefore presented an almost complete hiatus in the scientific knowledge of Alaska, and Mr. Leffingwell has performed a most valuable service in mapping its geography and geology. However, as this report will show, his researches were by no means limited to these subjects, for he has recorded facts and made interpretations relating to many problems in other fields of science.

Nearly all parties that have undertaken exploration in Alaska and polar regions have been large enough to permit both the scientific observations and the physical labor incident to travel to be divided among several men. Not so with Mr. Leffingwell's party, for most of the time after the departure of Mikkelsen, in 1907, he had only one white man to help him, and he one who could take no part in the scientific observations. In fact, he made many of his journeys with only one or two Eskimo companions, and he made some entirely alone. The field was one of his own choice, and the explorations were made at his own initiative and expense. Therefore the results here set forth are in every sense of the word entirely Mr. Leffingwell's own contribution to science and to a better understanding of Arctic Alaska.

The modest narrative of his explorations here presented gives but a very inadequate conception of the self-sacrifice and hardships he endured during the years of his exploration. The reader of this volume should, however, constantly bear in mind the very adverse conditions under which the field work was done, for only thus can he understand why it was not possible to obtain the full information necessary to a complete analysis of all the problems presented.

Mr. Leffingwell's cartographic work on the coast, the results of which are shown on the maps in this report (Pls. I–V, in pocket), was based on accurate mensuration and determination of geodetic positions. He presents the first accurate chart of the north Arctic coast of Alaska, and his coastal maps are a valuable contribution to the knowledge of shore-line topography in the polar regions. It was not possible with his facilities to map the inland region with the same degree of refinement. In this part of the field, however, Mr. Leffingwell has made a valuable contribution to our knowledge of Alaska's larger geographic features, and this work, together with his geologic reconnaissance surveys, will be an important link between the investigations made along the international boundary on the east and Colville River on the west.

Not the least of Mr. Leffingwell's contributions to science is his detailed study of the ground ice, the results of which are set forth in this volume. He has also not only discussed the physiography of the region, including both past and present glaciation, but has analyzed in detail the processes of erosion and deposition under polar climatic conditions.

Mr. Leffingwell has, I think, been wise in his form of presentation. He has given not only his deductions and generalizations but also a detailed record of the observed facts. This complete record is especially valuable as to those subjects in which it was not possible to make the field studies exhaustive, for it enables those who do not accept his conclusions to put their own interpretations on the facts presented. In my opinion, some of his conclusions can be called in question on the evidence presented, but this fact does not detract from the value of the report as a whole.

THE CANNING RIVER REGION, NORTHERN ALASKA.

By Ernest de K. Leffingwell.

INTRODUCTION.

OUTLINE OF WORK DONE.

In the spring of 1906 a small expedition was organized by Capt. Ejnar Mikkelsen and the writer for the purpose of exploring Beaufort Sea, which lies north of Alaska. This expedition received the rather pretentious name of Anglo-American Polar Expedition, owing to the fact that the Royal Geographical Society of London and the American Geographical Society of New York were contributors to the funds. Mikkelsen and the writer were joint commanders, and consequently the name Mikkelsen-Leffingwell Expedition has been sometimes used by the press. The arrangement made provided that each should furnish half the funds. The writer obtained his share from private sources, and Capt. Mikkelsen obtained his half from societies and individuals.

The expedition was to go to Banks Land, northeast of the mouth of the Mackenzie, and spend one year in scientific work on the southeast side of that island. In the second summer it was to advance along the west side of Banks Land as far as possible and then spend a year in explorations farther west over the Arctic Ocean, in search of the land predicted by Harris from the behavior of the tides.

The expedition sailed from Victoria, British Columbia, in the spring of 1906 in a sealing schooner without power, renamed the *Duchess of Bedford*, after one of the contributors to the funds. The party numbered eight, and included the two commanders, a doctor, a naturalist, and four sailors.

The *Duchess of Bedford* arrived at Point Barrow ahead of the United States revenue cutter *Thetis* and several steam whale ships. The ice was close along the beach east of the point, and the schooner could not make headway by beating among the floes against the constant head wind and current. After winter quarters had been chosen in Elson Lagoon a whaling captain kindly offered to tow the *Duchess of Bedford* eastward, and by this means the expedition reached Flaxman Island, on the north shore of Alaska. There the party wintered.

At the end of the first year the ship was found to be unseaworthy, so the expedition could proceed no farther. The crew was sent home by whale ship and Mikkelsen returned to civilization during the fall and published his narrative.[1]

The writer remained among the Eskimo for another year but was unable to do satisfactory work with the equipment at hand. Therefore, in 1908, he came back to civilization and refitted. In 1909 he returned to the same base at Flaxman Island and remained for three years. Another year was spent in the region in 1913–14. In the narrative here presented the chief operations are briefly mentioned.

During the 10 years between the organization of the first expedition in the winter of 1905–6 and the date at which this report was finished the writer's whole attention was given to the work here reported. To lessen the burden upon his pecuniary resources the writer made an attempt at whaling and trading. One whole spring was sacrificed in whaling at Point Barrow but without success. A few thousand dollars was obtained for furs collected during the last four years, but this sum was not quite sufficient to cover the extra outlay involved.

The total expense of the writer during these 10 years has been about $30,000, half of which was paid out for the first year's operations.

[1] Mikkelsen, Ejnar, Conquering the Arctic Ice, London, 1909.

SCOPE OF REPORT.

This report describes an area about 70 miles square south of Camden Bay, shown on Plates I and II (in pocket), which was explored sufficiently to bring out its broader topographic and geologic features and discusses the geographic features of the northern coast of Alaska, the topography of which is shown on Plates III–V (in pocket). (See fig. 1.)

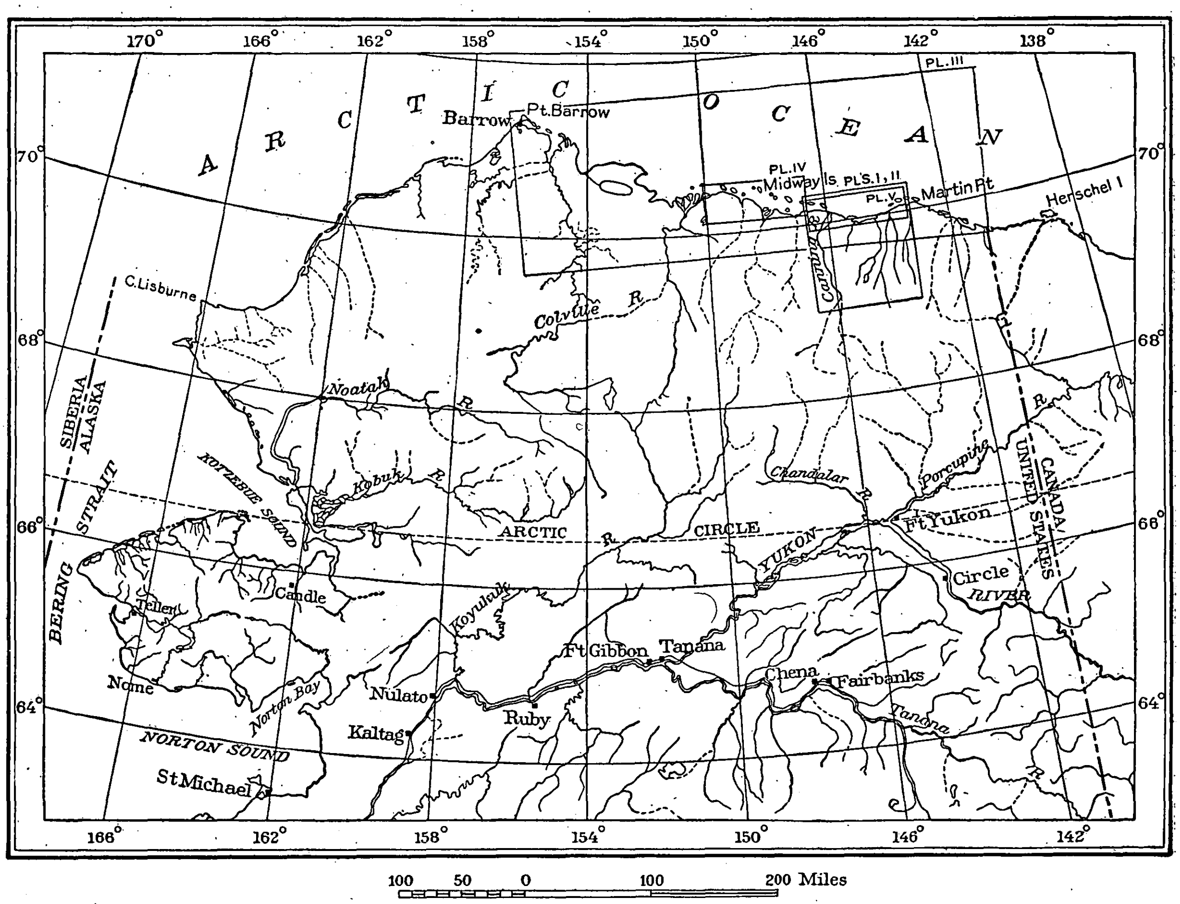


FIGURE 1.—Index map of northern Alaska, showing areas included on large-scale maps (Pls. I–V, in pocket).

In addition to the technical descriptions the report includes chapters of general interest, such as are customarily given in reports of exploring expeditions. The writer's training and chief interest lay in the study of the Pleistocene geology, so that Pleistocene phenomena have received more space in the discussion than those of all the other periods combined. The ground ice has been discussed in detail.

ACKNOWLEDGMENTS.

The writer is indebted to his father, Dr. Charles W. Leffingwell, for the funds by means of which the work has been carried on. He is also indebted to the patrons of the Anglo-American Polar Expedition for contributions toward the expenses of the first year. To Mr. Alfred H. Brooks, geologist in charge of the division of Alaskan mineral resources of the United States Geological Survey, he is indebted for advice and encouragement during the progress of the field work and for the privilege of writing this report in the office of the United States Geological Survey. The writer wishes also to express his appreciation of the many favors received from the members of the Geological Survey, both scientific and clerical.

Assistance from the United States Coast and Geodetic Survey is also gratefully acknowledged. Dr. Rollin A. Harris worked out the tidal observations, Mr. C. R. Duvall the occultations, and Miss S. Beall the latitudes. Dr. S. W. Stratton, of the National Bureau of Standards, lent the writer a steel tape and also calibrated several instruments. The United States Revenue Cutter Service several times transported small amounts of freight as far as Point Barrow.

To the members of the Canadian Arctic expedition, especially the southern party, under Dr. R. M. Anderson, the writer is indebted for transportation from Nome to Flaxman Island, as well as for hospitality enjoyed in their winter quarters. Acknowledgment is made for permission to use their large-scale map of Collinson Point, which shows numerous soundings.

Of the many to whom the writer is indebted for assistance in reaching the field of work, Mr. C. D. Brower, of the trading station at Barrow, should be mentioned first. The writer spent many weeks as his guest, during visits to that place. To Capt. George Leavitt, of the whale ship *Narwhal*, Capt. Steven Cottle, of the *Belvedere*, and Capt. John Bertoncini, of the *Jeannette*, the writer is indebted for transportation between Barrow and San Francisco in returning from his three different trips to Arctic Alaska. He wishes also to express his appreciation of the three years of loyal service by Samuel McIntyre.

ITINERARY.

The steps leading to the establishment of the base camp at Flaxman Island have already been mentioned. The following account of the writer's personal experiences is presented in the hope that it may be of service to those who are contemplating Arctic travel.

As more provisions were needed for the summer of 1907, the writer, accompanied by one white man, left Flaxman Island as soon as the ice was sufficiently firm, in October, 1906, on a sled trip to Herschel Island. Much delay was caused by open water and deep snow, not to mention the extreme friction of the Nansen sled upon salty ice. Herschel Island was reached late in November, after a trip of 35 days. The return trip was made in December, in three weeks of very bad weather. During the eastward trip a sketch map was made of the details of the coast that were visible from the line of march.

The next few months were spent at Flaxman Island, chiefly in preparing for the ice trip north. Observations for latitude and time were made with the altazimuth, and one occultation was observed.

During March, April, and May, 1907, a sled trip was made northward in search of land. Although no land was found, a series of soundings showed that the continental shelf extended 50 miles from the Alaskan mainland. A detailed account of this trip is given in Mikkelsen's book,[1] so that there is no need of enlarging upon it here.

When warmer weather set in, the ship began to leak so much that the crew were unable to keep the water pumped out. Consequently they moved to the shore and built a small cabin out of the interior woodwork of the ship. As it was impossible to make the vessel seaworthy, she was dismantled, and the crew were sent home at the earliest opportunity.

In May, 1907, the writer started eastward in company with a prospector, H. T. Arey, and his son, to explore Okpilak River. The party sledded to Arey's cabin, at the mouth of this river, and thence nearly to the mountains. The sled was then abandoned and further progress was made by packing. The river was explored to a point within sight of the head of the west fork, where further progress was impossible because of the deep snow that lay on top of the glacier. Much cloudy weather, with rain or snow, interfered with a complete survey.

The party returned to the coast on July 11 and were marooned, with no means of transportation, until August 1. Arey Island was mapped by using a micrometric control, and several points on the mainland were located. A boat arrived from Flaxman Island on August 1, and the writer was able to return to headquarters by August 5, after having mapped a few square miles near Collinson Point.

[1] Mikkelsen, Ejnar, op. cit.

As the crew of the *Duchess of Bedford* desired to return to civilization by whale ship, it was not advisable to employ any of them for trips away from the island, for a ship might pass at any time and afford them their only chance to leave the country. Both the small boats also would be needed to transfer them and their gear to the ship. During the later part of August they caught a ship—the *Narwhal*, Capt. George Leavitt—and as Capt. Mikkelsen was at Herschel Island the writer was alone for some days.

On account of the preparations necessitated by Mikkelsen's return to civilization, no field work could be done until October. A few days after Mikkelsen had left, the writer, accompanied by a native boy, sledded up Canning River on a surveying trip. Near Shublik the sled broke through the new ice that was constantly forming over the flood waters, and all the instrument boxes were filled with water, which afterward froze solid. In order to travel at all on flooding, ice-filled rivers, it is necessary to wade through the advancing water and to break the ice until farther on it becomes solid enough to bear one's weight. Ordinarily the water under the new ice is only a few inches deep, but on this occasion the sled broke through into a channel perhaps a foot and a half deep. As the instruments might be damaged by cleaning them in camp and as the map paper had been ruined, the writer returned to Flaxman Island.

During the second winter at the island, that of 1907–8, more astronomical observations were made, including three occultations. On January 23, 1908, the writer, accompanied by a native, his wife, and his small girl, and also by the same boy who had previously accompanied him on the sledding trip up the Canning, made a sledding trip to the head of Hulahula River. A micrometric stadia traverse was made for about 25 miles inland, but scarcely any details of the topography could be seen at that time of the year. Much difficulty was experienced with high winds, which caused the plane-table alidade to vibrate greatly. The survey in this neighborhood was accordingly postponed and the camp was moved to the head of the river. Here an area a few square miles in extent was mapped and observations for latitude and azimuth were made. At this time the native and his wife became dissatisfied, and there was nothing to do except turn them out of camp or give up work for a time. Scientific work with the best native assistance is unsatisfactory enough, but when the natives are surly it is almost impossible. Accordingly the writer discharged the natives and returned to headquarters.

In April a trip was made up the Canning to secure some specimens of Dall's sheep which had been purchased from a native.

Early in May the writer and an Eskimo boy sledded up the Canning to Ignek Creek, where about 10 days were spent in mapping and in investigating the geology. The boy, becoming lonely, decided to return to the coast, and as there was no way to keep him and to do work at the same time, he was given food enough to supply him till he could reach his family. The writer stayed on alone, and as soon as possible packed upstream, mapping both the geography and geology. His farthest camp was a short distance above the forks, on the east branch of the river. The heavy load of fossils could not be brought to the coast without double-tripping, so they were cached at Ignek Creek. The coast was reached July 7.

A week later a native canoe was procured and tracked up the west mouth of the Canning. This part of the river was mapped in detail by a paced traverse, and fairly good control was obtained by lines drawn to three determined points. From a point near the junction of the mouths the native boy (the same boy that had accompanied the writer on the former trip) went the remainder of the distance to Ignek Creek and brought down the fossils. In the meantime the writer mapped a part of the east mouth of the river.

Finding that he could not work to advantage with the equipment at hand and with native assistance, the writer returned to civilization in the fall of 1908 as the guest of Capt. George Leavitt, of the whale ship *Narwhal*.

During the winter of 1908–9 the writer provided himself with equipment for three years, especially with the instruments necessary for the higher grade of work which he hoped to accomplish. The owners of whale ships decided to send no ships to the Arctic Ocean in the summer of 1909, so the writer was forced to procure a boat of his own. After waiting some days he left Seattle in May, 1909, in a 12-horsepower gasoline yawl of 13 tons net. The boat was 50 feet long, 14 feet wide, and drew less than 4 feet of water. The voyage from Seattle to Unalaska, across the North Pacific, occupied more than a month. The weather was bad and the yawl was too frail to be forced into heavy seas, so that many days were spent heaved to.

From Unalaska, Capt. Steven Cottle, of the whale ship *Karluk*, kindly towed the yawl halfway to Nome at a much greater speed than was possible under her own power. The towline parted during rough weather, else the captain would have towed the yawl the entire distance. Ice was met about August 1 in Peard Bay, below Point Barrow. Here the yawl was held for two weeks. Point Barrow was passed on August 17, and Flaxman Island was reached on August 23. Stores were discharged, and then a trip was made back to Point Barrow for a second load, which had been landed there by a freight ship.

The second trip was completed by the middle of September, and then a new house was built next to the old one. Here the party was established, consisting of the writer and two other white men—Samuel McIntyre and Storker Storkersen. No field work was done in the fall of 1909. An astronomical pier was constructed, and the instruments were set up and adjusted, but no good observations were made until January, 1910.

On April 1, 1910, the writer started for Point Barrow on a whaling venture, during the northward migration of the whales, reaching there after a three weeks' trip. About a week was spent in camp while the natives hunted caribou. The object of this venture was to help pay the expenses of the scientific work, which were too heavy for the writer's resources. A full-grown whale was worth nearly $10,000 at the prevailing price of $5 a pound for whalebone. About six weeks were spent on the ice near Point Barrow, but no whale was killed.

On July 16 the party started toward Flaxman Island again, hauling a boat on a sled. Leisurely progress was made over the melting ice as far as Cape Halkett. Here the sled was cached on July 3, and the boat was navigated in the water that had formed on the shallow shore of Harrison Bay. Oliktok was passed on July 8 and Flaxman Island was reached on July 13. During this trip a sketch map was made of the details of the visible shore line between Point Barrow and Oliktok.

Two weeks were spent at Flaxman Island in getting the yawl into shape for the summer. During this time the coast near Brownlow Point and the spit running southeastward from it were mapped.

Between August 1 and 16 a trip was made to Point Barrow in the yawl for the purpose of getting provisions and mail. At Thetis Island a day was spent in erecting a beacon as an aid to navigation. This island is the first place picked up in crossing Harrison Bay from the west, and it is important that it should be recognizable. After returning to headquarters the party took the yawl to Arey Island, 50 miles to the east. Storkersen then left the party.

On August 31, 1910, McIntyre and the writer proceeded westward in an open boat along the chain of sand islands that extend more than 50 miles in that direction from Flaxman Island. All these islands were mapped and intervisible beacons were erected. It was impossible, however, to carry the line of beacons to Cross Island on account of its great distance from the next island to the east. From the Midway Islands the party went over to the mainland at the east side of Gwydyr Bay. From that place the shore line was mapped well down into Prudhoe Bay, but not the lower part of the bay. Camp was made at Heald Point and this neck of land was mapped during a period of delay caused by adverse winds. Heald Point was left on September 20 and Flaxman Island was reached on the evening of the same day.

No field work was done in the fall of 1910. The time was employed in getting driftwood for the winter, in banking up the house with snow, and in making tents and sleds.

In February, 1911, a trip was made up Canning River in order to carry a stadia traverse from the north front of the main range or Franklin Mountains to a point as near the head of the river as possible. Immediately after reaching the starting point selected for the traverse a spell of remarkably warm weather set in, so that the river ice was flooded with more than a foot of water. The maximum temperature was 44° F., and the unusually high temperature was accompanied by rain. Here the party was held for 10 days.

By the time the warm spell was over the supply of food was so low that it was necessary to return to Flaxman Island. A short time later the temperature on three successive nights fell below −50° F.

Between April 2 and May 2 a sled trip was made as far west as Oliktok for the purpose of establishing a system of topographic control by combination of micrometric stadia traverse and as many lines of triangulation as could be run. In this way a fairly complete control of more than a hundred miles of coast line was obtained, but it was not considered sufficiently accurate for a map drawn on the scale proposed.

Between May 10 and June 20, 1911, the writer, accompanied by two native boys, sledded up Marsh Creek to the foot of the mountains. There the sled was cached and further progress was made by packing. The farthest point reached was at Lakes Peters and Schrader. The topography along the route was mapped and a fairly good collection of Mesozoic fossils was obtained.

June 26 to July 31 were occupied in topographic work on the coast, chiefly west of Gwydyr Bay. A few triangulation stations were occupied with a more powerful theodolite, which had been constructed out of the parts of two instruments. Between August 1 and 12 a trip was made to Point Barrow in the yawl. During the next two weeks Flaxman Island was surveyed, and some soundings were made in its vicinity, but it was not until September 4 that the party could start westward to complete the mapping of the unsurveyed parts of the coast. The mainland was surveyed as far as the east mouth of the Sagavanirktok, from which point the party returned, reaching headquarters on September 21.

During the fall of 1911, as usual, no field work was done. The yawl was hauled out for repairs and left on the beach all winter. In January and February, 1912, a series of observations for latitude was made at Flaxman Island. A base line was measured and the base net of five or six stations was completed. Between March 7 and 24 a few triangulation stations, one as far west as Sagavanirktok River, were occupied. Between April 10 and May 15 the writer sledded as far west as Oliktok. The triangulation was completed, except the figures for two stations, where fallen signals or bad weather prevented success.

On June 7 the writer and two native boys started eastward, hauling a boat upon a sled. Most of the coast was mapped as far as Barter Island. The intention was to communicate with the expected survey party at the one hundred and forty-first meridian, but the ice hung on to the shore so late that the trip was given up. The party left Barter Island on July 14, but was delayed by the ice in Camden Bay, and did not reach Flaxman Island until August 3.

Early in August the yawl was turned over to McIntyre in payment of his wages, according to agreement, and a few days later he proceeded eastward with it into Canadian territory. The writer had made arrangements to take passage to Nome on a returning trading schooner, but the captain of the ship selected decided to spend another winter in the country. Having no means of transportation after the yawl had departed, the writer procured passage in an open whaleboat with a native family who were traveling to Point Barrow. As the boat was loaded with the belongings of its owner, only the most important of the writer's possessions—the records and fossils—could be taken along; the instruments and other valuable property were left behind in the storehouse.

The party left Flaxman Island on August 15 and stopped at Tigvariak Island until August 28, while the annual trading was taking place between the local natives and those from the east and the west. The winds were fair when the party left this island late in the night of August 28 and good progress was made. While the boat was sailing along the high bank east of Smith Bay good exposures of ground ice were seen above newly fallen blocks of tundra, but the surf was too high for landing, and in the snowstorm that was then prevailing the details of the exposures could not be well made out, else the problem of ground ice might have been solved in 1912, instead of in 1914.

Point Barrow was reached on September 2, and the writer became the guest of Mr. C. D.

Brower until a ship should put in. Two whale ships had gone past the place in August, and it was confidently expected that they would touch there before they started southward. Such ships usually leave Point Barrow during the first week in September, but it was not until late in the month that the *Belvedere*, Capt. Steven Cottle, put in there and offered the writer passage to San Francisco, where the ship arrived during the first week in November.

Mr. Brooks, of the United States Geological Survey, having kindly provided desk room at the office of the Survey in Washington, the writer spent four months there in preparing this report.

Although, as already noted, the chain of triangulation had broken down at two places, it was possible to bridge these gaps by means of minor angles and a rough plane-table traverse—work very likely to make the accurate triangulation beyond the gaps unserviceable. There were several thousand dollars' worth of instruments and personal property at Flaxman Island, and as the writer desired another opportunity to examine the ground ice, good exposures of which were not abundant during the five years he had spent in northern Alaska, he determined to make another trip to the region. Consequently, when the Canadian Arctic Expedition was organized under Stefánsson and Anderson, the writer offered his services as guide in return for transportation as far as Flaxman Island, and his offer was accepted.

Late in June, 1913, the writer went from Seattle to Nome on a passenger ship. At Nome, after waiting three weeks, until the expedition was ready to sail, he started in the gasoline schooner *Mary Sachs*, Capt. Peter Bernard, under the arrangement just mentioned. Ice was met at Point Franklin, and for nearly two weeks the boat was blocked at the bottom of Peard Bay.

On August 15 Point Barrow was finally rounded, and good progress was made through the shallow water to Flaxman Island, which was reached on August 18. Here the writer was landed with an outfit consisting of a large dory and provisions for two months. The island was then already covered with snow, and the pools were frozen over.

The party had expected to reach the island late in July, when, under ordinary conditions, it can easily be reached by a shallow-draft ship. Two larger ships, which had slipped past Point Barrow before the *Mary Sachs* reached the ice, had been able to get to Flaxman Island early in August, but when the party landed the natives, who always gather in the neighborhood for trading about the 1st of August, were now dispersed, so that no assistance could be obtained for the navigation of the large dory with its load of heavy cases of instruments and books. The writer thus had the alternative of returning empty-handed and having accomplished nothing or of remaining a whole year to do what he could with an insufficient outfit. The latter course was decided upon. The house was in good condition and was stocked with sufficient flour for the winter, so that there was no shortage of provisions.

The ice was forced so firmly against the island that the *Mary Sachs* was unable to proceed until a change of wind opened a narrow lead along the beach. She got off on August 26 and headed eastward, and for some weeks the writer was left alone.

The post that marked the north end of the base line was still standing, so it was decided to repeat the base net observations with greater accuracy. After the four stations on the island had been occupied a small hand sled was made and the theodolite was hauled upon it over to the mainland and the two stations there were occupied. About the middle of October the outfit was hauled 7 or 8 miles westward to an empty native hut, and from there one or two more stations were occupied.

During the fall the base net was adjusted by the method of least squares, not for the sake of accuracy but for mental employment. The astronomical instruments were not set up, for the latitude and azimuth were already known with more than sufficient accuracy. More occultations were desirable, but no ephemeris was available in which the predictions could be found.

Early in October a sled came up from the east with two members of the Canadian Expedition. Two of their ships, the *Mary Sachs* and the *Alaska*, were wintering at Collinson Point, only 35 miles beyond Flaxman Island.

The ice had been so heavy that none of the six ships that made the attempt had reached Herschel Island.

The writer was invited to spend Christmas with the expedition and even to become a member of the party if he cared to. Late in December he went to Collinson Point with a sled that was sent up for him and remained there for a month.

Plans had been made to devote the spring to completing the two gaps in the triangulation scheme and to strengthening some weak triangles by more observations. Also there were a few blunders in recorded minutes or degrees to be corrected.

On February 15, 1914, the writer and a small native boy with the aid of a single dog hauled the camp gear to Challenge Island, and were held there in camp by bad weather for eight days and forced to return without having made the desired observations.

On March 5 the writer sledded his camp gear to the mouth of the Kadleroshilik River, where he and the boy remained for 11 days. A signal was erected on Kadleroshilik mound, 12 miles inland, but it blew down during a gale before its geographic position could be determined. During the same gale, whose recorded maximum velocity at Collinson Point was 84 miles an hour, the theodolite case was blown some distance down the side of a mound, where it had been left overnight. The telescope, which was in a separate case, was found on a bare spot of ground, but the case out of which it had fallen was never seen again. The instrument was not damaged and was soon adjusted. During these 11 days only one station was occupied.

The writer and the native boy, with one dog, then worked as far west as Kuparuk River, occupying several stations. Continued bad weather and shortage of provisions prevented the completion of an important figure, but sufficient angles were measured to bridge the gap with a weaker figure than the one planned. On the return trip another stop was made at Kadleroshilik River until sufficient observations could be made to complete the gap at that place, after which the party returned to Flaxman Island, arriving there April 21.

Between April 29 and May 3 a trip was made to a station 20 miles up the Canning. Then about three weeks were spent at the island in occupying a few neighboring stations and in packing up gear for departure.

On May 20 the writer sledded to Collinson Point, where he was a guest of the Canadian expedition for a month. Several attempts were made to sled up Katakturuk River, but the flooded tributaries greatly hindered progress. A point about 20 miles from the coast was reached, and a little work was done.

About the 1st of July the writer was taken back to Flaxman Island by the kindness of Dr. R. M. Anderson. Two men who had come from ships that were wintering farther east and who desired to return to civilization offered their services in return for transportation to Point Barrow in the writer's dory. The party left the island on July 11, by which time a narrow lane of water had melted along the land. The party was blocked for 10 days in sight of the island until the lagoon ice broke up and moved westward during a gale. By August 2 the party had worked as far as Tigvariak Island and on August 3 reached Foggy Island, and thence had open water for about 100 miles. The distance between Foggy Island and the west side of Harrison Bay was covered in 50 hours. Ice was met again south of Cape Halkett, so that progress was slow to the east side of Smith Bay, which was reached August 9. Point Barrow was reached on August 17, and passage home was taken on the whale ship *Jeannette*, Capt. John Bertoncini. The ship left Point Barrow on August 21 and about six weeks later arrived at San Francisco.

To summarize, the writer has spent nine summers and six winters on the north shore of Alaska and has made in all 31 trips by sled and by small boat in the region, in addition to traversing the coast between Point Barrow and Flaxman Island 10 times by ship. He spent over 30 months on these trips, and during most of that time he lived in a tent. Camp was pitched about 380 times. The distance traveled has not been calculated exactly, but it is roughly estimated that about 4,500 miles was covered by sled or small boat. The 10 trips on shipboard add about 2,500 miles. The three round trips from Puget Sound to Point Barrow approximate 20,000 miles of ocean travel.

EQUIPMENT.

A complete discussion of Arctic equipment, such as may be found in the reports of many expeditions, lies beyond the scope of this paper, yet a brief description of some important items may be of interest.

HABITATION.

PLAN.

The writer's habitation at Flaxman Island consisted of a dwelling house, shed, storehouse, provision rack, and ice cellar. The house, shed, and storehouse were joined together in a line, and the rack and ice cellar were conveniently located near by.

In 1907 the crew of the *Duchess of Bedford* built a cabin out of the interior woodwork of the ship and banked it with sod, so that it was comfortably warm. It was so damp, however, that instruments rusted and other articles became covered with mold. In 1909 a substantial frame house was built at one end of the old cabin, so that the cabin might be used as an entryway. A storehouse was erected about 30 feet from the opposite end of the old house, and joined to it by a shed. This arrangement proved satisfactory, but it could have been improved in several details. The buildings are shown in Plate VI, *A*.

In designing a house for the Arctic regions it is desirable to plan to enter the living room through a series of compartments, so that the changes in temperature will be gradual. Thus the living room will not be chilled by a wintry blast every time the door is opened. The writer, after seven years' experience, suggests that one should enter first a shed, then an outer room, then a short passageway or entry into the house proper. The first room in the house should be the working room and the next the living room. If the outside temperature is —40° F. and the living room 70°, the working room may be kept at 40°, the passageway at 30°, and the outer room at 0° F.

SHED.

The shed may consist of an open framework covered with canvas. In summer the front of the shed is left open; in winter it is closed by slabs of ice, so as to provide a well-lighted outdoor working place. Here the dogs may sleep and be fed, and wood be cut up for the stoves. It is convenient to have the door, which should open inward, arranged so that sleds may be taken in and out. Then, during bad weather the sled may be loaded and the dogs hitched up under shelter.

OUTER ROOM.

The outer room may be built of driftwood or boards sodded over, or banked with snow in winter. It is used for storage of material which is not damaged by moisture and which must be kept away from the dogs. Firewood, ice for drinking water, barrels of provisions, and dog food are conveniently kept there for ready access. The entry to the house from the outer room is essential, because without it the outer cold will freeze the moisture which condenses on the door, so that it frequently becomes necessary to chip away the ice. If the entryway is kept only slightly below freezing, this difficulty will be lessened.

HOUSE.

The house may be divided into a workshop and a living room, or there might be sleeping and dining rooms and a kitchen, if there is sufficient fuel to allow each room a stove. The workshop may be warmed sufficiently by opening the door to the living room, but unless it has its own stove much frost will be formed along the base of the outside walls. This room should be sufficiently long for the construction or repair of the largest sleds used, and the doors leading into it should be so arranged that the sleds may be taken in and out.

The living room ordinarily combines kitchen, dining room, and sleeping room. If possible the bunks should be placed against the partition, for if they are placed against the outside walls frost will form between the bedding and the walls. It is especially important also to keep the lower part of the outside walls free from all obstructions that will prevent access of the heat of the room, for unless this is done frost will form.

The outside walls of the house must contain an air space. In the ordinary method of construction the studding is vertical, but this arrangement allows convection currents to cool the lower part of the walls and cause the frost, which gives so much annoyance in most Arctic houses. If vertical boards were fastened to horizontal beams the walls would be divided into small horizontal compartments. Thus the convection currents would not have so great a range, and the lower part of the walls would not be so cold.

The boarding on each side of the studding must be air-tight, or else the damp air of the house will enter the air spaces in the walls and roof and deposit frost during the winter. This frost will melt in the spring and drip down inside of the house. Additional insulation may be obtained by banking the house with sod, but this is not necessary if there is an air space in the walls and roof. In the winter the walls may be banked and the roof covered with snow blocks, which will make the house much warmer.

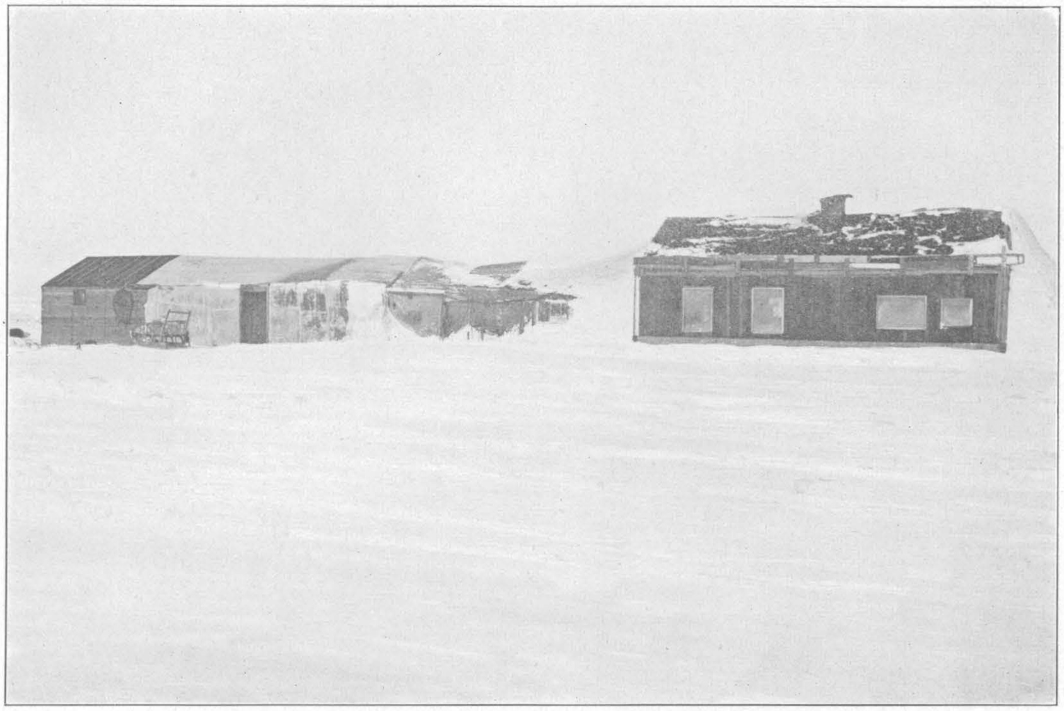
In a region like the north shore of Alaska, where the winds are strong, there is no need of a high pitched roof. All that is necessary is a sufficient slope to drain off water.

The windows may be either in the roof or in the sides of the house. Where storms are common the windows in the sides of the house may become buried by snowdrifts, so that it is preferable to have them in the roof. On the north shore of Alaska, however, the strong winds blow only east and west, so that the north and south sides of a house are free from snowdrifts unless there is some obstruction outside of the house in the lee of which drifts may form.

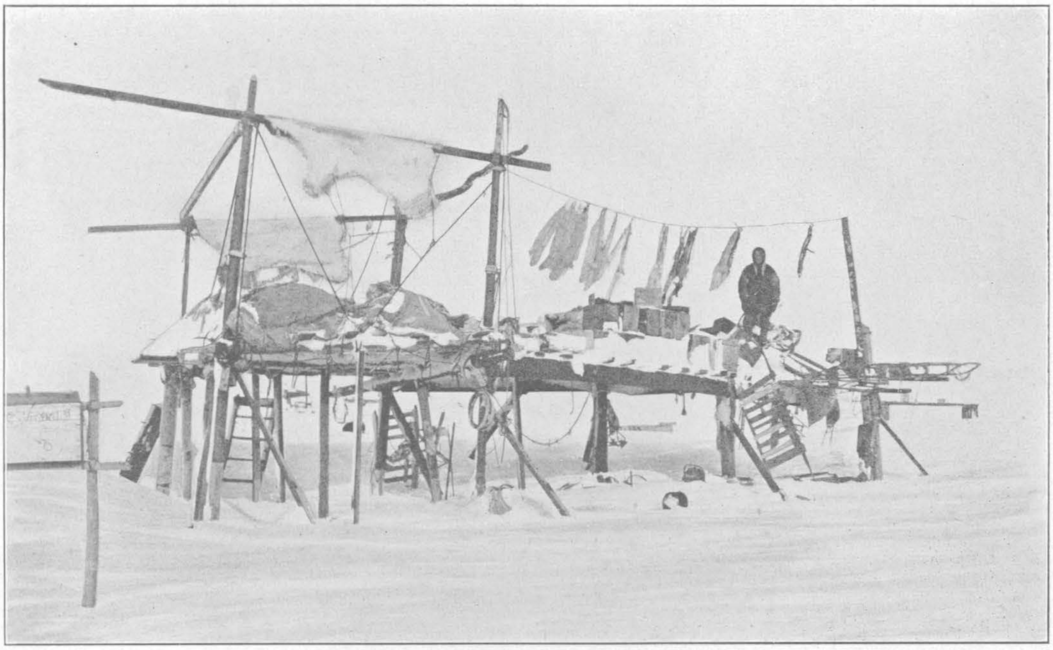
The windows should be double and preferably of small panes for the sake of greater strength. During violent gales the inside pane of a large window containing three thicknesses of glass vibrated in and out almost a quarter of an inch. If the air in the house is damp there will be annoyance from the moisture deposited at the base of even double windows. It is also difficult to make the space between the panes of glass air-tight, so that a film of frost is apt to be deposited over the outside pane in the course of a winter. To obviate this difficulty with frost it is desirable to have a strong framework into each side of which small panes of glass are inserted, so that each compartment is a small double window. This will reduce the scope of the convection currents and make a very strong air-tight window. Putty is a durable cement for the glass if there is not too much moisture. Moisture is deposited on the windows at night when the house is allowed to cool off. During the day the frost melts and runs down on the window sill, where it must be frequently mopped up. If shutters were arranged so that the windows could be insulated at night, the trouble from moisture would be greatly reduced. The shutters should be inside of the window, for the drifting snow would interfere with the action of outside shutters.

The ideal equipment for heating an Arctic house would be a hot-air furnace in a basement. The floor of the living room would thus be warmed, and a current of dry, warm air might be introduced where it would be most needed—that is, along the base of the outside walls. It is doubtful if there would be any annoyance from moisture with such a heating apparatus. The ordinary method of heating by stoves is unsatisfactory. The hot air goes immediately to the ceiling, so that the head may be uncomfortably hot while the feet are cold. An iron smokestack is a source of danger, and unless it is well insulated above the roof of the house by being inclosed in a box of sand a great deal of water will drip down each morning, when the heat melts the frost that has formed in the stack during the night. During gales the strong draft may ignite the soot in the stack and produce great heat, as it did three times in the writer's house. The stovepipe became red hot and was in danger of collapsing. The fire was checked only by throwing snow down the pipe from the roof until the draft was stopped.

As a well-constructed house should be air-tight, ventilation becomes important, not only that there may be fresh air for breathing but also for the sake of removing the dampness which accumulates both from breathing and from cooking. There is usually a sufficient circulation, inward through the cracks around the doors and outward through the stovepipe, to keep the air fresh enough for breathing but not to keep it dry. A ventilator, opening by a sliding door, is placed in the roof of some houses. Cold air that enters through the

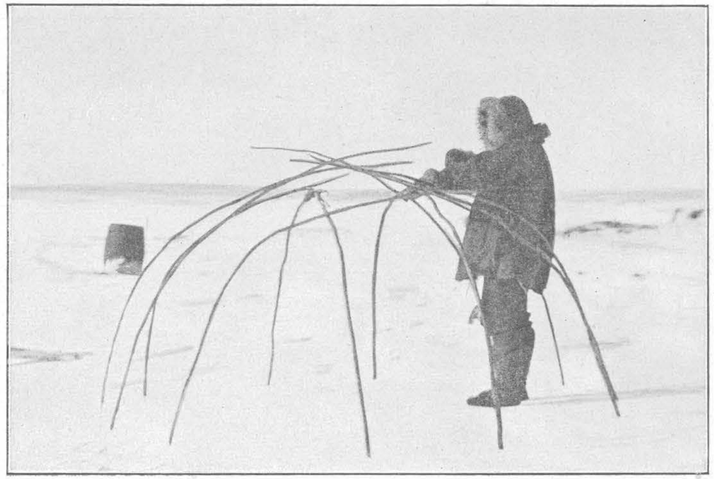


A. DWELLING HOUSE AND SHEDS AT FLAXMAN ISLAND.

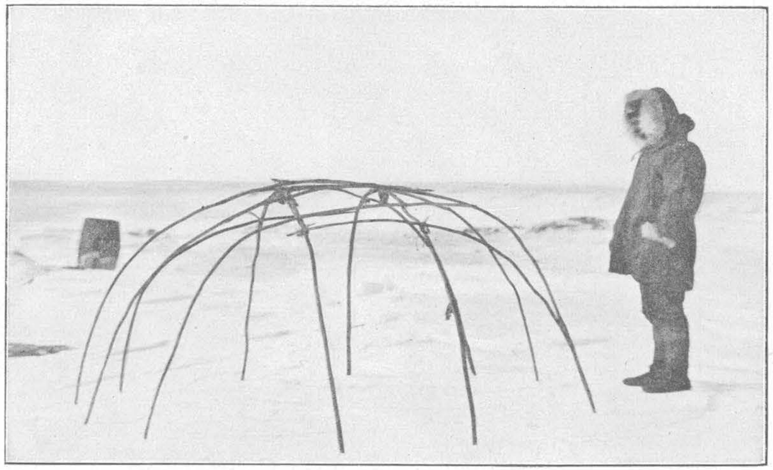


B. PROVISION RACK AT FLAXMAN ISLAND.

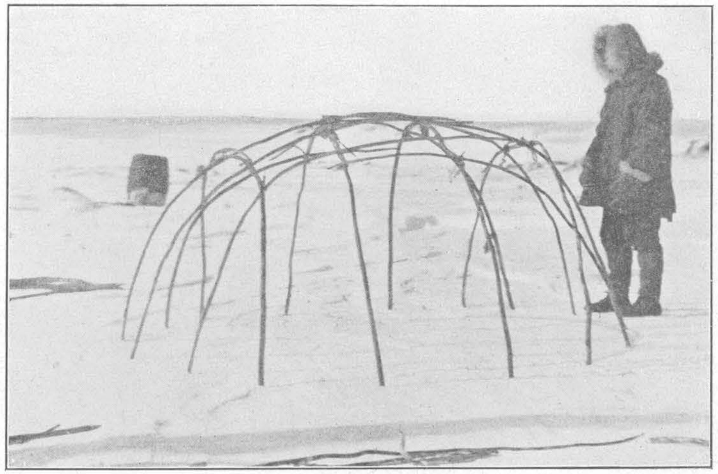
A. FIRST ARCHES.



B. SECOND STAGE.



C. THIRD STAGE.



D. FRAME COMPLETED.

FRAMEWORK OF ESKIMO TENT.

cracks around the door not only forms frost where it enters but descends immediately to the floor and increases the coldness there. A great improvement on such a system of ventilation would be to have fresh air piped to a receptacle surrounding the stove. A ventilator which drew the cold air from the vicinity of the floor would be another improvement. In this manner the air in the house might be kept fresh and dry and the floor would be warmer.

For light the writer used kerosene lamps, which were furnished with incandescent mantles, and they proved to be very satisfactory. On some expeditions acetylene has been used with satisfactory results. As kerosene lamps would probably be taken along also for use in case of a breakdown, it would not be advisable for a small party to encumber themselves with the apparatus necessary for acetylene light. Nansen used electricity derived from wind power, and in Nome gasoline is piped through small tubes to incandescent burners. Almost any method of illumination can be used in the Arctic regions, but kerosene seems the most convenient for use at a temporary station.

RACK.

Such articles of the outfit as will not be damaged by exposure to weather may be stored out of doors on a rack. If the platform on the rack is 5 or 6 feet above the ground the structure will not form snowdrifts, but the rack must be built in a place where there are no obstructions to the wind, else it may be buried by snow. The writer's rack is shown in Plate VI, *B*.

ICE CELLAR.

As permanently frozen ground is always to be found at a depth of a few feet, cold storage can be easily provided by digging a hole and providing it with a cover. Such an excavation is very convenient for storing fresh meat, as anything placed in it will keep frozen indefinitely.

FIELD EQUIPMENT FOR WINTER.

Winter travel in the Arctic is usually by dog sled, and the camps are made in tents or snow houses. A great deal of valuable information is given by Stefánsson,[1] and the writer is in accord with nearly all that he has to say upon Arctic equipment.

CAMP GEAR.

The most important part of the camp gear is, of course, the tent. A great variety of tents have been used on Arctic expeditions, but none of them appear to be comfortable and very few are safe in heavy gales. The first requisite is the ability to withstand the strongest winds. After securing this quality, warmth, lightness, and ease of erection may be considered.

The tent used by the Eskimo on the north shore of Alaska is the warmest and safest that is known to the writer. On the other hand, it is heavy and troublesome to put up and take down. The framework consists of about 20 light, curved willow sticks, which are stuck up in the snow and lashed into a hemispherical form. Over this framework two thicknesses of light cloth are thrown. Snow is then shoveled around the margin of the tent to hold the cloth in place. The low, rounded form and the numerous sticks enable this tent to withstand anything short of a hurricane. The two light covers with the inclosed air space are many times as efficient in insulation as a single thickness of the heaviest canvas, so that at night the heat emanating from the occupants will keep the temperature notably above that of the air outside.

As a rule, the sticks used by the natives are of willow. They select straight sticks, 8 to 10 feet long, peel the bark off, and bend them into the required curve. The sticks are then allowed to dry and the curve becomes permanent. No doubt bamboo would be stronger and lighter, and rigidity and lightness are required rather than weight.

In erecting the framework two parallel arches about 4 feet high are formed with four sticks. (See Pl. VII, *A*.) If the sticks are bent to the proper curve there is no need of lashing these arches. Then four or five sticks are set up on each side of these arches, so that a system of arches is formed at right angles to the first. (See Pl. VII, *B*.) These sticks are

[1] Stefánsson, Vilhjálmur, My life among the Eskimo, New York, 1913. See also Am. Geog. Soc. Bull., volumes for 1908 to 1913.

then lashed to the first arches, as shown in Plate VII, *C*. The lashing is most conveniently done by doubling a stout piece of cord about 15 feet long. A slipknot in the bight of the cord is placed over the central part of an arch, and the side sticks are lashed from the center outward, using each end of the cord. Next, a new arch is placed outside and parallel to each of the first arches, and lashed to the cross sticks in the manner described above. (See Pl. VII, *D*.) Sixteen to eighteen sticks, weighing about 20 pounds, are sufficient for a tent 9 feet in diameter.

The floor plan of the tent need not be round, for the sticks may be erected to form an oval or a nearly rectangular tent.

The ordinary cover used is of boat drill, but the writer has used silk and closely woven tent stuff and finds them preferable. For a tent 9 feet in diameter a sheet of cloth 15 feet square will be required. Such a cover of boat drill weighs when dry about 10 pounds, but as a great deal of frost forms in this cloth the weight after a few days of use approaches 20 pounds for each cover. The total weight of the tent is thus about 60 pounds. Where light tent stuff is used each cover may weigh no more than 5 pounds, and as it is of tight weave only 2 or 3 pounds of frost will adhere to it. Such a tent will weigh when in use about 35 pounds.

When the covers are in place over the frame the loose cloth at the corners and the trailing edges all around are folded under the edge of the tent. Then soft snow is shoveled around the margin of the tent to a thickness of about a foot and well tamped down. This snow will quickly harden and hold the cloth in place against severe winds. The completed tent is shown in Plate VIII, *B* (p. 24).

A doorway may be cut in one side of the tent between two sticks, and the cloth brought around the sticks and lashed inside of the tent. A bearskin door is then arranged so that it falls down over the doorway and is supported by the two arch sticks on each side. Two lashings from the top of the skin are brought up inside of the covers and fastened to the framework of the tent. The bearskin, with fur inside, by its own weight will completely close the doorway.

A simpler method of entering the tent is not to cut the cloth but to leave the covers free from the snow at one place, so that they may be lifted from the ground. The loose cloth may be weighed down inside the tent with any convenient object.

The writer does not recall the minimum time necessary for erecting such a tent in winter. With one assistant the ordinary time to put up the tent and start the fire in the camp stove was 45 minutes, but frequently it has been done in half an hour when there was need for haste. In summer, with three assistants, this tent was put up in 7 minutes. Five persons sleeping in a well-made camp of this kind will keep the temperature in the tent as much as 50° F. above that of the air outside in calm weather.

The writer has tried conical and square pyramidal tents, consisting of two thicknesses of cloth supported by a central pole. The walls were about 2½ feet high and the roof about the same. The inner tent was suspended so that it did not touch the outer one. This tent was light and warm, but it was unsafe unless surrounded by a wall of snow blocks which came to the projecting eaves of the roof. It usually took an hour to get the tent ready for occupancy.

Where there is wood, as there is nearly everywhere on the north shore of Alaska, a small sheet-iron camp stove is set up in one corner of the tent. The air inlet should be in the door of the stove to give the air better access to the center of the fire. The stovepipe need not be more than 3 inches in diameter. It should project above the highest part of the tent. It is advisable to have it made in one length of rather heavy iron so that it will not become bent in transportation. The ordinary thin jointed stovepipes are frequently so bent that it is difficult to join them even with bare hands. There should be a damper to control the draft during gales. A slot may be cut halfway through the pipe and a disk of iron inserted as far as is necessary.

The writer is unable to describe the method of constructing the domed snow houses that are used by the Eskimos in Canada and Greenland. In Alaska the natives do not seem to have ever made them in that shape. Before the introduction of tents both the natives and the white men slept in rectangular snow houses. The prospector Ned Arey, who had been in the country for 25 years, described the process of erecting these houses, so that the writer was able to construct the single snow house that emergency required. He had previously seen only one such house, which a native had built for use in trapping.

In building such a house a rectangular pit is cut out of snow of the proper degree of hardness. It is not possible to make the house very wide, but it may be as long as is desired. The maximum width seems to be 7 or 8 feet. The blocks sawed from the pit are set up around the edge of the pit, so that an inwardly sloping wall about 1½ feet high is formed. A gabled roof is then formed over the pit by means of large slabs of snow cut to the required length. This roof may be built by a single workman, if the first slab is propped at the proper angle by a gun or other article of camp gear. When the second slab is in place, half of it may be cut away so as to leave a support for the third slab. Each new slab will then be supported by half of the previous one. When the roof is complete the gables are trimmed to a slope so that the ends may be closed by tilted slabs. The cracks are then filled with soft snow, a hole is cut for a door, and the house is complete.

A makeshift camp may be made by building a wall of snow blocks and covering the top with a sled cover. Such a camp was used while occupying an inland station at a time when there were not enough dogs to haul the more comfortable tent.

The most comfortable form of covering at night is a sleeping bag made of winter caribou skin or, better yet, of mountain-sheep skin, with the hair inside. The sheepskin bags used by the writer weighed only 9 or 10 pounds, but in well-constructed camps he was always warm. The bag should be equal in length to the occupant, so that there will be plenty of slack to fold around the shoulders. The leather must be as soft as chamois skin, else it will not fit snugly. It is well to have the mouth of the bag sufficiently wide to allow the occupant to sit on the fur while undressing. The bag should taper toward the bottom, which should be circular. Some protection is required between the ground and the sleeping bag, else the bag will become wet, even upon snow. A caribou skin laid with the fur down answers this purpose, and it adds greatly to the warmth of the occupant. The clothing must be removed before entering the sleeping bag, for otherwise moisture will be carried in, especially when woolen clothes are worn, which are charged with frost. In Franz Josef Land, where everyone wore woolen clothes and slept with them on, in a short time the bags became very damp. After a week or two it was possible to squeeze water out of the fur, when it was thawed by the heat of the body. In Alaska, when the clothes were removed at night, the bags never became damp in the slightest degree, so that a refreshing sleep was always possible. Only once, when the thermometer was at —50° F., were the writer's feet cold.

An extended description of camp construction under the various conditions that arise would take up too much space in a scientific report, but a few notes may be helpful. Where possible, pitch the tent on snow that is soft enough to allow the heel to sink into it a couple of inches. Hard snow is porous and cold, and softer snow is apt to get into the camp gear. On account of the stove it is convenient to dig a pit to the ground near the door of the tent, but the sleeping gear should always be spread upon soft snow. All kinds of bare ground are cold, especially gravel, which lets the cold air pass through from the outside. If snow blocks are cut out so as to set the tent up in a pit for safety, then soft snow should be shoveled in for the bed, and snow should also be tamped around the edges of the pit to fill any spaces under the crust through which cold air may enter. A log of driftwood placed at the foot of the bedding keeps away the water from the snow which is melted by the stove. A flooring of pieces of driftwood between this log and the door soon becomes dry and adds greatly to the comfort of the tent. If the tent is pitched on top of the snow, the stove may be supported by sticks under each end. A deep hole will be melted under the stove, but if the hole is filled with firewood it will not expand beyond convenient limits for a couple of days.

Warmth and comfort are increased by building an alleyway of snow blocks in front of the door. At night the alley may be closed with a snow block or a piece of cloth and the floor of the tent will be warmer. If bad weather is expected, a wall of snow blocks should be set up around the tent for protection. If they are set close to the tent, the snow will drift in between the tent and the blocks; this does not disturb a willow-stick tent, though it might break down an ordinary tent. If the wall of snow blocks is set up at a distance equal to the height of the tent, little snow will lodge in the circle, so that the dogs may sleep there in comfort, and the firewood may be stored there.

The door of the tent should be at right angles to the wind, because a snowdrift forms over the lee side of the tent. When a native expects to remain some time at one camp, he may build a snow wall higher than the tent and roof it over with snow blocks supported by driftwood. A slab of ice in the top admits light. Such a camp, with a good alleyway, is so warm that water will not freeze in it at night, and after a day or so, when the snow blocks have become frozen, it is safe in a hurricane.

DOG SLEDS.

The dog sled should have a bed about 10 inches from the ground, and rails should run from bow to stern several inches above the bed. The bow of the sled should have a gradual rise from the ground for ease in overriding high snowdrifts or other obstructions. A steering bar at a convenient height above the stern is desirable, not only for guiding the sled but also for carrying the sled bag and other small items. Pliability is a great factor in the ease with which a sled may be drawn. A rigid sled will plow through inequalities in the snow, but a pliable sled will bend with the irregularities.

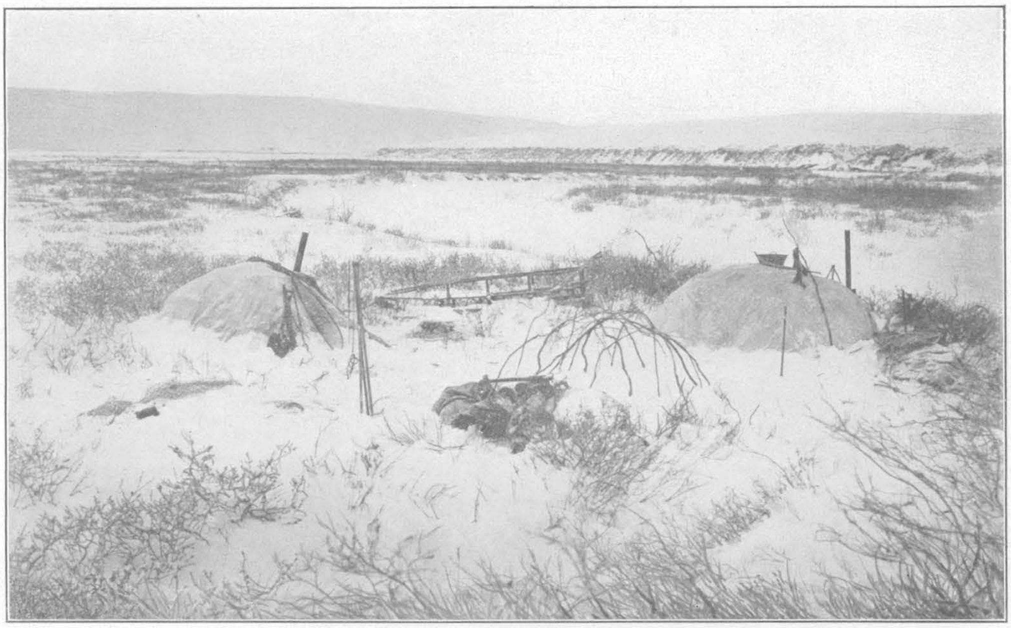
A sled made with boards set on edge for runners is very strong, but on account of its rigidity it does not haul so easily as one with an open framework. The ordinary construction consists of stanchions set into a square runner. Crossbars are mortised into these stanchions and slats are fastened to the crossbars to form the bed of the sled. A 10-foot sled of this construction, with a framework of oak or hickory about 1½ inches square, if shod with steel one-sixteenth of an inch thick, will weigh about 75 pounds. A load of 750 pounds may be safely carried over very bad roads.

After the first year the writer constructed his own sleds and felt well satisfied with them, but when he saw the utility of the Nome sleds that were brought in by the Canadian Arctic Expedition all others seemed crude in comparison. For 10 or 15 years skilled carpenters at Nome have vied in producing a sled which can stand the tests to which they are constantly put. There is no doubt that they have succeeded in turning out a sled which is by far the best in the world. Weight for weight they will carry more load, haul more easily, and last longer than any other sleds. On his last remarkable trip Stefánsson took a single Nome sled weighing 180 pounds. This sled was loaded with about 1,200 pounds of gear and was taken with ease over rough ice, amidst which several sleds of other design and carrying lighter loads were quickly broken.

Mild steel is considered the best shoeing for ordinary use. In travel for a long distance over salty sea ice a sled shod with ivory is said to run much more easily than one shod with steel. If ivory is used the runners must be rigid, or else the shoeing will be broken. The Eskimo formerly used the hard jawbone of the bowhead whale for shoeing, but this is not as good as steel. The Nansen sleds, which were used the first year, have wide wooden runners. On dry snow these go easily, but on salty ice they are almost immovable. Some of them were shod with a thin alloy, which gave less friction on the salty ice, but the metal was so soft that it was torn by the first sharp cake of ice that was struck by the sled. Nansen objected to steel on account of its rusting. The same objection would apply to its use for most other purposes. A steel-shod sled that was left with the runners on the ground for a month in the spring ran easily after a few hundred yards, and after half a mile no rust was noticed in the tracks.

Where the route lies over cold, dry snow all kinds of sled shoeing offer considerable resistance, but this resistance can be greatly reduced by icing the runner. Here, again, a rigid sled is preferable, for the ice will break off from the shoeing of a pliable sled. It is inconvenient to ice steel shoeing, but bone, ivory, or wood may be iced by filling the palm of the hand with water and passing it along each runner of a tilted sled. The natives take a mouthful of snow, and when it has melted use this water. (See Pl. VIII, *A*.) Such an

A. ICING THE RUNNERS OF A SLED.



B. ESKIMO TENT COMPLETED.

DOGS WITH PACKSADDLES.

icing is done in a few minutes and lasts perhaps an hour.

The writer made some rough experiments as to the relative coefficient of friction between steel shoeing and the same runners iced. The sled was about 6 feet long and shod with runners $1\frac{1}{2}$ inches wide, which were somewhat roughened by rusting. The traction was measured on common spring scales. The icing was formed by pouring water on the runners, and it was not smoothed down by hauling the sled some distance before the measurements were made. The plotted tractions for different loads, the heaviest 350 pounds, ran in a straight line, and the resistance of the iced runners was about six-tenths of the bare steel runners. A load of 300 pounds required a traction of 44 pounds with steel runners and 28 pounds with iced runners.

DOG HARNESS.

The simplest harness is that used by the Eskimo, which consists of two sealskin straps that run from the dog's hips along the back to the shoulders, where they are sewn together. They then pass on each side of the neck and are crossed at the chest where they are again sewn together. They are then brought inside of the front legs and around each side of the body and sewn to the back straps over the hips. A single trace a few feet long leads to the towline along which the dogs are fastened. This harness is easily slipped on and off, but the straps are apt to cut the dog's shoulders. The sealskin has the disadvantage of being edible.

A better harness consists of a pliable circular collar of cloth with a single strap of webbing leading from the top of the collar to the dog's hips. Two other straps lead from the bottom of the collar between the front legs and around the body and join above at the hips. The trace is fastened above the hips as in the sealskin harness.

It is obvious that in this simple harness the dog can not pull to advantage. At Nome they fit a padded leather collar to each dog. Tugs lead from each side of the collar to a singletree behind the dog, and the trace is fastened to the singletree. The tugs are kept in position by a loop which passes over the back of the dog and snaps together under his belly.

The Alaskan Eskimo hitch their dogs in a single line along a central towline, but this is an awkward arrangement when there are many dogs. At Nome the dogs are hitched in pairs with traces about 3 feet long. A short line leads from each dog's collar to the towline, so that they are kept in place. In many places in the interior, where the trails are narrow, the dogs are hitched tandem, between two long towlines. The Greenland Eskimo hitch each dog to the sled with a long trace, so that they are spread in fan shape. The leader is allowed a longer trace than the others.

In all these arrangements it is best to hitch the dogs up with snap hooks. The hooks that close with a flat spring are most convenient, but they are very easily broken. Those that close by means of a sliding rod are stronger, but are apt to be clogged by frost.

Where the trail is good and the dogs are well trained the tandem method is very good, but when one must use the average Eskimo dog it is sometimes difficult to untangle them after each halt. The same objection applies in less degree to the Nome method. In the method used by the Alaskan Eskimos there is the least difficulty; in the method used in Greenland the snarling of traces is a constant annoyance.

Where the trail is crooked, any method in which the dogs are strung out is objectionable, for the head dogs will pull the rear ones against obstructions when going around bends. If a hummock is encountered, the rear dogs in the tandem may be pulled to the ground as they mount over it.

The writer has tried all these methods of hitching dogs and prefers that of Nome for ordinary travel. Over rough ice he finds the fan-shaped system to be preferable, because each dog is free to pick his own path.

FIELD EQUIPMENT FOR SUMMER.

CAMP GEAR.

As the conditions in Arctic Alaska in summer are similar to those in regions that have milder climates, no special outfit is needed. A tent for the inland should be of light weight and mosquito-proof. The door may be a circular hole in the front of the tent that has a sufficient width of cloth sewn around the edges so that it may be gathered together at the center and tied. A cord run through rings around the edges of the loose cloth is convenient. It is better not to have any door at all but to crawl under the wall of the tent. On the coast, where transportation is by boat, a heavier tent may be used. Here a camp stove is necessary for comfort during cold gales.

DOG PACKSADDLES.

In traversing the interior, if canoes can not be used, it is necessary to pack the outfit, and for this work the natives make use of their dogs. A very simple packsaddle may be made by cutting a sealskin float halfway across the middle. The float is then bent over the dog's back and has an open pocket on each side. A strap is sewn at the front to go around the dog's neck and two short straps are sewn on the under side of the saddle, so that they may be tied under the dog's belly.

A good dog will pack half his weight all day, but he does not enjoy it. Dogs which were eager in a sled harness would slink away when the packsaddles were brought out. The saddles chafe them on the elbows, till they become raw or bleed. If there is a wrinkle in the material, the dog's back will become sore. The extra weight is also apt to make the animal footsore. Plate IX (p. 25) shows some native dogs loaded at the breaking up of an Eskimo camp. Pots and even tent poles are lashed to the packs to be dragged through the brush as best they may.

BOATS.

A river canoe of the Peterboro type is not suitable for travel along the coast. Even in the lagoons the waves are often sufficient to swamp such craft. The Eskimo skin canoe, the umiak, is seaworthy, and its shallow draft, together with its carrying capacity and light weight, make it especially adapted for use along shore. Two men can haul a 30-foot canoe out on the beach, or even one man, by taking it on broadside, end by end. These canoes sail well with the wind aft of the beam, but as they are without keel or centerboard, they can not beat against the wind.

Many of the natives possess whaleboats, which they have bought from the ships. These boats, about 30 feet long, are swift, even when close-hauled, and they can navigate in almost any weather, but their weight and draft of 1½ feet make them unfitted for coastal travel where many camps are made. As a rule they are anchored out while the party is in camp. Where a safe harbor is found, there is of course no danger in this, but boats anchored in exposed positions have often been broken by drifting ice or driven up on the beach by gales.

The best form of open boat for use along the north shore of Alaska is a dory with a centerboard. These boats have great carrying capacity with shallow draft. They are speedy with leading winds; they can make fair progress when beating against the wind; and they are acknowledged to be among the best in seaworthiness. They can be beached in a heavy surf, and as they are flat bottomed they may be brought broadside to the beach for ease in loading and unloading. They are so light that they may be easily hauled out. The writer, unaided, put his 27-foot dory up on the beach. A whaleboat of half the capacity requires half a dozen men.

Small motor boats would probably be useful for trips between known harbors, but for general exploratory service the writer does not think them suitable. They draw too much water and are so heavy as to be difficult to haul out. They can not sail, nor land in a surf, so that any engine troubles may bring disaster. No boat should be used in the Arctic regions which can not be relied upon to make the land in offshore gales. Sooner or later a helpless motor boat will bring up against the ice pack and be wrecked, if it is not previously swamped.

FOOD.

Fresh meat of some kind may be obtained in the country, so that it is not necessary to bring in canned or preserved meats, except bacon and salt pork. The appetite usually calls for an increased amount of fat in the diet, and as the seal and whale oil of the country is distasteful to most white men it is advisable to bring in plenty of butter, bacon, and salt pork. Oleomargarine does not deteriorate as butter does, and though it may not be as palatable as freshly made butter, it is probably better than most of the butter that reaches northern Alaska. The writer used it for two or three years with satisfaction. Bacon should be sealed from moisture, else it will spoil. Bacon that was double-smoked and packed in salt was always slightly tainted by the time it reached headquarters. The Canadian Arctic Expedition brought in a well-known brand of bacon which was incased in an air-tight compound. This bacon was delicious a year after it entered the country. Salt pork may be carried in the dry form known as "salt sides" or it may come in brine. As the fat is the part desired, the lean meat should be excluded.

Flour is not easily damaged by the elements, so it may be stored under canvas upon a rack. Sugar, of course, needs protection. Cornmeal, oatmeal, and most of such foodstuffs are spoiled by dampness. A very slight wetting will cause fermentation and subsequent mold, so that a whole sack is ruined.

The unsweetened form of condensed milk is curdled by freezing. It is said that the spoiled milk may be improved by warming it and stirring it with an egg beater, but the writer had no success in this. After several freezings the milk will be reduced to a mass of curdles with only a few drops of fluid, which, however, may be used in cooking. Dried milk is a very good form.

There are several methods by which it is said that frozen potatoes may be made palatable, but in the writer's experience all of them fail to remove the sweetish taste. Dried Australian onions do not seem to lose flavor by freezing, and they are much relished. It is said at Nome that all sorts of canned fruits are damaged by being frozen. Where unfrozen fruit is at hand for comparison, the difference may be apparent, but it was not apparent to the writer where all the fruit had been frozen. Tomatoes become watery, but the flavor seems unimpaired.

There are brands of dried fruits on the market which rival fresh fruit in flavor. Rhubarb and cranberries put up in air-tight tins will keep their flavor indefinitely. Many people use evaporated potatoes and onions, but the writer prefers rice to the former and dried onions to the latter. Evaporated eggs are on the market but are not palatable. They may be of use in cooking.

CLOTHING FOR WINTER.

On the Baldwin-Ziegler expedition the writer wore woolen clothes, and as his vitality was strong he managed to keep warm after a fashion. Nansen has expressed the opinion that fur clothes are too warm, and this opinion has been accepted as final by many explorers who have not had an opportunity to study the question independently.

A vigorous man may be comfortable during the winter in woolen clothes while in action, but the minute he stops to rest he will become chilled. As his circulation must be good, he will perspire when he is in action. This moisture penetrates through the pores of his clothes until it comes near the outside, where it is condensed as frost. Thus the clothes become stiff and heavy unless there are means of drying them frequently. The weight of the clothes is great to begin with, and they become unwieldy when the frost accumulates.

According to the writer's experience on the Baldwin expedition, when living at headquarters, where it was possible to dry out every night and to refresh himself by a warm night's rest, woolen clothes were sufficiently warm for outdoor work. If he became chilled from inaction, a short run would bring a glow of warmth. There was always the consciousness, however, that if he should become lost he would freeze to death as soon as he became too tired to keep on his feet. On extended sled trips the constant drain on the vitality was such that he could not become really warm even by running. In returning to camp with empty sled after having hauled provisions to an advanced depot, if he was too tired to run with the dogs but rode on the sled, his legs would often be so cold as to ache.

With good fur clothes he has hardly ever felt the slightest sensation of cold in the severest weather. At first the clothes are uncomfortably warm, so that one perspires freely, but after a few months the skin becomes accustomed to the heat, so that a man in good physical training will perspire much less than when dressed in woolen clothes. At first the fur stockings which the writer wore were soaking wet from a single day's travel, but after several years' experience his stockings would be comfortably dry even after three days.

On the upper part of the body a light fawnskin shirt is worn with the fur next to the body. A similar shirt is worn over this one, with the fur outside. When the snow is drifting, a light silk or cotton shirt is worn over all, to keep the snow out of the clothes. The writer preferred to wear a sleeveless woolen undershirt next to the skin, but this is objected to by others. Between the body and the inside fur shirt there should be nothing which will keep the bodily heat away from the fur.

These fur shirts are furnished with hoods which fit tightly around the face. There is usually a fringe of long fur, such as wolverine or wolfskin, around the opening to the hood. This fringe is supposed to keep the wind from the face, but fashion is one of the chief reasons for this decoration. These shirts are not open in front but are slipped on over the head and they are made full, so that they fall outside of the breeches, about halfway to the knees. In cold weather shirts are confined to the waist by a belt, but when the wearer is warm from exercise the belt is taken off. This allows the cold dry air to circulate inside of the clothes, so that the body is cooled off. The dampness of the body is carried off by the dry air, so that there is no trouble from moisture, except perhaps at the shoulders, where the air does not have access. In winter, after a day's travel, the fur on the inside shirt is so dry as to sparkle with electricity. The dryness persists chiefly because the outer shirt keeps the inner one so warm that no frost is formed. The damp air can not penetrate the leather to any extent, and so it does not reach within the influence of the cold.

The sleeves of both fur shirts should be large enough to allow the arms to be drawn inside, to warm them next to the body. This freedom of movement may save the hands from being frozen when a mitten is lost, and when the wearer is out in a blizzard it adds greatly to his comfort.

The inside shirt should be preferably of caribou fawn skin, with the hair not much over half an inch long. The weight should be 2½ to 3 pounds, and the leather should be as soft as chamois skin. The outer shirt may be heavier, if short-haired skins are not available. The skin of Dall's mountain sheep is better than that of caribou, as it is lighter and more durable. Two fur shirts will suffice for each winter, but toward spring they become somewhat worn.

A skull cap of some warm material, worn inside of the fur hoods, is almost necessary in order to keep the forehead warm.

The fur breeches are preferably of short-haired adult caribou, and they may be either full length or reach below the knees. For either length a puckering string is necessary to keep them in place over the stockings. The belt may be inserted through slits in the leather. The breeches are worn with the fur next to the body. For the sake of cleanliness, light cotton breeches may be worn outside. A second pair of breeches with fur outside would keep the clothing drier, but these would be cumbersome. The heat of the body keeps the fur dry, but frost condenses against the leather. In a warm place this frost melts and wets the leather, but it quickly dries out.

The fur stockings are of knee length or shorter, according to the length of the breeches. They may be of caribou or sheep skin, preferably short-haired, but if the hair is too long it may be clipped short with scissors. Like the other garments, they are worn fur inside. Light woolen or cotton socks may be worn next to the foot, as the fur can not easily be washed. It is necessary to put in a new fur sole when the old one becomes matted. The stockings run up under the breeches and are securely fastened by the puckering string, which keeps damp air from escaping to deposit frost against the bootleg. In very cold weather a person with tender feet may wear a slipper of thin fur, large enough to be drawn over the stockings.

The boots come to the knee and fasten with draw strings. For travel inland, where the snow is dry, the best boot has soles of bull caribou and uppers made from caribou legs. The soles are worn hair inside; the uppers may have the hair either in or out. For travel over sea ice, which is usually salty, soles of the hide of the bearded seal are the best which can be obtained in the country. Insoles of some kind must be worn for warmth and dryness. These insoles may be made of several thicknesses of blanket sewn together into shape or be made of grass or shredded rope.

A complete suit of such furs should weigh 11 or 12 pounds and should be warm enough to enable the wearer to weather the severest storms. It is possible to sit out all night with no more discomfort than can be relieved by occasionally getting up and stamping one's feet a bit. With woolen clothes, the loss of heat seems to make the wearer sleepy, and if he is unable to keep awake he may be frozen to death. With fur clothes this sleepiness does not seem to come; at least the writer has never heard of it. The natives who are sometimes forced by the weather to stay out all night sit down, pull their arms inside of their clothes, and doze away until morning. If the wind is drifting the snow, they may make a small snow house with their hunting knives.

CLOTHING FOR SUMMER.

The ordinary clothes of milder climates are suitable for summer wear. It is advisable, however, to take along an old fur coat for warmth in camp or during long boat trips, because after wearing fur clothes one is easily chilled.

The Eskimo water boot is one of the best known to the writer. It is more waterproof than anything else except the rubber boot and is very light. Sufficient stockings may be worn to keep the feet warm. Insoles are necessary for both warmth and dryness. The only objection to these boots is that the soles wear out in about a month unless patches are sewn on. To make a water-tight patch is difficult, so that work is usually left to the native women. The boots ordinarily on sale in settlements like Nome are made of poor leather and go to pieces in a short time. The best soles are made from the skins of the native canoes. These skins have been well cured, so that soles made from them will not shrink or quickly lose their shape. Bearded seal skins are considered the best, though white whale is locally used. The boots from Bering Sea are mostly made of walrus hide, but this material does not make a good sole.

MISCELLANEOUS ITEMS.

Guns should have powerful action and be easily cleanable. All grease should be removed from the works when cold weather sets in and the gun should be left outside the house. If a gun is carried inside it becomes at once heavily coated with frost, which melts and runs into the works. If the gun should be taken outdoors before this moisture is removed the freezing will clog the action. After the lubrication has been removed the action is very stiff. Automatic guns are nearly useless under these conditions. The standard rifles that are sold in the United States are used by the Eskimos, who find them satisfactory. Some of the higher priced foreign rifles were brought in by the Canadian expedition, and their simple mechanism was an advantage. It is not good economy to pay a high price for a rifle or shotgun which is subjected to such hard usage in a damp climate.

For the north shore of Alaska gill nets of 2½-inch mesh and 5 or 6 feet deep by 100 feet long are an important part of the outfit. Seines would be useful on some of the rivers, but gill nets will serve the purpose. Ordinary woodworking tools should form a part of the outfit. For iron work there should be an abundance of files, hack-saw blades, and drills. The combination of vise, anvil, and bench drill, which is on the market, would be a valuable addition. Where there is work to be done on engines a much more complete outfit is necessary, but the tools mentioned above will suffice for the ordinary iron work.

For cutting snow blocks an ordinary ripsaw with large teeth which have been given a strong set is very efficient. For trimming the cut blocks a 12-inch butcher knife is best used. In constructing a comfortable camp there is much snow work, so that these tools should be included in the sled load. An iron miner's shovel is also useful in making camp on hard snow.

SCIENTIFIC EQUIPMENT.

Astronomical instruments.—During the first two seasons latitude and time were obtained by means of a small altazimuth, made by Gaertner & Co., of Chicago. The 6-inch horizontal circle was read by verniers to 30″; the 5-inch vertical circle by micrometer microscopes directly to 10″ and by estimation to 1″. After some practice the latitude observations showed a probable error of $\pm 1.8''$ for a set of four pointings, two direct and two reversed. As the vertical circle was fixed the graduation errors could not be eliminated.

During these two years occultations were observed through a 2-inch Bausch & Lomb prism telescope. The reflections from the prisms caused so much diffused light that they were taken out and the image viewed directly.

The observations during the first winter were timed by a sidereal watch, compared before and after with the ship's chronometer. The same chronometer, regulated by sidereal time, was used in the observatory during the second winter.

On the writer's return to civilization in 1908–9 a special universal instrument was made for him by Gaertner & Co. The base was circular and split, so that the upper half would revolve around the lower. Firm clamps held it at any desired position. A telescope of the broken type carried a 2-inch lens of 12-inch focal length. There was not time to have a lens ground to suit the instrument, so that of the Bausch & Lomb telescope was used. This lens, even when stopped down to 1 inch, gave such faulty images that it was taken out and the lens of the theodolite, a 1¼-inch lens by Pettitdidier, was cemented into the seat. The eyepiece of the micrometer had a value for one turn of about 170″; the lever, for each division, a value of about 3″.

With this instrument the probable error of an observation for latitude upon a single pair of stars, was about ±0.6″. In observations for time on sets of four to eight stars the error was from ±0.16″ to ±0.04″. A single azimuth set of four pointings on star and mark, in both direct and reversed positions, gave an error of about ±1.5″.

A Negus break-circuit sidereal chronometer and a small chronograph made by Gaertner & Co. were also purchased in 1908–9. This chronograph ran at a rate of about 1 centimeter a second. An excellent 3-inch telescope by Pettitdidier completed the new astronomical equipment.

The observatory was merely an open-topped shelter, built of boxes and snow blocks.

Geodetic instruments.—During the first two years the altazimuth was used for determining horizontal directions, but the results were of a low grade of accuracy. A new horizontal circle was fitted to the instrument in 1908–9. This circle was 8 inches in diameter and was read by two verniers to 10″.

An instrument for carrying a micrometric stadia traverse was designed and constructed by Gaertner & Co. The telescope had a focal length of 12 inches and the micrometer a value for one turn of about 170″. Both the vertical and horizontal circles were read by verniers to 1′. This instrument was mounted on a tripod with a Johnson head.

The writer decided to control the topography by triangulation rather than by traverse, so he constructed a more powerful instrument by combining the altazimuth and the traverse instrument. The broken telescope of the altazimuth was unsuited for good work, so the wyes of this instrument were sawed off and those of the traverse instrument were lashed in their place with wire. To obviate the difficulty of adjusting disarranged verniers in the field, the micrometer microscopes of the 5-inch vertical circle were fitted to the 8-inch horizontal circle with wire lashings. The theodolite thus constructed gave satisfactory results, with careful handling. The weakest point lay in the instability of the microscopes.

Topographic instruments.—A small plane table with telescopic alidade, made by Gaertner & Co., was carried on the first field trip. This instrument proved to be too heavy to carry in addition to the share of the camp equipment and food that fell to the observer. Thereafter a light board mounted upon photographic tripod was used. The alidade was a simple ruler with folding sights. During the second trip to the region Mr. Brooks, of the United States Geological Survey, loaned the writer a stenometer. This instrument consisted of a prism monocular with a split objective whose halves were moved by a micrometer. Distances could be carried by this light instrument with sufficient accuracy for the scale of the map. Where traverses were paced, the steps were recorded by pedometers. Those possessed by the writer were of poor design, for although the units were easily determined, the hundred marks were so close together that a slight amount of lost motion introduced confusion in the readings.

Several azimuth surveying compasses were included in the outfit, but they were never used in detailed work. A very few bearings were taken with an ordinary pocket compass while making the sketch maps of the coast. Orientation in this class of work was usually determined by the direction of the snowdrifts.

Miscellaneous instruments.—Capt. Mikkelsen secured a light sounding machine in Denmark. Although it weighed not over 50 pounds it could reach depths of nearly 700 meters. In the meteorologic outfit there were the ordinary thermometers and aneroids. During the first year, when systematic observations were taken, there was no anemometer. In 1909 the writer secured an instrument of the windmill type for measuring velocities for short periods. This instrument was used only during exceptionally high winds as a check against overestimation of the velocity.

Notes on observing in cold weather.—In manipulating instruments it is necessary to use bare fingers, and therefore all adjusting screws should be insulated. If the instruments are made to order it is well to have the heads of the adjusting screws made of fiber, but metal heads can be wrapped with surgeon's tape, which will serve the purpose. After some difficulty with spider webs, which broke or buckled in the cold, the writer had all cross lines ruled on glass. All ordinary lubrication must be removed from the instrument. There may be some lubricating compound which will not freeze at —40°, but the writer has not been able to find one.

As only the end of the thumb and first finger must be free, thin woolen mittens were used, which protected the rest of the hand. These mittens kept the fingers pliable for a longer period than when the whole hand was bare. A large pair of caribou-skin mittens were put on over the thin mittens when the hands were not in use.

As the wood of a pencil is noticeably cold, the pencil should be wrapped in cloth or held in the mouth. The notebooks are also cold and awkward to handle, so it is well to use single sheets of paper fastened to a board. If observing is done at night the fingers may be kept pliable for a greater length of time by holding them against the globe of the lantern. Before a series of observations is completed the fingers may grow too stiff to make the required adjustments, but by means of the lantern they may be rendered pliable enough to finish the set. When the hands get too cold for further work the big mittens must be put on and the arms slapped across the chest until the hands are warmed again. It is well to let the hands get as cold as possible during the preliminary adjustments, for when they are warmed the glow lasts for some time.

If possible, the observations should be broken up into brief units, so that the hands may be warmed without disturbing the sequence. In observations for azimuth the hands are warmed while the striding level is becoming steady, and in observations for latitude and time there are intervals of waiting for stars to come into position. In observing horizontal directions with a theodolite there is no natural pause, except at the end of each set of direct and reversed measurements. However, continuous observations can be made by using alternate hands and by keeping one fur mitten on all the time. The telescope is pointed with the left hand. Then the warm fur mitten is shifted to that hand and the microscopes are set with the right hand. The recording is also done with that hand. When the set is finished the hands may be thoroughly warmed before commencing the next set.

The observatory need be no more than an open-topped shelter for protection from the wind. If this shelter is away from all buildings which may disturb the air currents, hardly any snow will lodge inside, even when the air is full of drifting snow for a hundred feet or more. During a whole winter not more than a few inches will accumulate inside the shelter, so that the instrument, if well covered, may be left in the observatory during the period of observations.

If bull's-eye lanterns are used for illuminating the telescope and azimuth mark, the heavy oils will freeze, so kerosene must be used. As the lamp warms up, the flame will rise and smoke the globe or melt the solder, unless it is watched. If the lamp is turned very low at the start, there will be the least difficulty. For all but exceptional temperatures ordinary brands of kerosene will burn in a lantern, but sometimes the oil becomes too stiff to flow, so that the lantern goes out. If the oil reservoir were wrapped with cloth, this accident would probably not happen.

CONSTRUCTION OF THE MAPS.

Before going into the Alaskan field the writer had had a little experience in exploratory mapping in Franz Josef Land. This experience was of use in making the sketch maps of the north shore of Alaska, but for the large-scale detailed map the whole subject had to be mastered from the beginning. Therefore not so much work was accomplished as an experienced man might have done in the same time.

While investigating the geology of the interior, a map was constructed as a base on which to plot the distribution of the formations. An area about 70 miles square is shown on this map (Pl. I, in pocket), on which the major details are drawn as well as the experience of the writer would allow.

As a survey of the coast line would be of great use to navigation, it was decided to devote the chief attention to this work.

The area under investigation occupies an isolated position, so that all the elements which enter into the construction of a map had to be determined. Astronomical observations were made for the latitude and longitude of the initial station and for the azimuth of one of the lines. Then a triangulation was made for the control of the topography, which was drawn upon detached sheets as opportunity occurred.

The area mapped by the writer in the interior is about 70 miles square, and the scale is 1:250,000 or about 4 miles to 1 inch. (See Pls. I and II.) About 150 miles of coast line was mapped on a scale of 1:125,000, or 2 miles to an inch (Pls. IV and V, in pocket), and about 300 miles on a scale of 1:1,000,000, or 16 miles to an inch (Pl. III, in pocket).

ASTRONOMICAL OBSERVATIONS.

Before starting on the Baldwin-Ziegler polar expedition in 1901–2, the writer spent some time at the office of the United States Coast and Geodetic Survey, where among other things he gained experience in making observations with a transit for time. This work consequently was not new to him when he went to northern Alaska, but he had never previously taken micrometric azimuth or latitude observations.

The programs for the observations were taken from the publications of the United States Coast and Geodetic Survey. These programs were slightly altered for the sake of overcoming the special conditions under which the observations were taken. The observations for time and latitude were naturally divided into short observing periods with rests between and so could be carried out as rapidly in cold weather as in warm. The program for the azimuth observations was arranged so that the hands could be warmed while the level was becoming quiescent.

OBSERVATIONS FOR LATITUDE.

About 55 observations for latitude were made upon 20 pairs of stars by the zenith-telescope method. The pairs were selected from the American Ephemeris and consequently consisted of stars having well-determined positions. A few stars that came into the field of the telescope during the observations were pointed upon and later identified and used in the calculations. The limit of time and difference of declination adopted by the United States Coast and Geodetic Survey for high-power telescopes were extended to half an hour in time and half a degree or more in declination. As the eyepiece of the writer's broken telescope was firmly held by the supporting Y, four pointings on each star were made instead of only one, with an increase in accuracy.

Great care was taken to protect the latitude level from the heat of the observer's body. A cardboard disk was placed in front of the level so that direct radiations from the face would not strike it. The reading lamp was never brought within 4 feet of it.

Field calculations were made by using extrapolated values given in an ephemeris of the previous year. The final calculations were made by Miss S. Beall, of the United States Coast and Geodetic Survey. All the observations were calculated for a single micrometer value, but as the writer was compelled to take the eyepiece out several times during the period of observations for the purpose of removing the accumulated frost, each change introduced a different value. With an objective of only 12 inches focal length a very slight change in the position of the micrometer diaphragm introduces a considerable change in the value of one turn. By dividing the observations into four groups and using four values instead of one, the probable error was made smaller, but the mean was unchanged.

The value used by the United States Coast and Geodetic Survey for one-half turn was 85.346″. Those used by the writer were 85.397″, 85.244″, 85.211″, and 85.346″. The Coast and Geodetic Survey's probable error for the result is ±0.11″, and the writer's is ±0.08″. For a single observation the Coast and Geodetic Survey gives ±0.8″ and the writer ±0.6″.

Below are given the results, by pairs, of the observations, which have been corrected for micrometer values by the writer.

Post A is 54 meters south of pier II, the permanent latitude station.

The correction to the latitude of post A is +1.8″, which gives a deduced latitude for the the permanent station of 70° 11′ 10.0″.

The difference of 2″ between this value and that found by the zenith-telescope method, is probably due to errors in graduation of the vertical circle of the altazimuth.

A few astronomical observations were made in other localities with the altazimuth before it was decided to control the surveys by triangulation.

At Ned Arey's house, in the Okpilak-Hulahula delta, the latitude by 16 observations on north and south stars was found to be 70° 04′ 49.2″±0.8″. In the bed of the creek that enters the Hulahula from the east, just north of the mountains, the latitude found by observing Polaris ex meridian was 69° 30′ 00″±05″. A short distance above the forks, at the headwaters of the same river, it was found by the same method to be 68° 51′ 20″±05″. The southwest peak of Mount Chamberlin was roughly in azimuth N. 25° 14′ W. from this place.

Observations for latitude.

No. of pair.	Name of pair.	Number of observations.	ϕ	v	v^2	w	$w\phi$	wv^2
			° ′ ″					
1	α Ursae Majoris; λ Pegasi	2	70 11 12.6	0.6	0.36	1.5	3.9	0.54
2	α Ursae Majoris; τ Pegasi	2	12.8	0.8	0.64	1.5	4.2	0.96
3	α Ursae Majoris; ν Pegasi	2	12.2	0.2	0.04	1.5	3.3	0.06
4	A Tauri; η Draconis	9	12.4	0.4	0.16	8.0	11.2	1.28
5	β Tauri; ω Draconis	4	12.3	0.3	0.09	5.0	11.5	0.45
6	δ Draconis; Pollux	7	11.6	0.4	0.16	3.5	5.6	0.56
7	δ Draconis; 60 Geminorum	5	12.1	0.1	0.01	3.0	6.3	0.03
8	δ Draconis; 64 Geminorum	2	13.2	1.2	1.44	1.5	4.8	2.16
9	δ Draconis; 59 Geminorum	1	11.7	0.3	0.09	0.7	1.2	0.06
10	δ Draconis; 65 Geminorum	1	12.5	0.5	0.25	0.7	1.8	0.18
11	11 Ursae Minoris; o Persei	4	11.8	0.2	0.04	5.0	9.0	0.20
12	γ Ursae Minoris; ξ Persei	6	11.6	0.4	0.16	4.0	4.6	0.64
13	11 Ursae Minoris; ξ Persei	2	12.0	0.0	0.00	2.0	4.0	0.00
14	γ Ursae Minoris; o Persei	1	13.2	1.2	1.44	1.3	4.2	1.87
15	χ Aurigae; ψ Draconis	1	11.3	0.7	0.49	1.3	1.7	0.64
16	χ Aurigae; ψ^2 Draconis	1	12.8	0.8	0.64	1.3	3.6	0.83
17	Polaris; η Ursae Majoris	2	11.0	1.0	1.00	3.0	3.0	0.00
18	ι Cassiopeiae; ϵ Bootis	1	11.8	0.2	0.04	1.3	2.3	3.39
19	48 Cephei; μ^1 Bootis	1	11.4	0.6	0.36	1.3	1.8	0.47
20	α Draconis; 5 Ursae Minoris	1	12.7	0.7	0.49	1.3	3.2	0.64
						48.7	99.2	14.96

$$e\phi = \pm \frac{0.455 \times 14.96}{19 \times 48.7} = \pm 0.08''$$

$$\phi = 70° \, 11' \, 12.04'' \pm 0.08''.$$

During the winter of 1906–7 latitude observations were made with the small altazimuth at post A, about 60 meters south-southwest of pier II, which was used later for the more accurate observations. The observations were all taken at culmination, and on only one night were they secured on stars both above and below the pole.

Observations for latitude with the altazimuth at post A.

Date.	Star.	Number of observations.	Latitude.	Probable error for night.	w	$w\phi$	v	v^2	wv^2
			° ′ ″	″		″			
Dec. 26, 1906	Polaris N	8	70 11 07.6	±2.9	1	07.6	0.6	0.36	0.36
Jan. 1, 1907	do	8	09.1	±1.8	2	18.2	0.9	0.81	1.62
Jan. 20, 1907	do	8	07.9	±1.2	4	31.6	0.3	0.09	0.36
Do	α Cassiopeiae S	4		±1.7					
					7	57.4			2.34

Resulting latitude for post A=70° 11′ 08.2″.

Probable error of $\phi=\pm\sqrt{\frac{0.46\times 2.34}{2\times 7}}=\pm 0.3''$.

OBSERVATIONS FOR TIME.

The observations for local time during the years 1906–1908 were made with the small altazimuth instrument previously described. During the first year a sidereal watch was used for noting the time, and this was compared, before and after the observations, with the ship's chronometer. During the second winter this chronometer was regulated to keep within a few seconds of sidereal time in the house, but its temperature coefficient was so great that it had a rate of about 25 seconds in the observatory, where the temperature varied between −13° F. and −31° F. Here the time was noted by the ear.

The time obtained by using the watch could not be brought within less than a whole second of error, but by using the chronometer a probable error as small as ±0.2 second was sometimes obtained.

During the years 1909–1912 a Negus break-circuit sidereal chronometer, well insulated, was used, and the time was recorded upon a small chronograph. The observations were made with the universal instrument of 12-inch focal length. The accuracy thus obtained, as calculated by Mr. Duvall, of the United States Coast and Geodetic Survey, for the longitude, runs from ±0.04 second to ±0.16 second, according to the number of the stars observed and the success of the writer in overcoming the effects of the cold.

OBSERVATIONS FOR AZIMUTH.

Several sets of observations for azimuth were made on the different marks employed, but the results of only the last two nights have been used. Their greater accuracy resulted from increased skill, as the difficulties of observing in cold weather were overcome. The level corrections were large, but of opposite signs on the two nights, so that any errors of level correction tend toward elimination. The close agreement of the two nights shows that the adopted level value was nearly correct.

The scheme of observations was adopted from the United States Coast and Geodetic Survey. A set consisted of four micrometric pointings upon the mark and four upon the star, reversal, and then four pointings on the star and four on the mark. The level was read in both positions. Each set required about 10 minutes, so that it was possible to secure six sets during the hour that Polaris was in the field at upper culmination. No observations at elongation were made, for there were no means of comparing the azimuth thus found with the north mark, whose azimuth was desired chiefly for correcting observations for time. The resulting azimuth found at upper culmination was of a higher order of accuracy than was necessary for the purposes of triangulation. As the north mark could not be made permanent, it was compared micrometrically with a mark 2½ miles to the south, which was within the field of the telescope.

The calculations were made by the writer, but they have not been checked, so that small errors may exist. The final result probably does not contain errors of magnitude sufficient to impair the accuracy either of the observations for time or the triangulation.

Observations for azimuth on Polaris at upper culmination.

Jan. 29, 1912.

Set	Mark west of north.
	"
II	10.4
III	5.9
IV	6.1
V	8.2
Mean	7.6±0.8

Jan. 30, 1912.

Set.	Mark west of north.
	"
I	6.1
II	7.9
III	6.6
V	8.1
VI	5.7
Mean	6.9±0.4

Final azimuth, north mark west of north=7.2″±0.3″.

Azimuth of south mark, east of south=81.8″±0.3″.

OBSERVATIONS FOR LONGITUDE.

Greenwich time was ascertained by 11 lunar occultations. The calculations, made by Mr. C. R. Duvall, of the United States Coast and Geodetic Survey, are given below.

The first four observations were made with a faulty 2-inch telescope and timed by an adjacent chronometer. Although they were taken under much less favorable circumstances than the later ones, their agreement is of the same order.

The last seven occultations were observed through an excellent 3-inch telescope, stably mounted, and the time was recorded upon a chronograph. Local time was obtained by a small transit instrument and compared with an excellent and well-protected chronometer by means of the chronograph. Nevertheless, the errors in the moon's position have such a controlling effect upon the deduced longitude that these more refined observations did not produce results noticeably superior to the earlier and less accurate ones.

In the field the occultations were weighted from ½ to 4, according to the conditions under which the observations were made. After finding that the errors in the ephemeris were so large and so uncertain that their effect was far

Longitude from occultations.

No.	Date.	Star.	Longitude.	Correction.	Corrected longitude.	v.	v^2.
			h. m. s.	*s.*	*s.*		
1	Jan. 22, 1907	*f* Tauri	9 44 28.2	− 6.2	22.0	(a)	(a)
2	Jan. 11, 1908	μ Ceti	19.8	− 5.9	13.9	3.1	9.6
3	Jan. 13, 1908	δ^1 Tauri	16.6	− 7.6	9.0	1.8	3.2
4	do	δ^2 Tauri	19.4	− 8.3	11.1	0.3	0.1
5	Jan. 20, 1910	ω Tauri	23.7	−15.2	8.5	2.3	5.3
6	do	227B Tauri	22.0	−14.6	7.4	3.4	11.6
7	Feb. 16, 1910	ω Tauri	26.5	−13.1	13.4	2.6	6.8
8	do	224B Tauri	22.8	−13.5	9.3	1.5	2.2
9	do	227B Tauri	26.2	−12.2	14.0	3.2	10.2
10	Feb. 7, 1911	72 Tauri	27.3	−18.4	08.9	1.9	3.6
11	do	125 Tauri	29.5	−17.4	12.4	1.6	2.6
	Mean				10.8		
	Total						45.2

[a] Rejected.

$$\text{Probable error of one observation} = \tfrac{2}{3}\sqrt{\frac{45.2}{9}} = \pm 1.50^s.$$

$$\text{Probable error of resulting longitude} = \pm\sqrt{\frac{1.50}{10}} = \pm 0.47^s.$$

$$\text{Longitude} = 9^h\ 44^m\ 10.8^s \pm 0.47^s = 146^\circ\ 02'\ 42.0'' \pm 7.0''.$$

greater than the errors of observation, the observations were all given equal weight.

In the table on page 35 are given the results of Mr. Duvall's calculations, corrected for the tabular errors of the moon's position obtained from the United States Naval Observatory.

TRIANGULATION.

The writer at first decided to control the map by stadia traverses supported by latitude and azimuth observations. Some work was done upon this scheme, but he decided that it was not sufficiently accurate for the scale upon which the topography was drawn. Then he decided to execute a triangulation of the coast, and attempted to attain the degree of accuracy demanded by the United States Coast and Geodetic Survey for tertiary triangulation.

About 150 miles of coast line have been thus covered, and in addition sufficient mountain peaks have been located to control the topography of an area about 70 miles square. There are 51 stations in the main scheme. The geodetic positions of 47 stations have been calculated and are given below.

All the calculations have been made by the writer, and they are unchecked, except those of the base line.

The positions of the stations may be seen in the accompanying map of the triangulation scheme (Pl. X, in pocket). The heavy lines indicate surveys made in both directions; the half heavy and half broken lines indicate observations made in only one direction.

The work was divided into four parts, comprising the base net at Flaxman Island, a series of complete figures running westward along the coast to Oliktok, the location of mountain peaks from points near Flaxman Island, and a series of simple triangles along the coast to the east, which should pivot on a single mountain station. The three first divisions were completed, but the fourth could not be carried out. Instead, a few points were located on the coast east of Flaxman Island by the three-point method.

BASE LINE.

In the winter of 1911–12 a base was measured in both directions between Flax and North stations. The 50-meter steel-wire tape loaned by Prof. S. W. Stratton, Director of the Bureau of Standards, was used. The odd meters were determined by a 15-meter Keuffel & Esser steel tape. Two thermometers fastened to the tape were read as each length was laid off, but the readings of one of them by the assistant were rejected because of confusion. The zero points were ascertained to be correct to within 0.1° C., but no calibrations were made.

The first 500 meters north of Flax were measured over sloping tundra; then came 800 meters over lagoon ice; then 50 meters over a sand spit. The whole distance was taped upon the surface of the ground, with the exception of one catenary over the sand spit. On the tundra there were one or two tape lengths in which the tape ran over hummocks less than 1 foot high, but the ice was quite level.

The measurements were recorded upon a board stamped into the snow. The assistant, a white man, set the rear end of the tape upon the mark. An Eskimo set the tension handle at the amount indicated by a piece of string tied around the scale, and the writer marked the position of the forward end of the tape.

The 50-meter wire tape was calibrated in 1907 and 1915, before and after the field work, at the National Bureau of Standards, and a shrinkage of 2.8 millimeters was found to have occurred during the six years that the tape was kept in the Arctic regions. The measurement of the base line was made at about the middle of this period. Tapes may become expanded by the tension employed while using them, but this contraction is not understood. It seems best to assume a uniform contraction with time, rather than any sudden change. The uncertainty in the tape length thus introduced is about 1 part in 40,000, which is much larger than that of the field measurements of the base line. There were several sections, measured at different times. The chief section is C–D. Below is given an abstract of the measurement. The calculations have been checked at the office of the United States Coast and Geodetic Survey.

Flaxman Island base line.

	Meters.
Length of section C–D, measured from south to north	1, 327. 176
Length of section C–D, measured from north to south	1, 327. 151
Mean length, uncorrected	1, 327. 164
Temperature correction (T=—20.1°C.)	—0. 617
Tape correction (assumed = —0.0014)	—0. 036
Grade correction	—0. 040
Corrected length of section C–D	1, 326. 471
Section Flax–A	+0. 012
Section A–B	+13. 935
Section B–C	+0. 030
Section D–North	—0. 025
Length of base line, Flax–North	1, 340. 42

BASE NET.

The base net at the island contains six stations from 1 to 3 miles apart. Posts were erected to support the theodolite and to act as signals for the longer lines. On the short lines a headless nail projecting from the center of the post marked the station. The theodolite could be centered accurately over this nail by means of a hole in the center of the base plate. The signals consisted of short sections of broom handles. Each signal had a hole bored in the center of one end, so that it could be slipped over the nail and plumbed.

The base-net stations were occupied in the winter of 1911–12, but such large closures were found, owing chiefly to eccentricity of both instrument and signals, that the work was done over again much more carefully while the writer was on the island in the fall of 1913. About 12 sets of directions were made at each of the stations, using six positions of the circle. The first six sets were not up to the writer's expectations, so the instrument was overhauled and six more sets were observed. As these sets were more accurate, they were given twice the weight of the earlier sets.

The base net contained 10 triangles with an average closure of 2″. In order to occupy his mind, after the light had become too dim for field work the writer adjusted the base net by the method of least squares. There were 10 condition equations. The probable error of a direction was ±0.70″ and the maximum error —1.75″. The accuracy of the base net is about that of the secondary triangulation of the United States Coast and Geodetic Survey.

BASE NET TO OLIKTOK.

A triangulation scheme of about 16 figures was drawn up for the coast west of Flaxman Island, in which the strength of the figures and the number of figures between bases were arranged in accordance with the requirements of the United States Coast and Geodetic Survey. The lines averaged about 5 miles in length. Owing to the loss of some signals during gales, and also to bad weather, a few of the figures were altered. Most of the stations were occupied, but owing to different causes not all the lines were observed in both directions. Each figure has at least one triangle with all the angles observed, except the westernmost figure, where the observations over one line were rejected owing to a blunder. The writer endeavored to measure another base line at the west end of the triangulation chain but did not succeed. The sum of R_1 for the 12 figures of this portion of the triangulation is 250. If the Kup-Ret-Bee figure had been completed there would have been 14 figures with $\Sigma R_1=200$.

A strong 3-sided central-point figure was planned between the Kup-Ret and Kup-Bee lines, but it could not be completed. Sufficient stations were occupied in the vicinity, however, to enable the writer to form a weak 7-sided center-point figure around Kup. The side equation of this figure gave a difference of 640 in the sixth decimal place. The discrepancy was found to be best corrected by postulating a blunder of 2′ in one of the angles. This reduced the discrepancy to about 90.

The 3-sided center point figure, Kup-Ret-Black, needed observations over only one line, Bee-Ret, for its completion, but this work remained unaccomplished. It snowed while the writer was at the Return mound, so that no observations could be made from this station. Then he camped on the coast near Kup for several days without being able to get angles upon Ret from Kup. Lack of provisions forced him to abandon the attempt for that season.

In April, 1914, the writer again sledded into Ret station, and as he was not able to see more than one other station through a haze, he built a snow house and remained overnight. The next day it was blowing hard and the weather was thick, so he returned to the coast without getting any sights. He hoped that the line Bee-Ret could be observed while he was on his way westward to secure passage home on a ship from Barrow, but he was detained so long by the ice near Flaxman Island that it did not seem advisable to stop for the length of time necessary for these observations.

At most of the stations two sets of directions were observed, one set being a series of pointings from left to right and the other set a series back again to the initial station. At a few places bad weather prevented the observation of more than one set.

The theodolite was supported by a frail tripod. When the sun was shining, a shade was rigged up out of a sled sail, but it often blew down. The signals were of driftwood, mostly poles with cross bars. They were often tilted by the wind so that the center of the station was indefinite. On the mounds tripods of logs were used and the resulting signal was very indefinite. Some native signals, irregular and tilted, were also used. In view of the shortness of the lines, the irregularity of the signals, and the uncertainty as to the eccentricity of the instrument when near an irregular signal, an average closure of 6″ is better than the writer expected.

Most of the stations were occupied during the winter, so that it was difficult to sink a subsurface mark very deeply. A hole was chopped into frozen muck or gravel to a depth of perhaps a foot, and a stone or a piece of lead was thrown in and the hole was filled again.

MOUNTAIN STATIONS.

The positions of half a dozen mountain peaks were desired for the purpose of controlling the inland topography. It was hoped that at least one of these peaks could be seen from the 141st meridian, so that the writer's survey could be tied to that of the Boundary Survey. A mound about 20 miles inland on Canning River, visible in clear weather, was selected for an intermediate station between Flax and the mountains. Owing to the nature of the country, the writer did not succeed in getting a strong connection with the mound. However, by executing the work with the same degree of accuracy as that of the base net, it is believed that the inland stations are located within limits allowable for the scale of the map.

TRIANGULATION EASTWARD.

A scheme was drawn up for covering the coast as far as Barter Island by a succession of simple triangles pivoting around Weller Peak. This scheme broke down in several places, but observations upon the three best-located peaks are thought to give the locations of the coastal stations with sufficient accuracy.

MINOR LOCATIONS.

From the stations occupied minor directions were observed upon posts and beacons erected for the purpose of controlling the topography. In this way the islands were located. The smaller ones had a single point and the larger ones two or three points thus controlled by the triangulation. The islands in the McClure group are weak in location, for their beacons were not visible from the mainland in the winter. A single bearing was secured from Pole Island, and then the positions were fixed by plane-table lines between the islands themselves and to portions of the mainland.

It was impossible to locate Cross Island. Anxiety Point was occupied three times in the winter and once in the summer, but Cross Island was never seen. The glare when the snow is on the ground makes distant signals very faint, especially the driftwood signals, which are so light in color as often to be indistinguishable against a light background.

A single bearing upon Reindeer Island of the Midway group was secured by mounting the theodolite on a 10-foot post on Stump Island. This bearing and the estimated directions and distances are all that could be employed in locating both the Midways and Cross Island. It is believed that their positions are correct within a mile or two.

LIST OF TRIANGLES.

The following table shows the error of closure of the triangles, the corrections from adjustment, and the corrected spherical angles:

Tables of triangles.[a]

Base net.

Station.	Error of closure of triangle.	Corrections from adjustment.	Corrected spherical angles.
	″	″	° ′ ″
Flax		+0.4	46 31 44.0
Northwest	+2.6	+1.3	50 37 58.8
North		+1.9	82 50 17.2
Flax		+0.1	77 50 22.1
North	+1.3	+0.1	55 16 41.8
Grave		+1.1	46 52 56.1
Flax		+0.5	124 22 06.1
Northwest	−0.8	+0.6	25 50 30.9
Grave		−1.9	29 47 23.0
North		+2.0	138 06 59.0
Grave	+5.7	+3.0	17 05 33.1
Northwest		+0.7	24 47 27.9
Flax		−0.9	102 08 08.0
Grave	−2.8	−0.1	59 19 13.5
South		−1.8	18 32 38.5
Northwest		−0.9	33 10 15.4
Flax	+1.2	+0.4	133 29 45.9
South		+1.7	13 19 58.7
Northwest		−0.3	59 00 46.3
Grave	−2.4	−2.0	89 06 36.5
South		−0.1	31 52 37.2
Northwest		−0.3	102 50 29.6
Grave	−2.6	−2.0	48 27 15.5
Rack		−0.3	28 42 14.9
Grave		0.0	40 39 21.0
South	−0.1	−0.4	86 23 46.7
Rack		+0.3	52 56 52.3
Northwest		0.0	43 49 43.3
South	−0.3	−0.3	54 31 09.5
Rack		0.0	81 39 07.2

	″
Maximum correction to an angle	+3.0
Mean error of an angle, $\sqrt{\frac{\Sigma\Delta^2}{3n}}$	±1.5
Average closure of the 10 triangles	1.98

Base net to Olik-Thetis.

Stations.	Observed angles.	Closure.	Corrected angles.
	° ′ ″	″	″
Northwest	38 29 04		03
Rack	99 02 10	− 3	09
West	42 28 49		48
Northwest	33 08 35		36
West	88 08 34	+ 4	36
No. 3	58 42 47		48
No. 3	84 31 29		28
West	60 42 59	− 2	58
Sweeney	34 45 34		34
No. 6	57 54 39		37
Sweeney	97 45 32	− 5	30
Bank	24 19 54		53
Challenge	65 00 13		14
Sweeney	47 56 32	+ 3	33
Bank	67 03 12		13
Challenge	37 55 46		47
Bank	100 41 28	+ 4	30
Mik	41 22 42		43
No. 15	26 17 37		37
Bank	49 36 03	+21	24
Mik	104 05 59		59
No. 15	72 53 02		00
Mik	57 53 33	− 6	31
Tig	49 13 31		29

Tables of triangles—Continued.

Base net to Olik-Thetis—Continued.

Stations.	Observed angles.	Closure.	Corrected angles.
	° ′ ″	″	″
Pole	64 59 36		38
Mik	38 15 36	+ 5	37
Tig	76 44 43		45
Tig	51 27 38		38
Shav	35 21 54	0	54
Ice	93 10 28		28
Tig	37 25 03		03
Shav	97 05 23	+ 2	24
Sako	45 29 32		33
Shav	21 04 30		32
Sako	132 08 32	+ 6	34
Anx	26 46 52		54
Anx	62 49 31		31
Sako	60 25 43	0	43
Poto	56 49 46		46
Anx	121 13 04		05
Sako	22 56 28	+ 2	28
Howe	35 50 26		27
Anx	58 23 33		36
Poto	39 21 28	+10	31
Howe	82 14 49		53
Howe	46 24 23		26
Sako	37 29 15	+ 8	17
Poto	96 06 14		17
Howe	32 27 39		41
Y	50 34 03	+ 7	05
Heald	96 58 11		14
Heald	80 53 34		32
Y	47 41 15	− 5	14
Gull	51 25 16		14
Gull	42 03 51		52
Y	84 36 36	+ 5	38
Prudhoe	53 19 28		30
Y	81 52 50		49
X	73 31 10	− 3	09
Prudhoe	24 36 03		02
Gull	50 53 08		12
Prudhoe	51 59 21	+12	25
Cent	77 07 19		23
Gull	29 17 10		08
Cent	114 34 46	− 7	43
Kup	36 08 11		09
Egg	153 46 20		21
Kup	12 34 20	+ 3	21
Long	13 39 17		18
Long	99 31 58		56
Kup	52 35 40	− 6	38
Bee	27 52 28		26
Long	126 09 49		49
Bee	28 40 47	+ 4	47
Cot	25 09 20		24
Long	26 37 51		51
Bee	36 15 35	+24	35
Cot	117 06 10		34
Cot	91 56 50		64
Kup	23 54 53	+14	53
Bee	64 08 03		03
Cot	76 43 15		16
Bee	47 29 40	+ 1	40
Bod	55 47 04		04
Bod	117 48 54		53
Bee	28 12 12	− 3	11
Leavitt	33 58 57		56

	″
Average closure of the 29 triangles	6.0
Maximum closure of the 29 triangles	+24

[a] Spherical excess negligible.

Where the closures were small, as in most of the triangles, the corrections were made by dividing the closure equally among the three angles. Where the closure was large, side equations were formed, and the corrections were made by inspection.

In the 14 strong figures west of Flaxman Island the average difference, in the sixth decimal place, between the logarithms of the farther side, found by two paths, is 8. In the two weak figures, due to failure to complete the proposed scheme, the difference between the logarithms is 126 and 90. The average difference for the 16 figures is 20.

STATIONS.

The stations occupied in the triangulation work are described as follows:

Flax.—The astronomical station at Flaxman Island. The mark is a barrel set partly into the ground and filled with concrete. A screw was set into lead in a 2-inch hole in the center of the surface of the pier to mark the center of the station. This hole was then filled with plaster of Paris. The reference mark is a concrete pier with a hole drilled into the top. Its distance is 10.935 meters to the north, in azimuth 180° 00′.

Northwest.—A temporary station at the northwest corner of the tundra portion of Flaxman Island, on a small mound about 13 meters from the bank.

North.—A temporary station on the spit north of the island. It was the north azimuth mark, and also the north end of the base line.

Grave.—A temporary station upon a slight mound, perhaps a hundred yards from the bank, on the east side of the bay east of Flax.

South.—A station on the mainland south of Flax, marked by the center of a post (part of a ship's boom) about 30 yards from the bank. The reference mark is a concrete-filled kerosene tin, flush with the ground, north of the station. A hole drilled into the southwest corner of the surface is 1.463 meters distant from the station in azimuth 179° 59′.

Rack.—A temporary post on a sand spit on the mainland southwest of Flax. There was a native rack on the tundra, about a hundred yards to the east.

Kug.—A station on the top of a boulder-covered mound at the northern edge of the upland, about 20 miles up Canning River. A hole was drilled into the top of a boulder, which was flush with the surface of the ground, and a galvanized spike was driven into the hole. Over this mark boulders were piled to a height of 3 feet.

Brown.—A station at Brownlow Point, on a mound about 4 feet high near the western bank, about 300 yards from the point where the spit joins the mainland. The station is marked by a post. The reference mark is a shallow hole drilled into a greenstone boulder, 4.18 meters distant in a line 82° to the left of Flax.

West.—A station on a small sand island close to the mainland about 4 miles west of Flax. It is near the west end of the island at its widest part. A malted-milk bottle was placed about 2 feet underground and a post was centered over it.

No. 3.—A temporary station on a shoal running southeast from Island No. 3.

Sweeney.—A station at Point Sweeney, on the mainland about 8 miles west of Flax. About a hundred feet from the apex of the point. A layer of small stones was placed about 2 feet underground and a post was centered over it.

No. 6.—A station located near the center of Island No. 6. The top of an inverted stump, tilted toward the west, marks the station. No permanent mark.

Challenge.—A station on the north side of Challenge Island. The mark was washed away in 1912–13 and could not be recovered.

Bank.—A station near the east end of the high bank south of Challenge. A greenstone with a hole drilled into it was placed about 1½ feet underground, and a beacon was centered over it.

Mik.—A station at Bullen Point at the base of the spit. The station is on the first gravel heap about 200 yards from the north shore and close to the beach on the west side. A malted-milk bottle 1½ feet underground marks the station.

No. 15.—A station on Belvedere Island of the McClure group, near the south side. No permanent mark.

Pole.—A station near the west end of Pole Island marked by the bottom of a tilted native pole.

Tig.—A station near the north bank of Tigvariak Island. The top of a tilted native pole was observed. A milk bottle a few inches underground, about a meter to the northwest of the base of the pole and approximately under its top, marks the station. Reference mark, a post 1 meter distant in a line 102° to the right of Shav.

Shav.—A station on top of a conspicuous mound about 5 miles from the coast southwest of Tig. There are three depressions and four elevations which trend about east-northeast across the more or less flat top. The station is on the elevation south of the central depression. A yellow metal spike was placed about half a foot underground and cobblestones were piled over it to mark the station.

Kad.—A station on the top of a 200-foot mound about 12 miles from the coast on Kadleroshilik River. From a distance two projections are seen to rise above the general level of the top. The center of the northeast cone-shaped projection is the station. Here a quartzite stone about 12 by 8 by 6 inches, with a hole drilled in it, was placed about a foot below the surface, and large cobblestones were placed over it.

Ice.—A temporary station on an ice hummock in Foggy Island Bay.

Sako.—A station on top of a 30-foot mound near the east mouth of Sagavanirktok River, about a mile from the coast. A few small stones were placed about 1½ feet below the surface of the ground.

Anx.—A station at the north end of Foggy Island, which was thought to be Anxiety Point. The station is near the west bank, near a low grassy mound.

Half a dozen fish-net weights of horn were placed about 2 feet underground.

Poto.—A station on a small silt dune, near the juncture of the eastern channels of Sagavanirktok River. A few twentypenny nails were driven into the ground to mark the station.

Howe.—A station at Anxiety Point, the eastern and highest part of Howe Island. The station is on the highest spot, close to the bank at the southeast corner. It is marked with a 15-foot beacon; no subsurface mark.

Heald.—A station at Heald Point, about 400 yards from the apex and 10 meters from the north bank. The subsurface mark is a fragment of pink granite(?). Over this mark a rounded pink quartzite stone is placed. The reference mark is the southwest stump of a native rack, distant 1 meter, in a line 47° to the left of Howe.

X.—A station on the top of the central dune of a row of half a dozen small grassy silt dunes, the last outliers to the south on the west bank of the west mouth of Sagavanirktok River. A piece of crystalline rock about 8 inches in diameter was partly sunk into the ground to mark the station.

Y.—A station on the highest of a small group of outlying silt dunes to the west of Sagavanirktok River. They are about 3 miles from the coast at the south side of a drained lake. A native reports that he placed a stone and some empty rifle shells in the ground when he erected the signal.

Prudhoe.—A station on top of a 30-foot mound about 3 miles inland from the lower end of Prudhoe Bay. The station is near the southwest side of the more or less flat top of the mound. A piece of lead was placed 6 to 8 inches underground and covered with cobblestones.

Gull.—A station on Gull Island in Prudhoe Bay. The beacon will probably be washed away. No subsurface mark.

Cent.—A station about 3 miles from the west side of Prudhoe Bay, on a grassy hummock about 2 feet high on the tundra west of a large pond. A large nail and a piece of lead were driven about 6 inches into the ground.

Kup.—A station on the top of a 30-foot mound, near the coast on the east side of Gwydyr Bay. It lies at the head of slack water in Fawn Creek. The top of a tilted beacon was observed. Two copper nails and a piece of lead were placed under the center, about 15 inches underground, and a pink quartzite stone, 10 to 12 inches in diameter, was placed over them, so that its surface was nearly flush with the ground.

Stump.—A station on Stump Island, about 3 feet southeast of an old native signal consisting of an inverted stump about 15 feet high. Subsurface mark, a piece of native blubber lamp with a hole drilled in it, about 2 feet underground. A post was centered over this mark.

Egg.—A temporary station on Egg Island, erected after the original station had been washed away.

Return.—A station on the top of a 60-foot mound about 8 miles inland, on the east side of Kuparuk River. A piece of lead about a foot underground, with a 6-inch stone over it, marks the station.

Black.—A temporary station on the apex of a sharply ridged silt dune in the Kuparuk delta. The highest part of the northernmost row. About 3 miles from Kup.

Long.—A station on Long Island near the east end, where it bends to the southeast. The station was washed away during a storm, and a spit was built out at the same place.

Gwydyr.—A station on the west side of Gwydyr Bay, close to the bank, at a point about 3 miles east of Beechey Point. A post of an old rack cut off at the ground marks the station.

Cot.—A station on the eastern tundra lump of Cottle Island, near the south corner, about 32 feet northwest from two low grassy hummocks. A vertebral disk of a whale was placed about 2 feet underground, and a beacon was centered over it. A post was erected 3 or 4 feet to the southeast, but the distance and bearing were not noted.

Bee.—A station on the top of a 60-foot mound about 4 miles back of Beechey Point. A post was erected near the middle of the top by a native boy.

Bod.—A station on Bodfish Island, at a hummock on the south side near the west end. Marked by a vertebral disk of a whale about a foot underground, with a post centered over it.

Leavitt.—A station on Leavitt Island, at about the middle of the north side, on top of a grass-covered sand dune, which has buried an old native house, immediately over the bank. A piece of gray granite about 3 feet underground marks the station. This mound is the second from the east end of the island.

Jones.—A station on top of a 20-foot mound about a mile from the coast behind Leavitt Island. No subsurface mark.

Thetis.—A station on top of a 25-foot mound about 3 miles southeast of Oliktok. A malted milk bottle filled with stones was placed underground by a native for a subsurface mark.

Olik.—At Oliktok near the apex of the gravel point. A pink quartzite boulder 10 to 12 inches in diameter, with a hole drilled into it, about 2½ feet underground. Over this boulder was placed a square masthead about 4 feet high, painted white, with a yellow metal name plate. A signal was erected about 4 meters to the northwest in a line leading from Thetis.

Kong.—A station at Konganevik, in Camden Bay. The center of the highest part of a large angular greenstone boulder, which rises about 3½ feet above the level of the tundra. It lies about 250 yards from the southeast corner of the point and about 500 yards from the north side.

Col.—A station at Collinson Point near the point where the spit joins the mainland. The station is a 25-foot pole erected by the trader O'Connor, in 1912, about 20 yards south of his house. It is about 13 meters north of the latitude station of the Canadian Arctic Expedition, in 1913–14. No permanent mark.

Sad (Boy's stick).—A station at Point Anderson, where the spit joins the mainland. The mark is on the tundra close to the spit and to the sea cliff. No subsurface mark.

Arey.—A station 150 feet southeast of Ned Arey's old house in the Okpilak-Hulahula delta. Latitude observations were taken here. Not marked.

Barter.—A station on Barter Island, at the southwest corner of the upland, beyond which extends the low flat grassy part of the island. The subsurface mark is composed of a copper nail and a lead seine weight, with a quartzite stone 4 to 5 inches in diameter over them, about a foot underground. A beacon was erected over this mark.

Mount Salisbury.—A conspicuous snow-clad double-peaked mountain, about 70 miles south of Flaxman Island, on the west side of Canning River. The northeast peak was sighted upon.

Mount Copleston.—About 50 miles from the coast, at the west end of the Shublik Mountains. On the top, which is several hundred feet higher than its immediate surroundings, are two knobs. The highest part of the southeast knob was sighted upon.

Peak A.—A proposed plane-table station a few miles northeast of Mount Copleston. A projection rising above the general level of that part of the mountains was sighted upon.

Mount O.—An inconspicuous but definite peak on the north side of Sadlerochit Mountains.

Mount Weller.—A pyramidal peak about 20 miles south of Collinson Point at the head of Marsh Creek. It rises several hundred feet above its surroundings, so that it can be identified from all directions.

B_1 Hill.—A station on an outlying sandstone hill on the east side of the head of Marsh Creek. An 8-foot cairn was erected at the southwest corner of the top.

Mount Chamberlin.—A conspicuous glacier-covered double-peaked mountain, which rises 2,000 to 3,000 feet above its surroundings, at the head of Sadlerochit River. The lower northeast peak was observed.

Mount Michelson.—The highest of a group of two or three ice-covered peaks at the outside of the Romanzof Mountains, between Okpilak and Hulahula rivers.

TABLE OF POSITIONS.

The latitude and longitude of each point are given on the Flaxman Island datum. The position of the initial station, Flax, was obtained by astronomical observations. (See pp. 32–35.) The length and azimuth of lines between the stations are also given and the logarithms of the distances.

The last figure in the numbers is uncertain, with the exception of the logarithms, which are uniformly given to six places, although two of the figures may be uncertain.

A few unimportant stations, whose positions were unnecessary in the calculations, have been omitted.

Positions of triangulation stations in Canning River region, northern Alaska.

Coastal stations west of Flaxman Island.

Station.	No.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.	Logarithm.
		° ′ ″	° ′ ″	° ′ ″	° ′ ″		*Meters.*	
Flax	0	70 11 12.04	146 02 42.00	359 58 38.2	179 58 38.4	South	4,081.55	3.610825
				133 28 24.1	313 26 32.3	Northwest	1,720.28	3.235600
South	1	70 09 00.34	146 02 41.85	179 58 38.4	359 58 38.2	Flax	4,081.55	3.610825
				166 38 39.7	346 36 47.8	Northwest	5,411.50	3.733317
Northwest	2	70 11 50.22	146 04 40.81	313 26 32.3	133 28 24.1	Flax	1,720.28	3.235600
				346 36 47.8	166 38 39.7	South	5,411.50	3.733317
Rack	3	70 09 46.28	146 08 15.22	210 23 09.4	30 26 31.1	Northwest	4,453.82	3.648732
				292 02 16.6	112 07 30.2	South	3,787.62	3.578366
West	4	70 10 34.39	146 14 18.62	248 46 30	68 55 34	Northwest	6,513.2	3.813791
				291 15 18	111 21 00	Rack	4,104.1	3.613217
No. 3	5	70 12 41.22	146 16 30.24	281 83 02	102 04 10	Northwest	7,617.6	3.881817
				316 06 31	136 14 17	Rack	5,715.1	3.875935
Sweeney	6	70 11 14.46	146 25 40.36	244 58 39	65 07 17	No. 3	6,374.7	3.804460
				279 44 16	99 54 57	West	7,275.4	3.861855
No. 6	7	70 13 29.87	146 25 33.78	284 43 53	104 52 24	No. 3	5,901.4	3.770952
				307 23 26	127 34 01	West	8,938.0	3.951239
Challenge	8	70 14 20.26	146 36 10.27	283 04 41	103 14 40	No. 6	6,856.8	3.836120
				310 57 41	131 07 34	Sweeney	8,769.0	3.942950
Bank	9	70 10 40.90	146 39 15.20	238 38 23	58 51 16	No. 6	10,094.1	4.004068
				262 58 18	83 11 04	Sweeney	8,630.9	3.936057
No. 15	10	70 17 00.12	146 52 27.55	295 41 48	115 57 08	Challenge	11,372.7	4.055865
				324 37 35	144 50 01	Bank	14,395.1	4.158214
Mik	11	70 10 59.92	146 49 37.88	233 41 02	53 53 42	Challenge	10,510 0	4.021610
				275 03 49	95 13 35	Bank	6,574.7	3.817875
Tig	12	70 13 59.11	147 10 29.17	243 31 14	63 48 12	No. 15	12,644.1	4.101887
				292 44 42	113 04 19	Mik	14,266.1	4.154304
Kad	K	70 01 46.36	147 37 09.45	216 24 03	36 49 08	Tig	28,288	4.451603
				239 56 51	60 41 32	Mik	34,639	4.539564
Pole	13	70 18 13.34	147 01 21.08	292 03 44	112 12 06	No. 15	6,023.6	3.779858
				331 08 51	151 19 53	Mik	15,322.6	4.185336
Shav	14	70 08 13.14	147 25 46.20	221 50 22	42 04 55	Tig	14,419.4	4.158946
				256 57 25	77 31 24	Mik	23,402.7	4.369266

Positions of triangulation stations in Canning River region, northern Alaska—Continued.

Coastal stations west of Flaxman Island—Continued.

Station.	No.	Latitude.	Longitude.	Azimuth.	Back azimuth.	To stations.	Distance.	Logarithm.
		° ′ ″	° ′ ″	° ′ ″	° ′ ″		Meters.	
Sako	15	70 11 58. 40	147 41 46. 94	259 00 31	79 29 58	Tig	20, 064. 3	4. 302424
				304 30 02	124 45 08	Shav	12, 285. 4	4. 089389
Anx	16	70 17 11. 90	147 43 51. 55	325 32 39	145 49 40	Shav	20, 216. 2	4. 305703
				352 19 31	172 21 28	Sako	9, 802. 5	3. 991337
Poto	17	70 14 03. 42	147 57 99. 24	234 56 31	55 09 02	Anx	10, 195. 1	4. 008391
				291 41 17	111 55 45	Sako	10, 428. 2	4. 018210
Howe	18	70 18 35. 74	147 53 23. 98	329 14 06	149 25 02	Sako	14, 317. 0	4. 155852
				15 38 32	195 35 00	Poto	8, 762. 9	3. 942649
Y	19	70 17 26. 28	148 12 15. 87	259 32 35	79 50 21	Howe	12, 028. 2	4. 080201
				303 23 18	123 37 31	Poto	11, 388. 9	4. 056483
Heald	20	70 20 29. 81	148 07 13. 90	292 05 00	112 18 02	Howe	9, 359. 5	3. 971254
				29 03 14	208 58 30	Y	6, 504. 0	3. 813180
Gull	21	70 21 37. 29	148 16 28. 68	289 48 04	109 56 46	Heald	6, 152. 4	3. 789042
				341 13 18	161 17 16	Y	8, 215. 0	3. 914605
Prudhoe	22	70 16 34. 94	148 22 53. 82	203 11 07	23 17 10	Gull	10, 197. 4	4. 008487
				256 30 38	76 40 38	Y	8, 862. 2	3. 836464
Kup	23	70 23 11. 65	148 36 15. 97	283 08 50	103 27 28	Gull	12, 710. 0	4. 104143
				325 38 11	145 50 46	Prudhoe	14, 875. 5	4. 172472
Ret	24	70 17 27. 44	148 47 03. 78	212 16 43	32 26 53	Kup	12, 629. 5	4. 101386
				275 55 53	96 18 38	Prudhoe	15, 258. 7	4. 183518
Stump	25	70 24 27. 24	148 29 14. 97	303 19 44	123 31 46	Gull	9, 560. 6	3. 980484
				61 55 14	241 48 37	Kup	4, 967. 8	3. 696161
Long	26	70 27 48. 61	148 41 42. 72	308 41 16	128 53 01	Stump	9, 963. 2	3. 998399
				338 22 28	158 27 36	Kup	9, 230. 8	3. 965238
Bee	27	70 26 00. 92	149 06 19. 16	257 31 13	77 54 24	Long	15, 683. 6	4. 195443
				285 23 39	105 51 58	Kup	19, 471. 2	4. 289393
Cot	28	70 29 12. 30	148 57 56. 41	309 26 26	129 46 51	Kup	17, 531. 0	4. 243806
				41 23 30	221 15 36	Bee	7, 897. 8	3. 897503
Bod	29	70 30 59. 07	149 07 56. 73	297 57 20	118 06 46	Cot	7, 040. 9	3. 847627
				353 44 24	173 45 56	Bee	9, 295. 3	3. 968264
Jones	30	70 28 53. 74	149 22 25. 88	246 32 25	66 46 04	Bod	9, 801. 4	3. 991288
				297 58 35	118 13 46	Bee	11, 370. 4	4. 055774
Leavitt	31	70 32 31. 85	149 19 44. 24	325 21 05	145 33 44	Bee	14, 709. 1	4. 167586
				13 55 10	193 52 38	Jones	6, 963. 6	3. 842834
Thetis	32	70 27 43. 06	149 34 13. 31	225 02 08	45 15 47	Leavitt	12, 690. 5	4. 103479
				253 16 45	73 27 52	Jones	7, 654. 4	3. 883913
Olik	33	70 29 51. 76	149 42 12. 18	278 10 08	98 28 46	Jones	12, 419. 1	4. 094091
				308 43 27	128 50 58	Thetis	6, 367. 1	3. 803924
Coastal stations east of Flaxman Island.								
Brown	A	70 09 43. 93	145 51 25. 32	79 21 02. 4	259 10 26. 0	South	7, 250. 45	3. 860365
				111 04 28. 2	290 53 51. 6	Flax	7, 642. 60	3. 882217
Kong	B	70 01 39. 4	145 10 32. 5	289 36 39	109 56 09	Collinson	14, 031. 0	4. 147122
				357 59 03	178 01 21	Mount O	45, 057	4. 653764
Col	C	69 59 06. 2	144 49 47. 1	3 19 20	183 16 03	Weller	38, 906	4. 590016
				16 25 13	196 07 57	Mount O	41, 965	4. 622884
Sad	D	70 00 36. 9	144 29 20. 6	11 11 37	190 48 44	Chamberlin	82, 761	4. 917828
				30 18 37	209 42 14	Mount O	49, 760	4. 696880
Arey	E	70 04 49. 0	143 59 50. 0	21 47 23	200 56 49	Chamberlin	95, 846	4. 980574
				35 06 05	214 15 56	Weller	60, 147	4. 779215
Barter	F	70 06 12. 0	143 40 31. 6	27 52 22	206 43 42	Chamberlin	103, 100	5. 013262
				47 03 49	225 41 36	Mount O	77, 501	4. 889307
Inland stations.								
Kug	b	69 53 49. 34	146 18 01. 5	196 38 40. 9	16 53 05. 2	Flax	33, 747. 9	4. 528246
				209 32 34. 3	29 57 34. 4	Brown	34, 073. 9	4. 532422
Weller	c	69 38 12. 9	144 53 15. 5	118 40 22	297 20 50	Kug	61, 792	4. 790934
				148 03 02	327 08 24	Brown	67, 408	4. 841413
Mount O	d	69 37 26. 4	145 08 06. 0	124 37 53	303 32 17	Kug	54, 354	4. 735227
				155 33 46	334 53 05	Brown	66, 130	4. 820397
Chamberlin	e	69 16 55. 3	144 53 44. 7	142 05 44	320 46 45	Kug	87, 743	4. 943211
				159 42 11	338 48 05	Brown	105, 000	5. 021180
Peak A	f	69 32 35. 3	145 58 11. 7	162 12 17	341 53 41	Kug	41, 505	4. 618100
				183 32 43	3 39 05	Brown	69, 197	4. 840086
Copleston	g	69 30 20. 0	146 05 37. 3	169 42 26	349 30 48	Kug	44, 398	4. 647361
				186 58 34	7 11 54	Brown	73, 827	4. 868216
B_1 Hill	i	69 42 00. 7	144 47 38. 4	....	317 58 36	Flax	72, 385	4. 859649
					337 56 06	Kong	39, 361	4. 595070
Michelson	j	69 18 38. 3	144 15 43. 2	....	343 24 09	Collinson	78, 402	4. 894328
					6 56 18	Arey	86, 474	4. 936886

ELEVATIONS.

As the observations of vertical angles on the different peaks were taken at a distance from the mountains they do not give accurate values. In winter the refraction is sometimes so great as to distort the distant sky line into unrecognizable shapes. At Kug station, at an elevation of about 50 meters above the sea, the house on Flaxman Island, at sea level, had a zenith distance of less than 90°. On account of the low weight of such observations only a few were taken. Below are the resulting elevations.

Elevations of mountain peaks in Canning River region, northern Alaska.

	Meters.
Michelson from sea level at Arey	2, 816
Chamberlin, northeast peak, from Arey	2, 783
Chamberlin, southwest peak from Flax	2, 784
Weller from Arey	1, 500
Weller from Flax	1, 467
Salisbury, northeast, from Flax	2, 044

The southwest peak of Mount Chamberlin is from 50 to 100 meters higher than the northeast peak, so that 2,800 and 2,750 meters are better values.

TOPOGRAPHY.

The work of mapping the details of the topography was divided into two sections, that of the coast and that of the interior. The coastal work was done with great care and with as great accuracy as possible under the conditions. The interior mapping could not be brought up to the same standard, both from the inexperience of the writer and the difficulties under which he worked. The lines are drawn solid where they have been actually surveyed with an accuracy in keeping with the character of the map in which they appear. The lines that have been observed but not surveyed are drawn broken. Probable lines, chiefly derived from native information, are drawn dotted.

COASTAL TOPOGRAPHY.

This work was done with two grades of accuracy—(1) simple sketching of details along the route traversed by sled or boat and (2) plane-table work. The coast between Herschel Island and Flaxman Island was sketched during a sled trip in the fall of 1906. As the portion between Flaxman Island and Barter Island was afterward done in detail by the writer and that between Herschel Island and the 141st meridian by the Canadian Arctic Expedition, only the remainder, between the 141st merdian and Barter Island, is shown on the map in this report (Pl. III, in pocket).

Several sled and boat trips were made between Flaxman Island and Point Barrow, and many details, not shown on the existing charts, were sketched. A map of the coast line between Oliktok and Point Barrow was constructed by adjusting these details to the existing charts (Pl. III).

The topography shown on the large-scale maps (Pls. IV and V) between Barter Island and the Colville was drawn upon a small plane table, an open-sight alidade being used. The distances were determined by pacing. Numerous posts or beacons were erected, which were located by triangulation for the purpose of controlling the traverse. The field scale was slightly larger than 1:80,000. Two thousand paces, assumed to be 1 mile, were drawn equal to 2 centimeters on the sheets. The paces were counted by a pedometer, but as the hand which marked the hundreds of paces had much lost motion, a check was made by mental counting. In some places it is probable that there was a miscount of an even hundred, judging from the intersections on distant points. Where the coast was fairly regular and the walking was along a hard sand beach the intersections were very satisfactory, but where the traverse was along the top of an eroded bank the many detours interfered with accurate work.

These field sheets were entered upon an office map which had a scale of 1:80,000, and thus they had to be reduced slightly. This reduction was done by making a tracing of the sheet and adjusting this tracing to the office map by closely spaced offsets. The closures noted below are partly due to the larger scale and partly to errors of the paced distance.

The coast west of Flaxman Island had so many points located by the triangulation that there are not many places where stretches greater than 4 or 5 miles are uncontrolled. The weakest stretch is around the lower part of Mikkelsen Bay, a distance of about 10 miles.

Here there was a closure of about a mile, so this stretch was probably incorrectly mapped.

East of Flaxman Island there were few points of control, and so the map is correspondingly weaker. Between Brownlow Point and Konganevik, about 20 miles, the closure was half a mile. The area between the Hulahula delta and Manning Point was controlled by two micrometric base lines, so that it is fairly accurate.

Every line drawn solid has been actually paced or viewed from such a short distance that all the details were visible. Both sides of the narrower sand islands could be mapped from the middle, but on Pole and Cross islands both sides were paced. The outside of Long Island was paced, and frequent halts were made to sketch the details of the inside from places previously located. Some stretches where details could not be seen are drawn with broken lines. The outside of Leavitt Island was paced, and a part of the inner side sketched as in mapping Long Island. The Spy Islands were not paced, but good locations were secured upon beacons at their extremities, so that their position is fairly accurate.

No topographic line has been drawn solid to represent features which were viewed from snch a distance that details might be overlooked. In a westward extension of the topographic map of the Boundary Survey the east end of Icy Reef was drawn in solid lines upon a field scale of 1:45,000, as viewed from a distance of 1 or 2 miles. On the writer's map the east end of Stump Island has been drawn with broken lines, although it was camped upon, as well as viewed from the mainland about a mile away.

The coast line in the neighborhood of Collinson Point was mapped by the writer in 1912, with the exception of about a mile of the spit. In 1913 the topographers of the Canadian Arctic Expedition made a map of the same stretch and included a part of the interior. Their map, of about twice the scale of the writer's, has been reduced and entered upon his map. A tracing was kindly furnished and permission was given to use it. The portions common to both maps were practically identical.

Constant changes in the shore line are taking place, so that many of the details mapped by the writer will be lost within a few years. Even during his field work such changes were noticeable. The first beacon erected on Egg Island was entirely cut away and about a hundred yards was added to the west end of the island between 1911 and 1914. In addition, a new islet was built up north of the west end, so that there was difficulty in recognizing the locality. At the east end of Long Island the shore was cut back as far as the beacon erected for a triangulation signal between 1911 and 1913. In 1914 a spit about a hundred yards long had been built out at the same place.

In general, the sand islands are rather permanent, for driftwood in an advanced stage of decay is found on some of them, as well as grass and moss. Native houses that were ancient before the present inhabitants came into the country also are found on some of them.

INLAND TOPOGRAPHY.

In the map of the interior (Pl. I, in pocket) great accuracy has not been attained for either distances or elevations. The writer had had no previous experience in drawing contours, so that this work does not express the nature of the topography as well as it should.

On the first inland trip up Okpilak River a small plane table with a telescopic alidade was carried. This alidade had a micrometric eyepiece, with which the writer endeavored to get horizontal control by the erection of cairns a known distance apart, after the method employed by Peters in constructing his map of the Colville. Owing to various causes, complete control was not attained.

The telescopic alidade was too heavy for summer work, where everything had to be carried on the back, so it was discarded, and an open-sight alidade was used in mapping the Canning. The topography was drawn upon separate sheets at each station, with estimated distances and known horizontal angles. The vertical angles were estimated or determined by a hand clinometer. These separate sheets were afterward used to draw the office map by using as a base the distance apart of two peaks located from the coast and then proceeding by a triangulation worked out of the sheets themselves. Of course, this was a very rough method, but it was much the best under the circumstances. Some extra details were secured from ordinary photographs taken at the stations.

An attempt was made in the winter of 1910–11 to get a better control by a micrometric traverse with a 3-meter bar, but it was not successful.

Such a traverse was made on the lower 25 miles of Hulahula River and abandoned on account of continued bad weather. Some details were mapped at the headwaters of the same river by the use of this form of control, but they are not within the area embraced by the published map and so have been omitted.

While surveying Sadlerochit River the writer was greatly aided by a stenometer loaned by the United States Geological Survey. Several small sections were mapped from a base line measured in this way. The coordination between these separate portions when they were combined was very good. The topography around Lakes Schrader and Peters was mapped by a traverse paced upon the smooth ice of those lakes. The scale was checked by stenometric measurement.

The elevations shown by the contour lines are only approximate, for they are deduced from aneroid observations. On the Sadlerochit they may be considered to be most accurate, for the field barometric readings were compared with a series of readings taken by the writer's workman at Flaxman Island, more than 50 miles away. Elsewhere there were no corrections possible for the varying state of the atmosphere.

The ultimate control of the topographic map was secured by prominent peaks located from the coast. The mapping of the area within view of one or more of these peaks is probably fairly accurate as regards distances, but that of the area around the upper part of the Canning, which lacks any such control, may be faulty.

HYDROGRAPHY.

During the numerous trips of the writer's yawl between Flaxman Island and Point Barrow soundings were made, ordinarily at 15-minute intervals. In the open-boat journeys also as many soundings as possible were taken. In this manner about 1,500 recorded soundings have been made, mostly between Flaxman Island and the Colville. The soundings taken in boat trips close along the islands or the mainland are all easily located and can be entered with confidence upon the map. Many of those taken from the yawl during thick weather are doubtful. These soundings were first entered with as much accuracy as possible, and if there was any discrepancy between neighboring soundings they were erased. The soundings appear to be regular, except near the inside of the deeper entrances between the sand islands. The writer hoped to develop the topography of the bottom in important places but was unable to do so, except between Flaxman Island and the mainland.

In addition to the soundings alongshore, a line of soundings was made to the north at about the 150th meridian. No bottom was found at 300 fathoms at a distance of more than 50 miles from the shore.

METEOROLOGY.

Observations.—A series of daily observations, consisting of readings of the thermometer and barometer, direction and force of the wind, and notes upon the weather, was made by the officers of the ship at Flaxman Island for a period of one year in 1906–7. The records have not yet been worked up and hence are not available for publication.

Auroras.—Some notes on the auroras were entered in the meteorologic report. There was nearly always an irregular strip of greenish haze extending, according to the writer's memory, from southeast to northwest. Colors or noticeable motion were rare. Probably not more than half a dozen displays were sufficiently striking to cause general interest. The writer noticed on several cloudy moonless nights that almost as much light came through the windows as during the full moon. This light could only have come from the aurora.

Parhelia.—No paraselenae were noted, and only a few poorly developed parhelia were seen on the coast, but during a spring trip up Canning River, while camping for several days in the vicinity of Shublik Springs, the writer witnessed an almost constant display of parhelia. The steam from these copious springs filled the air with ice crystals during a spell of calm, clear weather. The most complete parhelia are shown in figures 2 and 3. In reading Hastings's textbook on light[1] the writer finds that the subject has been developed theoretically.

In Hastings's work[2] a rare feature is discussed. This has been described by several observers as a downward-facing semicircular arc, tangent to the circle of 22° around the sun. Hastings's calculations call for a parabolic arc at this place. In the sketches made by the writer this feature was drawn and noted to be a parabola. No measurements were made of the radii of the different arcs.

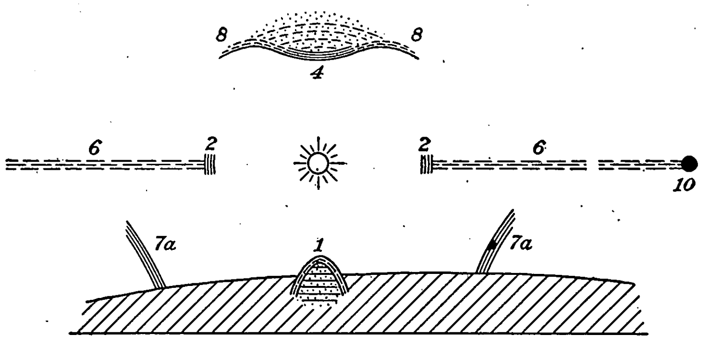


FIGURE 2.—Parhelia, Canning River, April 9, 1908, noon to 2 p. m. 1, Dazzling; a straw-colored parabola, white inside. 2, Brilliant; colored successively red, orange, blue, outward from sun. 3, Faint white arcs or complete circle of about 45° diameter; area within darker than that outside. 4, Brilliant; colored successively red, orange, and blue, outward from sun; straw and white, once noted here also. 5, Very faint colored, as in 2 and 4. 6, Faint white horizontal band, sometimes encircling the horizon. 7, Faint white circle of about 90° diameter. 7a, Bright; colored red, orange, green, blue, outward from sun. This part sometimes seemed linear and sometimes to be convex to the sun. 8, White. Above 4 and between the two wings, 8, the air was full of bright flashes of light from the nearer ice crystals. 9, White, vertical. 10, A faint white spot diametrically opposite the sun and at the same altitude.

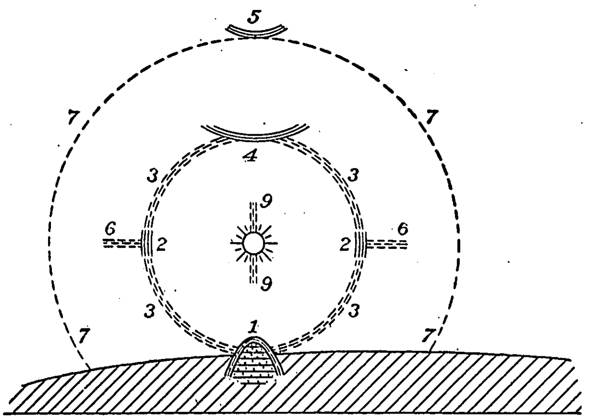


FIGURE 3.—Parhelia, Canning River, April 10, 1908, 2 to 6 p. m. For explanation see figure 2.

TIDAL OBSERVATIONS.

Hourly staff readings, supplemented by quarter-hourly readings near the times of high and low waters, were made by Capt. Mikkelsen for nearly three months during the fall of 1906. These records were eagerly seized upon by Dr. Rollin A. Harris, of the Coast and Geodetic Survey, and within a couple of months the calculations were finished. They have since been published.[3]

MAGNETIC OBSERVATIONS.

The writer had neither the instruments nor the time for comprehensive magnetic observations, but as he believed that even rough observations of the declination would be of value he made a few shortly before leaving the field. The bearing of the north mark was noted with two ordinary azimuth compasses. These compasses were afterward forwarded to the Coast and Geodetic Survey, which determined the corrections. Of course, this calibration is correct only for the latitude in which it was ascertained, but it is better than none at all. The following table will give an idea of the probable accuracy of the magnetic observations:

[1] Hastings, C. S., Light, New York and London, 1901.
[2] Idem, p. 218.
[3] Harris, R. A., Arctic tides, U. S. Coast and Geodetic Survey, Washington, 1911.

Observations for magnetic declination at the astronomical pier on Flaxman Island, northern Alaska.

Date.	Hour.	Compass A.	Compass B.	Mean A (+ correction).	Mean B (+ correction).	Corrected mean of A and B.
1914.		°	°	°	°	°
May 6.	8.25 a. m.	139.2	143.3			
			143.7			
	8.25 a. m.	139.3	143.2	139.4	143.3	142.0
				+3.6	−2.2	
	8.30 a. m.	139.6	143.2	143.0	141.1	
	8.30 a. m.	139.6	143.2			
	Mean	139.4	143.3			
May 6.	11.30 a. m.	139.2	143.6			
	3 p. m.	139.4	143.8	139.4	143.7	
				+3.6	−2.2	142.2
	6 p. m.	139.5	143.8	143.0	141.5	
	Mean	139.4	143.7			
May 13	11.30 a. m.	138.7	142.3			
	12.40 p. m.	138.6	141.9	138.5	141.7	
				+3.6	−2.2	140.8
	4.45 p. m.	138.2	141.8	142.1	139.5	
		138.5	141.7			
May 15	12.30 p. m.	139.4	142.9			
	6.30 p. m.	139.0	142.8	139.1	142.8	
				+3.6	−2.2	141.6
	8 p. m.	138.9	142.8	142.7	140.6	
		139.1	142.8			

Mean bearing of north mark=141.6°.
Declination, east of north=38.4°.

ETHNOLOGY.

Considerable attention was given to the compilation of an Eskimo grammar and dictionary before it was realized that years of study would be necessary before sufficient knowledge of the language could be attained. Serious work was given up after learning that the missionary at Point Barrow had already gathered much more material than the writer could hope to procure. Stefánsson, who came into the country as an ethnologist, was able to devote his entire attention to this one subject.

Many ancient Eskimo implements were obtained by digging out old house sites or by purchase. These objects have been presented to the United States National Museum.

ZOOLOGY.

At first some material was gathered as to the habits of the conspicuous birds and animals, but Dr. Anderson, who later worked in the same area, was so much better fitted for this work that the writer gave up such observations. The small amount of material he had collected was turned over to Dr. Anderson. Some observations on the animals of the region are given on pages 62–66.

GEOGRAPHY.

LOCATION AND GENERAL FEATURES OF THE CANNING RIVER REGION.

The Canning River region, as shown on the reconnaissance map (Pl. I, in pocket), embraces an area about 70 miles square south of Camden Bay. Geographically the region consists of two well-marked provinces, the mountains on the south and the Arctic slope on the north.

The larger physiographic features of northern Alaska have been described by Brooks,[1] as follows:

> A new name, Arctic Mountain system, is proposed for the east and west trending mountain system of northern Alaska formerly regarded as part of the Rocky Mountain system. Recent investigations by Canadian and American geologists have shown that this is a distinct system from the Rocky Mountains, although they are connected by the flat-topped Richardson Mountains, forming the Mackenzie-Porcupine divide. The Arctic Mountain system stretches westward from the international boundary to the Arctic Ocean north of Kotzebue Sound. It is not everywhere sharply differentiated from the plateau region to the south, for in many places the dissected plateau remnants merge with the foothills of the ranges. In its western part the northern limit of the lowland of the Kobuk Valley affords a definite line of demarcation. On the north the mountains, so far as known, everywhere fall off abruptly to the Arctic slope. This scarp affords a definite boundary line between the two provinces. The system is made up throughout its extent of two or more parallel ranges and includes some broad lowlands. These lowlands are specially striking topographic features in the western half of the chain. The Arctic Mountain system is continued east of the boundary by some mountains of lesser altitude. These end in a scarp at the Mackenzie delta, east of which they have not been recognized.

[1] Brooks, A. H., The physiographic provinces of Alaska: Washington Acad. Sci. Jour., vol. 6, pp. 252–253, 1916.

The Arctic slope region has two subdivisions, the Anaktuvuk Plateau and the Coastal Plain. The first forms a piedmont plateau, sloping northward from the base of the range. Along the Colville River it has a width of about 50 miles, but it narrows to the east. At the boundary it appears to be entirely absent, for here only a narrow coastal plain intervenes between the mountains and the sea. The westward extension of Anaktuvuk Plateau is unexplored. On the north the plateau is bounded by a scarp which separates it from the Coastal Plain. This plain varies from a width of less than 10 miles at the boundary to over 150 south of Point Barrow.

Both provinces—the mountains and the Arctic slope—are drained by closely spaced northward-flowing rivers. Between the Colville and the 141st meridian there are ten large rivers, five of which are reported to head against the Yukon drainage, the Turner, Hulahula, Sadlerochit, Canning, and Sagavanirktok. Two more, the Aichillik and Jago, may reach the divide, but the Okpilak, Shaviovik, and Kuparuk are known not to reach it.

Of these rivers the writer has examined the Okpilak, Hulahula, Sadlerochit, and Canning.

ARCTIC MOUNTAIN SYSTEM.

GENERAL CHARACTER.

As stated above, the Arctic Mountains run nearly east and west across Arctic Alaska. At the boundary line on the east they are about 60 miles wide, according to Maddren.[1] Along the 146th meridian, where the writer explored them, the width is probably 150 miles. Along the 152d meridian, according to Schrader,[2] they are 100 miles wide.

Along the 141st and the 152d meridians the highest elevations are about 6,000 feet, but farther west, near Cape Lisburne, they are less than half this height. In the region south of Camden Bay, described in this report, although the general elevation along the central part of the range is probably about the same as that found to the east and west—6,000 feet—there is a small group of snow-covered mountains, which reaches an elevation of 9,000 feet.

Only two of the boundaries of the Arctic Range are at present definitely known—the Arctic slope on the north and the Arctic Ocean on the west. The eastern limit lies near the boundary line, but the details of the relation of the Arctic and the Rocky Mountain systems have not yet been determined. The southern limit has been defined in places, but there are still gaps where the dividing line between the Arctic Range and the Central Plateau has not yet been decided upon.

The echelon arrangement mentioned by Brooks[3] has not been observed in the area south of Camden Bay, although there are suggestions of it east of Jago River. From an elevated outlook toward the east, on Okpilak River, outlying ridges can be seen, but from the coast between Barter Island and the boundary the mountain front appeared to present an unbroken line. From Jago River to the Okpilak the front runs approximately east and west, but on the west side of the Okpilak it trends to the northwest as far as Hulahula River. At this point the front of the main mountain mass recedes in echelon form several miles, and then trends westward as far as the Canning. Between Hulahula and Canning rivers there are three small belts of mountains, which form outliers parallel with the northern front of the main range. These outliers terminate abruptly at the Canning, and the mountain front recedes several miles again to that of the main range and then extends about west-southwest as far as the eye can reach.

Schrader's map[4] shows the mountain front east of the Colville curving northeastward toward the ocean. The writer's observations indicate the same approach of the mountains toward the coast. They are not clearly visible from the ocean west of the 148th meridian. From a point on the 150th meridian in the clearest winter weather occasional glimpses were caught of mountains lying to the southeast, and peaks were thought to be identified which lay in the 147th meridian. This points to a rather abrupt change in direction of the mountain front somewhere west of the 147th meridian. Whether this change is in echelon form or is a simple bend in a continuous front is not yet known.

[1] Oral communication.

[2] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, p. 39, 1904.

[3] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 43, 1906.

[4] Schrader, F. C., op. cit., pl. 2.

SUBDIVISIONS.

Various names have been given to portions of the Arctic Range by the early explorers, and some of them must be omitted. The term British Mountains has been adopted by the boundary survey for the crest line on the 141st meridian. This name has been extended by the writer to cover the northern portion of the Arctic Range between the boundary line and Jago River, where the Romanzof Mountains begin. Schrader[1] has used the term Endicott Mountains for the portion between the 145th and 154th meridians. The terms Romanzof and Franklin Mountains were applied by the discoverers to portions of the Arctic Range which lie in the area discussed in this report.

The term Romanzof was first applied by Franklin[2] to the high snow-clad mountains between Jago and Hulahula rivers. A few days later he saw some more mountains near Canning River and he included them under the same name. As the mountains first discovered are separated from those near the Canning by a structural break, the term Romanzof is confined in this report to the high snow-clad group at the northern front of the Arctic Range between Jago and Hulahula rivers. Franklin's description is as follows:

> At 6 this evening [near Point Griffin] we passed the termination of the British chain of mountains and had now arrived opposite the commencement of another range, which I named after the late Count Romanzof. * * * The day was very clear [at Arey Island] and exposed to our view the outline of the Romanzof chain of mountains, whose lofty peaks were covered with snow.

The term Franklin Mountains was applied by Dease and Simpson[3] to the portion of the Arctic Range that lies west of Canning River and is visible from the coast. The writer has used the term to cover not only the portion west of the Canning but also the part south of the three outlying ranges between the Canning and the Hulahula. The southern limit can not be fixed at present, from lack of information. It seems probable that there is a continuous rugged belt at least as far south as the Arctic-Yukon divide. The eastern termination is against the Romanzof Mountains on the north, but there does not seem to be any break between the Franklin and British mountains south of the Romanzof Mountains. The western limit is also at present indefinite, for no break could be seen from an elevated outlook on the Canning. It is not known whether the Franklin Mountains grade into the Endicott Mountains or are separated by a break at the northward-facing crescent (p. 49) east of the Colville.

The outer two of the three outlying ranges south of Camden Bay have been given separate names by the writer. The southernmost range is simply called the Third Range.

FRANKLIN MOUNTAINS.

The northern boundary of the Franklin Mountains is everywhere sharp. In most places there is a bold escarpment that rises 2,000 to 3,000 feet above the rolling upland. The southern boundary, which for the present is arbitrarily placed near the Yukon-Arctic divide, is, of course, indefinite. On the northeast the Franklin Mountains end definitely against the higher Romanzof Mountains, but on the southeast border they appear to merge into the British Mountains. Nothing is at present known of their boundary to the west.

Along the northern front the Franklin Mountains are in general about 5,000 feet high, but between the forks of the Sadlerochit there is an area where they reach 7,000 feet. At the headwaters of the Hulahula they are probably not over 6,000 feet. Two notable peaks, Mounts Chamberlin and Salisbury, rise above the general level of these mountains. Mount Chamberlin, which is south of Lakes Peters and Schrader, is the most prominent feature of the interior landscape west of the Romanzof Mountains. Its double-peaked ice-clad summit, which rises 3,000 feet above the neighboring mountains, reaches a total elevation of 9,000 feet above sea level. Mount Salisbury, which is on the west side of the Canning, about 60 miles from the coast, is also double peaked, but as it is not so high as Mount Chamberlin it does not stand out so conspicuously. Mount Chamberlin is shown in Plate XI, *A* and *B*.

A better idea of the topography of the Franklin Mountains may be gained from the illustrations (Pls. XI, *B*; XV, *A*, p. 58) than

[1] Schrader, F. C., op. cit., p. 40.

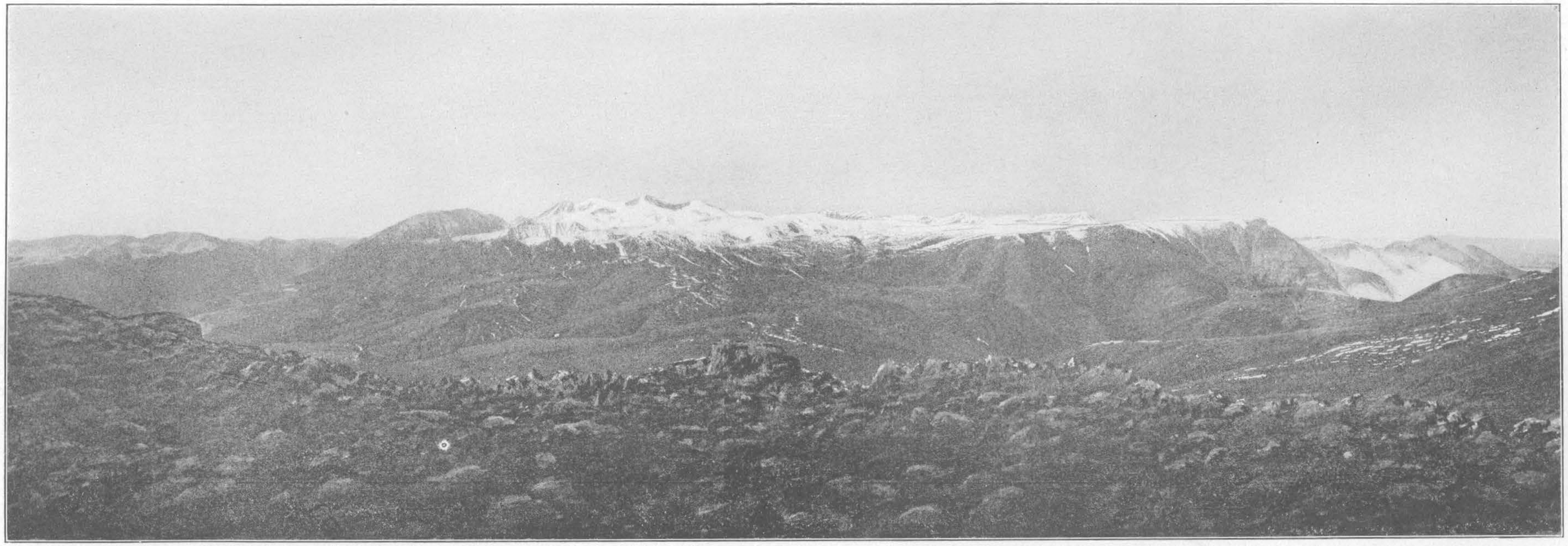
[2] Franklin, Sir John, Second expedition to the Polar Sea, pp. 145, 147, London, 1828.

[3] Simpson, Thomas, Discoveries on the north coast of America, p. 125, London, 1843.

A. MOUNT CHAMBERLIN FROM LAKE SCHRADER.

B. LAKES PETERS AND SCHRADER.

Mount Chamberlin at the right.



PANORAMA OF THE NORTHERN FRONT OF THE ROMANZOF MOUNTAINS.

can be given in words. From an elevated outlook very few separate peaks stand out against the even sky line, except at the headwaters of Sadlerochit River. In general, the mountains visible from the coast are free from snow in summer.

ROMANZOF MOUNTAINS.

This name is applied to a small group of high mountains covered with snow and glaciers confined to a roughly circular area about 15 miles in diameter, between the headwaters of Jago and Hulahula rivers. They are bounded on the east, west, and south by the British and Franklin mountains. On the north there is only a narrow fringe of lower mountains between the Romanzof Mountains and the Anaktuvuk Plateau.

They have been observed from all sides except the east to rise with a gradual but definite slope from the general mass of the Arctic Mountains. There is little variation in the elevations of the highest summits. They may be observed from Flaxman Island, rising slightly over the nearer ranges, but east of Camden Bay they are very prominent. During the summer of 1912 Maddren did not see them from the coast at the 141st meridian. During this time the atmosphere was very hazy, probably from the eruption of Mount Katmai. The engineers of the Boundary Survey, however, sighted upon high snow-clad peaks to the west. The angles and estimated distance of these sights indicate that the points are in the southeast part of these mountains.

They are much more jagged than the other mountains of the region, and many separate peaks and ridges stand out from the general sky line, though as a whole, when viewed from a distant elevation, the mountains appear to be a solid mass. Snow and ice caps occur wherever a lodging place is found, and glaciers are numerous. Some of the individual peaks and ridges are concealed by domes of ice. The Romanzof Mountains are shown in Plate XII.

OUTSIDE RANGES.

Of the three short mountain ranges that lie north of the Franklin Mountains, between Sadlerochit and Canning rivers, the Sadlerochit Mountains are the northernmost. They run east and west for about 50 miles at a distance of 25 to 40 miles from the coast. At the east end they are about 10 miles wide and at the west end about 5 miles wide.

The northern front is crescentic and for most of the distance a bold fault scarp rises about 2,000 feet above the rolling upland. On the south side the mountains rise more gradually out of Ignek Valley and with an even slope. At both ends they have a general elevation of over 4,000 feet, but in the middle, near Katakturuk River, they are noticeably lower. They are traversed near the eastern end by the broad, open valley of Itkilyariak Creek, and near the middle, according to the natives, by Katakturuk River. The crest line, though narrow, is fairly even. Only two peaks stand out sharply enough to be recognizable from different directions, so that they can be used for triangulation stations.

The middle range, called the Shublik Mountains, is shorter, wider, and in general higher than the Sadlerochit Mountains. The western end juts out several miles to the west of the Sadlerochit Mountains, but the eastern end is hidden from view from the coast. The Shublik Mountains are sharply bounded on the north by a fault scarp, but on the south the slope is more gradual, and there are a few foothills at their base. The eastern end gradually descends to the open basin of Sadlerochit River, but the western end is more abrupt against the Canning. An outlier is cut off at the west end, but the rest of the range, as viewed from both ends, seems to have no transverse valleys.

The third range from the coast, which is called in this paper the Third Range, is very narrow between the Canning and the Sadlerochit, and the crest line is a single ridge. In the open basin of the Sadlerochit there are a couple of isolated mountains which have been cut off from the Third Range, and a short range that abuts against Hulahula River seems to fall in the same line.

ARCTIC SLOPE.

ANAKTUVUK PLATEAU.

There is a rolling tundra upland between the Arctic Mountains on the south and the coastal plain on the north, which is in strong physiographic contrast to the mountains, but only moderately so to the coastal plain. On the west side of the Canning this upland is about 40 miles wide. From an elevated outlook it could be seen to extend westward with increasing width to the limit of vision. There can be little doubt that this upland continues westward beyond the Colville, where Schrader[1] describes a similar upland under the name of Anaktuvuk Plateau. It is 80 miles wide at the Colville. Collier[2] describes a similar feature still farther west, at Cape Lisburne.

In front of the Sadlerochit Mountains a fairly uniform width of about 20 miles is maintained, but at Sadlerochit River the upland ends toward the east in a bold scarp. It continues southeast around the eastern end of the outside belt of mountains and swings into the open basin of Sadlerochit River and across the front of the Romanzof Mountains.

On Okpilak River the upland is less than 15 miles in width. Only a narrow bench could be seen in front of the British Mountains. To the east, where these mountains approach the boundary line, nothing of the upland was seen from the coast. Maddren reports[3] that here there are interstream benches, which probably mark the level of the Anaktuvuk Plateau, but no upland area along the mountain front.

O'Neill, of the Canadian Arctic expedition,[4] finds that east of the boundary a narrow coastal plain passes abruptly into a rolling plateau, which slopes gradually upward and terminates at the north face of the mountains.

As stated above, the southern boundary of the upland is everywhere very definite against the bold front of the mountains. There was no place observed by the writer where the escarpment was not at least a thousand feet in height. The northern boundary, though as a rule definite, is by no means so marked as the southern. As far to the west as the upland was observed, the northern front rises with a slope of 15°–20° from the flat coastal plain, and this slope is generally present elsewhere. In one place only, on Katakturuk River, the break is scarcely noticeable from a distance. The maximum observed break is near Sadlerochit River, where the upland may rise as much as 300 feet above the coastal plain.

The upland slopes gradually seaward throughout the area studied. West of the Canning, near the mountains, it has an approximate elevation above the river bed of 1,000 feet and above the sea level of 1,500 feet. Where it ends on the north it rises roughly 100 feet above the coastal plain and 300 feet above sea level, the decrease in height being 1,200 feet in 35 to 40 miles. On the east side of the Canning, opposite Sadlerochit Mountains, the elevation is much lower than that on the west side, but on the northern front the upland is approximately the same height on both sides of the river. On Okpilak River the elevation is about 3,500 feet, which is apparently maintained for some distance eastward.

The upland seems a nearly featureless plain when viewed from an elevation. The only noticeable projections above the general level are a few foothills at the head of Marsh Creek and a gentle ridge between this creek and Katakturuk River, near the coast. On the east side of the Canning there are a few irregularities of surface due to glacial deposits. The upland as a whole is a fairly level plain cut by valleys that trend north and south. The evenness of the sky line upon the Canning is shown in Plate XIII, *A*, and on the Hulahula in Plate XIII, *B*. In these areas only one lateral stream has made a noticeable cut in the sides of the main valley. On the other hand, the area between Katakturuk and Sadlerochit rivers seems to be in a more mature stage of erosion. Here there are numerous side streams, and the country is more open and rolling.

COASTAL PLAIN.

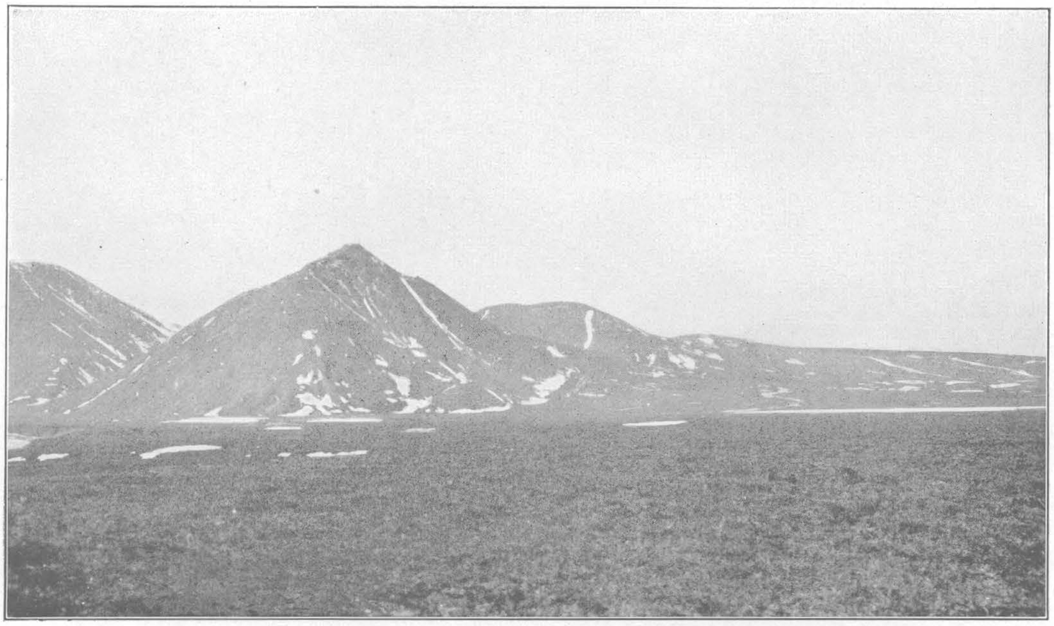
The writer has examined the outer margin of the coastal plain along the entire north coast of Alaska. Between Barrow and Sagavanirktok River the plain is so wide that its southern margin can not be seen from the coast. The upland comes into view east of this river and continues in sight from the coast as far as Martin Point. The width of the coastal plain on the Colville is 80 miles, and it narrows

[1] Schrader, F. C., op. cit., pp. 45–46.

[2] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 14, 1906.

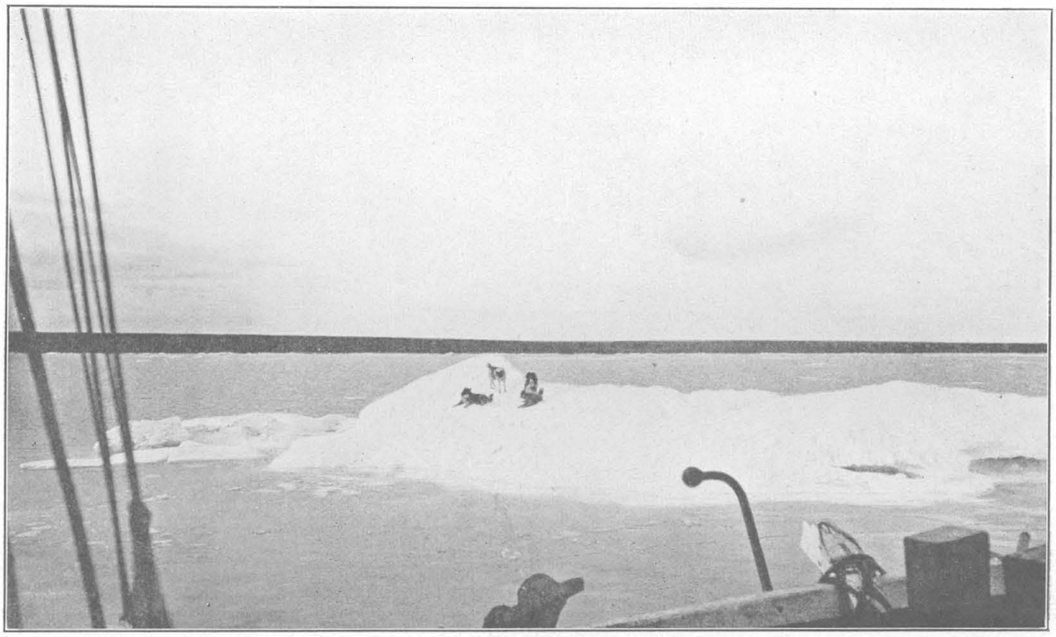
[3] Oral communication.

[4] O'Neill, J. J., Canadian Arctic expedition: Canada Geol. Survey Summary Rept. for 1914, pp. 112–113, 1915.



A. RELATION OF THE ANAKTUVUK PLATEAU TO THE ARCTIC MOUNTAINS, CANNING RIVER.

B. RELATION OF THE ANAKTUVUK PLATEAU TO THE ARCTIC MOUNTAINS, HULAHULA RIVER.



A. COASTAL PLAIN, SOUTHWEST OF POINT BARROW.

B. WILLOWS ON CANNING RIVER.

toward the east until near Collinson Point the upland fronts the sea. East of the Sadlerochit it abruptly widens to about 50 miles and then narrows where the British Mountains approach the ocean at the boundary line.

The coastal plain is definitely limited on the south by the Anaktuvuk Plateau. The northern boundary is, of course, the Arctic Ocean, but there is only a slight break in the profile at the coast line. The maximum break, at Barter Island, may be 30 feet, but this is exceptional. The average high bank is not more than 15 feet above sea level, and there are many places where there is scarcely a break of 1 foot. From a height only slightly above the sea level the coastal plain rises very gradually to a height of about 200 feet at its southern margin on the Canning, where it is about 20 miles wide. On the Okpilak, 40 miles from the coast, the altitude was about 1,200 feet. The grades on the two rivers are 10 and 30 feet to the mile, respectively.

The coastal plain is so featureless that there are many places in which one would become lost without a compass (Pl. XIV, *A*). In all directions there may be simply a flat tundra plain dotted with shallow ponds and lakes. Many of the larger rivers flow through such shallow cuts that their existence might not be suspected at a distance of half a mile. There is an exception to the usual dead level of this tundra plain at Barter Island and the area south of it. This island has a rolling surface, which may rise as much as 50 feet above the sea. South of the island the mainland is only a few feet above the sea, but 6 to 8 miles southward, the plain increases perceptibly in height and becomes somewhat undulating. Herschel Island, about 500 feet high, is so notably above the level of the coastal plain that it can not be considered a part of it. There are also two outliers of the upland a few miles out on the coastal plain east of Okpilak River.

Locally the dead level is broken by large mounds, which rise abruptly from the surrounding plain. These mounds are usually in the form of rounded domes whose altitude above the plain may reach a maximum of nearly 300 feet, although most of them are less than 50 feet high. They are very abundant in the neighborhood of Kadleroshilik and Kuparuk rivers, as many as 40 being counted from a single place. A detailed description of these mounds is given under the heading "Cenozoic deposits" (pp. 150–155).

A minor feature, yet one that is noteworthy in a region of such slight relief, consists of low grassy hummocks, from 1 to 3 feet high, which are scattered sparingly over the flat tundra plain. They have a heavy coating of turf and support a luxuriant growth of vegetation. Probably they are in part formed by the lodgment of wind-blown material, but within them the ordinary superficial formations, in some places containing pebbles, have been found above the general level of the plain. There was evidently a slight bulging of the ground, which later was built up by vegetation. No doubt in the formation of these hummocks the action of frost is concerned, but the process is not clear.

The polygonal markings upon the surface of the coastal plain are fully described under the heading "Ground ice" (p. 205). There are two different phases of this phenomenon. The more conspicuous phase is a division of the surface into rectangles by a system of parallel ridges, which often inclose ponds. The relief of the ridges above the bottoms of the ponds may be nearly 3 feet. The ridges themselves are separated by a depression of not more than 1 foot. In the bottom of this depression there is usually an open frost crack about an inch wide. (See Pls. XXIX, *B*, p. 205, and XXX, *A*, p. 206.)

The other phase of the polygonal surface topography consists of a network of shallow depressions, which surround higher blocks of the tundra. The relief is about 1 foot, but near banks the depressions may be deepened by erosion, so that the blocks stand out in strong relief (Pl. XXX, *B*, p. 206). A map of one of these areas is shown in figure 26 (p. 210).

In the deltas of the rivers the western banks are usually covered with silt dunes. They are typically developed as a single row immediately over the bank, but on the Sagavanirktok they are massed together over a belt several hundred yards wide.

Even the larger rivers have cut very slightly into the plain. Banks 10 feet high are exceptional, and the maximum observed height was probably less than 15 feet. The drainage originating in the plain itself has established very few lines. The surface waters collect into ponds and lakes, and the overflow seeps through the grass to the nearest stream. Some of the larger lakes have definite outlets in the form of widely meandering surface streams so narrow that one can step across them. Some of these streams are deep and carry a large flow of water. Near the river banks and the coast these streams have cut gulleys, but on none of the creeks examined by the writer do these gulleys run back for more than a mile. This slight development of the drainage of the coastal plain is only true in the areas where the plain is narrow. West of the Colville, where the plain is over 100 miles wide, the streams have probably developed high banks.

The writer has made no attempt to map the drainage of the coastal plain beyond the details seen in winter trips. In the northwest corner of sheet No. 1 of the International Boundary Survey a group of ponds along the one hundred and forty-first meridian is shown. Only one of these ponds has a mapped outlet.

COAST LINE.

Between Point Barrow and the Colville there are three notable bays; east of the Colville there are none. Camden Bay is simply an undulation in the generally straight coast line. As Schrader has described the stretch between the Colville and Point Barrow,[1] the writer will discuss the coast line east of the Colville.

Between Colville River and Herschel Island, a distance of 300 miles, the coast is so straight that a vessel could set a course and never be more than 20 miles from land. The first hundred miles of coast, to Flaxman Island, has hardly a bend; then there is a slight bend in and out of Camden Bay, and again a straight line from Martin Point to the boundary line. The land along the whole coast is very low, being often invisible from a small boat 2 or 3 miles at sea. A bank 15 feet high is a landmark for many miles, and 20 feet is exceeded in few places. For a few miles east of Collinson Point the upland fronts the ocean and rises to an altitude of more than 200 feet within a mile from the coast.

Most of the coast is fringed with islands in the form of barrier reefs, which inclose stretches of water locally called lagoons. These islands are composed chiefly of sand and gravel, but there are half a dozen which consist of the same formation as the mainland. The rivers have mud flats in keeping with their size and the degree of protection from the waves or current of the ocean. There are a few small bays sufficiently prominent to receive names, but in a region of greater complexity they would be unnoticed. West of Tigvariak Island a few isolated mounds are usually in sight from the coast.

To sum up, the north shore of Alaska is characterized by low mud banks, shallow lagoons, sand spits and islands, and mud flats.

CONTINENTAL PLATFORM.

There is a wide continental platform north of Russia and Siberia, from which rise the several groups of islands between Spitzbergen and Wrangell Island, and another wide platform north of Canada. There was, therefore, good foundation for the belief that the continental shelf was as wide north of Alaska as it is known to be both to the east and to the west. Not many miles from the coast, near Herschel Island, McClure had taken a few soundings approaching 200 fathoms without reaching bottom, but these were held to be doubtful from the report that they were taken with a rope. Near Point Barrow some depths over 140 fathoms are reported, so that the platform was believed to be narrow at Point Barrow, but to widen abruptly on either side.

In the spring of 1907 Capt. Mikkelsen and the writer, accompanied by a sailor, made soundings through the sea ice to a point about 100 miles from the coast between the 148th and 150th meridians. At about 50 miles from shore the depths increased from 30 to 320 fathoms in $2\frac{1}{2}$ miles. Beyond this point no bottom was found at the greatest depth reached by such sounding apparatus as was at hand (about 320 fathoms). The profile of the ocean bottom at this place is given by Mikkelsen.[2] There is no doubt that this abrupt increase in depth marked the outer margin of the continental shelf.

The writer has taken numerous soundings in depths less than 8 fathoms, and has found the bottom very regular, except in the neighbor-

[1] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 48–49, 1904.

[2] Mikkelsen, Ejnar, Conquering the Arctic ice, p. 439, London and Philadelphia, 1909.

hood of the barrier islands and mud flats. There are a few shoals, which comprise the submerged parts of the barrier reefs, but in depths greater than 7 fathoms the soundings alongshore change gradually.

DRAINAGE.

In the mountains the rivers flow through more or less marked glacial troughs; in the upland through open valleys; and in the coastal plain nearly at the surface of the tundra. In view of their length their close spacing is remarkable. Where the mountain structure is not complex, as on the Canning, the main stream cuts across the strike and the tributaries follow the strike, as was described by Schrader[1] for the Colville. On the Hulahula and the Okpilak, where the rock is granite or schist of more or less uniform hardness, this rectangular drainage is not observed.

OKPILAK RIVER.

The Okpilak heads among the glaciers of the Romanzof Mountains and flows 70 miles northward to the Arctic Ocean. Near the head two forks come together from southwest and southeast and form the main stream. The upper 20 to 30 miles of the course lies in a deep glacial trough and the succeeding 10 or 12 miles in a straight open trench in the Anaktuvuk Plateau. Throughout the remainder of the distance the river flows nearly at the level of the coastal plain.

The west fork has its source in a glacier which fills the upper 6 or 8 miles of the valley. The whole area around the head of this glacier is so covered with snow and ice that scarcely a rock can be seen even in the summer. Dome-shaped ice-covered peaks and rounded ridges here rise several hundred feet above the general level of the glacier (Pl. XVIII, p. 156). Below this region steep rock cliffs appear, broken by the lateral feeders to the main ice stream.

The lateral glacial streams join with the subglacial waters at the end of the glacier to form the west fork, which flows rapidly through rock gorges or in an undulating course between alluvial cones and moraines from the side glaciers. The mountains here rise between 3,000 and 4,000 feet above the river bed, with such steep slopes that the higher peaks are invisible from the valley floor.

The east fork repeats the same features as far as it was explored. It is apparently shorter and narrower than the west fork. It is not known whether it heads in a glacier, but where it comes into view from the south several lateral glaciers were seen to reach nearly to the river bed.

The main stream below the forks flows in a deep, well-marked glacial trough to the edge of the mountains. For the first 5 miles the valley has a rock floor three-quarters of a mile wide, covered with moss and boulders, into which the river has intrenched itself 20 to 30 feet. This rock floor pitches down and under a gravel floor, which attains a width of over a mile near the edge of the mountains. Numerous alluvial cones are built out on the flat valley bottom. Benches formed by talus slumping are a conspicuous feature also.

Beyond the mountains the river flows in a trough cut about 1,000 feet into the Anaktuvuk Plateau. The steep valley walls are formed by two even-crested ridges, which separate and die out into the coastal plain about 12 miles farther north. In the coastal plain the valley is about a mile wide and is bounded by mud banks generally only a few feet above the river bars. The maximum recorded height is 15 feet. Within these banks there are wide brush-grown flats almost at the level of the stream.

After leaving the rock gorge below the forks the river spreads out in many channels, which meander among low, brush-covered gravel bars. At ordinary stages of water there are three or four shallow streams which can be easily waded, but after a hot day, when the river is swollen by melted snow and ice, there may be a dozen streams more than knee-deep and many more less than a foot deep. At the edge of the mountains the river is contracted into a single channel by a glacial moraine. Below this moraine, although the river spreads out again, it is difficult to cross, owing to its rapid current. It is probable that much of the drainage in the mountains was underground among the gravels, for, though the river was easily crossable anywhere within the mountains, the

[1] Schrader, F. C., op. cit., p. 43.

writer's party was unable to ford it in July anywhere between the mountains and the coast.

A few miles from the coast the bank which separates the Okpilak from the Hulahula terminates, and the flood plains of the two rivers unite to form a flat several miles wide. About a mile from the ocean the two rivers join and enter their common delta, where they split up into four or five distributaries among as many silt islands.

The Okpilak has a higher grade than any other river investigated by the writer. In only 70 miles it falls about 5,500 feet (the approximate elevation of the lower end of the glacier on the western fork), which is 80 feet to the mile. In some of the steeper stretches in the rock gorge in the mountains one frequently hears the sound of rolling boulders. The swift current keeps up to the slack water near the head of the delta. It is doubtful whether the Okpilak is boatable without extreme effort. In July there were many places outside of the mountains where the depth was less than 2 feet, but the current was so swift that it was impossible to keep one's footing.

HULAHULA RIVER.

The Hulahula was explored nearly to its source by sled in the winter. Hardly any notes were taken on this winter trip, as the writer intended to return in the summer for detailed work in geology. As this proposed trip was not made, the information is rather scanty.

The Hulahula heads against the Chandalar drainage and flows northward in a nearly straight line for about 80 miles. The upper half is within the mountains in a moderately open valley, and the lower half is in the upland and coastal plain. Two branches join from the south and northeast near the headwaters to form the main stream. The south fork has a reported open pass to the Yukon drainage. The northeast fork heads about 15 miles away on the southern slopes of the Romanzof Mountains. It is probable that this fork comes close to the headwaters of Jago River, but no information could be obtained from the natives on this subject.

The main valley below the forks is wide, and though it shows the effects of glaciation they are much less conspicuous than they are on the Okpilak. Near the northern front of the mountains the river flows for a mile or two in a narrow canyon, which is cut perhaps 200 feet into a compact greenstone. From its aspect in winter this canyon is probably not passable in summer by boat or on foot. Below this canyon the river leaves the mountains and spreads over a flat half a mile wide, at the bottom of an open valley in the upland. This wide floor continues northward for 10 to 15 miles; then it narrows, and the river meanders through an area of glacial drift in a flat only a couple of hundred yards wide. Beyond the northern edge of the upland the river runs for a few miles in a narrow channel cut 5 to 10 feet into the coastal plain. About 20 miles from the coast the banks separate, and the river spreads out over a flat perhaps a mile wide. In winter this place is continually flooded and a notable thickness of ice is built up.

Near the coast the Hulahula joins the Okpilak, as noted above. The main channels of the delta are reported to be 3 or 4 feet deep and the river itself to be boatable for at least 20 miles and possibly to the edge of the mountains.

SADLEROCHIT RIVER.

The Sadlerochit heads in several northward-flowing branches in the high area southwest of Mount Chamberlin. These branches gather into a single river in the open basin behind the east end of Sadlerochit Mountains. The river then curves around the east end of these mountains and flows directly north to the ocean. The total length is estimated to be about 80 miles. There are two important branches—the west branch or main river, and the lake branch, which drains some glacial lakes.

From an elevation in the open basin the main river could be seen flowing northward out of a narrow valley in the jagged mountains. It then turns northeast in the basin and cuts northward through two gaps in the east ends of the outlying ranges; it then flows northeast along the south side of the Sadlerochit Mountains, where it is joined by the Lake Fork. Below this point it swings in a big curve around the east end of the range, cutting strongly against the eastern banks. Between the mountains and coast the river was not examined. It was seen from a distance that it flows against the scarp of the upland which lies on the west side.

The delta is about a mile wide and has the usual mud flats and silt dunes. There are reported to be two distributaries.

From the outlook at the head of the glacial lakes, the Lake Fork of the Sadlerochit was observed to curve from the east and run straight north for about 4 miles in a deep glacial trough whose sides were so steep that it was impossible to see the upper slopes from the valley floor. Several ice caps and cliff glaciers were observed at the limit of vision, and there was one glacier which reached nearly to the river bed. This trough continued northward a few miles farther to form the basin for the upper glacial lake.

The upper lake, Lake Schrader, which is about 4 miles long and a mile wide, fills the whole valley floor, so that the water washes the steep rock walls on each side. The mountain sides are here about 3,000 feet high, and the trough is so strongly U-shaped that Mount Chamberlin can be seen from only one place on the lake, although it is 6,000 feet higher than the lake and only 3 miles away (Pl. XI, *B*, p. 50).

The lower end of the lake is dammed by an alluvial flat that extends out from the west side nearly across the valley, leaving a narrow channel which leads a few hundred yards to Lake Peters. Here the high mountains cease, and the lake lies in an open basin whose slopes rise only a few hundred feet above the water. The lower end of Lake Peters is formed by a morainic dam, but there is little surface evidence of this fact. The area around its outlet is a gently rolling, boulder-covered upland similar to that on all sides.

Both these glacial lakes are reported to be very deep, and to judge from the topography this may well be true. The writer was unable to make sounding except near the beach. Here a few yards from shore, near an alluvial cone that projected out into the lake, he found 6 fathoms. The ice was 5 or 6 feet thick in June, and it is reported to last until September.

The outlet of Lake Peters is a narrow valley with gentle slopes 30 to 50 feet high. The flat floor was paved with boulders, and no water was flowing out at the time of visit in June. In fact, seepage from melting snow banks was flowing upstream and into the lake. High water marks were shown by beaches that curved into this outlet about 4 feet above the level of the lake at that time. As there was a heavy inflow into the lake by the still-flooded streams, a corresponding subflow must take place through the glacial dam. This outlet valley was followed for a few miles, and the gathering stream could be stepped across at any place. Near the main river the Lake Fork receives several feeders from east and west so that it carries a considerable volume of water.

The chief feeder is a short stream which heads in an open valley north of Lake Peters, and there can be little doubt that it receives the subflow of the lakes. Six miles below the lake the stream was of such large volume that it could be crossed only with difficulty. After following it for some distance a crossing was made where it undercut a heavy bed of ice.

CANNING RIVER.

The Canning is the largest of the four rivers examined by the writer and is probably exceeded only by the Colville, the Sagavanirktok, and the Turner. Schrader[1] quotes S. J. Marsh as estimating the length to be 280 miles, but this must be an error, for Marsh's map, in the files of the United States Geological Survey, shows a length of not over 160 miles. The writer, after comparing his own measurements with those of Marsh in the lower portion common to both maps, estimates that the length is not more than 120 miles.

About 70 miles from the coast, near the writer's farthest station, the river divides into two forks. The forks are reported to head close together and to flow nearly parallel for 50 miles until they join. Here the east fork or main river is notably larger than the other, as can be seen in Plate XV, *A*. The valley is open and trough-shaped, and the slopes rise on both sides to a height of 3,000 feet. The west or Marsh Fork is also trough-shaped, but narrower. Below the forks the river flows to the northwest in an open basin as wide as the two upper valleys combined. The flat floor, nearly a mile wide, was covered at the time of visit in June, by a deposit of ice at least 12

[1] Schrader, F. C., op. cit., pp. 30–31.

feet thick, through which the river was flowing in a narrow canyon. A few miles below it turns sharply north again and flows for several miles in a wide, open valley to the edge of the Franklin Mountains. There the river, which had spread out over a wide flat, narrows abruptly into a single stream and flows through a rock gorge perhaps 50 feet deep and not many hundred feet wide.

Beyond the Franklin Mountains the river enters an open basin, west of which the surface rises about 1,000 feet to the Anaktuvuk Plateau and east of which it slopes to a low area at the junction of two tributaries. Eight miles farther north the river cuts close to the west end of the Shublik Mountains and then flows past the Sadlerochit Mountains and continues through the upland. The hills withdraw from the west side of the river, but close along the east side a bluff about 100 feet high runs to the edge of the upland, about 20 miles from the coast. From that point the river flows almost at the surface of the flat coastal plain, splitting into two distributaries, which empty into the ocean about 10 miles apart.

REPORTED DRAINAGE.

Turner River is probably the largest stream between the Canning and the Mackenzie. It empties behind Icy Reef, west of Demarcation Point. The natives say that it heads well behind the headwaters of Aichillik River and affords an easy pass for sleds to the Yukon drainage. It flows about northeast until it is out of the mountains and then bends toward the coast. The natives say that it is longer than the Canning. There is much willow for firewood along its course and many fishing places.

Aichillik River empties a short distance to the west of the Turner, and the writer has seen the mud flats and silt dunes of its delta. It is reported to head in a jagged, mountainous region, where glaciers are numerous. The passes to other rivers are few and difficult, even for packing. There is very little willow for firewood along its course.

Jago River also heads in a region of snow-clad mountains. The western branches drain the Romanzof Mountains and the main branch heads behind them, probably against the Hulahula. No native had ever ventured up this river until recently, as they believed it contained devils. No passes for sleds have been found and no native has ever crossed over to the Hulahula. Wood and fish are very scarce, so the natives do not often enter the mountains on this river, even though now the devils have been driven off.

Shaviovik River heads in the northern edge of the Franklin Mountains. Several branches gather a sufficient volume of water to make a good-sized river near the coast. It is probable that canoes could be taken up it for 20 miles.

The Sagavanirktok is the second largest river west of the Mackenzie. Two important branches gather most of the northward-flowing drainage of the Arctic Mountains between the Colville and the Canning. Only two white men have ascended it from the coast, but there are reports of prospectors who have come over to its headwaters from the Yukon. H. T. Arey, the prospector who went up the west branch in February, 1910, in an attempt to reach Coldfoot on the Koyukuk, reports it to be 250 miles long. As Arey's estimates usually exceed the writer's measurements by a definite amount, a length of about 200 miles is probable. Wood is abundant almost to the divide. Natives had reported an easy pass over to the Yukon drainage, but Arey failed to find one, after searching until his food was nearly gone. Later investigation brought out the fact that a pass does exist, over which a sled may with great difficulty be transported. Natives from the coast have taken canoes many miles up the river and no doubt could take them nearly to the head had they any reason for doing so. The delta of this river is about 15 miles wide. The Sagavanirktok has two distributaries like the Canning.

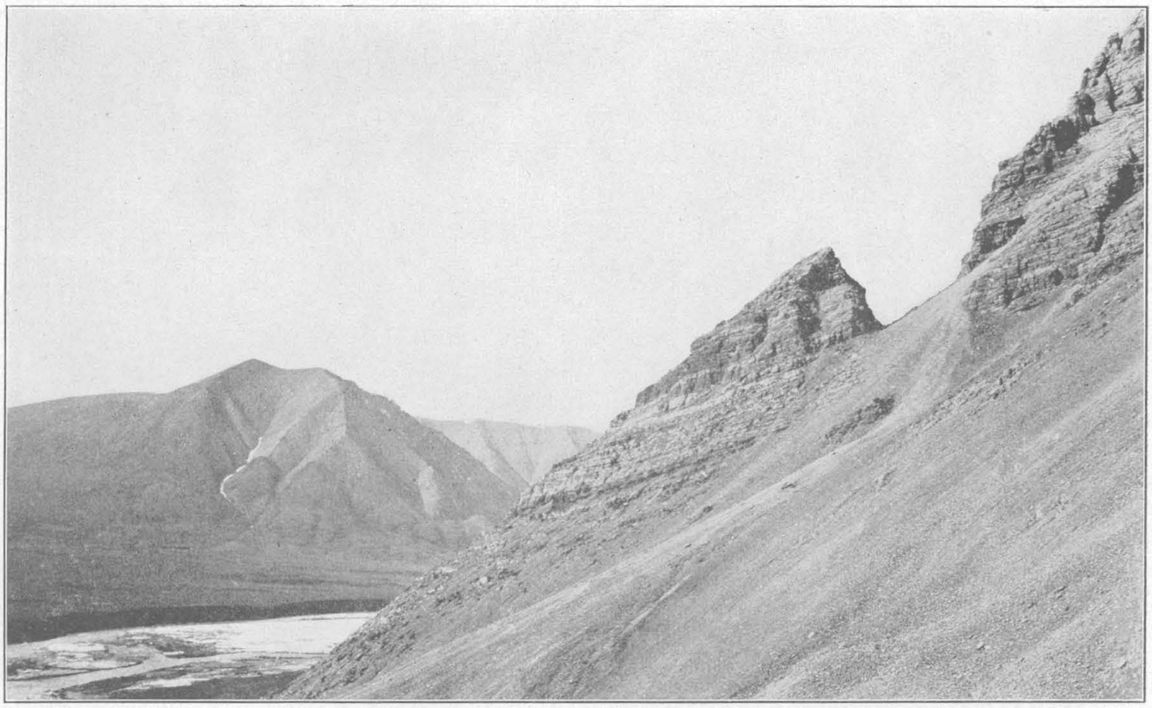
Kuparuk River is reported to head near the north front of the mountains in a lake. Its delta is of about the same size as that of the Canning. Kuparuk River has little wood and is boatable for only a few miles.

Itkillik River heads behind the Kuparuk and flows west of north until it empties into the head of the Colville delta.

SPRINGS.

There are two springs which deserve mention. The larger one by report is the Shublik spring, at the west end of Shublik Mountains,

A. FORKS OF CANNING RIVER.



B. NOTCH CUT BY LATERAL GLACIAL DRAINAGE, CANNING RIVER.

at the contact of the Lisburne limestone and the Sadlerochit sandstone. Several large springs gush out of the lower slope of the mountain, at an elevation of about 400 feet above the river, and gather together into a foaming torrent that can not be crossed on foot. These springs flow all winter, and the river is locally kept open. In June the water in one of the outlets had a temperature of 43° F.

The other springs are reported by the Canadian Arctic expedition to be similarly located at the northeast end of Sadlerochit Mountains. The temperature of the water in October was 50° F. at some distance from the source.

EVIDENCES OF LAND NORTH OF ALASKA.

As the discovery of the land which is supposed to exist in the Arctic Ocean was the object of the expedition in which the writer entered the northern Alaskan region, and as an actual search was made, though with negative results, it seems of interest to outline the arguments for its existence. Eminent geographers had long held that a considerable area of land existed in the unexplored portion of the Arctic Ocean, but not until Dr. Harris, of the United States Coast and Geodetic Survey, brought out the evidence from the tides, did the theory have a firm scientific basis. In his earlier investigations Dr. Harris had gone so far as to outline the distribution of this land.[1] In his latest reports, which embody the tidal observations taken by Peary in Greenland and by Mikkelsen and the writer at Flaxman Island, Alaska, he presents his conclusions still more emphatically. The latest evidence from the tides is published at some length,[2] and a shorter article sums up the evidence from all sources.[3] Mikkelsen in his narrative of the expedition of which he and the writer were joint commanders also gives an outline of the state of opinion at the time of his writing.[4]

The main line of argument from the tides is as follows: The tides of the Arctic Ocean are of the Atlantic type and are propagated from a wave which enters the Arctic Ocean between Greenland and Spitzbergen. If there were no obstructions in the polar basin, this wave would reach the northern shores of Siberia and Alaska at nearly equal times and with nearly equal amplitudes. As a matter of fact, there are sufficient tidal records along these shores to show that the Atlantic wave first strikes Siberia and then proceeds eastward with decreasing amplitude. This behavior can be explained only as being caused by an obstruction which occupies a notable portion of the Arctic Ocean. The boundaries of this supposed land are indicated by the drifts of the *Jeannette* and the *Fram*, as well as by less evident phenomena.

With reference to the portion of this land which is nearest to Alaska, Harris[5] in 1913 gave the following statements:

> That there is a northern coast to Beaufort Sea, in some such position as that shown in the diagram and extending from north of Point Barrow nearly to Banks Island, can be inferred from the following considerations:
>
> 1. The ice in Beaufort Sea does not drift freely to the northward and is remarkable for its thickness and age. * * *
>
> 2. The observations * * * indicate not only a considerable westerly drifting when the wind is from an easterly direction but also little or no movement of the ice when the wind is westerly. These circumstances, as far as they go, tend to show that Beaufort Sea is nearly landlocked in all directions except the west.
>
> 3. * * * Observations made * * * just west of Point Barrow * * * show that a west-southwest wind may, in extreme cases, cause the daily sea level to stand nearly 3 feet higher than when the wind is from the east-northeast. Observations taken on the south side of Flaxman Island * * * show that * * * the fluctuation in the daily sea level amounted to 2 feet, the lowest stage occurring at the time of northeasterly winds and the highest stage on westerly or southwesterly winds. Messrs. Leffingwell and Stefánsson have informed me that effects similar to these are common all along the northern coast of Alaska.
>
> The natural inference from this is that the unknown coast line in question is not very remote from the northern coast line of Alaska, and that the unknown land approaches the known Arctic Archipelago in one or more points, thus making a fairly complete land boundary to the north of Beaufort Sea.

[1] Harris, R. A., Evidences of land near the North Pole: Eighth Internat. Geog. Cong. Rept., pp. 397–406, 1904. See also Nat. Geog. Mag., vol. 15, pp. 255–261, 1904; U. S. Coast and Geodetic Survey Rept., 1904, pp. 381–389.

[2] Harris, R. A., Arctic tides, U. S. Coast and Geodetic Survey, 1911.

[3] Harris, R. A., Undiscovered land in the Arctic Ocean: Am. Mus. Nat. Hist. Jour., vol. 13, No. 2, pp. 56–61, 1913.

[4] Mikkelsen, Ejnar, Conquering the Arctic ice, London and Philadelphia, 1909.

[5] Harris, R. A., Undiscovered land in the Arctic Ocean: Am. Mus. Nat. Hist. Jour., vol. 13, No. 2, pp. 59–60, 1913.

To these arguments of Harris the writer adds another from the behavior of the ice pack under different winds. The only strong winds along the north shore of Alaska blow from between east and northeast and from between west and southwest. The easterly winds blow diagonally on the land and the westerly winds blow diagonally off the land. In summer, during a strong wind from the east, the ice pack drifts rapidly westward along the coast and the pack as a whole retreats from shore, although there is a component of the wind which tends to force it against the shore. At the same time the scattered cakes are driven against the beach, leaving an open lane of water outside. When the wind blows from the west the loose cakes are cleaned off from the beach, but the main pack gradually approaches the shore against a component of the wind. If it blows continually from the east the season is open, but if it blows from the west the season is icy.

This behavior of the ice is a parallel to that of the sea level and can only be explained on the theory that the sea is landlocked on all sides except the west. An east wind carries away the ice and a west wind jams the closed sea so full of ice that it is forced toward the Alaskan shore, even though the wind is blowing somewhat off the land.

The argument from Eskimo traditions of northern lands would not be taken seriously by anyone acquainted with the many fantastic tales told them by their medicine men. Formerly there was scarcely a shaman who was not credited with powers of flight. Even trips to the moon were not thought extraordinary.

The actual reports of land by whalers and Eskimos have been thought by some to be reliable. Keenan Land, in the vicinity of which Mikkelsen and the writer failed to reach bottom at more than 300 fathoms, is still seen on some maps.

It is the opinion of the writer that this undiscovered land, of which the evidence is so strong, should be named after the man to whose labors our most reliable information is due. Not only was a small expedition organized under Mikkelsen and the writer to search for it but recently the Canadian Government sent a well-equipped party under Stefánsson and Anderson for the same purpose. Other expeditions will undoubtedly be sent to clear up this last area in the Arctic within which discoveries of magnitude may be expected. It is to be hoped that the discoverer will give this land the name "Harris Land."

CLIMATE.

In addition to the systematic observations of the weather made in 1906–7 by the officers of the *Duchess of Bedford*, the writer kept a daily journal for the six years in which, during the periods spent at headquarters, he entered the minimum and maximum temperatures. In the field minimum temperatures were recorded until the registering thermometers were broken; after that only the temperatures of the daytime were noted. Though these observations have not yet been worked up, it is possible to present some general remarks upon the climate which may be of interest.

There are probably more clear nights for astronomical observations during January than during any other month. The sun comes back about the 20th. In February there was usually a warm wave, with storms. The maximum temperature observed was 43.5° F., accompanied by a shower. The light is then strong enough for several hours of work with a theodolite. March is perhaps the most disagreeable month in the year. Low temperatures and frequent high winds may be expected. About the 1st of April it is necessary to wear colored goggles to prevent snow blindness. The first half of this month is usually cold, but during the later half a sudden change comes to the milder temperature of spring. It seems that more snow falls in April and May than at any other time.

During May the first birds come back—snow buntings, sea gulls, geese, and ducks. It is light enough to travel at night by the 1st of the month. About May 20 Canning River breaks out and probably the other large rivers also. They flood a large area of the sea ice at their mouths, but this water soon finds an escape through cracks into the ocean, so that the ice is drained again. The snow softens during the day and hardens at night, so that traveling is best after midnight. The mountains are now nearly free from snow, and by the last of the month it is no longer possible to sled along the valley bottoms.

In June pools of water form between the snowdrifts on the sea ice, and the snow gradually melts on the coastal plain. The weather is clear and warm, altogether the most pleasant of the year. Travel along the coast is now by a boat upon a sled. The rivers have eaten away large areas of the sea ice, and water has formed in the shoal places, so that the boat may often be used to advantage. In July the fine weather continues, the pools of water on the ice become deeper and connected together, so that it is possible to paddle a light canoe for some distance before hauling over a neck of ice to the next pool. Many holes are now melted completely through the ice, and tidal cracks are widened, so that it is difficult to find a crossing. There is a clear course over the shoaler waters, except where large snowdrifts under the lee of high banks have protected the sea ice.

As a rule the ice in the lagoon west of Flaxman Island breaks up and drives westward in front of an east gale before the middle of July, but it may not move from the outside of the barrier islands until much later. About the time that the break-up occurs, the weather changes from the genial climate of the preceding month to raw, windy, cloudy, and foggy. Drizzling rains are common, but heavy rains seldom occur. The stars become once more visible during the later part of August.

During the first three weeks of September the shoal waters are usually navigable, but new ice may form any time after that. As a rule there is ample warning of the close of navigation. The pools on the land become frozen over, and the shoal ocean waters may be several times crusted over, before the ice becomes permanent. The ground is covered with snow by the last of September. While the sea ice is becoming solid enough to support the weight of a man, there is a period of about a week when travel is at a standstill, as the ice is too thick for progress by boat and not yet safe for a sled. The *Duchess of Bedford*, though only a hundred yards from the beach, was thus cut off from the land for several days. The slush from drifting snow was over a foot thick yet a pole could be thrust through it.

By the middle of October coastal travel is once more feasible. Raw gales continue, with temperatures as low as —5° F. November and December are both stormy months, so that very few astronomical observations can be made. The sun sets for the winter about November 20, but there are six hours of twilight all winter, sufficient for traveling. At noon of the winter solstice one can read by holding a book close before a large window.

The average temperatures can only be estimated. During June, July, and August the thermometer at the coast is usually about 40° F., with ordinary extremes of 50° and 30° F. The highest recorded temperature on the coast was 70° F. and the highest in the mountains 72° F. There is a noticeable change from the raw coastal weather at a distance of half a dozen miles inland in the summer.

The coldest months are January, February, and March, when —20° F. is the ordinary coastal temperature. The temperature is below —40° F. on perhaps not more than a dozen days each winter. There were only two short periods during the six years when the minimum temperature was below —50° F. There were three such days in March, 1910, when the minimum was —54° F., and three days in February, 1907, when temperatures were the lowest observed during the six years. The minimum shown by three uncalibrated thermometers is as follows:

Minimum temperatures in February, 1907, at Flaxman Island, northern Alaska.

	° F.
N. & Z., 98893	—57.1
Green, 5327	—61.0
Green, 5330	—60.1
Mean	—59.4

The chief winds are from the east-northeast and from the west-southwest. They may vary somewhat, but probably nine-tenths of the movement is from these directions. East winds prevail as a rule during the summer and west winds during the winter. Sometimes there is no change in direction for a month or more; at other times there are almost daily alterations. The strongest gales come from the west. Many times the west winds have been estimated at 60 miles an hour, and a few times at 70 miles. The heaviest blow the writer encountered was estimated at 70 miles, but it had a recorded velocity of 84 miles at Collinson Point, where the Canadian Expedition had erected an anemometer.

The gales from the east have never been estimated higher than 50 miles an hour, and this for only short periods. Continuous winds from the east, having a velocity of about 30 miles, have several times lasted more than a week.

The windiest months are November, December, and March. At Collinson Point the records of the Canadian Arctic expedition for 1913 showed for November a total movement of 10,670 miles and a mean velocity of 15 miles an hour. The maximum velocity was 56 miles. It blew from the east during 18 days and from the west 12 days. In December the average velocity was 14 miles an hour, and the maximum was 44 miles. There were 19 days of east winds and 12 days of west winds. March is perhaps not quite so windy but is more disagreeable on account of the lower temperature.

Of the summer months, June is the only one in which high winds are not of frequent occurrence. As soon as the ice breaks up the gales commence again, but they are not so strong nor so continuous as in winter.

A comparison of observations at Flaxman Island and those taken at different distances out over the sea ice shows that the winds decrease in velocity toward the north until at 100 miles from land they have hardly half the force. The same is true toward the west. Where the mountains become invisible from the coast, 50 or 60 miles west of Flaxman Island, the winds are not so strong. Eastward, as far as Herschel Island at least, there seems to be no change.

Within the mountains, in the north and south valleys, the writer found that calm weather prevailed, except during the warm winds, which occasionally come from the south.

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-topped receptacle placed on the ground would probably remain empty on account of the peculiar air currents set up.

Although there is much rainy weather in summer, the total amount of precipitation is probably not over 2 or 3 inches. The snowfall is perhaps between 3 and 4 feet, to judge from the depth accumulated among the willows in the mountains, where drifting could not occur.

VEGETATION.

The coastal plain and the upland are covered with the ordinary forms of tundra vegetation. There are no trees or even bushes. Stunted willows occur in the valleys of the upland, increasing in height toward the mountains. Within the mountains the older gravel bars of most of the rivers are overgrown with willows, which rarely exceed 12 or 15 feet in height. On the Canning a few patches of cottonwood trees were observed. The conditions on the Canning are shown in Plate XIV, *B* (p. 53). The cottonwoods appear lofty, but they actually measure about 25 feet in height. No evergreen trees were observed north of the divide on any of the rivers traversed by the writer, but they have been reported near the 141st meridian.

The writer is unable to make any personal statements as to horse feed. He is informed by A. G. Maddren, of the United States Geological Survey, who was geologist on the Boundary Survey, that it is possible for a party with half a dozen hardy range horses to traverse the Arctic slope in summer without bringing in horse feed with them. Sufficient grass is found on the river bars to keep up the horses' strength if they are not overworked.

ANIMAL LIFE.

Several zoologists have worked in the region discussed in this report. Dr. R. M. Anderson has already published a list of the animal life in the appendix to Stefánsson's narrative.[1] Several collectors for the Harvard Museum wintered on the coast in 1913–14. It may be of interest to insert a few notes in this report upon those forms of life which are of economic importance.

GAME ANIMALS.

The barren-ground caribou is easily the most important animal of the region, both for food and clothing. Formerly they could be seen in

[1] Stefánsson, Vilhjálmur, My life among the Eskimo, New York, 1913.

numerous large herds scattered over the tundra, but within a very few years they have become much reduced in number. The international boundary surveyors report that caribou were abundant on the Arctic slope along the 141st meridian in 1911 and 1912. In the spring of 1907 so many haunches were offered to the writer's party that they were finally refused, after a large store had been laid up in the ice house. In 1911–12 and 1913–14 not over half a dozen haunches were procured.

The native hunters have long been furnished guns and ammunition in abundance by the whale ships wintering at Herschel Island. Of course, the natives hold out an ample supply of ammunition for trading. The same is true of the Point Barrow natives, so that every native in the country has a modern repeating rifle and one or two thousand cartridges every year. As they have no better knowledge of conservation than white men, they soon drove the caribou out of the country.

At present caribou are reported to be fairly abundant on the Yukon side of the divide. The few bands that come over to the Arctic side are soon rounded up and killed or driven back again through the mountains.

Most of the deerskins necessary for clothing are now brought in by trading ships. These skins are procured from the reindeer herds of Siberia.

Domesticated reindeer have for many years thrived in Arctic Alaska, but their number has not grown with the demands of the country. There is ample grazing ground for millions of reindeer and yet there is a shortage of fresh meat and deerskins. If the white men imported animals, this need could be met without in the least interfering with the native herds.

As the caribou decreased in numbers, the natives began to hunt the mountain sheep more energetically. 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 Jago and Okpilak rivers were taboo, and the sheep 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.

Polar bears are not abundant. The writer saw none near the land and only two at a distance of more than 25 miles at sea. The natives in the vicinity shot perhaps a dozen each year, mostly females that were giving birth to young in snow caves under high banks on the land.

There is a law that protects polar bears within Alaskan territory, but as most of them are killed at a distance of more than 3 miles at sea the law has little effect. Locally they are regarded much as wolves are in a cattle country, and the sentiment is rather toward offering a bounty for each one killed. They are occasionally dangerous to man, especially those which are forced to come to the land by hunger.

There are two or three varieties of inland bear in the mountains, the largest of which is of the grizzly type. The smaller ones are probably not yet described. They are fierce and will usually attack man.

The bowhead whales migrate northward past Point Barrow in May and June each year and are not seen again until they arrive in the Mackenzie Sea. In the fall they return along the north shore of Alaska and thence go over toward Wrangell Island. They have been hunted by the natives for centuries, but the white men did not follow them east of Point Barrow until about 1850. Undoubtedly they are becoming reduced in numbers, but the smaller catches of recent years are due rather to increasing wariness than to a noticeable falling off in the supply. The whalemen at Point Barrow say they go past there by thousands, yet the writer counted only 34 whales during a month of observations in May, 1910.

White whales migrate along the north shore but were observed only once from Flaxman Island. Their summer grounds are father east. Walrus hardly ever go east of Point Barrow.

The writer found one dead and saw 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.

The bearded seal is not abundant near Flaxman Island. Most of the skins for canoe covers and boot soles come from Point Barrow.

The small Point Barrow seal is abundant and does not seem to be decreasing. They are hunted chiefly in the spring, when they are asleep on the ice. The writer has calculated that as a result of poor marksmanship the natives wound ten seals for each one they secure. In the winter the seal are shot in lanes of open water in the ocean ice. When there is no open water the natives are unable to get them, for they seem to have lost the art of spearing them at their breathing holes. Netting is an efficient method of catching them, and at favorable localities many may be secured in this way. It is easy to lay up enough seal meat and blubber for a year's consumption, so an Eskimo has no excuse for starving.

The spermophile, commonly called ground squirrel, is abundant along the bars of most of the rivers. They are easily secured by traps or snares and can be counted on for dog food in the summer. Some of them have an extremely disagreeable taste, but as a rule the natives can be relied on to cull out the bad ones. The others are fairly good to eat. Foxes are eaten by some of the natives and by curious white men and found good. The writer has never investigated this matter, nor has he tried snowy owls, which are said also to be edible.

Of the game animals, the caribou, in the writer's opinion, is the best for food. Mountain sheep are tough and lean, except in the fall, at which season the writer has never secured any.

Seal and polar bear are not appetizing when one has recently eaten caribou, but after a period without meat of any other kind for comparison they form a welcome addition to the table. Among the white men there is a strange prejudice against both seal and bear meat. Some whale-ship captains will not allow them to be served aboard their ships, even when there is no other fresh meat.

GAME BIRDS.

Eider ducks are very abundant in summer, and form an important part of the food supply. The King eider is probably the most abundant and next is the Pacific eider. Steller's eider and the spectacled eider are much less common. These ducks migrate northward past Point Barrow in May, following the lanes of water. Thence they turn east and follow the lanes of water that generally occur 10 to 20 miles from the coast. They do not come to the land until June, when the ponds have begun to melt.

While on the ice 4 or 5 miles from Point Barrow in May, 1910, the writer witnessed the spring migrations. There was a heavy flight for about two weeks, during which time one or more large flocks were generally in sight. A rough estimate was made of the number which passed in half an hour. Individual flocks were estimated by tens and hundreds, and a total of about 1,000 was obtained for the half hour. At this rate a daily migration of 50,000 is indicated and for the two weeks of migration 700,000. At the same time other flocks were following the land and were consequently out of the range of vision. The numerous reports of the guns of the natives who were killing ducks indicated that the total must have reached a million.

These eider ducks start on their southward migration in July and continue until late in September. The males leave before the eggs are hatched. Then come the females and finally the young. To the east their path covers a wide belt along the coast, but as they approach Point Barrow they follow the mainland and pass over the base of the spit. Here thousands have been killed each year since firearms were introduced into the country. During heavy flights 400 or 500 ducks are not unusual for a single gun in one day, unless there are too many hunters.

Black brant are numerous enough to be an important element in the food supply. The best place for them as well as for the white-fronted goose is between Smith and Harrison bays. At Flaxman Island, during the summer of 1907, about 400 eider ducks and brant were stored in the icehouse for winter consumption, in addition to all that a crew of eight men were willing to eat.

White-fronted geese migrate in numbers past Flaxman Island on their way from the east toward their breeding grounds near Harrison Bay. A very few were secured. Hutchins's geese were sometimes brought into camp.

Oldsquaw ducks are exceedingly numerous everywhere along the coast, probably exceeding the eider ducks several times in abundance. Their migrations are not conspicuous. They gradually increase in abundance in spring, and in the fall they gather into large flocks, which fly from place to place over the ocean in search of food. Shortly afterward they disappear.

In the fall a very few young pintail ducks come down to the coast from the interior.

Ptarmigan seem to fluctuate in numbers from year to year. In 1907, on Okpilak River, not more than a couple of dozen were obtained with a shotgun. In 1908 perhaps 50 were shot on the Canning. During May and June of 1912 on Marsh Creek and Sadlerochit River 25 were obtained with a small rifle in a single day's march. About 250 were secured in all, before the ammunition gave out. In 1914 the Canadian expedition at Collinson Point consumed about 20 birds daily for two or three months. Most of these ptarmigan were secured within 15 miles of their camp.

The ptarmigan retreat to the willows in the mountains in the winter, at which time they are hard to approach. As soon as the first bare spots appear on the land in spring, usually in April, they come in flocks to the coast and are especially numerous among the silt dunes of the river deltas. They are now much tamer and are reluctant to fly, so that a flock can be rounded up and driven into a net or be followed for hours with a gun. By the last of May they have paired off and scattered everywhere over the tundra. This is the period when the greatest execution is done among them, for it is possible to approach a pair within 30 or 40 feet and shoot first the female and then the male. Their loud calls draw the hunter's attention to them when they might otherwise escape destruction.

After they begin nesting only a few males may be seen, and after the males also have attained their summer plumage it is rare to see a ptarmigan until they turn white again in the fall. During October they may still be found along the coast, but after that they disappear for the winter.

Of the various game birds the ptarmigan, in the writer's opinion, is the best for food. Eider ducks and brant are good, but after eating them almost daily for several months they no longer appeal to the taste. Oldsquaw ducks are not considered fit for food by the white men of the country, but the writer finds them the equal of eider ducks, although one or two individual birds were unpalatable. Pintail ducks are delicious in comparison with either eider or oldsquaw ducks.

Duck eggs are sometimes procured in such quantities as to deserve mention. A few nests of king eider and oldsquaw may be found by chance almost anywhere, but the Pacific eider build their nests only on the islands which fringe the coast. Nearly every island has a few nests, but there are certain islands which have hundreds of nests. These islands are frequently raided by the natives, with the result that some of them have become abandoned by the birds. Duck Island, in the mouth of Sagavanirktok River, is an example of such a "rookery." Sometimes 300 or 400 eggs in all stages of incubation are secured by a single raid.

A large black-billed loon was seen near Barter Island. The bird was in the water close to the tent, and at first it was taken for the common large yellow-billed loon. The two native boys quickly called attention to its black bill, for they had never seen such a bird before. They had heard of only one such bird several years before at the Colville. This large black-billed loon was, of course, the common loon of the northern United States. It could not be confused with the smaller black and red throated loons.

FISH.

During the months of July and August fish are abundant almost everywhere along the coast. With a gill net of 2½-inch mesh it is possible to catch more fish at the camps than can be eaten. Half a dozen to a dozen fish may be obtained in a few hours almost anywhere, but at favorable localities and during "runs" hundreds may be caught. The best places known to the writer are at Oliktok, Beechey Point, and Brownlow Point. On the north side of Brownlow Point more than 300 fish, averaging 1½ pounds, were secured in 18 hours with four nets. At Oliktok in two days about a thousand pounds of fish were caught for dog food with three nets. On the east side of Beechey Point, 30 fish were caught in one hour.

The fish do not seem so abundant along the coast west of Harrison Bay, but they are reported to become more abundant toward the Mackenzie.

The larger rivers have abundant fish during the whole year, but the best time for securing them is just before the rivers freeze over in the fall. The water is then low, so that the shoals may be waded in order to seine the pools. In this way a native caught more fish in two weeks on Shaviovik River, than he thought he could use in two years. He used a gill net, and so many fish became entangled in it that it was lifted from the bottom, and most of the fish escaped as he swept each pool.

The natives who live on the rivers in the winter catch fish by "jigging" through holes in the ice. In favorable localities they can catch enough in this way to keep them going from day to day.

Salmon trout are caught both on the coast and in the rivers. The largest that became entangled in the writer's net weighed about 8 pounds, and the average weight was about 1½ pounds. The so-called whitefish is caught only on the coast, but locally it is nearly as abundant as the trout. The grayling is found only in the rivers, where they are locally very abundant. The big catch on the Shaviovik, referred to above, was mostly of grayling.

The writer once caught half a dozen fish that he considered to be small humpback salmon, and once a large dead salmon of unknown species was found.

FUR-BEARING ANIMALS.

Now that whaling has ceased to be profitable on account of the low price of whalebone, trapping and the fur trade are the chief industries of the region. The white fox is by far the most valuable fur animal. An industrious trapper may secure between 50 and 100 skins each season. The total number of skins taken between Point Barrow and the 141st meridian each year will average perhaps 2,000. The number of white foxes differs greatly from year to year. The change is so great that it probably represents a migration rather than a natural increase or decrease. During a single year the number in any locality may differ greatly also. This change may be due to migrations along the coast or to and from the sea ice.

Red foxes are seldom taken along the coast. In the mountains they are somewhat common. Blue foxes are held by the natives to be a sport of the white fox. Their proportion was about one to a hundred in the skins that came under the writer's observation. A very few silver foxes are caught on the coast. Ermine and mink are almost negligible. About a hundred polar-bear skins are shipped each year from Point Barrow.

POPULATION.

Whites.—The permanent white dwellers on the northern coast of America, west of the Mackenzie, do not number more than a dozen. At Herschel Island there are usually two or three Canadian Mounted Police and sometimes a missionary. At Point Barrow there has been for many years a whaling and trading station. At present there are only two or three men employed. The Government school teacher and the missionary at Point Barrow complete the list. Between Herschel Island and Point Barrow there is only one permanent resident, although an occasional trader or prospector may enter the country and stay for a year or so. In the winter of 1913–14 the coast was unusually populous, as there were two whale ships and three exploring ships wintering between Humphreys Point and Collinson Point.

Natives.—The only permanent settlements are at Herschel Island and Point Barrow. There were perhaps 50 natives at Herschel Island and five or six times as many at Point Barrow during the writer's sojourn. In 1906 there were only two or three families living on the coast between these two villages, but lately the natives at Point Barrow have erected winter houses at intervals along the coast as far east as Harrison Bay for the purposes of trapping.

Formerly the inland Eskimo were abundant on every large river, but with the diminution of game they have been gradually forced to come to the coast for trapping or to leave the country. Many have gone into the Mackenzie delta and others to Point Barrow. At present there is a single family group on the Sagavanirktok, and a few others on the Colville. The census taker in 1910 found about 65 Eskimo of all ages in the area between Point Barrow and the 141st meridian.

Much information about the Eskimo is given in Stefánsson's book.[1] There are many ancient native houses along the coast, some of which were excavated by the writer. Stefánsson in 1912 made a large collection from Point Barrow and in 1914 Jenness, of the Canadian expedition, was employed in examining the two large village sites near Barter Island. On the spit running east from Barter Island between 30 and 40 old house sites were counted, and there are perhaps as many on Arey Island, 5 miles to the west. Midway of the north shore of Leavitt Island there are a dozen or more old house sites.

TRANSPORTATION AND COMMUNICATION.

FREIGHT AND SUPPLIES.

In 1912 freight could be forwarded by ship from Seattle to Point Barrow for $25 a ton. Its arrival might be expected during the first half of August. Sometimes small trading vessels sailing from Nome would take up a few tons for about the same price. Beyond Point Barrow and as far as Herschel Island the price was about $40 a ton for freight and its delivery was very uncertain.

Supplies may be brought in by way of the Mackenzie, but the charges are excessive. The Canadian Government pays about 10 cents a pound for freight delivered at Herschel Island for the mounted police.

All ordinary supplies may be bought at the trading station at Point Barrow. Flour in large amounts is usually kept on hand. The prices of all kinds of supplies average about twice those of Seattle, except for such articles as coal, in which the freight is the chief element of cost.

SUMMER ROUTES.

The ordinary manner of reaching the north coast of Alaska is by ship. There are no regular passenger ships, but passage can sometimes be obtained on the United States revenue cutter or on one of the whaling or trading ships which make the annual summer cruise to Point Barrow. These ships generally touch at Nome early in July, and at that time personal arrangements may be made with the captain. The date of arrival at Point Barrow is about August 1.

Some ships go east of this point as far as Herschel Island, or even across the mouth of the Mackenzie, and as the ice usually compels them to follow the shore they can easily land a party at any desired point.

Herschel Island may be reached by way of the Mackenzie early in July. Steam vessels go from the vicinity of Edmonton to Fort McPherson, at the head of the Mackenzie Delta. Thence passage may be procured on the small boats that carry the Government freight to Herschel Island.

The coast may be also reached from the Yukon in summer, by canoe or on foot, by way of most of the large rivers. Ensign W. L. Howard came down by way of the Colville and Ikpikpuk; Schrader and Peters by the Colville. (See p. 84.) Two prospectors are reported to have reached the coast on the Sagavanirktok on foot and two deputy marshals reached Flaxman Island by Canning River. The Indians sometimes come down by the Hulahula, but the route by the Canning is probably shorter. Turner River is probably a good route, but no white man has been known to traverse it in summer. The boundary survey party, which started from the Porcupine with pack trains, had little difficulty in reaching the coast along the 141st meridian.

Canoes have been used by parties that come down the Colville and Ikpikpuk early in the season. Sagavanirktok, Canning, and Turner rivers are probably boatable almost from their headwaters, but navigation may be dangerous until the flood ice is cut away. In July, 1908, Canning River near the forks was still running

[1] Steffánsson, Vilhjálmur, My life among the Eskimo, New York, 1913.

through a narrow canyon in a field of ice more than 12 feet thick. Large undermined blocks of ice were continually breaking off and falling into the water.

A boat of some kind is almost a necessity for traversing the coast in summer. Not only are there unfordable rivers at short intervals but there are numerous small bays and inlets around which detours must be made. On account of the continuous daylight progress may be maintained without interruption, except from bad weather or the ice. By native canoe it is about a 10 days' trip from Flaxman Island to Point Barrow in average weather. By whaleboat, with the prevailing east winds, from three to five days are required.

A place to camp may be found almost anywhere except among the mud flats of the river deltas. There are very few other stretches of coast more than 2 miles in length where there is not a camp site with wood and water. The sand islands seldom have pools of fresh water, but sea ice may nearly always be obtained for drinking water. In the highest parts of all but the smallest and lowest sand islands water capable of sustaining life may be obtained by digging holes. It is, of course, brackish, but it seems objectionable only to the taste.

In order to leave the country as early as possible in the summer it is best to go to Point Barrow by small boat as soon as water forms along the coast. By starting early in July, as is usually possible, one may nearly always arrive before the 1st of August and catch the United States revenue cutter. If ships are known to be to the east and if the ice is close to the land, passage may be obtained by waiting at some favorable spot until the ships pass on their return journey. This method is unsatisfactory on account of the fogs, when the ships may pass without being seen.

The returning ships invariably touch at Point Barrow before turning southward, usually about the 1st of September, and their captains are glad to offer passage to anyone who desires to leave the country. It is necessary, of course, to sign the ship's articles and become a member of the crew.

WINTER ROUTES.

Travel by dog sled is the universal method in winter east of Point Barrow, but reindeer teams are successfully used along the coast west of that point. The country may be entered by sledding to Point Barrow along the western coast or by any of the larger rivers mentioned above. The passes on the Colville from the Yukon basin are reported to be of easy grade. Two prospectors who attempted to sled over the Sagavanirktok divide were unable to find a pass, but the natives report that one exists. Carter Pass, on the Marsh Fork of the Canning, is reported to be easily traversed in one day. There is also a pass on the east fork, according to report. The Eskimos often go over to the Chandalar drainage from Hulahula River. The writer has been within a few miles of this divide and Dr. R. M. Anderson has sledded over it. Turner River is reported to have several passes. The usual winter route from Herschel Island is by way of the Firth.

Winter travel by automobile would probably be possible along the coast and on the rivers. Most of the coast line is protected by islands or shoals, so that there are long stretches of unbroken ice. At the few places where the sea ice crushes against the mainland detours might be made over the tundra. The sea ice is, of course, covered with snow, usually in the form of hard drifts much cut up by the winds. Over such a rough road a speed of more than 5 miles an hour would be difficult to attain. Newly fallen snow is scarcely ever more than 6 inches deep and would not cause difficulties.

MAIL.

The United States revenue cutter brings mail to Point Barrow each summer. Twice each winter mail is brought in to the same place and sent out by dog or reindeer sled. According to the writer's memory a team leaves Barrow post office in November and returns by January. Another round trip is made between January and May.

Every fall, about the first of December, mail is taken out from Herschel Island by the Canadian Mounted Police. Letters are brought in during July, when the freight arrives from Fort McPherson. When several whale ships winter at this island, they may send a special team over the divide to Fort Yukon. the round trip requiring about two months.

HISTORY OF EXPLORATION.

The writer has examined the literature of the exploration of the north shore of Alaska as completely as possible in order to trace the origin and fix the application of the place names. With very few exceptions the names found on existing charts between Point Barrow and the 141st meridian have been verified. The original data regarding nearly all the details of the shore line shown on the map have also been ascertained. An abstract is given of the publications that have been consulted, so that the important facts connected with each exploration may be readily found.

In addition to the names of places on the coast line, the names of places inland as far as the Arctic-Yukon divide, from Colville River to the 141st meridian, have also been traced.

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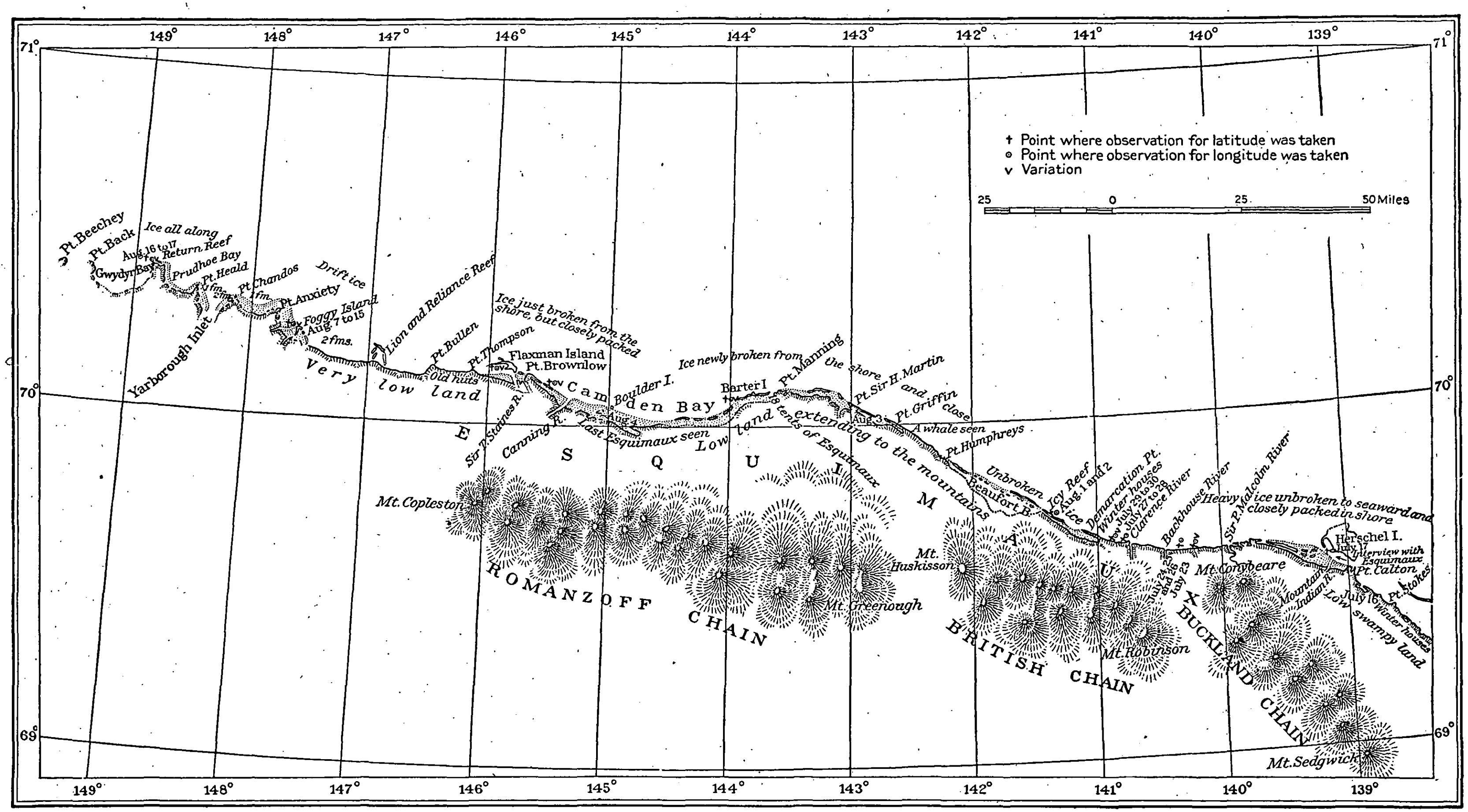


FIGURE 4.—Reproduction of Franklin's map of the north coast of Alaska.

ABSTRACTS OF NARRATIVES.[1]

BEECHEY, 1826.

Capt. Beechey, who entered the Arctic Ocean through Bering Strait in 1826, was not able to push his ship, the *Blossom*, beyond Point Franklin, on the northwest coast of Alaska, so he decided to detach a party to make farther explorations in an open boat. Accordingly Messrs. Elson and Smyth left the *Blossom* in August and proceeded northeastward along the coast (p. 304). A chain of sandy islands was found, which lay some distance from the mainland. They were called the Sea Horse Islands. The name Cape Franklin was applied to the point where the chain bent to the southeast (p. 306) to join the mainland. The bay thus inclosed was named after Lieut. Peard, of the *Blossom*. Cape Smyth was the name given to the point where the land began to diminish in height until it terminated in a low point named Point Barrow (p. 307).

On the eastern side of this point was the largest native village yet seen by the party. The point was found to jut out as a spit for several miles from the regular coast line. The spit did not exceed 1½ miles in width and in some places was apparently less. They did not land at the cape, as they were afraid of the natives, but from a point about a mile at sea they secured observations from which they deduced the position of the extreme point as in latitude 71° 23′ 31″, longitude 156° 21′ 30″.

Their explorations terminated here, and they returned to the ship, which they reached in September.

FRANKLIN, 1826.

[See fig. 4.]

After wintering at Fort Franklin on Great Bear Lake, Franklin started to explore the Arctic shore of Alaska westward from the mouth of the Mackenzie during the last of June, 1826 (p. 84). Fifteen men accompanied him in two open boats, the *Reliance* and the *Lion*. The Arctic Ocean was reached by way of the Mackenzie on July 7, and Herschel Island on the 17th (p. 99). On July 21 they climbed Mount Conybeare (p. 134), an outstanding mountain about 12 miles from the coast and 25 miles east of the Alaska-Canada boundary. From this elevation they discovered the British chain of mountains (p. 135), which lay mostly on the Alaskan side. They were "high-peaked mountains, mostly covered with snow." The mountains at the extremities of this chain were named after the Right Hon. Mr. Robinson, Chancellor of the Exchequer, and after a Mr. Huskisson.

On July 27 a wide river was reached (p. 139), which was "the most westerly river in the British dominions on this coast, and near the line of demarcation between Great Britain and Russia." It was named the Clarence, after His Royal Highness the Lord High Admiral. A tin box, containing a royal silver medal and an account of the expedition, was deposited under a pile of driftwood on the most elevated point of the coast, near the mouth of the Clarence.

On July 31 Point Demarcation was reached, "so named from being situated in longitude 141° W., the boundary between the British and Russian dominions" (p. 142). That night they camped on the mainland behind a long reef, as their advance was blocked by mud flats. The next day, August 1, they dragged their boats over the flats to the reef, only to find that heavy ice prevented their progress outside of Icy Reef. On August 3 (p. 144) they dragged their boats for four hours through the mud flats to the eastern part of a bay which was named after Capt. Beaufort. Thence they proceeded outside of the chain of islands that stretched across the bay to Point Humphreys (p. 145). Beyond this point they went through closely packed ice to Point Griffin, where they landed on a gravel reef, having run 28 miles. Here they passed the western termination of the British Mountains and arrived opposite the commencement of another range, named after Count Romanzof.

From Point Griffin they rowed outside of a chain of islands to Point Martin (p. 146), beyond which they were tempted by the appearance of a bay to steer within the reefs, but the water was too shallow. After passing Point Manning, they met a large Eskimo encampment on a low island. They landed 5 miles farther on, at the western part of Barter Island, in latitude 70° 05′ and longitude 143° 55′ (p. 147). Thence they started to cross a bay, which they named after Marquess Cam-

[1] The page references given in these abstracts are to the original reports, which are listed in the preceding bibliography (p. 69).

den. Ten miles farther on they observed some tents planted on a reef (p. 148). Beyond this reef, at about 2 miles from land, the boats touched ground several times, and they concluded that they were steering into a bay, although its outline could not be seen. Soon afterward, when the wind freshened, they discovered an island, upon which they camped. The island was a deposit of earthy mud covered with verdure and about 20 feet high. A chain of low reefs extended from its northern point for several miles westward. An adjoining island seemed to be a collection of boulders, whence its name of Boulder Island.

On August 5 (p. 149) they proceeded upon the outside of the reef, frequently touching the bottom at 2 miles from the land, especially when opposite to a large river named in honor of Mr. Canning. Three miles farther their progress was stopped by ice that was closely packed against a reef (p. 150) in latitude 70° 07′ and longitude 145° 27′. The Rocky Mountains were observed to terminate abreast of this place or else to recede so far to the south as to be invisible from the coast. The western mountain was named after Dr. Copleston, provost of Oriel College. After two hours of forcing the boats through the ice they reached Point Brownlow, at the beginning of a bay that opened to view, trending to the south. The bay was in every part flat and strewn with stones. Two miles farther to the west they saw an island, which they reached after some trouble with the ice between the central reef and the island, where the pieces of ice were much tossed by the tide (p. 151). They tried to go inside of the island close to the south shore, but after repeatedly grounding they gave it up. They camped on the north side of the island about 30 feet above the water, in latitude 70° 11′ and longitude 145° 50′. The island received the name of Flaxman, after the eminent sculptor. It was "about 4 miles long and 2 broad and rises at its highest elevation about 50 feet."

After being held at this island for a day or so a high tide allowed them to get inside of the island, where the water deepened gradually to 3 fathoms (p. 152). They continued in smooth water until they reached Point Thomson, when having lost the shelter of the ice, which was aground on a tongue of land projecting from Flaxman Island, they became exposed to a swell. Their course continued past Point Bullen to an island that lay 3 miles from the shore, which proved to be connected with the mainland by a reef. One of the boats, the *Lion*, was nearly swamped by running aground on this reef, so they pulled to the windward of the island where they set sail and stood along the shore looking for shelter (p. 153). At length they effected a landing on a point in latitude 70° 16′ 27″, longitude 147° 38′, but had to carry part of the cargo 200 yards through the water. They ascertained that they were on an island that was separated from the mainland by a channel fordable at low water. They were detained eight days at the place by fogs, and gave it the name of Foggy Island (p. 155).

During the temporary lifting of the fog a point was seen to bear northwest by west about 3½ miles distant, but while attempting to reach it the fog shut down. As they were surrounded by shoals, they returned to Foggy Island. They made a second attempt later and arrived abreast of the point in clear weather, but found a reef over which the waves washed stretching to the northwest beyond the extent of their view. Fog again shut down and they were prevented by shoals from reaching any landing place excepting Foggy Island (p. 156). A stream of fresh water was passed, but fog prevented them from seeing the mouth of the river.

When they finally left their camp on August 16, they steered westward parallel to the coast, with a fair wind (p. 158). The depth of water was never more than 3 to 6 feet for the first 7 miles, until they passed around the reef which projected from the point they had so often attempted to reach, and which was named Point Anxiety. Land was occasionally seen between Point Anxiety and Point Chandos, which was 8 miles farther to the west. After rounding Point Chandos they lost sight of land and steered westward across the mouth of Yarborough Inlet, the sounding ranging from 5 feet to 2 fathoms (p. 151). The freshening wind created such a swell upon the flats that it became necessary to haul farther from the land. An attempt was made to land at Heald Point and another at the western point of Prudhoe Bay, but both were frustrated by the shoalness of the water and the height of the surf. Standing out to sea in the fog, they fell among some gravelly reefs, and arriving at the same time suddenly in smooth water they effected a landing on one of the reefs. This reef they found to be a patch of ground about 500 yards in circumference, with only enough wood for one fire. They were surrounded by gravel banks nearly on a level with the water but protected to seaward by grounded ice. The position was latitude 70° 26′, longitude 148° 52′, and the magnetic variation 41° 20′ E. (p. 166). They could trace the land around Gwydyr Bay to its outer point, bearing S. 79° W. which was 10 miles distant and which they named after Lieut. Back. A hummock bearing S. 84° W. about 15 miles distant, was named after Capt. Beechey.

Franklin's positions on the Arctic coast of North America.

[Appendix, p. 134.]

	Latitude north.			Longitude west.		
	°	′	″	°	′	″
Herschel Island, south point	69	33	38	139	03	10
Between Clarence River and Demarcation Point	69	38	23	140	51	00
Icy Reef	69	43	30	141	29	45
Barter Island, west end	70	05	11	143	54	55
Between Canning River and Brownlow Point	70	07	14	145	29	45
Flaxman Island, north side	70	11	22	145	49	57
Foggy Island	70	16	27	147	38	04
Return Reef	70	25	53	148	52	00

As Franklin believed that there was great risk of being caught by winter before reaching Bering Strait, he decided to retrace his path to the Mackenzie from this farthermost point. The ice was more broken up and the sea around the camp was clear, but every wind toward the land brought the ice against the shoals (p. 161). They quitted Return Reef on August 18 and proceeded eastward (p. 166). That afternoon they reached Foggy Island, where they erected a square pile of driftwood under which was deposited a tin case containing records, a silver medal, and a halfpenny. On August 21 they camped in sight of Flaxman Island (p. 168), after having seen a whale. On the 22d they passed inside of Flaxman Island, finding the water much deeper than before, and camped at Barter Island. On the 23d they landed at Point Manning for water (p. 169), and camped at Point Griffin. On the 24th they camped at Demarcation Point (p. 170). Herschel Island was reached on August 26 (p. 171), the mouth of the Mackenzie on the 30th, and finally their former winter quarters at Fort Franklin, on Great Bear Lake, on September 21.

DEASE AND SIMPSON, 1837.

[See fig. 5, p. 74.]

In the year 1836 an expedition was fitted out by the Hudson's Bay Co. for the purpose of exploring the northern coast of America with especial emphasis toward completing the gap between the explorations made by Beechey and by Franklin. The expedition was placed in charge of Messrs. P. W. Dease and Thomas Simpson, officers of the company, with instructions to proceed from Fort Chippewyan on Athabasca Lake.

On June 1, 1837, the party of 14 men started down Mackenzie River in two open boats, 24 feet long (p. 82). They reached the Arctic Ocean on July 9 (p. 107), and Herschel Island on July 14 (p. 115). On the 15th they breakfasted at Demarcation Point (p. 116), where the latitude observed was 69° 40′ 31″. That night they supped at Point Humphreys (p. 117). The next morning they camped near Point Griffin; they got off again at noon and landed on a reef near Point Manning for supper (p. 118). They carried the boats across the reef to the open water inside, but steered outside of Barter Island and sailed on until 3 o'clock in the morning of the 17th, when they were forced by the heavy ice to land. On the 18th they made only a league, and camped at the foot of a green hill, near a stream. About midnight of the 19th they started again and reached Flaxman Island about 5 o'clock in the morning of the 20th (p. 129). They passed inside of the island and along the mainland and landed for breakfast at Point Bullen. The ice then became heavier and they were obliged to keep within Lion and Reliance reefs. In Foggy Island Bay they were entirely arrested. Here during clear weather they found that the Rocky Mountains did not terminate with the Romanzof Chain, but another chain, less lofty perhaps, was seen to extend westward. To these mountains they gave the name of the Franklin Range (p. 125). An incredible number of seals was seen on the shores of the bay.

At 7 in the morning of July 22 they stood out for Point Anxiety, but were forced to land about 3 miles to the west of their former camp (p. 126). The position was 70° 09′ 48″ and the longitude, deduced from Foggy Island, was 147° 30′. Here they had a distinct view of the Franklin Mountains, the central and highest peak bearing south by east (true), about 20 miles distant. On the 23d they once more set sail for Point Anxiety, but were forced by the ice to go far from land, until at Yarborough Inlet the coast was 6 miles distant (p. 127). Return Reef was reached that night.

On July 24 they coasted along Gwydyr Bay, which was less extensive than drawn by Franklin (p. 128). The names Point Back and Point Beechey were applied to the projections agreeing nearest with the hummocks of land seen by Franklin. The bearings were found to be different, and Point Beechey, distant 12 miles from Return Reef, was invisible from thence in any state of the atmosphere. The whole bay was protected from the sea by a chain of gravel reefs. The soundings here varied from a quarter to 1 fathom (p. 129). Opposite Point Beechey, and at the distance of 1 mile seaward, the gravel reefs were succeeded by a range of low islands 8 miles long, which were named after Rev. David T. Jones. From Point Milne they enjoyed a transient prospect of another magnificent mountain range, about 50 miles to the west. The coast trends westward for 12 miles from Point Beechey to Point Berens, which proved to be the commencement of a very extensive bay, the land turning from thence to the southwest. About 8 miles beyond Point Berens the water shoaled from 7 or 8 feet to less than 2 feet, and they were forced to stand out to sea (p. 129). A large river falls into the bottom of the bay, which was named after Andrew Colville, esq., of the Hudson's Bay Co. (p. 130).

They had great difficulty with the shoals off the Colville delta and were many hours lost in the fog, until they finally made land at Point Comfort (p. 131) about midnight of July 24, having fasted for 24 hours. Here observations showed latitude 70° 43′ and longitude 152° 14′ (p. 131). Some of the men had another view of the Pelly Mountains, now distant about 20 miles to the southeast (p. 132). About a mile to the north they discovered a "splendid river," flowing from the southwest, and named it after Nicholas Garry, Esq. (p. 132). On the 26th they proceeded across some shoals and passed the mouth of the Garry, which they found to be a mile wide. Its banks were thickly covered with drift timber, evidently brought down by the stream (p. 133). From thence the land trended northeast for about 8 miles to a small island separated from the mainland by a channel too shallow for boats.

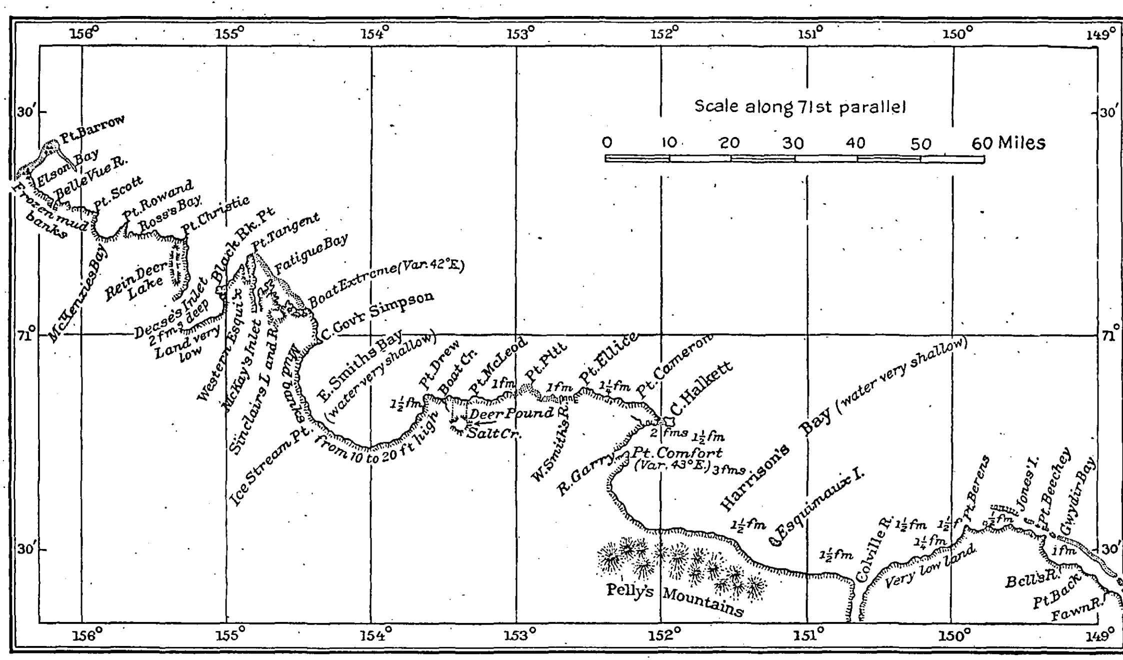


FIGURE 5.—Reproduction of Dease and Simpson's map of the north coast of Alaska.

Latitude 70° 47′ 45″ and longitude 151° 55′ 30″. were observed. This remarkable point was named Cape Halkett, after one of the directors of the Hudson's Bay Co. It terminates the great bay that extends 50 miles to Point Berens. The name Harrison Bay was given in honor of the deputy governor of the Hudson's Bay Co.

For 15 miles west of Cape Halkett nothing save low frozen mud banks were seen, but after rounding a point, named Point Ellice after Rev. Edward Ellice (p. 134), a considerable river was observed to enter the ocean. This was named Smith River, after Mr. William Smith. Here the mud banks were succeeded by a chain of ground reefs which lined the coast for 10 miles. On these reefs large mounds of mud and shingle had been raised by the pressure of the ice. The channels within the reefs were not navigable. Point Pitt, the northernmost point passed during the day, is situated in latitude 70° 53′ and longitude 152° 54′. A few miles on either side of it they observed a stream of discolored fresh water rushing through the reefs, probably from a large lake, but the atmosphere was too hazy for ascertaining the fact. At the last of these streams the mud banks recommenced, and some distance beyond they were forced to land and camp upon a 20-foot bank. On July 27 they discovered a deer pound, formed by double rows of turf, which led from the beach toward a lake of some magnitude (p. 136). The point upon which they were camped was named Point McLeod, and one of equal elevation 4 miles farther west, Point McPherson.

About noon of July 27 they were able to get off again, and after 7 miles rounded a point named after Richard Drew (p. 137), where the land turned suddenly at a right angle to the south. Here they entered a large and very shallow bay, which was named after Chief Factor Smith. Countless herds of deer were observed upon the flat shores of this bay. After much difficulty with shoals and ice and fog they reached a sharp projecting point, upon which they encamped (p. 138). This point, situated in latitude 70° 59′ and longitude 154° 21′, was named after George Simpson, governor of the Hudson's Bay Co. On the 28th they made only 2 or 3 miles and camped in latitude 71° 01′, longitude 154° 22′ 53″. (p. 140). On July 31 they made 2 miles more (p. 141). From this place they decided to send a party on foot to explore the coast as far as Point Barrow.

Simpson, accompanied by five men, quitted Boat Extreme on August 1 at 8 a. m., while Dease and the other men remained to guard the boats (p. 143). The men of Simpson's party each carried a load of about 50 pounds, and one of them had a canvas canoe. They followed the coast line and were constantly wet to the waist from fording innumerable salt creeks (p. 144). A deep, strong river and a shallow inlet half a mile wide were crossed by means of the canoe. The river was named the Sinclair, after one of the men, who found that it issued from a large body of brackish water about 5 miles from the point where they crossed it near the coast. The inlet was named after McKay, another of the men. After accomplishing 20 miles by 7 p. m., they passed a miserable night on the wet tundra, where they found a few pieces of driftwood (p. 145). On August 2 they resumed their march up the west side of McKay Inlet and soon reached a place whence the land turned sharply off to the south-southwest, forming an acute angle, well termed Point Tangent. A chain of ground reefs, which was separated here from the muddy beach, extended in a direct line 11 miles eastward to Boat Extreme, inclosing the irregular-shaped bay of which they had made the tedious circuit (p. 146). This bay was consequently called Fatigue Bay.

About 10 miles from Point Tangent, where the coast turned off to the east of south, a wide inlet lay before them. The first and only rock seen in the whole extent of the coast, an angular mass of dark-colored granite, lay off the point they had reached (p. 149). Luckily they were able to borrow an Eskimo umiak from some natives whom they found at the point. After steering west for 5 miles they reached the opposite shore of the inlet, which was named after Dease. On August 3 they breakfasted on a point of land on a sand reef in latitude 71° 12′ 36″, longitude 155° 18′ (dead reckoning). This point was named after Chief Factor Christie. From thence the low coast turned westward for 8 miles (p. 151). Point Charles and Point Rowland on the east and west sides of Ross Bay were passed, and then a semicircular bay 4 miles in diameter, which was named after Chief Factor Roderick Mackenzie (p. 152). A depth of 1½ fathoms and a sandy bottom were found in the middle of the bay. Seven miles beyond Point Scott they passed the mouth of a fine deep river a quarter of a mile wide, which they called the Bellevue. Shortly afterward Point Barrow was reached (p. 153). This point they found to be a long, low spit composed of gravel and sand. At the spot where they landed it was only a quarter of a mile across, but was considerably wider toward its termination, where it subsided into a reef that ran some distance in an easterly direction and was partly covered by the sea.

After some hours of communication with the Eskimo at the village they left Point Barrow on the noon of August 4 and headed back on their old route along the mainland (p. 162). The natives called to them to go toward the extremity of the spit, but they distrusted their motives and did not follow their "insidious" advice (p. 163). At Point Rose they were blocked by the ice and camped. On August 5 they reached the Eskimo camp on the east side of Dease Inlet, having found 2 fathoms halfway across the inlet. They continued to use the Eskimo canoe for the remainder of the trip, and soon rounded Point Tangent and proceeded along the outside of the sand reefs that inclose Fatigue Bay. At 5 a. m. on August 6 they reached their comrades at Boat Extreme. Their position here was latitude 71° 03′ 24″, longitude 154° 26′ 30″.

Shortly after noon on August 6 they started eastward again, steering across Smith Bay and landing at Boat Creek, behind Point McPherson. Here they found abundant driftwood (p. 169). Thence after sailing along the land all night they reached Cape Halkett at noon of August 7, where they halted for some time. After proceeding 11 miles in a direct course for Point Berens they found a depth of 3 fathoms (p. 170), the deepest water noted during the whole voyage. As a westerly gale came up, they shaped their course more into the bay, until they came within sight of the land. They ran all night close reefed, the boats shipping much water in crossing the flats of Colville River. During this stormy run they fell in with a small island about a league from the main shore and 12 miles from the Colville. The water between Eskimo Island and the mainland was fresh, and the island contained a quantity of driftwood. The actual mouth of the Colville appeared to be fully 2 miles wide. They thought that it was probably the mouth of the Yukon, the river reported by the Indians to have its source in a large lake a thousand miles to the southeast (p. 173).

Still under closely reefed sails and with the waves breaking over the boats they scudded inside of the Jones Islands and camped in the afternoon in a cove scooped out by a small river in the mainland opposite Return Reef (p. 174). The next day, August 9, their camp at Fawn River was found to be in latitude 70° 25′ 03″ and longitude 148° 24′ 45″. Return Reef bore east-northeast about 2 miles distant. Their determination of the latitude agreed with Franklin's, but their longitude differed from his determination by about half a degree. Their longitude at Point Barrow agreed with that of Elson, and they were at a loss to understand the divergence at Return Reef. In the afternoon of the 9th they proceeded under oars, landing that night near Point Anxiety (p. 175), where numerous boulders of granite were strewn on the beach. On August 10 they sailed outside of Lion and Reliance reefs and inside of Flaxman Island and landed about noon on a reef in latitude 70° 09′ 08″. Camden Bay was crossed at a rapid rate and they landed at Barter Island at night (p. 176). Before midnight they reembarked and steered inside of the reefs for some time; outside they encountered a heavy sea. They landed at Demarcation Point for breakfast on August 11 and were forced by the ice to encamp. Herschel Island was passed on the 15th (p. 180), and the Mackenzie was entered on the 17th (p. 184). They tracked the boats up this swift river at the rate of 30 to 40 miles a day, reached Fort Norman on September 4 (p. 192), and on the 25th the winter quarters that had been erected for them on Great Bear Lake.

In a letter addressed to the governors of the Hudson's Bay Co. and published in the Journal of the Royal Geographical Society, Dease and Simpson gave a summary of their journey. There is little additional information in this communication. One point of interest lies in the size of the deer pound mentioned on page 135 of Simpson's volume. The distance from the beach to the lake is given as 4 miles.

PULLEN, 1849.

In the summer of 1849 Lieut. W. J. Pullen, of the British ship *Plover*, Commander Moore, traversed the north coast from Wainwright Inlet, about 100 miles southwest of Point Barrow, to the Mackenzie, with the hope of finding news of Sir John Franklin's expedition. He left the *Plover* July 25, 1849, with four boats and a crew of 25 men (p. 24). He passed Point Barrow on August 2 and landed the next afternoon at a low sandy spit in latitude 71° 06′ and longitude 154° 31′ (p. 25). Cape Simpson was passed before noon of the 4th, and a little later, an observation was made in latitude 70° 58′ 33″ (p. 26). In crossing Smith Bay they shipped much water on the shoals, so they landed on the east side and spent a day or so in drying out their provisions. They got off on the 7th, and landed a few miles beyond Point Drew for dinner. That night they camped at the deer pound mentioned by Dease and Simpson. On the 9th they landed at the extremity of Cape Halkett (p. 27). Thence they steered a course across Harrison Bay toward Point Berens. Ice grounded in 5 fathoms was seen. As the wind freshened from the west the sea became so rough that one of the boats was nearly swamped. Provisions were thrown overboard, and they managed to reach land about 2 miles south of Point Berens.

On the morning of August 11 they landed at this point and met a great many natives. Thence they sailed between Jones Islands and the mainland, following the land as close as the shoal water would permit. When abreast of the eastern island of the Jones group, they crossed over and followed its southern shore. Then they crossed to the mainland and landed, early on the morning of the 12th, on a very narrow beach about a mile east of Point Beechey (p. 28). Here they had trouble with an Eskimo encampment and were forced to move to the reef, where they barricaded themselves until the head wind moderated (p. 29). At noon on the 13th they landed about 2 miles from the western part of Return Reef, and that night reached a low shingly point 2 miles to the east of Foggy Island.

The next day they passed Lion and Reliance reefs. On the morning of the 16th they landed on the eastern part of Flaxman Island. Thence they passed inside of the island and landed again on the low sandy beach that extends from the high eastern part of the island. That night they were prevented by shoals from reaching the land, so they made fast to a grounded berg and slept in the boats. They camped on the southwest part of Barter Island on the night of the 17th (p. 30). At noon of the 18th they landed on a small island east of Manning Point and erected a post near some buried pemmican. That night they camped on a small spit off Point Martin.

On the evening of the 21st they camped near Herschel Island. They entered the Mackenzie on August 27 (p. 41) and reached Fort Good Hope on September 14, Fort Norman on the 23d, and Fort Simpson on October 3. From this place the preceding account was forwarded to England.

HOOPER, 1849.

Lieut. W. H. Hooper, one of the officers who accompanied Pullen on his boat from Wainwright Inlet to the Mackenzie in 1849, also published an account, which contains very little additional information. The party tried to go inside of Lion and Reliance reefs, where they slept on the night of August 14 (p. 252). They were hardly ever more than 2 or 3 miles from the shore, between that locality and Flaxman Island. The cliffs at the east end of this island were estimated to be 40 feet high.

MOORE, 1850.

In the summer of 1850 Commander Moore, of the *Plover*, made a boat journey as far east as Cape Simpson from a locality below Point Barrow. The following details are taken from his narrative:

On July 28, east of Point Barrow, he discovered several sand islands which he named the Plovers group (p. 38). At the first entrance to Elson Bay, east of the point, he found 8 to 9 fathoms of water. He reached Dease Inlet that night and camped in a bay on the east side.

On July 29, while tacking toward Point Tangent, in about 1¾ fathoms, he saw land to the north-northwest, which proved to be two islands, a large one and a small one. He landed on the small one, where he found many nests and erected a post. The latitude was found to be 71° 13′. This island was named Martin Island, and the larger one Cooper Island, after officers of the *Plover*. He then worked eastward nearly to Cape Simpson, but was forced to run back into Dease Inlet for shelter, where he camped on the same day as before, and named it Return Cove.

On July 30 he was held in camp. The latitude was found to be 71° 11′ 18″ and the longitude 155° 46′.

On August 1, while standing out to the northward, he discovered several islands. He landed on the third island and erected a post. The latitude was 71° 15′ 40″. Then he steered east one-half north along the island nearly to Cape Simpson. At 1 o'clock in the afternoon he turned about and by 3 o'clock was beating between Cooper and Martin islands and the mainland.

On August 2 he was inside of the Plover group at 3.45 a. m. and reached Point Barrow at 4.30 a. m. There were four islands in the group.

McCLURE, 1850.

In January, 1850, Capt. Robert McClure sailed from England in command of the ship *Investigator*, with directions to enter the Arctic Ocean through Bering Strait and to sail eastward along the northern coast of America in search of Sir John Franklin. Capt. Collinson, on the *Enterprise*, left at the same time with similar orders. The following summary is taken from the account of McClure's voyage, edited by Capt. Sherard Osborn.

Point Barrow was passed in an open sea at midnight of August 5, 1850 (p. 60). On the 8th a boat was sent to Point Pitt, where a cairn was erected (p. 62). On the 9th much heavy ice was observed to be aground in 40 feet of water. The party landed upon Jones Island, in latitude 70° 33′ and longitude 150° 16′ and found that it contained a great swamp (p. 73). The beaches were strewn with driftwood. On the 14th the ship was much hampered among the low and dangerous islands which lined the coast in longitude 148° 17′ (p. 78). On the 15th they anchored off Yarborough Inlet (p. 80) and on the 18th passed Flaxman Island. Shortly afterward the ocean appeared open, and they steered out from land and ran on until noon of the 19th in fog and snow squalls, when they found themselves to be in a blind lead, about 70 miles from land. To clear the ice they were forced to turn southward, and on the 21st they were abreast of the Mackenzie. The *Investigator* was abandoned on the north shore of Banks Land a few years later. Her crew crossed the ice to the Parry Islands, whence they were carried home in the ships of another expedition.

A communication from McClure to the Secretary of the Admiralty is published in the British Blue Books. This is also found among the reports of the Arctic searching expeditions. There is little additional information, except that they landed and erected a cairn at Point Drew (pp. 25, 57). Two old Eskimo caches were found at Pitt Point (p. 26). A cairn was erected on Jones Island (p. 26).

COLLINSON, 1851–1854.

Collinson, who sailed from England on the *Enterprise* at the same time as McClure, rounded Point Barrow about July 25, 1851, and was held within sight of it until the 30th (p. 144). On August 2 his party crossed Harrison Bay in thick weather and so did not see the Pelly Mountains (p. 145). At noon of this day their observations put them 2 miles inland, according to their charts. Therefore Collinson placed the coast line 5 miles farther south than the line drawn by Simpson (p. 146). When the Romanzof Chain opened to view, the necessary angles for determining the position of the most remarkable peaks were obtained. True south, at about 2 miles, lay a low shingle bank, beyond which Point Anxiety could be seen, and to the west a low chain of islets, 2 to 4 miles from the mainland, could be traced as far as Chandos Point (p. 147). Lion Reef was reached about midnight of the 5th, and the sand banks were found to continue that far. Flaxman Island was glimpsed, and east of it four sand banks, and then a broad opening, the entrance to a large "lagune." Several huts were noticed on Barter Island. The cliffs of Manning Point were from 30 to 40 feet high, the highest land seen since they left Point Barrow (p. 148). Thence they soon passed into British territory, where they spent two winters before starting on their return westward. In September, 1853, they passed Herschel Island again and a few days later were blocked at the long sand bank which fringes the coast west of Point Manning (p. 299). On the 14th they got free and ran until they sighted Flaxman Island (p. 201). Abreast of it they were compelled to go into 2¾ fathoms and nearly grounded. Near by they tied up to a floe grounded in 7½ fathoms, being hemmed in by heavy ice. Here, on September 26, they were frozen in for the winter.

On October 4 Collinson started over the ice toward Barter Island, and at noon reached a low point. Thence they went inside of Boulder Island and along the shore in hazy weather (p. 305). At 5 o'clock they reached a low cliff where the coast range of hills began. After crossing a long, shallow bay the next morning, they arrived at 10 o'clock at a shingle point, upon which were 10 small huts and one large one. They continued alongshore, passed some cliffs, and reached another point by noon. Here there was a settlement. Then they crossed what was most probably the mouth of a river, but very shoal, and camped on low ground. On October 7, in thick weather, they camped before noon and were storm bound until the 10th (p. 306). Thence they retraced their steps and camped on the point with the 10 huts. The next day they camped early and did not recognize their locality. On the 12th, after being confused in thick weather, they reached the ship (p. 307).

In the last of April, 1854, Collinson made an attempt to explore to the northward but was forced by the roughness of the ice to give it up (p. 312). On May 15 he set out to find the Canning. The coast was traced to the east, but the embouchure was not discovered. The second morning he struck inland and found that the land rose suddenly to 50 feet at a distance of 2 miles from the shore and then formed a table-land, here and there traversed by broad watercourses. On the 17th it was foggy, but at 3 p. m. they reached a steep acclivity, where they camped (p. 313). In the morning they found that the mountains rose like a wall close at hand. They climbed up a slope of 35°, formed of sandstone talus, and brought up in the mist on a narrow shelf at an elevation of 2,200 feet. The summit, which was not the highest part of the chain, was estimated to be 700 feet above them. During the day they crossed over a patch of red clay. They returned to the ship during a thick haze, without the extended view which they had hoped for (p. 314).

On July 5 they set off again to obtain some observations upon the elevation of the Romanzof Chain (p. 316), and soon discovered that what they had taken for the eastern bluff of Flaxman Island was in reality the embouchure of the Canning. The westward trend of the river had confirmed their error. The Staines was considered to be another outlet of the same river and Brownlow Point to be a large island. The ice still remained packed on the sand banks to the east and west, and in no place was there so much water as immediately opposite the ship (p. 317).

On July 10 Lieut. Jago departed in a whaleboat for Point Barrow, as there was sufficient water along the shore to allow him to clear Brownlow Point.

On the 15th the ice began to move. The ship broke free the next morning and brought up off Point Brownlow, where the ice was still against the shore (p. 319). On the 20th they passed Flaxman Island, but could not go within the sand banks (p. 321). On the morning of August 5 they were 2 miles from a low sand bank to the west of Jones Island, and a boat was sent to erect a mark on it (p. 323). Point Barrow was reached on the 8th (p. 324), and Port Clarence on the 21st (p. 330).

Lieut. Jago's account of his boat trip to Point Barrow (pp. 324–327) is as follows:

July 10.—Left the ship about noon and, being blocked by the ice in the afternoon, portaged over a shingle bank and proceeded inside and rounded Point Brownlow. Camp was made about 8 miles beyond.

July 11.—Worked among the ice cakes and at 10 o'clock launched across Lion Reef. Passed inside of Foggy Island.

July 12.—Off Point Anxiety at 5.30 a. m. Ice close in, so launched over the point. The ice still remaining close in, went ashore and camped, in thick weather.

July 13.—Worked heavy ice until noon and reached open water off Yarborough Inlet. Rounded Point Heald at midnight.

July 14.—Landed on a reef in the morning, passed Return Reef about noon, and worked inside the reefs, poling and sailing.

July 15.—Landed at Point Milne at 6.30 a. m. Ice close inshore. Observed a mark at Point Berens, examined it, and found it to be that erected by the *Plover's* party in 1849, with three tins of pemmican buried near it. Landed again on a reef about 10 miles west of Point Berens, and buried a boat, a sledge, boat's rudder, and slings, and some bread in a black bag.

July 16.—Working across Harrison Bay and at noon rounded a point in very shoal water. Some huts seen on the shore.

July 17.—Working ice; some fog; camped on land.

July 18.—Sailing and poling along the land in shoal water.

July 19.—Sailing and poling along the land in shoal water.

July 20.—Thick fog; ran to westward in about 2 feet of water and no land seen. Camped at Cape Simpson.

July 21.—Remained in camp.

July 22.—Passed Point Tangent in evening and camped in Dease Inlet.

July 23.—Rounded Point Christie and camped on Point Charles.

July 24.—Arrived at Point Barrow.

In his short communication to the Admiralty, published in the British Blue Books, Collinson gives no information of interest which was not embodied in his narrative.

Collinson's communication to the Royal Geographical Society contained his astronomical positions but little else of importance (p. 266).

Collinson's positions on the Arctic coast of Alaska.

	Latitude north. ° ′	Longitude west. ° ′
Point Barrow, extreme point[1]	71 24	156 15
Cape Halkett (islet)	70 50	152 18
Sand bank off Colville River	70 34	150 27
Sand bank off Yarborough Inlet	70 30	148 17
Flaxman Island (northeast point)	70 11	145 44
Mouth of Canning (west bank)	70 06	145 32
Manning Point	70 06	143 41

The route map which accompanies this report contains no new details of the shore of Camden Bay.

MAGUIRE, 1852–1854.

[See fig. 6.]

In accordance with the plans for the relief of Sir John Franklin and also of the ships which had gone to the east in his search, Commander Maguire of the *Plover* wintered in Moore Harbor at Point Barrow between 1852 and 1854. His narrative for the first winter is given in the appendix to McClure's book and also in the reports of the Arctic searching expeditions and in the British Blue Books. His map is published in each of the two last-mentioned volumes.

The following abstract follows the paging of the British Blue Books:

Maguire left Port Clarence with the *Plover* on August 2, 1852, and reached Point Barrow on September 3 (p. 165). Here he succeeded with some difficulty in warping over the shoals that guarded the westernmost entrance to Elson Bay (p. 166). On the 21st he made a boat trip to the east as far as Dease Inlet (p. 167). At first he went out from the land into 5 fathoms, but in running toward the land again they became entangled among a series of sand spits. They then steered along the outside of the low chain of sandy islets and camped on one of them. Maguire was puzzled about his position, for he considered it impossible for the early explorers not to have noticed these islands. After steering south the next day they landed on a point which proved to be Point Christie. Here a mark was erected. Then they crossed Dease Inlet, finding the depth 11 feet in the middle and the shores very shoal. Thence they returned to the ship.

Dease Inlet was further examined by the second master in the month of May, and the southern shores were traced. Four inconsiderable rivers empty into the inlet, two on each side. The chain of islands which commenced at the ship and abutted on Point Tangent, the western part of which was discovered by Capt. Moore and named the "Plover's group," were found to number 10, but only 2 or 3 of them bore vegetation. The only channel between them of sufficient depth for a ship was at the winter quarters. In November a 13-day trip was made over the ice as far eastward as Point Drew, where a cache of food was made for the spring trip (p. 161). In the middle of February, 1853, Maguire made a sled trip southwest along the coast for about 40 miles (p. 178). In April he made another sled trip to the east for 25 days (p. 161). No details of this trip are given, but from the route map it is seen that he reached the Jones Islands. No winter huts were found along the coast (p. 162).

During the summer of 1853 Maguire went to Port Clarence to refit and returned to winter

[1] After Pullen.

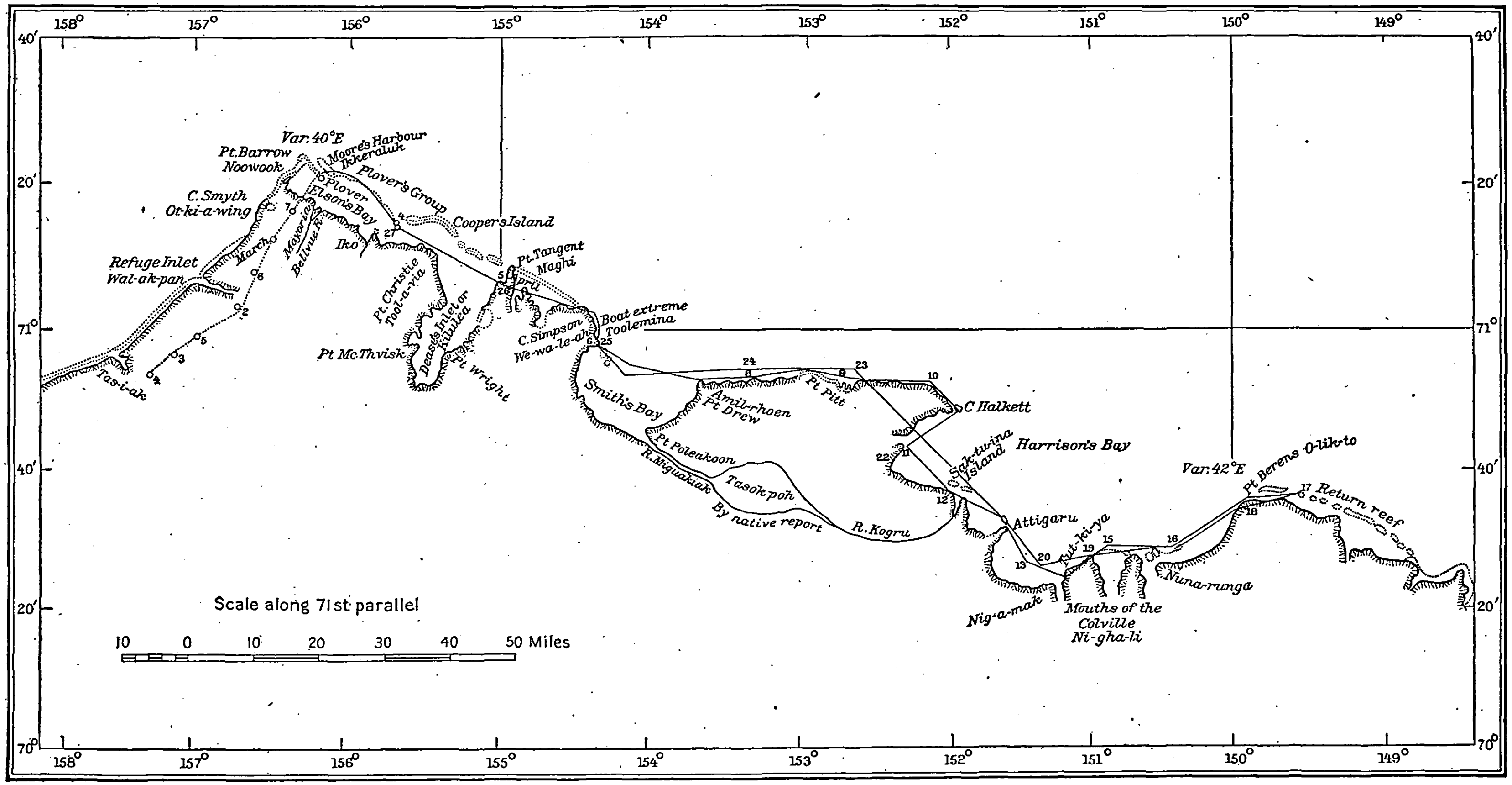


FIGURE 6.—Reproduction of Maguire's map of the north coast of Alaska.

16344°—18——6

again at Point Barrow. The following is an abstract of his second trip:

He reached the former berth in Elson Bay on September 7 and immediately placed the ship in winter quarters (p. 907). In October he made a sled trip as far east as Cape Halkett and buried 120 pounds of pemmican. In April and May another trip was made as far as Point Berens (p. 909). In July the *Plover* left Point Barrow and reached Port Clarence by August 1 (p. 912). Thence the expedition returned to civilization.

A valuable account of the Eskimo of northern Alaska is given by Surgeon John Simpson of the *Plover*. Some native information as to the country is also given, and a native map of the north coast between Point Barrow and Humphreys Point. The native who drew the map denied the existence of the Pelly Mountains and was most positive that no hills even were visible from the coast on the west side of the Colville (p. 937).

WHALE SHIPS SINCE 1854.

The first whale ships to go beyond Point Barrow are reported to have done so upon the recommendation of Capt. Collinson after his return from the east in 1854. From that time they each year advanced a little farther eastward, until in 1889 the first whalers are reported by Stockton to have advanced beyond the Mackenzie and to have wintered at Herschel Island. Since that time as many as twenty ships have cruised along the northern coast in a single summer. As the land is low and has few marks by which localities can be distinguished, the whalers knew but few details of the coast line. As their observations are not published, it is impossible to credit them with their discoveries. Such features as the Midway Islands and Cross Island, named by Stockton, were of course known long before the *Thetis* entered that part of the ocean. Pole Island of the charts is believed to be another of their landmarks. Barter Island of Franklin is an inconspicuous sand island, and Manning Point is in reality an island with the highest cut banks of the whole coast, and thus the whalers have applied the name of Barter Island to Manning Point. This name has long been the local usage.

Hunting parties from ships wintering at Herschel Island have been reported to travel as far to the west as Aichillik River. Several parties have gone to the Yukon by way of the winter route up Firth River.

In navigating this low coast in thick weather the lead is constantly employed. In dangerous localities two men sound alternately as fast as they can. In this way the whalers have gained an intimate knowledge of the soundings, but unfortunately the knowledge is personal with each captain and can not be made available. Their rule is to follow 7 fathoms, if possible, when east of Point Barrow. This depth takes them clear of all dangers except, of course, the danger from the ice.

RAY, 1881–1883.

Point Barrow was selected for one of the International Polar Stations of 1881, and Lieut. P. H. Ray, United States Army, was placed in charge of it. The party of 10 men reached Point Barrow on September 8, 1881, and landed about 8 miles southwest of the point near the Eskimo village (p. 22). Here winter quarters were established and a series of scientific observations were carried on for two years. In March, 1882, Ray made a trip into the interior, of which an account was transmitted to his superiors (p. 24). Another trip was made southward in March and April, 1883, during which Meade River was partly mapped (p. 27). At his farthest camp, from an elevation 175 feet above the river, he discovered a low range of mountains about 50 miles to the south. These were named the Meade River Mountains (p. 28). The expedition returned to the United States in September, 1883.

The latitude of the base station was determined by a few observations of the sun with sextant and theodolite, and the longitude by chronometric comparisons between San Francisco and Point Barrow in the summer of 1882. This work was supplemented by three sets of lunar distances. The positions adopted by the Coast and Geodetic Survey for the observatory at the station (p. 449) are latitude $71° 17.7' \pm 0.3'$, longitude $156° 39' 45'' \pm 02'$ (?).

An account of Ray's first trip eastward, mentioned above as having been transmitted previously to his superiors, was found in the United

States Signal Service Notes. The abstract is as follows:

In March, 1882, he made a sled trip southward in order to purchase some caribou meat from the natives (p. 37). He discovered a river which was named after Gen. G. G. Meade, United States Army (p. 38). In April he proceeded inland for 35 miles, in the direction E. 23° S., and found that the Meade emptied into the ocean by five mouths, in latitude 70° 59′ and longitude 154° 32′. The details of his astronomical observations for the position of winter quarters are given in the same report (pp. 25–34).

STONEY AND HOWARD, 1885.

In December, 1885, Lieut. G. M. Stoney, United States Navy, left his winter quarters on the Kobuk and reached the headwaters of the Colville by way of the Noatak (p. 39). He traveled for several miles down the Colville to the native village of Issheuk, near the northern limit of the mountain range. Learning from the natives that it would be impossible to reach the Arctic coast at that time of year, he returned to winter quarters.

In February he again reached the Colville waters, this time at Chandler Lake, but was again unable to persuade the natives to accompany him to the Arctic coast (p. 44).

In April Ensign W. L. Howard was directed to go to the headwaters of the Colville at Issheuk and thence to Point Barrow (p. 66). At first he traveled down the Colville by sled with the Eskimo (p. 70). Near the outside of the mountains they sledded in one day to the headwaters of the Ikpikpuk (p. 71), which he renamed the Chipp (p. 73). In June they were able to descend this river in native canoes. Near the mouth the river divided into two branches. Howard took the west one, but was informed that the other also reached salt water (p. 75). He was detained nearly three weeks at the mouth until the sea ice broke from the shore (p. 76). Then he proceeded along the coast, mostly in fog, until he reached Point Barrow on July 15, 96 days after leaving his winter quarters (p. 77). He returned by sea to headquarters near Kotzebue Sound.

STOCKTON, 1889.

In 1889 Capt. C. R. Stockton, of the U. S. S. *Thetis*, was assigned the duty of looking after the whaling interests in the Arctic Ocean. The expedition arrived at Point Barrow on July 29 and found Ray's house still standing (p. 181). A house of refuge for shipwrecked whalers was erected near by. Here they met a man named Joe Tuckfield, who had just come from the Mackenzie in an open boat, having gone eastward the previous summer (p. 183). The *Thetis* proceeded eastward from Point Barrow on August 8 and on the 9th was abreast of the Colville (p. 184). Here they failed to find the Pelly Mountains, and from the testimony of the whalers they concluded that they did not exist. Thence they skirted along some long, low islands which stretched between the mouth of the Colville and Return Reef. These islands, which were not shown on the charts, were designated the Thetis Islands. Later, as the ice was heavy, they anchored near a small island which was marked by a wooden cross and to which the name Cross Island was given (p. 185). On making soundings they found the water inside of Cross Island was too shoal for the *Thetis*. They passed Lion Reef and entered Camden Bay, where they again anchored (p. 186). They found that the shore line of the charts was too far north, as their position near Flaxman Island put them well inland. At Manning Point they met several whale ships returning from the Mackenzie. As ice conditions were reported favorable, the *Thetis* proceeded eastward (p. 187), and in the afternoon of August 15 anchored off the southwest end of Herschel Island (p. 188). Later, they steamed around the north side of the island and found two whale ships anchored there (p. 189). A snug harbor was found near by and surveyed. It was given the name of Pauline Cove. The waters between the island and the mainland were found to be too shoal for a ship channel. Returning toward Point Barrow, they passed the Midway group (p. 191) and skirted along the long and narrow island which bore the name of Thetis Island. Point Barrow was reached on August 25, whence they returned to civilization.

In a communication to the Hydrographic Office of the Navy Department, Stockton furnishes the following additional details of the voyage of the *Thetis:*

Some shoals a few miles east of Cape Halkett, in Harrison Bay, were named Pacific Shoals, after the whale ship whose master, Capt. Knowles, had reported them. The Midway Islands are described as the west end of Lion Reef, midway between Lion Reef proper and Return Reef. On one of them the whalers had erected a cross, so the name of Cross Island was applied to this one. The position of this island was latitude 70° 27′ 30″, longitude 147° 52′ 30″. Stockton received reports that whalers had entered the lagoon within this chain of islands near a small island marked with a pole, west of Bullen Point, which is a part of Lion Reef. They reported that they steered at first for the small inshore group of islands marked on the charts, and then westward, and found nowhere less than 3 fathoms. This inside channel had been used when the ice lay against the chain of islands.

A good anchorage was found off a sand spit in the lower part of Camden Bay, shown on the charts. This spit Stockton named Collinson Point, after the captain of the *Enterprise*, who wintered near by in 1853–54. The bay behind the spit was named Simpson Cove.

Stockton's position for Ray's station, near Point Barrow, is latitude 71° 18′ 30″ and longitude 156° 39′ 04″. The observation spot at Herschel Island was in latitude 60° 32′ 45″, longitude 138° 57′ 15″.

TURNER, 1890.

In March, 1890, Mr. J. H. Turner, of the United States Coast and Geodetic Survey, sledded from the international boundary at Porcupine River to the Arctic Ocean. His route lay across the Arctic Mountains and down a small river which brought him to the coast opposite Herschel Island. This river was named the Firth, after one of his companions. That part of the mountains which formed the Arctic-Yukon watershed he named the Davidson Mountains.

This information is from the report of the United States Coast and Geodetic Survey. No additional information was found in the National Geographic Magazine.

FUNSTON, 1894.

While acting as special agent engaged in botanic exploration for the Department of Agriculture, Mr. Frederick Funston (afterward major general, United States Army) spent the winter of 1893–94 at Rampart House on Porcupine River, near the Canada-Alaska boundary. During the spring of 1894 he made a trip overland to the Arctic Ocean. The two short accounts published in Harper's Weekly contain no mention of the discovery and naming of Turner River, with which he has been credited. After an extended search, the manuscript of his report to the Department of Agriculture was found in the files of Dr. Frederick V. Coville. The following details have been abstracted:

Funston left Rampart House on March 10, 1894, accompanied by a single Indian. His coarse was irregular, at first northwestward for about 150 miles and then northeastward to the Arctic Ocean. After nine days' travel he reached a band of Indians encamped about 175 miles northwest of winter quarters. The country was rolling and treeless, excepting in sheltered localities.

He left the Indian camp on the 23d, traveled northeast up the valley of the Sheenjek, and camped in a grove of spruce trees less than 2 miles south of the Arctic-Yukon divide. The next day he crossed the divide by a low pass into the headwaters of a river which he named the Turner, after J. H. Turner, of the United States Coast and Geodetic Survey. He then descended this river, and after traveling northeastward along its frozen surface for four days he reached the Arctic Ocean a short distance west of Demarcation Point. After a two days' trip eastward along the coast he reached Herschel Island, where he found seven whale ships in winter quarters.

After a brief visit he retraced his steps to Rampart House. The return was made in 15 days. In the 39 days of absence he had traveled more than 600 miles.

PETERS AND SCHRADER, 1901.

In the summer of 1901 Messrs. W. J. Peters and F. C. Schrader, of the United States Geological Survey, made a trip from the Yukon to the Arctic Ocean. They started from Bettles, on the Koyukuk, in June, 1901, and went up to the head of John River by canoe. Then they portaged 5 miles to Anaktuvuk River and descended this river into the Colville (p. 17).

After mapping part of the Colville delta they proceeded westward along the coast to Smith Bay, where, on account of the lateness of the season, they gave up plane-table work and traveled to Point Barrow with some Eskimos, whose boats were more seaworthy than the Peterboro canoes.

The main channel of the Colville delta is the easternmost (p. 23). It was over 12 feet deep at the head of the delta and was not explored to the sea. They did not find the native village of Nigaluk, for they had failed to notice the westernmost channel. The delta is estimated to be 20 miles wide.

S. J. MARSH, 1901–1903, AND OTHER PROSPECTORS.

Two prospectors, S. J. Marsh and F. G. Carter, wintered in the Camden Bay region in 1901 and explored some of the inland drainage (p. 103). Three large rivers are reported between the Canning and the Colville (p. 103). The Kupowra (Kuparuk), which has its source opposite an eastern tributary of the Colville; the Sawanukto (Sagavanirktok), a larger stream entering the Arctic through a broad delta 20 miles east of the Kuparuk; and the Savaovik. Barter (Sadlerochit) River enters the ocean at Manning Point.

Marsh and Carter arrived at Collinson Point in September, 1901, and established winter quarters on the beach (p. 260). In April, 1902, Marsh hauled provisions inland as far as Cache Creek, a tributary of the Canning. During the summer he explored the headwaters of this stream and then descended to a point within 25 miles of its mouth. Here he met F. G. Carter and Ned Arey, and they all wintered in the mountains (p. 261). In February, 1903, Carter went up the right fork of the Canning and over into the Yukon drainage, and Marsh followed in April, naming the pass after Carter. He and Carter remained within 30 miles of the pass until the southward-flowing river was navigable, when Marsh built a raft and floated downstream until he met with a mail carrier, who informed him that he was on the Chandalar. Shortly afterward he reached Fort Yukon.

The prospector H. T. Arey, locally known as Ned Arey, sledded to the Canning from Point Barrow in 1901 and wintered for 11 years in that neighborhood. He was thus the first white man to have a detailed knowledge of the coast line as a whole, and also of much of the inland. He was the first to enter Canning, Hulahula, Okpilak, and Jago rivers, and probably several of the others. He gave Marsh the native maps of Kuparuk, Sagavanirktok, and Shaviovik rivers, which were later transmitted to the United States Geological Survey and appeared on the map of 1903. His intimate knowledge of the coast between Point Barrow and Herschel Island was of the greatest assistance to the writer in finding his way when the country was new to him and in planning for the detailed surveys. Arey's information was clear and definite, except that he overestimated distances and his forms of the native names were inexact. Like most of the other white men who come into the country he accepted the first pronunciation he picked up, regardless of its source or accuracy. He is mentioned several times in Stefánsson's book, as well as in Mikkelsen's.

Several other prospectors have penetrated the country from the Yukon. Messrs. James L. Reed and Walter Lucas [1] are reported to have explored a part of the Colville in 1903. Others have been reported to the writer to have come to the coast by the Sagavanirktok.

STEFÁNSSON AND ANDERSON, 1909–10, 1912.

In the summer of 1908 Vilhjálmur Stefánsson made a trip to the Arctic coast of North America, accompanied by Dr. R. M. Anderson. The expedition was under the auspices of the American Museum of Natural History; its object was to investigate the Eskimo of Dolphin and Union straits, east of the Mackenzie. Three years were spent in Canada and one on the north shore of Alaska. Stefánsson and Anderson reached the Arctic Ocean by way of the Mackenzie during the later part of July, 1908, and proceeded to Herschel Island, hoping to get provisions from the incoming whalers. As no ships arrived by the middle of August, Stefánsson went to Point Barrow on the returning whaler *Karluk*, and Dr. Anderson remained with the outfit to get along as best he could (p. 42). At Point Barrow Stefánsson procured an outfit from the whalers and started

[1] Schrader, F. C., and Peters, W. J., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, p. 31, 1904.

eastward in a small boat in September to find Anderson. They got into difficulties among the shoals in the lower part of Smith Bay, which they had entered thinking it was McKay Inlet, just east of Point Tangent (p. 53). Stefánsson declares that the two bays on the charts between Point Tangent and Smith Bay are purely mythical (p. 54). They were frozen in at Smith Bay, but as soon as the ice would bear them they proceeded eastward by sledge. The lower part of Smith Bay was found to contain the delta of a large river, the Mayoriak, which is the outlet of the Tasirkpuk, or "big lake" (p. 58). East of the Colville they passed a point known to white men and Eskimo alike as Oliktok but which on the charts is called Beechey Point (p. 64). They reached Flaxman Island in October and found Dr. Anderson living in Leffingwell's house.

Plans were then made for the winter. Dr. Anderson went into the mountains back of Barter Island, while Stefánsson returned to the whaling station at Point Barrow (p. 69). He left Flaxman Island on October 20 (p. 71) and arrived at an Eskimo village near the point where Itkillik River empties into the head of the Colville delta (p. 80). On November 28 he reached Point Barrow (p. 84) and remained in the neighborhood as guest of the white men until March 6 (p. 94). Then he sledded eastward to Flaxman Island. Here he met Dr. Anderson, who had just returned from living all winter with the Eskimo upon the resources of the country (p. 100).

On April 16 Stefánsson left Dr. Anderson at Flaxman Island (p. 101) and returned to Point Barrow, arriving on the 30th (p. 103). There he was a guest of the school-teacher until May 16, when he again started eastward (p. 106). At Smith Bay he found that Dr. Anderson, according to his expectations, had already reached the cache made the previous fall, and had hauled everything to Pitt Point. Thence they slowly moved their heavy load over the softening ice, until they were blocked on June 12, about 15 miles west of the Colville delta (p. 108). On the 23d they were able to launch their native canoe and proceed in the water that had formed along the shore (p. 113). On the 25th they entered the western edge of the Colville delta, and on the 30th they reached the Eskimo trading site of Nirlik. They left this place on July 5 and went up the western branch of the river until they reached the mouth of Itkillik River. Then they proceeded down the eastern arm, reaching Oliktok on the 14th (p. 115). Although their boat drew no more than a foot of water, they spent half of their time wading over the barely submerged mud flats, seeking for the narrow and intricate channel where alone they could float (p. 115).

They reached Flaxman Island on August 5, and thence proceeded along the coast to a point within 30 miles of Herschel Island (p. 117). Stefánsson left Dr. Anderson to follow on with the Eskimos and started ahead with a light boat but soon obtained passage on a whale ship (p. 118). He reached Herschel Island in this way on August 18 and procured passage beyond the Mackenzie on a whaling ship, leaving Dr. Anderson to work his way along the shore with the Eskimos.

After remaining in Canadian territory during the winters of 1909 to 1912 Stefánsson left Dr. Anderson to care for and bring out the collections and sledded westward to Point Barrow (pp. 368–369). He stopped at Collinson Point (p. 378) and Flaxman Island and arrived at Point Barrow on June 13, 1912 (p. 386). Here he was guest of the white men until he obtained passage on the revenue cutter *Bear* on August 12 (p. 389). About a month later he reached the United States.

Dr. Anderson remained east of the Mackenzie with the ethnologic and zoologic collections, until he was able to get passage on one of the two whale ships which had sailed that far eastward. He arrived at San Francisco in November.

In the winter of 1908–9 Dr. Anderson crossed over the divide between the Hulahula and the Chandalar. He was the first white man to enter the headwaters of this portion of the Yukon drainage (p. 436).

ALASKA-CANADA BOUNDARY SURVEY, 1912.

In the summer of 1911 the survey of the 141st meridian, under the direction of Thomas Riggs, jr., was carried northward from a point on Porcupine River to a point about 20 miles from the Arctic Ocean. In 1912 the party reached the ocean. A strip of territory 4 miles wide was mapped in detail and prominent peaks outside of this area were located. Near the coast the topographers mapped several additional miles east and west of the line. Their work includes a portion of Firth, Malcolm, and Clarence rivers, and Demarcation Bay. The topographic maps of the boundary have recently been published, but in 1915 no official report had been made available.

CANADIAN ARCTIC EXPEDITION, 1913–14.

In the summer of 1913 Stefánsson and Anderson entered the Arctic Ocean through Bering Strait for the purpose of exploring the area northwest of Prince Patrick Island and also of carrying on scientific observations on the Canadian mainland. There were three vessels and about 50 men. The expedition was divided into two parties—the northern party, under Stefánsson, the southern party under Anderson.

The expedition was still in the field when this report was written, but the following particulars are given from the writer's knowledge:

The northern party's ship—the *Karluk*—was caught in the ice pack some distance off from the north shore of Alaska and was carried by the westward drift nearly to Herald Island, off the Siberian coast, where she was crushed and lost. Stefánsson and three or four men were on the Alaskan shore when the ship drifted away and could not rejoin her.

The southern party, in two small gasoline schooners, reached the safe harbor behind Collinson Point, where they wintered. Here they were joined by Stefánsson and his companions. In this scientific party there were two topographers, a geologist, an ethnologist, a marine biologist, and a zoologist. The topographers made a detailed survey of the neighborhood of Collinson Point after the ice had formed and obtained soundings by cutting through the ice. A rapid sled trip was made up Sadlerochit River in October and a route sketch was drawn. In this trip they rounded the east end of the Sadlerochit Mountains and went up the river to a point opposite Ikiakpuk Valley. The geologist found a good exposure of Triassic rocks at the farthest camp and brought back some fossils. In the spring of 1914 Stefánsson, who had in the meantime traveled back and forth from the Mackenzie, started out over the ice of the Arctic Ocean to take soundings toward the north. The story of this trip has appeared in the newspapers.

About the same time the topographers and the geologist went into Canadian territory and are reported to have made a survey of the coast from Demarcation Point to Herschel Island while the snow was still on the ground and also to have mapped the lower part of the Firth and to have examined the geologic formations. In the early summer part of the Mackenzie Delta was mapped, and then the expedition moved from Collinson Point into the country east of the Mackenzie.

At the writer's suggestion the ethnologist, Diamond Jenness, gathered all the native place names possible and put them into the simplest form of spelling he could devise. Nearly all his forms were in close agreement with the writer's, but both Jenness and the writer differed from Stefánsson in spelling. The following is a portion of a personal communication from Jenness, dated Barter Island, July 15, 1914:

> I inclose a few names of places whose meaning or supposed meaning I have ascertained from the Eskimos here. I give my own peculiar spelling and what seems to be the nearest equivalent in current use, as you suggested. I seem to have noticed considerable variety in the pronunciation of words, and it is probable that many of our forms disagree where our original sources disagreed. Of course you will prefer your own spelling. * * * I felt much more comforted about my spelling, though, when I found that we agreed so nearly.

GEOGRAPHIC NOMENCLATURE.

INTERPRETATION OF THE LITERATURE OF EXPLORATION.

FRANKLIN.

Franklin was the first to use the term Rocky Mountains for the range which extends across northern Alaska. The British Mountains, which he discovered, are described as terminating abreast of Point Griffin at the commencement of a new range, the Romanzofs. The Romanzof Mountains terminated abreast of Flaxman Island. The writer has applied the term British Mountains to the portion of the Arctic Mountains lying east of the Romanzofs and north of the Yukon-Arctic divide. The mountains which Franklin discovered from Point Griffin were undoubtedly the higher snow-clad granite mountains about the headwaters of Okpilak River. As the mountains which end abreast of Flaxman Island belong to an entirely separate group, the term Romanzof is restricted to the higher granitic mountains between Jago and Hulahula rivers.

Clarence River has been mapped by the Boundary Survey. The name is correctly applied on their map to the first river east of Demarcation Point. The mud flats with which Franklin had so much trouble behind Icy Reef are doubtless those at the mouth of Turner River. Beaufort Bay, which extends from the western end of Icy Reef to Humphreys Point, is locally called a lagoon, so the name of Beaufort Lagoon has been adopted on the writer's map.

There is some confusion in the local usage of the names which Franklin gave to Points Griffin, Martin, and Manning, and to Barter Island. Franklin's description and astronomical observations and his map are clear as to Barter Island and Manning Point, but local usage has transferred the name of Barter Island to Franklin's Manning Point, which is in reality an island. The high banks on the north side of this tundra island are the chief landmarks for many miles, and the misapplication of the name of Barter Island is firmly established among the whalers and traders. It is thought best to accept this change and to transfer the name Manning to the small tundra peninsula which lies a few miles to the east. The writer has applied a new name, Arey Island, to Franklin's original Barter Island.

On Franklin's map Points Manning and Griffin are separated by a shallow bay, which might be the same as that at Pokok on the writer's map. However, the distance between Points Humphreys and Martin, on Franklin's map, is much too great to correspond to the stretch of mainland which fronts the ocean west of Humphreys Point on the writer's map. The best solution seems to be to apply the name Point Griffin to the western end of this bank and Point Martin to the general region where the coast bends toward the south around the delta of Jago River. There is need of such a general term, for incoming ships are often held up by the ice at this place.

Camden Bay is shown on Franklin's map as extending from Arey Island (his Barter Island) to Brownlow Point, but the writer has restricted the term to the more apparent limits of Point Anderson and Konganevik.

The shoals upon which Franklin grounded, about 12 miles from the eastern side of Camden Bay and the bay into which he seemed to be steering were undoubtedly the mud flats and mouth of Sadlerochit River. In 1912 the sand reefs east of that place, on which Franklin saw natives encamped, were all awash and inconspicuous.

Boulder Island and its neighbor have since been cut entirely away. The older natives have confirmed their former existence. The writer grounded upon shoals near the former location of Boulder Island, to which he has given the name of Boulder Shoals.

The outside chain of mountains which Franklin observed to terminate abreast of Flaxman Island had no conspicuous peak to which his term Mount Copleston could be applied. There is, however, a peak in the Shublik Chain which the writer occupied in surveying, and, as it is visible from the place where Franklin gave the name, it is possible that this is the one he had in view.

The depth, gradually increasing to 3 fathoms, which Franklin noted on the journey westward from Flaxman Island, still persists today. It is evident that in his course along the mainland he saw none of the chain of islands which extend for 50 miles west of Flaxman Island. Point Thompson, which is indefinitely located on the mainland about 8 miles east of the island, has been applied to a long spit in approximately the same locality. Point Bullen is definitely located, from his map, at the east side of the writer's Mikkelsen Bay.

The island which lies about 3 miles from shore beyond Point Bullen and is connected with the mainland by a reef is located by the description and its position on his map, although the shape shown on the map is far from accurate. The shoal upon which the *Lion* grounded may have been either the mud flats of the Shaviovik or the shoal which extends some distance from the northeast point of the island.

The native name for this island is Tigvariak. As Franklin's original name, Lion and Reliance Reef, is misleading, it seems best to adopt the native name. The name Lion has been misapplied on the charts; on some it refers evidently to Tigvariak Island, near the mainland, and on others to the chain of islands lying several miles to the north. The writer has entered Franklin's names on the northeast and northwest points of the island at Point Lion and Point Reliance. Foggy Island is easily identified from the description and the map, and also Anxiety Point.

There has been much difficulty in adjusting Franklin's names west of Anxiety Point. He was far from land and often in fog. His position for Return Reef is evidently more than 10′ of longitude too far west, and in adjusting his map to this erroneous position he has increased all the distances between Foggy Island and Return Reef. Point Chandos is located tentatively as the western side of the delta of the Sagavanirktok, and Return Reef at the writer's Egg Island, but all the names between those points are in confusion. The writer's solution has been to drop Yarborough Inlet and Point Chandos, for no inlet exists, unless it is the western mouth of the river. Heald Point is then located at the western side of the delta. Prudhoe Bay lies west of this point.

At Return Reef Franklin saw a large bay to the west, beyond which lay a point and a distant mound. From Egg Island such a bay and point and mound are visible, though not quite as he describes them. The local usage, starting with the later explorers, has been to apply the term Return Reef to the chain of sand islands that fringe this portion of the coast. The term Return Islands has been adopted for this chain on the writer's map. Point Beechey has been applied to a point behind the easternmost of the Jones Islands, abreast of the mound to which Franklin probably gave the name. Point Back is put in an approximate position on the unsurveyed shore line on the west side of Gwydyr Bay.

In the charts there are errors in putting Beechey Point near the mouth of the Colville, and an entirely new name, Becher Point, near Gwydyr Bay.

Franklin's observed latitudes seem correct within 0° 1′, but his longitudes are about 0° 5′ too far east wherever this observation spot is fairly definite.

It has been impossible to identify his Mounts Greenough and Huskisson among the numerous peaks in the localities where they are placed on the map.

DEASE AND SIMPSON.

Jones Islands are definitely located from the description. At present there are six distinct tundra blocks, which are connected by sand spits into three islands. Point Milne has been placed on a conspicuous point on the mainland in the approximate position indicated by the Dease and Simpson map. Point Berens is also easily located. The charts, as mentioned above under Franklin, have incorrectly put Beechey Point here and have entirely dropped the name Point Berens. Local usage has adopted the native name—Oliktok—for this point, and the writer has followed this usage.

The name of the adjacent river is spelled Colvile in their text but Colville on their map. All succeeding maps have adopted the latter spelling. The "splendid" Garry River on the west side of Harrison Bay, whose banks were covered with driftwood brought down by the stream, is nothing more than the small estuary of a small creek, which is reported to head in a lake a few miles from the coast. The Pelly Mountains, seen by their men here for the second time, do not exist. The writer camped at the mouth of Garry Creek and saw no point at which Point Comfort could be definitely located. Cape Halkett is definitely located at the tundra island, now connected with the mainland by a spit. Point Ellice is approximately located from the description, though it is now a high bank rather than a point of land. Most of the reefs described west of this point are now submerged. Pitt Point is located from the description as the northernmost point of land in this stretch of coast. Dease and Simpson's observations place it nearly where it has been drawn by the writer. William Smith River proves to be a creek, so inconspicuous that the writer has not applied any name to it. The considerable lake, which they surmised to lie behind Pitt Point, has been found. The names Point McLeod and Point McPherson have now no reason for existence along the unbroken high bank and have been omitted from the writer's map.

Point Drew is put at the approximate location given by Dease and Simpson, at the bend in the high bank. The sharp projecting point at Cape Simpson has been cut away, so that it is difficult to apply the name at present. The writer's usage covers the general locality where the coast bends at the western side of Smith Bay. Boat Extreme is omitted by the writer. The recorded distances and observed position place it where there is at present a featureless high bank, within 3 or 4 miles of Cape Simpson. The name has not been adopted by the people of the country, nor does it appear on recent maps.

Fatigue Bay, McKay Inlet, Point Tangent, and Dease Inlet have been identified, but thence to Point Barrow their route lay along a portion of the mainland which the writer has never visited.

Boat Creek, near Point Drew, has been identified, and the probable position of Eskimo Island in Harrison Bay. This latter name has been extended to cover the two islands. Their view of the mouth of the Colville must have been erroneous, for the writer has never been able to see any details of the delta when in water less than 2 feet deep. Fawn River is approximately located from their description. Their observations put it some miles at sea. The name has been changed to Fawn Creek.

It has been impossible to compare more than three of their positions with those of the writer. The latitude of Demarcation Point is correct within a minute. That at the head of Foggy Bay puts them more than 2 miles inland on the map, and that of Fawn River is a mile at sea. The only longitude, that of Fawn River, is about 10′ too far east.

It seems certain that neither Franklin nor Dease and Simpson saw any of the sand islands that extend 50 miles west of Flaxman Island.

LATER EXPLORERS.

Pullen.—Little was added to geographic knowledge through Pullen's trip. The water close to the mainland behind Jones Islands was shoal then, as now. Hooper states that they went inside of Lion Island [Tigvariak]. Evidently they did not see any of the chain of sand islands west of Flaxman Island.

Moore.—Plover's group, the name originally applied to the first four sand islands east of Point Barrow, has been extended to cover all the chain as far as Tangent Point, and the name is changed to Plover Islands. It is probable that Cooper and Martin islands of Moore were close to Tangent Point and that those which he discovered on August 1 were west of Cooper Island. Later usage, beginning with Maguire's map, has put the name Cooper Island at a crescentic island about halfway between Tangent Point and Point Barrow. In the absence of a definite location the writer has adopted this usage. Martin Island has been placed at the next island east of Cooper Island, although the chart of Moore Harbor puts it next to Point Barrow.

McClure.—The Jones Island upon which McClure landed is either Thetis Island or Leavitt Island of the writer's map. If it is Thetis Island there is an error of 16′ in his longitude, and if Leavitt Island there is an error of 1°. The shoals he met off Yarborough Inlet were undoubtedly the Midways. He was thus the discoverer of the long chain of islands that extend from the Midways to Flaxman Island, and his name has been given by the writer to the first group east of Cross Island, as those first seen by him have already been named the Midways.

Collinson.—Collinson seems to have first made the error with respect to Lion Reef that has been upon the charts for many years. He seems to have observed the outlying chain of islands throughout most of their extent. There has been a general belief that Collinson wintered at Collinson Point, for the charts place his position well within Camden Bay. His own position and description place the ship about 4 miles northeast of the east mouth of Canning River. It is difficult to follow his October trip to the east. Boulder Island was still in existence. The first long low point was undoubtedly Konganevik. His party probably followed the shore line behind this point and camped near the long bank behind Collinson Point. The bay they crossed next morning was probably Simpson Cove, and the shingle point with 10 huts was probably Collinson Point. A number of old huts are there at present. The next point, which they reached in two hours walking along shore, after passing some cliffs, is most probably Point Anderson, but the distance seems rather too great for the time they spent in walking to it. The mouth of the river is probably that of the Sadlerochit.

The only spot the writer recognizes in their inland trip is the area of red clay at the base of the mountains. Such an area he has observed at the head of Katakturuk River.

The details of the bottom of Camden Bay, which appear upon the charts after Collinson's return, were undoubtedly furnished by him, but the writer has not been able to find any original map which contains them.

Lieut. Jago seems to have gone along the sand islands west of Flaxman Island. He speaks of launching across Lion Reef and passing inside of Foggy Island, both of which are extremely improbable. He stated also that he launched across Anxiety Point and went ashore near by and camped, which would be a difficult proceeding.

The reef on which Jago landed and buried some gear, about 10 miles west of Point Berens, is undoubtedly Thetis Island.

Maguire.—The chain of islands between Point Barrow and Tangent Point, which comprised 10 islands in 1852, still contains approximately the same number. The narrower ones are constantly being cut through and joined again, so that from season to season the number changes somewhat.

In Surg. John Simpson's native map a number of names for the coast east of Point Barrow appear for the first time. Niako is a small island at Heald Point of the writer's map. Shiningrua has not been located. Sherang is Flaxman Island; Kogruak, the Canning; Nuwaak, Collinson Point; Shudtaroshik, the Sadlerochit; Kaktuwing is Barter Island; Siko is back of Icy Reef; Pokang is between Points Humphreys and Griffin, at Pokok.

Ray.—On Ray's eastward trip in 1882, he found that the Meade emptied into the ocean by five mouths, which he placed on his map at the lower end of McKay Inlet.

Howard.—If Ray's map is accepted as correct the Ikpikpuk, which was discovered by Howard three or four years later, can not empty into Dease Inlet. Very likely Meade and Ikpikpuk rivers have a common delta. The lower part of Dease Inlet or even Smith Bay are more likely localities than McKay Inlet.

Stockton.—The islands which were discovered between the Colville and Return Reef, and which were named Thetis Islands, had already been discovered and named Jones Islands by Dease and Simpson. The name Thetis has been transferred to the westernmost sand island, about 7 miles northwest of Oliktok. Cross Island has been located by the existence of the cross as well as by information furnished by the whalers. Stockton's observations place it a couple of miles to the south, in approximately the same longitude in which the writer has placed it.

The Midway Islands, according to whaler usage, consist of three small islands 5 or 6 miles west of Cross Island, and the writer has followed this usage, for he believes it was the original application of the name. The charts have also thus used the term. Stockton's statement that Point Bullen is a part of Lion Reef contains two errors, for both are on or near the mainland, and Stockton was speaking of the chain of sand islands several miles north of the mainland. The report that whale ships have entered the lagoon near Pole Island is difficult to verify, for there is no agreement on this point. It is established, however, that one of them—the *Newport*—went into the lagoon near this point, but she is reported to have come out again at the same place.

The name Simpson Cove has not become established in local usage, as the term Collinson Point is sufficient to cover this general locality. It is an insignificant spot with which to honor Simpson's great services, and the writer has accordingly omitted the name from his map. Dease Inlet is much more important geographically than Simpson Cove, yet Simpson was the real soul of the expedition. His name has been placed at Simpson Lagoon, behind Return Islands and Jones Islands, as he was the first white man to traverse this body of water.

Turner.—Firth River, which Turner explored, had been discovered and named Mountain Indian River by Franklin. The whalers call it Herschel Island River. The charts have placed the Firth near the locality where the Malcolm is. The Boundary Survey maps correctly give the name Firth to the portion that cuts the 141st meridian.

Funston.—Turner River first appeared on the charts of the United States Coast and Geodetic Survey as a small river flowing into the Arctic Ocean at Demarcation Point. The writer was unable to find any such stream in the locality indicated on the maps, and the natives were positive that it did not exist.

The map of the Boundary Survey, which covers that area, shows only a creek where Turner River was supposed to exist. On this account the name was at first omitted from the writer's map. Finally, when Funston's manuscript was found in the files of the Department of Agriculture, it became certain that he had discovered and named the large river which empties into the ocean 15 to 20 miles west of Demarcation Point. This river, which is called Kongakut by the natives, is shown on the small-scale map which accompanies this report (Pl. III, in pocket).

Marsh.—Marsh's spelling of Eskimo names was adopted from Arey's pronunciation, and the result is far from accurate. According to information furnished by Arey, Marsh went up the writer's Marsh Creek, over to Itkilyariak Creek, through Sunset Pass to Sadlerochit River, up this river and over to Cash Creek, which flows into the Canning. While at winter quarters he went a short distance up the East Fork of the Canning—a little beyond the writer's farthest camp. No such name as Kuselik [Ooselik] Creek is known to the writer.

Peters and Schrader.—The Itvelik River of Peters and Schrader is probably a blunder, for on a native map among their records it is put down correctly. The word is Itkillik, meaning "Indian." It was spelled approximately this way on earlier maps. The Itkillik, from native maps in the possession of the writer, as well as from Stefánsson's remarks, must enter at the head of the Colville delta, and not 20 miles above it, as on Peters's map. The Colville's east mouth could never have been much farther east than now, certainly not as far as Gwydyr Bay, where the Kuparuk enters. The west mouth of the Colville, which flows by the trading site of Nigalik, was not discovered.

Stefánsson and Anderson.—In stating that no bays existed between Tangent Point and Smith Bay, Stefánsson is in error. Fatigue Bay certainly exists, and there are several indentations in the shore, one of which, McKay Inlet, is so deep that the head can not be seen from the sand islands which here fringe the coast. In some of his numerous articles in Harper's Magazine he speaks of the "mythical Gwydyr Bay," which is another error.

NEW PLACE NAMES.

After the original names had been entered on the map as accurately as possible it was found that many new names were necessary for the purpose of geographic description. As far as possible the Eskimo names have been ascertained and used. The brief description in the alphabetic list suffices for most of them, but a few require more extended remarks. Where the original names were shifted or changed, the reasons were given under the discussion of the literature.

Westward on the map from the one hundred and forty-first meridian, Jago River is the first name to require explanation. There seems to have been no ancient name for this river. The modern native name is "Jags," or as near that as the natives can pronounce the English word. It is the whaler's nickname for a drunken native who first braved the devils that were supposed to dwell on the river. As the writer desired to place the name of Lieut. Jago, of Collinson's ship, on the map, the slight change in spelling was made. Hulahula River also seems to have no ancient name. The modern name was given within 20 years by a party of natives from Herschel Island, who had a big dance on the river after the killing of many caribou. The word evidently came from the Kanaka members of the whale-ship crews.

The islands in the chain west of Flaxman Island have been named after ships, chiefly of the whaling fleet, to which the writer is indebted for favors or which have been conspicuous in navigating the region.

It is difficult for a white man to learn the correct pronunciation of an Eskimo name and more difficult to arrive at a spelling which is fairly representative of the name ascertained. This difficulty would exist even if all the natives pronounced it the same way. At present there are several different dialects represented on the northern coast, and one may hear a place name pronounced in as many different ways as there are dialects. The writer has endeavored to ascertain the names used by natives of the tribes which originally dwelt in the locality.

The information as to native names given by the white men who live in the country is decidedly unreliable, for neither have they trained ears nor are they interested in the exactness of their usage. The locative plural case, Oliktone, is used for Oliktok by white men who have lived among the natives for many years. A very good example of such carelessness is shown in Ray's native name for the village at Cape Smyth. The name on Maguire's map was Otkiawing (a corruption of the locative case), yet Ray called it Uglaamie. Both Stefánsson and the writer agree upon Utkiavik.

Ray is also responsible for the corruption of the suffix puk ("big") in such words as Ikpikpung. If an Eskimo were asked, "Where are we?" he would naturally say, "Ikpikpungme"—that is, "at Ikpikpuk."

Most of the Eskimo names used by the writer have been discussed with Stefánsson and Jenness. We are in substantial agreement throughout, except in the use of the letter "r" in such syllables as "irk" by Stefánsson. The writer is under obligations to Stefánsson for calling his attention to faulty pronunciations adopted from the white men.

LIST OF GEOGRAPHIC NAMES.

The following list of geographic names includes names for the north shore of Alaska between the 141st meridian and Point Barrow, and also names north of the Arctic-Yukon divide and east of Colville River. With the exceptions here mentioned all the names have been traced to their original sources. Admiralty Bay and Doctor, Ikalue, Pingolee, Rutland, and Whale islands appear on the British Admiralty charts published after the return of the Arctic Searching expeditions. All these names are given to features in the vicinity of Point Barrow, so they probably originated with Maguire. The writer was unable to find the original source of the name Itkillik. It is credited to E. L. Bosqui in the "Geographic dictionary of Alaska."[1]

In the following catalogue the names in bold-faced type have been entered on the writer's map. The authority comes next after the place name, and then the source of the name—where it has been ascertained.

[1] U. S. Geol. Survey Bull. 299, p. 331, 1906.

Admiralty; bay. British Admiralty Chart No. 2435. Lower part of Dease Inlet.

Aichillik; river. Leffingwell. Empties into the Arctic Ocean near the 142d meridian. Spelled Aitshillik by Jenness. Meaning uncertain.

Alaska; island. Leffingwell. After the schooner *Alaska*, of the Canadian Arctic Expedition. One of the Maguire group, west of Flaxman Island.

Amaudliktok; island. *See* Thetis Island.

Amilrhoen; point. *See* Drew.

Anaktuvuk; plateau. Peters and Schrader. After Anaktuvuk River. Upland along the northern front of the Arctic Mountains.

Anaktuvuk; river. Peters and Schrader. A tributary of Colville River. Means "defecating place." The writer's spelling is Anaktovuk.

Anderson; point. Leffingwell. After Dr. R. M. Anderson, of the Canadian Arctic Expedition. At the mouth of Sadlerochit River on the east side of Camden Bay.

Anxiety; point. Franklin. A conspicuous point at the east end of Howe Island in Sagavanirktok delta.

Arctic; mountain system. Brooks. The range extending east and west across Arctic Alaska between the Yukon and the Arctic Ocean.

Arey; island. Leffingwell. After the prospector, H. T. Arey, who lived in the neighborhood several years. A long sand island west of Barter Island. Originally named Barter Island by Franklin, but local usage has changed the name Barter Island to the tundra island to the east.

Argo; island. Leffingwell. After the yawl *Argo*. The eastern island of the Midways, west of Flaxman Island.

Argo; shoals. Leffingwell. After the yawl *Argo*. Shoals southeast of Argo Island.

Attigaru; point. Maguire's map. Point on south side of Harrison Bay. Not identified. At-ligga-ru, John Simpson.

Back; point. Franklin. After one of his officers. On the west side of Gwydyr Bay. Not located accurately.

Barrow; point. Beechey. After Sir John Barrow. Northernmost point of Alaska. Eskimo: Nuwuk, "point of land."

Barter; island. Franklin, Leffingwell. A tundra island near the 144th meridian. This island was named Point Manning by Franklin, but local usage has changed the name. Franklin's Barter Island is called Arey Island on the writer's map. Eskimo: Kaktoavik, "seining place." Stefánsson spells it Kaaktovik.

Barter; river. *See* Sadlerochit. Given by Marsh for a river south of Barter Island. Probably the same as Sadlerochit River on the writer's map.

Beaufort; bay. *See* Beaufort Lagoon.

Beaufort; lagoon. Franklin. After Capt. Francis Beaufort, R. N. Lagoon between Icy Reef and Humphreys Point. Named Beaufort Bay by Franklin.

Becher; point. *See* Beechey.

Beechey; mound. Leffingwell. A conspicuous mound 3 miles inland from Point Beechey. Used in triangulation.

Beechey; point. Franklin. On the mainland behind Jones Islands. On the charts this locality is called Point Becher, and Point Beechey is put at Oliktok (Point Berens), near the Colville.

Bell; river. Dease and Simpson's map. On west side of Gwydyr Bay. Not located. Dease and Simpson call it Bells River.

Bellevue; river. Dease and Simpson. Empties into Elson Lagoon, within sight of Point Barrow. Eskimo name, Mayoria, on Maguire's map. Not located.

Belvedere; island. Leffingwell. After the whale ship *Belvedere*. One of the Stockton Islands, west of Flaxman Island.

Berens; point. *See* Oliktok.

Bernard; harbor. Leffingwell. After Capt. Joe Bernard, of the schooner *Teddy Bear*, who wintered there in 1909–10. At the northeast corner of Barter Island.

Bertoncini; island. Leffingwell. After Capt. John Bertoncini, of the whaling fleet, known as "Johnny, the Painter." One of the Jones Islands.

Black Head. *See* Black Rock Point.

Black Rock; point. Dease and Simpson's map; not mentioned in their text. On east side of Dease Inlet. Not located. Probably the same as Black Head of British Admiralty Chart No. 593.

Boat; creek. Dease and Simpson. At Point Drew, east side of Smith Bay.

Boat Extreme; point. *See* Tulimanik. Dease and Simpson. Westernmost locality reached by boats. Name not established, and location indefinite.

Bodfish; island. Leffingwell. After Capt. Bodfish, of the whaling fleet. One of the Jones Islands.

Boulder; island. *See* Boulder Shoals.

Boulder; shoals. Franklin, Leffingwell. In Camden Bay. The island named Boulder Island by Franklin has since been washed away, leaving shoals.

British; mountains. Franklin. A chain of mountains near the international boundary, first seen from Mount Conybeare. The western limit is against the Romanzof Mountains.

Brower; point. Leffingwell. After C. D. Brower, long a resident at Barrow. The northern end of Foggy Island.

Brownlow; point. Franklin. On the mainland 2 miles east of Flaxman Island.

Bullen; point. Franklin. On the mainland in longitude 146° 50′. Eskimo: Shavugavik, "working place."

Cache; creek. Marsh. The second tributary on the east side of the Canning. Flows through Ikiakpaurak Valley.

Camden; bay. Franklin. After Marquess Camden. Originally between Barter Island and Point Brownlow. Restricted to the area between Point Anderson and Konganevik on the writer's map.

Cameron; point. Dease and Simpson's map; not mentioned in their text. A few miles west of Cape Halkett. Location indefinite.

Canning; river. Franklin. After "the late Mr. Canning." Empties by two mouths near Flaxman Island. The eastern mouth is the original Canning and the western mouth, the Staines. Eskimo: Kugruak, "old river." Marsh spelled it Kooguru.

Carey; creek. Marsh. Probably after H. T. Arey (Ned Arey). Tributary to the Canning. Location unknown.

Carter; creek. Leffingwell. After the prospector, F. G. Carter. Empties into Camden Bay a few miles east of Collinson Point.

Carter; pass. Marsh. After the prospector, F. G. Carter, who first crossed it. Pass from Marsh Fork of the Canning to the east branch of the Chandalar. Not located.

Challenge; entrance. Leffingwell. After the schooner *Challenge*, which is believed to have been the first vessel to pass through it. Between the Stockton and Maguire groups of islands, west of Flaxman Island.

Challenge; island. Leffingwell. After the schooner *Challenge*. One of the Maguire group, west of Flaxman Island.

Chamberlin; mountain. Leffingwell. After Prof. T. C. Chamberlin. A conspicuous peak, 9,000 feet high, at the headwaters of Sadlerochit River.

Chandos; point. Franklin. Location doubtful, west of Anxiety Point.

Charles; point. Dease and Simpson. On the mainland of Elson Lagoon, west of Point Christie. Not located.

Chipp; river. Howard. After Lieut. Chipp, of the *Jeannette* expedition. Heads near the Colville and enters the ocean between Dease Inlet and Smith Bay. Eskimo: Ikpikpuk, "big bank." Ray and others erroneously spell it Ikpikpung, a corruption of the locative case, Ikpikpungme, "at Ikpikpuk."

Christie; point. Dease and Simpson. After Chief Factor Christie, of the Hudson's Bay Co. The northwest point of Dease Inlet. Not located. Maguire's map gives Toolavia as the Eskimo name.

Clarence; river. Franklin. After His Royal Highness the Lord High Admiral. Alaska and Yukon, Canada, debouching near Demarcation Point.

Coblura; point. Maguire's chart. A projection on the south side of the spit running eastward from Point Barrow, near Plover Point.

Collinson; point. Stockton. After Capt. Richard Collinson, R. N. A sand spit in Camden Bay. Collinson did not winter here, as is often stated. Eskimo: Nuwuak, "influenza" (?).

Colville; river. Dease and Simpson. After Andrew Colville, of the Hudson's Bay Co. Enters the Arctic Ocean near the 150th meridian. Spelled Colville on Dease and Simpson's map and all succeeding ones. The Eskimo name for the lower river is Kupik, "big river." Schrader and Peters spell it Gubik. The headwaters are called Kangianik. The approximate meaning is "headwaters."

Comfort; point. Dease and Simpson. West side of Harrison Bay. There is no conspicuous point at the locality described. Not located.

Cooper; island. Moore. After one of his officers. One of the Plover Islands. Location indefinite. Eskimo: Iglurak, "small iglu." Stefánsson spells it Iglorak.

Copleston; mountain. Franklin. After Dr. Copleston, provost of Oriel College. Applied to western extremity of the chain of mountains which ends abreast of Flaxman Island. Located by the writer at the west end of Shublik Mountains.

Cottle; island. Leffingwell. After Capt. Steven Cottle, of the whaling fleet. The easternmost of the Jones Islands.

Crescent; island. On Maguire's chart of Point Barrow and Port Moore. Second Island east of Point Barrow. Name not established by local usage.

Cross; island. Stockton. An isolated sand island about 10 miles north of Anxiety Point.

Davidson Mountains. Turner. The Arctic Mountains at the Arctic-Yukon divide along the 141st meridian. Not located. *See* Endicott.

Deadman; island. *See* Doctor Island.

Dease; inlet. Dease and Simpson. After Peter Warren Dease, of the Hudson's Bay Co. Southwest of Tangent Point at the eastern end of Elson Lagoon. Eskimo name (Maguire's map), Kilulea.

Demarcation; bay. International Boundary Commission, 1912. Behind Demarcation Point near the 141st meridian.

Demarcation; point. Franklin. Near longitude 141°, the boundary between Canada and Alaska.

Doctor; island. The first sand island east of Point Barrow. On the east side of Moore Channel. The same as Martin Island on Maguire's chart. Known as Deadman Island among the residents at Barrow. Called Doctor's Island on British Admiralty Chart No. 2435.

Drew; point. Dease and Simpson. After Richard Drew, Esq., of the Hudson's Bay Co. On the east side of Smith Bay. On Maguire's map the Eskimo name is given as Amilrhoen.

Duchess; island. Leffingwell. After the schooner *Duchess of Bedford*, of the Mikkelsen-Leffingwell expedition. One of the Maguire group west of Flaxman Island.

Duck; island. Leffingwell. A small silt island in the Sagavanirktok delta west of Foggy Island.

Eagle; creek. Marsh. Flows through Ikiakpuk Valley into the Canning.

Egg; island. Leffingwell. One of the Return Islands. Probably Franklin's original Return Reef.

Ellice; point. Dease and Simpson. After Right Hon. Edward Ellice. A bend in the coast at a high bank west of Cape Halkett.

Elson; bay. *See* Elson Lagoon.

Elson; lagoon. Beechey. After Master Thomas Elson, R. N., of H. M. S. *Blossom*. The lagoon extending eastward from Point Barrow as far as Point Tangent. Named Elson Bay by Beechey.

Endicott; mountains. Allen and Schrader. That portion of the Arctic Range between the 145th and 154th meridians.

Endicott; plateau. Schrader. A plateau out of which the Endicott Mountains were supposed to have been carved.

Eskimo; islands. Dease and Simpson, Leffingwell. Originally applied to a single island in Harrison Bay, but on the writer's map to two islands near the place where Dease and Simpson put the name.

Esquimaux; island. *See* Eskimo Islands.

Evasha. *See* Ivishak.

Fatigue; bay. Dease and Simpson. Shallow and irregular bay east of Point Tangent. Name not established. The locality is covered by the name Mackay Inlet.

Fawn; creek. Dease and Simpson. On the east side of Gwydyr Bay. Called Fawn River by Dease and Simpson.

Fawn; river. *See* Fawn Creek.

Firth; river. Turner. Flows from Alaska northeastward through Canada and empties opposite Herschel Island. Named Mountain Indian River by Franklin, and Herschel Island River by the whalers.

Flaxman; island. Franklin. After the sculptor Flaxman. A tundra island on the 146th meridian. Eskimo: Sidrak (?), "fox hole."

Foggy; island. Franklin. On the eastern side of the Sagavanirktok delta.

Foggy Island; bay. Dease and Simpson. Bay between Tigvariak and Foggy islands.

Franklin; mountains. Dease and Simpson. Originally the chain of mountains west of the Canning but used by the writer to include the part of the Arctic Range west of the Romanzof Mountains and north of the Yukon-Arctic divide.

Garry; creek. Dease and Simpson. After Nicholas Garry. Empties into the west side of Harrison Bay. Called Garry River by Dease and Simpson.

Garry; river. *See* Garry Creek.

Gordon; point. Leffingwell. After Tom Gordon, long a resident at Barrow. A point on the mainland 5 miles east of Point Bullen.

Greenough; mountain. Franklin. At eastern end of Romanzof Mountains. On his map but not mentioned in text. Not located.

Griffin; point. Franklin. At the east side of the lagoon east of Martin Point. Position doubtful from text and map.

Gubik; river. *See* Colville.

Gull; island. Leffingwell. A small sand island in Prudhoe Bay.

Gwydyr; bay. Franklin. Behind Return Islands.

Halkett; cape. Dease and Simpson. After one of the directors of the Hudson's Bay Co. A tundra island on the northwest side of Harrison Bay, connected to the mainland by a spit. Eskimo: Ishuk, "end." Stefánsson spells it Isuk.

Harrison; bay. Dease and Simpson. After the deputy governor of the Hudson's Bay Co. A large bay into which the Colville empties. Eastern limit at Thetis Island and western at Cape Halkett.

Heald; point. Franklin. On the east side of Prudhoe Bay. Called Point Herald in the Philadelphia edition, 1828.

Herschel Island; river. *See* Firth.

Hopson; point. Leffingwell. After Fred Hopson, long a resident at Barrow. On the mainland 15 miles west of Flaxman Island.

Howe; island. Leffingwell. After Dr. George P. Howe, of the Mikkelsen-Leffingwell expedition. A conspicuous silt island in the delta of the Sagavanirktok. Anxiety Point is at the eastern end of this island.

Hoola-hoola; river. *See* Hulahula.

Hulahula; river. Marsh. River entering the Arctic Ocean at the 144th meridian. The name is of Kanaka origin, and was introduced by the whalers. The meaning is "dance." Stefánsson spells it Oolahoola and Ulahula; Marsh, Hoolahoola.

Hull; point. Maguire's chart. After Master Thomas Hull, R. N., of H. M. S. *Plover*. On east side of Moore Channel, east of Point Barrow.

Humphreys; point. Franklin. On west side of Beaufort Lagoon. Spelled Humphrys once in text, but elsewhere and on his map Humphreys.

Huskisson; mountain. Franklin. Western extremity of British Mountains. After Mr. Huskisson. Not located.

Hyaks; creek. Marsh. A tributary to the Canning. Location unknown.

Ice Stream; point. Dease and Simpson's map, not mentioned in text. In Smith Bay. Not located.

Icy; reef. Franklin. A long sand island a few miles west of Demarcation Point.

Igalik; island. Leffingwell. The easternmost of the Plover Islands. Means "window" (?). Probably the same as Ikalue on British Admiralty Chart No. 593.

Iglorak. *See* Cooper Island.

Iglurak. *See* Cooper Island.

Ignek; creek. Leffingwell. The first tributary on the east side of the Canning. Means "fire." Jenness spells it Ignik.

Ignek; valley. Leffingwell. One of the three structural valleys between Canning and Sadlerochit rivers.

Ikalue Island. *See* Igalik.

Ikiakpaurak; valley. Leffingwell. One of the three structural valleys between Canning and Sadlerochit rivers. Means "small valley."

Ikiakpuk; valley. Leffingwell. One of the three structural valleys between Canning and Sadlerochit rivers. Means "big valley."

Ikiraaluk. *See* Moore Channel.

Ikkeraluk. *See* Moore Channel.

Iko. Maguire's map. Eskimo name for Mackenzie Bay (?) in Elson Lagoon.

Ikpikpuk; river. *See* Chipp.

Ikpikpung; river. *See* Chipp.

Illuitkuk; islands. *See* Plover Islands.

Ishuk; cape. *See* Halkett.

Isuk; point. *See* Halkett.

Itkillik; river. Credited to E. L. Bosqui in "Geographic dictionary of Alaska." A large river entering the Colville from the east at the head of the delta. Peters and Schrader spell it Itvelik. Means "Indian."

Itkilyariak; creek. Leffingwell. A tributary to the Sadlerochit. Means "Route by which the Itkillik travel." Marsh calls it Ooselik.

Itvelik; river. *See* Itkillik.

Ivishak; river. Marsh. The chief tributary of the Sagavanirktok. Marsh spells it Evasha. Means "red earth" (hematite?).

Jago; river. Leffingwell. After Lieut. Jago, of Collinson's ship. Empties into the Arctic Ocean at Martin Point, near the 143d meridian. The Eskimo name is Jags.

Jeannette; island. Leffingwell. After the whale ship *Jeannette*. One of the McClure group of islands west of Flaxman Island.

Jones; islands. Dease and Simpson. After Rev. David T. Jones. A chain of low tundra islands between Oliktok (Berens Point) and Point Beechey. Renamed Thetis Islands by Stockton.

Kaaktovik. *See* Barter Island.

Kadleroshilik; mound. Leffingwell. A mound rising 400 feet above sea level about 13 miles inland from Foggy Island Bay. Perhaps means "possesses something on top" or "which seems to approach" (?).

Kadleroshilik; river. Leffingwell. After the mound of the same name. Enters the ocean at Foggy Island Bay.

Kalokut; creek. Leffingwell. A creek emptying into the Arctic Ocean between Aichillik and Turner rivers.

Karluk; island. Leffingwell. After the whale ship *Karluk*. One of the McClure group of islands west of Flaxman Island.

Katakturuk; river. Leffingwell. Empties into Camden Bay, Arctic coast. Perhaps means "a narrow place" (?).

Kilulea. *See* Dease Inlet. Maguire's map. Eskimo name for Dease Inlet.

Kogru. Maguire's map. Eskimo name for a stream emptying into the west side of Harrison Bay, Arctic coast.

Kongakut; river. *See* Turner.

Konganevik; point. Leffingwell. A point on the west side of Camden Bay, Arctic coast. Jenness spells it Kongangevik. Means "place where there is a deer pond."

Koopowra; river. *See* Kuparuk.

Kugruak; river. *See* Canning.

Kuguru; river. *See* Canning.

Kulgurak; point. *See* Tangent.

Kuparuk; mounds. Leffingwell. Two mounds near the coast on the east side of Kuparuk River.

Kuparuk; river. Marsh. Enters ocean at Gwydyr Bay, near 149th meridian. Means "rather large river." Marsh spells it Koopowra.

Kupik; river. *See* Colville River.

Kupowra; river. *See* Kuparuk.

Leavitt; island. Leffingwell. After Capt. George Leavitt, of the whaling fleet. The largest of the Jones Islands. Eskimo name, Pingok, "a mound."

Lion; point. Franklin, Leffingwell. After one of Franklin's boats. The northwest point of Tigvariak Island. The name originally applied to the island.

Lion and Reliance; reefs. *See* Tigvariak Island.

Long; island. Leffingwell. After Capt. Long, of the whaling fleet. The westernmost of the Return Islands.

McClure; islands. Leffingwell. After Capt. Robert McClure, R. N. The group of islands next east of Cross Island, in the chain of sand islands extending westward from Flaxman Island.

McIntyre; point. Leffingwell. After Samuel McIntyre, who worked for the writer for three years. On the mainland opposite the east end of the Return Islands.

McPherson; point. Dease and Simpson. Near Point Drew, east of Smith Bay. Does not appear on their map. Omitted as unnecessary.

McTavish; point. British Admiralty Chart No. 593. Southwest part of Dease Inlet. McThvisk on Maguire's map.

McThvisk; point. *See* McTavish.

Mackay; inlet. Dease and Simpson. After one of Dease and Simpson's men. Between Dease Inlet and Smith Bay. Given as McKay's Inlet by Dease and Simpson.

Mackenzie; bay. Dease and Simpson. After Chief Factor Roderick Mackenzie. On the mainland in Elson Lagoon. Not located. Probably the bay called Iko on Maguire's map.

Macleod; point. Dease and Simpson. East of Point Drew. Given as Point M'Leod by Dease and Simpson. Omitted as unnecessary.

Maghi; point. Maguire's map. *See* Tangent.

Maguire; islands. Leffingwell. After Commander Rochfort Maguire, R. N. The group of sand islands west of Flaxman Island, comprising Challenge, Alaska, Duchess, North Star, and No. 3 islands.

Manning; point. Franklin. A peninsula 2 miles east of Barter Island. Name originally applied to the island called Barter Island on the writer's map.

Marsh; creek. Leffingwell. After the prospector S. J. Marsh. Empties into the Arctic Ocean at Collinson Point, in Camden Bay.

Marsh; fork of Canning River. United States Geographic Board, 1906 (U. S. Geol. Survey Bull. 299, p. 426). After the prospector S. J. Marsh. The left or west fork of Canning River. Called Right Fork by Marsh.

Martin; island. Moore. After one of his officers. One of the Plover Islands. Original location indefinite near Point Tangent. On Maguire's chart it is put at Moore Channel. On the writer's map it is put next east of Cooper Island. Eskimo name, Shiningarok, "he slept."

Martin; point. Franklin. After Sir Henry Martin. Original locality doubtful. On the writer's map it is applied to the bend in the coast line 10 miles east of Barter Island.

Mary Sachs; entrance. Leffingwell. After the schooner *Mary Sachs*, of the Canadian Arctic Expedition, which first passed through the entrance. An entrance into the lagoon west of Flaxman Island.

Mary Sachs; island. Leffingwell. After the schooner *Mary Sachs*, of the Canadian Arctic Expedition. First sand island west of Flaxman Island.

Mayoria; river. *See* Bellevue.

Mayoriak; river. Stefánsson. Empties into Smith Bay, Arctic coast. Reported outlet of Teshekpuk. Not located.

Michelson; mountain. After Prof. A. A. Michelson. A glacier-clad peak on the west side of Okpilak River.

Midway; islands. Stockton. A name used by the whalers. A group of three sand islands about 8 miles north of Prudhoe Bay.

Miguakiak; river. Maguire's map. River at bottom of Smith Bay, Arctic coast. Reported outlet of Teshekpuk. *See* Mayoriak.

Mikkelsen; bay. Leffingwell. After Capt. Ejnar Mikkelsen. Between Point Bullen and Tigvariak Island.

Milne; point. Dease and Simpson. Original location indefinite behind Jones Islands.

Moore; channel. Maguire's chart. After Commander T. E. L. Moore, R. N. Channel leading into Port Moore. Eskimo name on Maguire's chart is Ikkeraluk; on Ray's map, Ikiraaluk, "a worthless provision rack" (?).

Moore; port. Maguire's chart. After Commander T. E. L. Moore, R. N. In Elson Lagoon, 3 miles east of Point Barrow.

Mountain Indian; river. *See* Firth.

Narwhal; island. Leffingwell. After the whale ship *Narwhal*. One of the McClure group of islands, west of Flaxman Island.

Neruokpuk. *See* Lake Peters and Lake Schrader.

Newport; entrance. Leffingwell. After the whale ship *Newport*, which is reported to have entered the lagoon at this place. Entrance to the lagoon west of Flaxman Island, between McClure and Stockton groups.

Newport; island. Leffingwell. After the whale ship *Newport*. The western island of the Stockton group, west of Flaxman Island.

Nigalik; native trading site in the Colville delta. Means "goose." Maguire, Nighali; Simpson, Nigalek; Peters and Schrader, Nigaluk; Stefánsson, Nirlik.

Nighali. *See* Nigalik.

Nigamak. Maguire's map. On the west side of the Colville delta. Probably an error for Nigalik.

Nighali. *See* Nigalik.

Nirlik. *See* Nigalik.

North Star; island. Leffingwell. After the schooner *North Star*. One of the Maguire group, west of Flaxman Island.

Nos. 3, 6, 11, 12, 13, 19, 20; islands. Leffingwell. The numbers used in surveying. In the chain of sand islands west of Flaxman Island.

Nunarunga. Maguire's map. On the east side of the Colville delta.

Nuwuak; point. *See* Collinson.

Nuwuk; point. *See* Barrow.

Ocean; point. Peters and Schrader's map. Near the head of the Colville delta.

Okerokovik; river. Leffingwell. A tributary from the east to Jago River. Means "place where there is a blubber cache." Jenness spells it Ukerukuvik.

Okpilak; river. Leffingwell. Enters the Arctic Ocean at the 144th meridian, having a delta in common with Hulahula River. Means "no willows."

Okpirourak; creek. Leffingwell. A tributary to Jago River from the west. Means "a few willows."

Olikto; point. *See* Oliktok.

Oliktok; point. Pullen. East of the eastern mouth of the Colville. Means "it shakes or trembles." Spelled Olikto by the early explorers. Named Point Berens by Dease and Simpson, but this name has not become established. Called Point Beechey on the charts.

Oolahoola; river. *See* Hulahula.

Ooselik; creek. *See* Itkilyariak.

Owens; shoals. Stockton. After Capt. Owen, who reported them. Doubtful shoals north of Point Barrow.

Pacific; shoal. Stockton. Reported by Capt. Knowles, of the whaler *Pacific*. Originally a few miles east of Cape Halkett, in Harrison Bay. Used by the writer to cover the shoals that extend around the upper end of the bay.

Pelly, mountains. Dease and Simpson. Reported to be near the coast west of the Colville. That no such mountains exist was first reported by Stockton.

Peters; lake. Leffingwell. After W. J. Peters, of the United States Geological Survey. One of two lakes on the headwaters of Sadlerochit River. Eskimo: Neruokpuk, "big lake." Jenness spells it Narivukpuk.

Pingok, island. *See* Leavitt.

Pingolee, island. British Admiralty Chart No. 593. One of the Plover Islands. Not identified.

Pitt; point. Dease and Simpson. The northernmost point on the coast between Harrison and Smith bays.

Plover's group. *See* Plover Islands.

Plover; islands. Moore. The chain of sand islands between Point Barrow and Point Tangent. The original name, Plover's group, included only the four westernmost islands. On Maguire's chart the native name Illuitkuk is used to designate the western islands. This is not an established name and is probably incorrect.

Plover, point. Maguire's chart. After H. M. S. *Plover*. Extreme eastern end of spit running eastward from Point Barrow, Arctic coast. Not established.

Pokang. *See* Pokok bay.

Pokok; bay. Leffingwell. Between Points Humphreys and Griffin. The name Pokang is given on Surg. John Simpson's native map of 1854.

Pole; island. Whalers. A sand island of the Stockton group, about 20 miles west of Flaxman Island. This may not have been the original location, for there is no settled usage among the whalers.

Poleakun; point. Point Poleakoon on Maguire's map. Southeastern shore of Smith Bay, Arctic coast. Not located.

Prudhoe; bay. Franklin. West of the mouth of Sagavanirktok River. Probably this bay includes Yarborough Inlet.

Prudhoe; mound. Leffingwell. A small mound at the bottom of Prudhoe Bay, used in triangulation.

Red; hill. Leffingwell. At the west end of Sadlerochit Mountains.

Reindeer; island. Leffingwell. After the whale ship *Reindeer*, which was wrecked in the vicinity. The westernmost of the Midway Islands west of Flaxman Island.

Reindeer; lake. Dease and Simpson's map. Not mentioned in text. On west side of Dease Inlet. Not located.

Reliance; point. Franklin, Leffingwell. After one of Franklin's boats. The northeast point of Tigvariak Island. The name originally applied to the island.

Return; cove. Moore. Northeast side of Dease Inlet. Not located.

Return; islands. Franklin, Leffingwell. A chain of sand islands extending across Gwydyr Bay. The original name, Return Reef, was applied to a single sand island northeast of Gwydyr Bay, but it has been established to cover the whole chain of islands.

Return; mound. Leffingwell. A conspicuous mound used in triangulation, about 8 miles inland on Kuparuk River.

Return; reef. *See* Return Islands.

Right Fork, of Canning River. *See* Marsh Fork.

Robinson; mountain. Franklin. After the Right Hon. Mr. Robinson. Eastern extremity of British Mountains. Not located.

Rocky; mountain system. Franklin. Mountains extending across Arctic Alaska.

Romanzof; mountains. Franklin. After Count Romanzof. Described by Franklin as lofty peaks covered with snow, which commence at the western termination of the British Mountains abreast of Griffin Point and extend to the Canning. Name restricted by the writer to the higher area of granite mountains around headwaters of Okpilak River.

Rose; point. Dease and Simpson. Doubtful point in Elson Lagoon, not on their map. Not located.

Ross; bay. Dease and Simpson. On the mainland of Elson Lagoon. Not located.

Rowand; point. Dease and Simpson. On the mainland of Elson Lagoon. Not located.

Rutland; island. British Admiralty Chart No. 593. One of the Plover Islands. Not identified.

Sadlerochit; mountains. Leffingwell. The northern front range of the Arctic Mountains between Sadlerochit and Canning rivers.

Sadlerochit; river. Leffingwell. Empties into the Arctic Ocean near longitude 144° 30′. Means "the area outside of the mountains" (?). Probably the same as Marsh's Barter River.

Sagavanirktok; river. Marsh. A large river entering the Arctic Ocean between Foggy Island Bay and Prudhoe Bay, at longitude 148°. Means "strong current." Marsh, Sawanukto; Anderson, Sharavanaktok. The spelling Sagavanirktok has been adopted by the United States Geographic Board. The writer perfers Shagavanuktok.

Saktuina; island. Maguire's map. Eskimo name for an island in Harrison Bay. Probably one of the Eskimo Islands.

Salisbury; mountain. Leffingwell. After Prof. R. D. Salisbury. A conspicuous double snow-clad peak a few miles west of Canning River.

Salt; creek. Dease and Simpson's map; not mentioned in text. Runs into a lake back of Point Drew. Not located.

Savaovik; river. *See* Shaviovik.

Saviovik; river. *See* Shaviovik.

Sawanukto; river. *See* Sagavanirktok.

Schrader; lake. Leffingwell. After F. C. Schrader, of the United States Geological Survey. One of two lakes on the headwaters of Sadlerochit River. Eskimo: Neruokpuk, "big lake."

Scott; point. Dease and Simpson. On the west side of Mackenzie Bay, Elson Lagoon. Not located.

Sentinel; hill. Peters and Schrader's map. On Colville River, about 50 miles from the Arctic coast. Not located.

Shagavanuktok; river. *See* Sagavanirktok.

Sharavanaktok; river. *See* Sagavanirktok.

Shaviovik; mound. Leffingwell. A mound about 80 feet high, visible from the coast, west of Shaviovik River. Used for a triangulation station.

Shaviovik; river. Marsh. Enters ocean near longitude 147° 10′. Means "place where there is iron." Marsh and Stefánsson spell it Saviovik.

Shavugavik. *See* Bullen Point.

Shiningerok; island. *See* Martin.

Shublik; springs. Leffingwell. General locality near a large spring on Canning River. Means "a spring." Jenness spells it Sublik.

Shublik; mountains. Leffingwell. An outlying chain of mountains, between Canning and Sadlerochit rivers.

Sidrak; island. *See* Flaxman.

Siko; creek (?). Leffingwell. Surg. John Simpson's native map shows Siko Island at this locality. A creek or locality behind Icy Reef, where ice remains the year around. Spelled Siku by Stefánsson.

Siku. *See* Siko.

Simpson; cape. Dease and Simpson. After George Simpson, governor of the Hudson's Bay Co. On the west side of Smith Bay. The original sharp projecting point has been cut off by the waves so that the exact location is indefinite. Used to cover the bend in the coast line on the western side of the bay. On Maguire's map the Eskimo name is Wewaleah, which is probably incorrect.

Simpson; cove. Stockton. After Thomas Simpson. Behind Collinson Point in Camden Bay. The name has not become established and is not necessary.

Simpson; lagoon. Leffingwell. After Thomas Simpson, of the Hudson's Bay Co. Behind Return and Jones islands.

Sinclair; river. Dease and Simpson. After one of their men. Enters ocean between McKay Inlet and Smith Bay. Not located.

Smith; bay. Dease and Simpson. After Chief Factor Smith, of the Hudson's Bay Co. The first important bay east of Point Barrow.

Smith; river. Dease and Simpson. An inconspicuous creek near Pitt Point.

Spy; islands. Leffingwell. After the schooner *Spy*, which went inside of them about 1881. Two or three closely connected sand islands north of Oliktok.

Staines; river. *See* Canning.

Stockton; islands. Leffingwell. After Capt. C. H. Stockton, United States Navy. The group of sand islands west of Flaxman Island, comprising Newport, Pole, Belvedere, and Nos. 11, 12, and 13 islands.

Storkersen; point. Leffingwell. After Storker Storkersen, who worked for Mikkelsen and Leffingwell and later for Stefánsson. On the mainland at the east side of Gwydyr Bay.

Stump; island. Leffingwell. The easternmost of the Return Islands.

Sunset; pass. Marsh. Pass through the east end of Sadlerochit Mountains at the head of Itkilyariak Creek, leading to Sadlerochit River.

Sweeney; point. Leffingwell. After Dan Sweeney, who worked for the writer. On the mainland 10 miles west of Flaxman Island.

Tamayariak; creek. Leffingwell. A tributary which enters the Canning from the east, near the coast. Means "route where some people were lost."

Tangent; point. Dease and Simpson. At the eastern end of Elson Lagoon. Northeast of Dease Inlet. Maguire gives Mâghi for the Eskimo name and Surg. John Simpson (native map), Kul-gu-rak.

Tapkaluk; islands. Leffingwell. Eskimo name for several nearly connected islands west of Cooper Island in the Plover group.

Tasekpuk; lake. *See* Teshekpuk.

Tasirkpuk. *See* Teshekpuk.

Tasokpoh. *See* Teshepuk.

Teshekpuk; lake. Maguire's map. A large lake behind Pitt Point, on the Arctic coast. Means "big inclosed coastal waters" or "big coastal lake." Stefánsson spells it Tasirkpuk. It has other spellings.

Thetis; islands. *See* Jones.

Thetis; island. Leffingwell. After the U. S. S. *Thetis.* A large sand island about 7 miles northwest of Oliktok. Eskimo name, "Amaudliktok," perhaps the "Pacific eider." The whalers call this "West Thetis Island."

Thetis; mound. Leffingwell. A mound 3 miles southeast of Oliktok, used in triangulation.

Thomson; point. Franklin. On a sand spit about 5 miles west of Flaxman Island. Original location doubtful. Given "Thomson" in text and "Thompson" on map.

Tigvariak; island. Leffingwell. A conspicuous tundra island at the mouth of Shaviovik River. Originally called Lion and Reliance Reef by Franklin. Means "route by which they went over," or "portage."

Tomasagnu (?) river. British Admiralty Chart No. 593. On the east side of Dease Inlet. Not located.

Toolavia; point. *See* Christie.

Toolemina. *See* Tulimanik.

Tulimanik. Maguire's map. East end of chain of sand islands running from Point Tangent across Mackay Inlet. Given on Maguire's map for Boat Extreme and spelled Toolemina. Spelled Tullimanirk by Stefánsson.

Turner; river. Funston. After J. H. Turner, of the United States Coast and Geodetic Survey. Empties into the Arctic Ocean behind Icy Reef, west of Demarcation Point. Eskimo: Kongakut, approximately "deer pond."

Tutkiya. Maguire's map. West side of Colville Delta.

Ulahula; river. *See* Hulahula.

Weller; mountain. Leffingwell. After Prof. Stuart Weller. A peak near the east end of Sadlerochit Mountains.

Wewaleah. *See* Capé Simpson.

Whale; island. British Admiralty Chart No. 593. A sand island in the Plover group. Not identified.

Wright; point. Maguire's map. East side of Dease Inlet. Not located.

Yarborough; inlet. Franklin. East of Return Island. It has been necessary to omit either Yarborough Inlet or Prudhoe Bay. As there is a bay and not an inlet, the name Yarborough Inlet has been dropped.

GENERAL GEOLOGY.

GEOLOGIC WORK IN THE CANNING RIVER REGION.

The writer's aim was to work out a complete section of the formations on the north side of the Arctic-Yukon divide, and, so far as possible, to decipher the geologic history rather than to map out the different rock formations. Consequently the time in the field was spent in searching for fossils and contacts rather than in tracing the boundaries of formations.

Fossils were locally abundant, and a great number might have been obtained, but on account of the difficulty of transporting them to the coast by packing them on the back, or by dogs, only a few were brought out. One large brachiopod, considered to be *Productus giganteus*, 6 by 4 by 3 inches in size, was reluctantly left behind, on account of its weight, after smaller forms of the same species were found.

The faunas represented by the collections have proved to be more similar to those of the European section than to those of the United States, so that to the paleontologists of the United States Geological Survey they are unfamiliar forms, especially the Mesozoic fossils. Even some of the genera are in doubt. The Arctic Alaskan Carboniferous faunas seem to be allied with European faunas like those of the *Productus giganteus* zone, the *Schwagerina* zone, and the Artinskian. The Triassic faunas have representatives in other areas of Alaska which have been already studied, but the Jurassic faunas are almost unknown on this continent.

Prior to the field work in the Canning River region other geologists had studied sections in the Arctic Mountains, and the writer had the advantage of their publications. At Cape Lisburne, at the west end of this belt of mountains, some fossils were collected by the early explorers,[1] but Maddren[2] in 1900 was the first to obtain accurate knowledge of this region. The same area was briefly studied by Schrader on his homeward journey from his trip down the Colville in 1901. Collier[3] studied the Cape Lisburne region in detail in 1904. Kindle[4] a few years later investigated the section at Cape Thompson, about 50 miles south of Cape Lisburne.

In 1901 Schrader[5] crossed the Arctic Mountains from the Yukon side and descended the Colville to the Arctic Ocean, thus making a complete section along the 152d meridian.

Although the south side of the Arctic Mountains has been investigated at several places, the report by Smith[6] on his work in the Noatak-Kobuk region in 1910 and 1911 is the only one that is frequently cited in the descriptions of the formations of the Canning River region. In 1901–2 the prospector S. J. Marsh[7] crossed the Arctic Mountains from the Arctic Ocean to the Yukon, and made some notes on the geology, which were sent to the United States Geological Survey.

During the period of the writer's investigations on the Canning River region, Maddren was working on the international boundary along the 141st meridian. A preliminary paper was published immediately after Maddren's return,[8] but most of the information embodied in this report has been received in conversation with him. During the season of 1913–14 the Canadian Arctic Expedition wintered at Collinson Point, on the north coast of Alaska, in the area considered in this report. The geologist of the expedition, John J. O'Neill, made a winter trip up Sadlerochit River. At one place he found a good exposure of Triassic rocks, including portions of the section not found by the writer. Mr. O'Neill kindly allows the publication of his discoveries in this report. During the spring of 1914 he observed a section on the lower part of Firth River, which flows northeastward across the international boundary line and empties near Herschel Island in Canadian territory. He has published a brief account of his work, with the remark that the succession of formations greatly resembles that in the Canning River region.[9]

The investigations of the geology of the Arctic Mountains and the Arctic slope provinces have established the sequence of late Paleozoic and early Mesozoic events, but the sequence before and after this era still contains gaps. It is probable that the pre-Devonian history will be made out only after painstaking study over the entire area, but the post-Lower Jurassic history can be easily deciphered if only better exposures can be found. For this reason it is advisable to plan new work in fields where the later rocks are presumably exposed rather than to go over the known areas a second time more carefully. The chief problem to be solved is the time at which the rocks in the Arctic Mountains were deformed. This deformation has been assumed to have taken place at the end of the Mesozoic era, but recently this time has been questioned. The deformation may have taken place in Eocene time.

From the descriptions of Maddren and O'Neill, the area near the 141st meridian seems to have been much more disturbed than the Canning River region, so that a representative section of the Arctic Mountains can hardly be obtained there. The absence or the metamorphism of the Mesozoic and Tertiary beds in this region also makes it unfavorable. From reports of natives the area between the 141st meridian and Okpilak River is also unfavorable, but a section could probably be studied along Turner River. This river is reported to have easy passes from the Yukon drainage and to have abundant willows for firewood, which is unlike the other rivers.

West of the Canning the coastal plain and the Anaktuvuk Plateau grow wider, so that the softer post-Paleozoic rocks are probably exposed in the river cuts. Sagavanirktok

[1] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 6, 1906.

[2] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 66–67, 1904.

[3] Op. cit.

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

[5] Op. cit.

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

[7] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 260–262, 1906.

[8] Maddren, A. G., Geological investigations along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 297–314, 1912.

[9] O'Neill, J. J., The Canadian Arctic Expedition: Canada Geol. Survey Summary Rept., 1914, pp. 112–115, 1915.

River heads against the Yukon drainage, and though the passes are reported to be steep they can probably be crossed by pack horses. A trip down the west or Ivishak fork of this river, up the east fork, and over to the Canning by an easy pass to a creek which is reported to come out a short distance above the forks of the Canning would, together with the results of the writer's work below the forks of the Canning, give sections along two rivers, and the parties could return to the Yukon without the possibility of being marooned on the Arctic coast from lack of transportation.

Eventually Schrader's section should be retraced along the 152d meridian, especially in order to divide his Fickett series into the several formations which it seems to contain. Another trip which has promise of both geologic and geographic interest would be to follow down the Colville from its headwaters and to cross over the reported pass to the head of Chipp or Ikpikpuk River and to follow that stream down to the Arctic Ocean. The native name means "big bank," so that good sections of the softer rocks may be expected. The location of the mouth of the Ikpikpuk is in doubt, and the accurate representation of this feature on the map as well as the neighboring mouth of Meade River are two important objects to be attained by exploration on the north coast of Alaska. These rivers empty within 50 miles of Point Barrow, whence transportation southward may be secured as late as the 1st of September.

GEOLOGIC RECONNAISSANCE MAP.

No attempt was made to follow the line of contact between the formations, so that the areal distribution of the formations could not be accurately placed on the map. Only such boundaries as could be seen from the line of traverse or from elevated positions occupied in drawing the topography were entered in the notes. There was no base map on which to place the distribution of the formations. The observations were entered on detached topographic sheets as they were drawn, or else in notebooks in the form of sketches or in writing. After the topographic map had been drawn in the office the geology was placed upon it as accurately as possible. (See Pl. II, in pocket.) There is no doubt that errors have occurred, especially as some of the formations were entered from memory or from photographs.

Although six years were spent in the region, very little of this time was spent studying the rock formations of the mountains. Winter trips were unsatisfactory on account of the concealment of much of the country by snow. The summers were devoted chiefly to the construction of the large-scale map of the coast (Pls. IV and V, in pocket), so that very little time was afforded for trips to the mountains. The usual plan was to sled an outfit to the mountains in May before the snow was gone, and then proceed by packing the outfit. On one of the trips the writer was entirely alone, so that the time available for geologic studies was short. At all times it was necessary for every member of the party to carry his share of the outfit, so that between camps much country was passed over almost without notice. It was also necessary to secure game for subsistence, so that the geologist was more apt to be looking for ptarmigan than to be studying the rocks along the line of march. The construction of the map consumed most of the time available for field work, so that on many days geologic work was done only on the route between the camp and the station occupied.

On Okpilak River six weeks were spent during one summer. The Hulahula was traversed in a brief winter trip. Sadlerochit River and Marsh Creek were studied during a summer trip of about five weeks. The Canning was explored during a trip that lasted about seven weeks, and for a month of this time the writer had no assistance. Several winter trips also were made up the Canning, but they added little to the observations secured during the summer.

SUBDIVISIONS OF THE ROCKS.

The following table shows the age and general character of the rocks of the Canning River region.

Geologic formations in the Canning River region of northern Alaska.

Age.	Formation.	Lithologic character.
Recent.		Sand, silt, and ice.
Pleistocene and Recent.		Ground ice, gravel mounds, sands, silts, peat, and muck.
Pleistocene.	Flaxman formation.	Foreign glacial deposits confined to the coast.
		Local glacial deposits.
		Coarse gravels and boulders distributed over the upland.
Pliocene.		Blue-gray soft shale containing scattered pebbles.
Tertiary (?).		Sandstone on Canning River and at Peard Bay.
Jurassic(?).	Ignek formation.	Black shale and subordinate sandstone, coal, or red beds.
Lower Jurassic.	Kingak shale.	Black shale.
Upper Triassic.	Shublik formation.	Dark shale, sandstone, and limestone.
Pennsylvanian.	Sadlerochit sandstone.	Light sandstone or dark quartzite.
Mississippian.	Lisburne limestone.	Gray limestone, subordinate dark limestone, basaltic effusives.
Mississippian or Devonian.		Black shale and slate.
Pre-Carboniferous.	Neruokpuk schist.	Quartzite schist.

PALEOZOIC (?) SEDIMENTARY ROCKS.

NERUOKPUK SCHIST (PRE-CARBONIFEROUS).

CHARACTER AND OCCURRENCE.

The Neruokpuk formation, which consists chiefly of quartzite schist, occurs in a belt that trends eastward, with increasing width, from a point west of the Canning to the Hulahula and probably to the Okpilak and beyond. Both the upper and lower contacts of the formation are believed to be fault contacts. Another area of somewhat similar schist was observed around the headwaters of Hulahula River. Whether or not the two schists are identical is not known, but they will be discussed as one formation. They will be called the lower and upper belts in the following description. The schist is typically developed on three sides of Lake Peters, also near the forks of the Canning. Neruokpuk is the Eskimo name for Lakes Peters and Schrader.

Two representative specimens of the schist from the lower belt on the Canning, have been described by J. B. Mertie, jr., of the United States Geological Survey, who reports as follows:

Rocks of lower belt of the Neruokpuk schist.

No. L. 24, Canning River. Quartzite mica schist. Texture: Schistose. Constituents: Quartz, sericite, and a little iron hydroxide.

No. L. 25, Canning River. Quartzite schist. Texture: Schistose. Constituents: Quartz and sericite.

The prevailing color is greenish, but areas of blue-gray schist were also noted. The formation is in places massively bedded, and has a distinctly sedimentary aspect. On the Canning the schist commonly approaches quartzite in texture. Pebbles as large as an eighth of an inch in diameter were observed in it at a few places. The aspect on Sadlerochit and Hulahula rivers is much the same, but on the Okpilak the schist is either lacking or has been metamorphosed by the granite. On the Canning the distance across the schist measured at right angles to the planes of schistosity is approximately 20,000 feet, but probably this does not represent the thickness of the formation. Here the width of the schist belt is about 8 miles.

The upper belt on Hulahula River is separated from the lower belt by Carboniferous limestone and shales. Only the northern 5 or 6 miles were traversed, so that it is impossible to state the width of the belt. As a whole the schist is pale green, but there are dark bands and patches. There is much quartz associated with graphite, neither of which were found in the lower belt. The lower contact, against the Lisburne limestone, is probably along a fault plane. In the field the writer was under the impression that the schist of the upper belt differed lithologically from that of the lower belt, but Mr. Mertie's determination is that they are both quartzite schists.

Rocks of upper belt of the Neruokpuk schist.

No. L. H. 6. Forks of Hulahula River. Quartzite mica schist. Texture: Schistose. Constituents: Quartz and sericite.

The southern contact on the Canning between the schist and the overlying Carboniferous limestone is plainly visible on the side of the mountain which separates the two forks of the river. On the east side of the east fork, where the writer was camped, the side stream seemed to flow along the contact, for although outcrops of schist and limestone were found within 100 feet of each other the actual contact was not found. The main river was too high to be forded at the time of visit, so the contact, which was plainly visible upon the west side, could be observed only by the use of field glasses.

The contact forms a straight line, which dips southward about 15°, at a lower angle than the bedding of the underlying schist. The limestone beds lie nearly parallel to the contact. The bedding is monoclinal at the contact, but plications occur not far from it. No signs of dragging or of basal conglomerate were observed, so it is uncertain from the aspect of the rocks whether the unconformity here is due to faulting or to deposition.

On the Hulahula black Carboniferous shales end against the schist at the northern contact of the lower belt in a manner that can only be explained by faulting, so it is probable that the contact on the Canning is also along a fault. It does not seem probable that limestone would be deposited against the schist without gradations which would be visible with field glasses at a distance of half a mile.

The northern contact on the Canning is also against the Carboniferous limestone and shales. The actual contact was not found, but shales dipping steeply northward were found within 200 yards of the southward-dipping schist. From the aspect of the mountain slopes to the east the writer inferred that the schist overrode the younger rocks.

The schist thus appears to be bounded on both the north and the south by fault planes. On the north the schist has been thrust up against the younger rocks, and on the south the younger rocks lie upon the schist.

STRUCTURE.

As a whole the Neruokpuk schist strikes eastward in accord with the general trend of the other formations. The dip of the schistosity, where observed, was usually 30° or more to the south. Local infolding was observed near the northern limit on the Canning. No evidence of faulting was observed within the formation.

There were, as a rule, three sets of joint planes, but only those on the Canning and Okpilak were measured. The true directions of the joint planes on these streams are as follows:

Direction and spacing of joint planes in schist on Canning and Okpilak rivers.

	Strike.	Dip.	Distance apart (feet).
Canning River:			
A	N. 20° W.	90°	3–4
B	S. 15° W.	90°	½–4
C	S. 65° W.	35° NNW.	4
Okpilak River at forks:			
A	N. 70° W.	70°–75° SSW.	1–5
B	S. 25° W.	75° NW.	1–5
C	N. 70° W.	±5° NE.	....

The schistosity on the Canning strikes S. 65° W. and dips 35° SSE.; on the Okpilak it strikes N. 70° W. and dips 70°–75° SSW.

On Sadlerochit River a set of older quartz-filled joints lies at a slightly different angle to the open ones. The beds of the upper belt on the Hulahula strike northeast and dip 45° to 50° SE. The chief joint plane strikes northwest and dips 60° SW.

AGE AND CORRELATION.

As the contacts of the Neruokpuk schist with other formations are apparently the result of faulting, the relative ages of the Carboniferous rocks and the schist can not be determined by their relations at the contacts. The metamorphism of the schists is so much greater than that of any other sedimentary rocks that there can be no hesitation in calling the Neruokpuk formation pre-Carboniferous. This information as to age is all that was obtained in the region under study.

Schists are widely distributed in the Arctic Mountains and are noted in the reports of nearly every geologist who has investigated their geology. Schrader,[1] Mendenhall,[2] Smith,[3] and Maddren[4] have all described mica, quartz-mica, or graphitic schists on the south side of the mountains. Schrader[5] describes two schist belts along the 152d meridian, which, together with those found by Maddren on the 141st meridian, form probably the equivalents to the east and west of those described above in the Canning River region.

Schrader's Totsen series, composed of mica and quartz-mica schists, which locally contains graphite and abundant quartz, resembles the upper belt of the writer's Neruokpuk schist. Schrader's assignment of his Totsen series to the Silurian rests upon its supposed relations to his Skajit formation, which contained fossils whose age might be anywhere from Silurian to Mississippian. Brooks[6] says that the evidence presented as to the age of the Totsen might almost equally as well indicate that the Totsen underlies the Skajit.

Schrader's Fickett series also contains schists which are stated to be Carboniferous. The writer is of the opinion that this "series," which contains quartzite, schists, and fossiliferous limestone, must be divided into several components, and that the Carboniferous fossils have no bearing upon the age of the schists.

It is thus seen that no new light as to the age of the schist is obtained from the Colville region.

Maddren[7] has found two metamorphic series in his section on the 141st meridian in the Arctic Mountains. There is a lower phyllite schist, which he considers to be pre-Cambrian, and an upper quartzite-slate series of probably Lower Cambrian age.

PALEOZOIC SEDIMENTARY ROCKS.

BLACK SHALE (MISSISSIPPIAN OR DEVONIAN).

CHARACTER AND OCCURRENCE.

This formation, which consists of more than 1,000 feet of black shales, slates, and possibly minor amounts of sandstones, is considered to overlie the Neruokpuk schist by fault contact. It apparently underlies conformably the Lisburne limestone. It was found only upon Canning and Hulahula rivers and can probably best be studied on the Hulahula. The type locality is on the east side of the Canning, a couple of miles within the Franklin Mountains.

At this locality on the Canning the formation consists of a fine, hard black rock, which splits into many slabs about an inch thick. There are some beds of black slate which have good cleavage and are perhaps suitable for roofing slate. There are local gash veins of quartz, red and yellow rusty veins, and many thin yellow beds apparently stained by limonite. It is estimated that the thickness of the beds exposed at this place is 700 feet. The actual contact of the black shales and the overlying limestone was not found. The nearest outcrops of each rock are 200 feet apart in section, and the dips are conformable. The lower contact is against the limestone in definite fault relations. Here the limestones are vertical, and the shales dip about 45° S. The actual contact was concealed, but outcrops of both formations were found within 200 yards of one another.

[1] Schrader, F. C., Preliminary report on a reconnaissance along the Chandlar and Koyukuk rivers, Alaska, in 1899: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 472–475, 1900.

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

[3] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 55–61, 1913.

[4] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, pp. 34–47, 1913.

[5] Schrader, F. C., Reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 58–60, 67–72, 1906.

[6] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 215, 1906.

[7] Oral communication.

Two or three miles above this locality, at the blank space on the geologic map, there is a complicated area containing black slates and one or more beds of hard, light-gray sandstone. These black rocks seemed to rise conformably from beneath the limestone in the syncline south of the doubtful area, and they are on this account thought to belong to the black shale.

A couple of miles above this doubtful locality, at the "corner" of the mountains at the bend in the river, there is exposed about 20 feet of the same hard, black shaly rock, with wavy cleavage. Rusty veins are more numerous than in the other exposure, and the rock weathers to a dirty red, so that its outcrops are noticeable from a distance. The beds dip steeply northward and are parallel to the overlying limestone, which is exposed only a few feet away. The actual contact is concealed by talus. The beds rest on the Neruokpuk schist and the contact is at a fault. Exposures of the shales and schist are 200 yards apart, but here also the contact is concealed.

On the Hulahula a black slate is exposed in the bluffs along the river about 30 miles within the mountains. The mountains abreast of these slates are capped by a heavy bedded formation which rises above a talus slope of apparently softer rock (Pl. XXIV, *B*, p. 166). The upper rock had the appearance of the Lisburne limestone, and the river wash here showed coralliferous limestone, which has been identified as Lisburne. The apparent thickness of the shale exposure is about 1,000 feet.

STRUCTURE.

The black shale is folded and faulted with the rest of the Paleozoic rocks, but as it is less resistant it has undergone greater alteration than the overlying limestones. The shales have been locally crumpled and in places have developed slaty cleavage. In the first exposure described there are many minor plications and faults. There were several S-shaped folds less than a hundred feet in length, one of the smallest of which could be spanned with the arms. In these small folds the fissility was nearly vertical. There were places also where small anticlines have pushed up through several beds of apparently softer rocks.

AGE AND CORRELATION.

No fossils were found in the black shale, but from its apparent conformity with the overlying Lisburne it is thought to lie immediately below the limestone in the geologic section. The Lisburne limestone is shown to be Mississippian, so the black shale is placed in the basal Mississippian or Upper Devonian from the evidence afforded in the Canning River region.

Black shales were found below the Lisburne limestone by Collier[1] at Cape Lisburne, by Kindle[2] at Cape Thompson, and by Maddren on the 141st meridian. In the first two localities at the west end of the Arctic Mountains there are coal beds and plant remains which fix the age as lower Mississippian. In Maddren's section, near the east end of the Arctic Mountains, there are carbonaceous shales with plant remains of undeterminable age.

The key to the stratigraphy of the Cape Lisburne region is found in Kindle's section 14, at Cape Thompson.[3] His divisions (a) and (b) show black slates and gray sandstones underneath (c), the *Productus giganteus* zone of the limestone. The writer's black shale is correlated with (a) and (b) of Kindle's section.

In Collier's section there are a thousand feet of shales, slates, cherts, and limestones, between the Lisburne limestone and the coal-bearing shales. As later investigation has shown that Collier's middle formation contains Triassic fossils, it must be removed from the Carboniferous section. This brings the Carboniferous shales next below the Lisburne formation, as Kindle found them.

G. C. Martin, of the United States Geological Survey, has reviewed Collier's section, and as it is necessary to refer to this revision several times the writer quotes at length from Martin's manuscript,[4] as follows:

> The rocks south and southeast of Cape Lisburne were divided by Collier[5] into three supposed lower Carboniferous formations as shown below:

[1] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 16–27, 1906.

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

[3] Idem, p. 523.

[4] Martin, G. C., Triassic rocks of Alaska: U. S. Geol. Survey Bull. — (in preparation).

[5] Collier, A. J., op. cit., pp. 16–27.

	Feet.
(1) Lisburne formation, consisting of massive limestones interbedded with white cherts, with an extensive coral and bryozoan fauna	3,000+
(2) Thinly bedded shales, slates, cherts, and limestones, with marine invertebrate fossils	1,000+
(3) Thinly bedded black shales, slates, and limestones, with several coal beds; contains fossil plants and possibly in one place marine invertebrates	500+

The fossils of the upper and lower formations show beyond doubt that they are of lower Carboniferous age. Collier considered that the three formations were in conformable sequence, and as the fossils of the middle formation were considered as of rather indefinite character, the Carboniferous age of the entire sequence was not doubted.

The fauna at some of the localities referred to the middle formation has recently been determined as Upper Triassic.[1] This makes it necessary to reconsider the evidence of the age of this formation and its stratigraphic and structural relations to the Lisburne limestone and to the lower coal-bearing formation.

The "middle formation" has been recognized in three or four areas in the Cape Lisburne region. One of these areas which has yielded most of the Triassic fossils (lots 4 AC 15, 4 AC 18, 4 AC 21, 4 AC 81, 4 AW 33, 4 AW 34) is a belt about 2 miles wide, which extends southeastward from a point on the coast about 2 miles east of Cape Lisburne, between the area of supposed Cretaceous rocks on the northeast and an area of the Lisburne limestones on the southwest. The contact of the "middle formation" with the supposed Cretaceous rocks was regarded by Collier as probably an overthrust fault. The relation between the "middle formation" and the Lisburne limestone is not so clear, for it is stated that the Lisburne limestone seems to overlie the cherty rocks but that "along the poorly exposed contact there is brecciation and the evidence of faulting." In view of this suggestion of faulting in the recorded field observations, together with the testimony of the fossils to the effect that the apparently underlying beds are the younger, an overthrust fault along the southwestern as well as on the northeastern boundary of the cherty rocks may reasonably be assumed.

The same Triassic fauna has been collected about 3 miles north of Cape Lewis (4 AW 38), from chert beds 450 or 500 feet thick. These cherts seem to be both overlain and underlain conformably by limestone. The underlying limestone contains Carboniferous fossils (4 AW 39).

Chert beds similar to those containing the Triassic fauna, but from which no fossils have been obtained, occur also about a mile south of Cape Lewis. Collier says of the "middle formation" of this locality: "It seems to rest conformably on the coal-bearing formation and to be overlain conformably by the massive limestone" (Lisburne formation). The notes taken by Chester Washburne at this locality read: "The underlying limestone on the right (in the sketch) is thin-bedded, black, and in places somewhat sandy. It contains many brachiopods and corals, of which collection 4 AW 35 is a sample. This limestone is about 200 feet thick. Above it is a thin-bedded, varicolored chert, mostly black, about 250 feet thick and somewhat contorted. Above the chert and probably overlying it conformably is another thin-bedded limestone, purer than the first, and with an exposed thickness in the next hill north of [several?] thousand feet. The basal 500 feet of this limestone contains considerable interstratified nodular and broken chert, and numerous fossils (4 AW 36). Above 500 feet from the base chert fragments are comparatively rare." It is evident that either the chert beds at this locality are not Triassic, or that there is a fault between the chert and the limestone which apparently overlies it.

The "middle formation" is also represented on the map at a locality 4 miles south of Cape Lisburne. No fossils have been collected at this locality, nor have the local relations been described.

[1] Kindle, E. M., op. cit.

At the time of writing Maddren had not completed his report upon the 141st meridian. In conversation with the writer he has mentioned that carbonaceous shales underlie the Lisburne limestone, in probable conformity. Plant fragments occur as at Cape Lisburne.

Schrader does not report any dark Carboniferous shales in the Colville region, but as they have been found on each side of that field, they are to be expected near the Colville also. His Fickett series may include them in its large assortment of rocks. His Stuver series,[2] which he assigned to the pre-Devonian, has some dark slates and shales near the top, which may be the equivalent of the black shale. The Stuver "series" is believed to be conformably below the Lisburne limestone, which was formerly held to be of Devonian age.

Kindle[3] mentions some black or dark shales, with sandstone and limestone, on Porcupine River. The plant remains which are associated with these shales are considered to be basal Mississippian. Brooks and Kindle[4] describe, under the Nation River series, gray clay shales with conglomerate and sandstone, on the upper

[2] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 60-61, 1906.

[3] Kindle, E. M., Reconnaissance of Porcupine Valley: Geol. Soc. America Bull., vol. 19, pp. 330-336, 1908.

[4] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, pp. 294-297, 1908.

Yukon. There are small beds of coal of which the flora is considered to be Carboniferous. These shales are overlain by a limestone which is believed to be upper Carboniferous (Pennsylvanian). Above the limestone there are beds of Triassic age as in the Canning River region.

LISBURNE LIMESTONE (MISSISSIPPIAN).

CHARACTER AND OCCURRENCE.

The principal rock in the northern front of the Arctic Mountains in the Canning River region is a light-gray limestone, to which the writer gave a local name in his field notes. However, as all the sections across these mountains reveal limestones so similar in lithology and fauna to the Lisburne limestone, it seems best to adopt that name for them all. The name Lisburne was used by Schrader for both the Cape Lisburne and the Colville region; Smith has adopted it for the Noatak; and the name seems to be applicable in the Canning River region also.

The Lisburne formation, which consists of about 3,000 feet of gray limestone, that carries subordinate black limestone near the base, overlies the Carboniferous (?) shales in probable conformity and underlies the Sadlerochit sandstone in definite conformity. It is the predominant rock in the northern part of the Franklin Mountains along the Canning, and it forms almost the entire bulk of the three outlying belts of mountains.

At the west end of the Sadlerochit Mountains a belt more than 3 miles wide is exposed. The limestone is there light gray, with thin beds and nodules of brown and buff chert. Cherty fossils, especially crinoid disks, are characteristic. There is a brecciated fault zone, which is cemented with white quartz. The exposed thickness is probably over 2,000 feet. The upper contact is apparently conformable with the Sadlerochit sandstone. The actual contact was not found, but the massive gray limestone graded with parallel bedding through brown sandy limestone and yellow sandy limestone to yellow sandstone within a distance in the section of a hundred feet. The lower contact was not exposed.

At the east end of the Sadlerochit Mountains, along Itkilyariak Creek, the limestone belt is about 8 miles wide. The character of the rock here is the same as at the western end, but there is an interbedded diabase or basalt flow. The thickness here exposed may be as much as 3,000 feet, but the basal contact was not observed. The Sadlerochit formation lies apparently conformably above the limestone.

In the Shublik Mountains the limestone belt is about 8 miles wide, and the maximum exposure is perhaps 3,000 feet, but the underlying formations are not revealed. On the south side of these mountains, at their base, in the banks of the stream which flows toward the west end of the "Third Range," the gray limestone was succeeded by a 20-foot interval of talus, and then came hard dark quartzite in beds parallel to those of the limestone. The fossils collected at this place (locality 19) show no faunal break, for the single specimen from the limestone may belong equally well to either the Lisburne or the Sadlerochit fauna. From an outlook near this locality the writer observed what he believed to be the actual contact, unconcealed by talus. The two formations graded together within a few feet.

Within the Franklin Mountains on the Canning the lower part of the limestone first comes into view. The upper part is still light gray, but there is much more chert of dark color. In the rock gorge at the edge of these mountains beds of chert, whose greatest thickness is 3 feet, are numerous near the upper contact. At the corner of the mountains, where the river bends, there are a few hundred feet of beds at the bottom of the Lisburne formation in which the limestone is darker, and there are one or two heavy beds of black limestone and a little black chert. Below this dark limestone the black shales are exposed.

The base of the limestone is exposed in two places in this belt, but the overlying sandstone has been removed from the neighborhood of each exposure, so that the thickness is not easily measured. Here, where the thickness is best revealed, an estimate of somewhat over 3,000 feet was made.

Seven miles up the Canning from this lower belt of limestone, at the forks of the river, there is a second belt, which is separated from the first belt by the Neruokpuk schist. The width of the upper belt is more than 5 miles, but its southward termination is beyond the region traversed by the writer. This limestone is noticeably darker than the outer belts and it contains much black chert. Colonies of corals are abundant and nearly every large talus block has one or more. Clusters as much as 2 feet in diameter are common. In the field books this limestone was separated by its color from the more northern belts, but the fauna is apparently the same.

The lower contact is upon the Neruokpuk schist in what is thought to be a zone of faulting. As the deformation of these mountains was brought about by compression in a north-south line, the limestone was probably thrust higher upon the schist than it formerly stood. The evidence from the structure alone may indicate that the schist was thrust up bodily through the limestone which lies on each side of it.

The Lisburne limestone on the Lake Fork of the Sadlerochit is confined to a thin vertical belt not more than 1,000 feet wide. It is exposed on both sides of the Hulahula at the north face of the mountains and is underlain at some unknown distance by the greenstones described under the heading "Paleozoic and Mesozoic igneous rocks" (p. 125). A second belt of limestone occurs beyond the lower schist belt similar to the arrangement on the Canning. This limestone was also noticeably darker than that seen farther north. The limestone float in the river bed here has been determined by its fossils to be Lisburne. The width and thickness of this belt were not noted.

On Okpilak River the limestone which overlies the granite occurs in a single plicated band only 1,000 feet thick. The rock is crystalline and contains scattered crinoid disks. It is so shattered that it breaks up into blocks of the size of hand specimens. The lower contact is against the granite and the upper against the crumpled and altered younger beds. From native reports the writer judges that the Lisburne limestone is not as extensively developed east of the Okpilak as it is to the west.

STRUCTURE.

The dominant structure of the Lisburne limestone, like that of the Arctic Mountains in general, is the result of overturned folding or thrust faulting. The strike of the folds and faults is parallel with the trend of the mountains. Joints are nearly everywhere conspicuous, but as a rule only two planes are well developed.

AGE.

The age of the Lisburne formation is now considered to be early Carboniferous (Mississippian) instead of Devonian. The fauna is more closely allied to the European section than to that of the United States, so that there is at present some doubt as to the exact position of the Lisburne in the American section. Mr. G. H. Girty, of the United States Geological Survey, who has examined the Carboniferous fossils, has made the report that is here presented. To the right of each lot number is given the writer's locality number.

Girty's division of the Lisburne into two faunal zones is borne out by the stratigraphy. All the lots placed in his lower division, with one exception, fall within the lower few hundred feet of the limestone, where the color is dark or black. The exception, lot 7125 (locality 29A), was in the gray limestone at a horizon which was more than halfway down in the formation. Girty states that at the type locality, at Cape Lisburne, there is a lower Carboniferous (Mississippian) fauna and flora which has not come to hand from the Canning. It has been shown above that the black shale formation is probably the equivalent of this pre-Lisburne formation.

For the purpose of following Girty's remarks, the list of Lisburne fossil localities is given below.

Fossil localities in the Lisburne limestone, Canning River, Alaska.

1 A. Gap between Red Hill and the west end of the Sadlerochit Range. Four hummocks of limestone 10 to 15 feet high beyond the ponds. Thirty to forty feet exposed. Abundant fossils. Horizon unknown but probably well within the formation.

1 B. A locality 200 to 300 yards east of 1 A and apparently close below, 100± feet exposed. Fossils scarce.

5. Cherty limestone outcropping along bluff on creek at west base of Sadlerochit Range. Sixty to eighty feet exposed.

5 A. Gray limestone, buff and brown chert, abundant crinoid stems of brown chert.

5 B. About 10 feet below A.

5 C. About 50 feet below A, cherty.

5 D. Scattered outcrops and loose blocks on surface of hill west of localities 5 A to 5 C. All about the

same horizon, as surface of hill is nearly parallel to the dip. About the same horizon as locality 5 A. Localities 5 A to 5 D are near the top of the Lisburne formation.

8. Top of northwest spur of the Sadlerochit Range. Much broken chert, corals flattened. Well up toward top of limestone.

12. Top of Mount Copleston and down the north side across fault line.

12 A. Top of the mountain.

12 B. In talus 50 feet below locality 12 A.

12 C. Talus halfway down the mountain.

16. Stream wash from west end of Shublik Mountains. Each bag, A, B, and C, from a separate boulder.

23. Gorge at edge of Franklin Mountains. One crinoid found among fragments of brachiopods and crinoid stems. Horizon is near top of Lisburne.

25. On the east side of the river, at the forks, at base of mountains. This horizon is well down toward the bottom. Most of the specimens come from talus blocks, but a few were in place. Corals are very abundant everywhere, and nothing else was seen but a few crinoid disks. Many colonies are 1 to 2 feet in diameter, and nearly every large talus block contains them. This limestone is somewhat darker than that to the north, and has much black chert. It is separated from the other localities by an area of schist 6 to 7 miles wide.

26, 27. "Corner" of the mountains. This locality is at the base of the Lisburne limestone.

26 A. Dark flaky limestone and black chert; specimens mostly from loose blocks but some in place.

26 X. At 200 feet above A is a band of black limestone talus, about 100 feet wide, that contains large brachiopods, a few small trilobites, and some coral—all from talus, none in place. The dip is steep, and the talus is confined to this belt. Above this dark area comes 2,000± feet of gray Lisburne limestone.

27 A. A locality 200 to 300 feet below locality 26 A; a coral in dark limestone; 20 feet exposed.

27 B. A band of black chert 1 foot wide in very coralliferous black limestone.

27 C. Rock specimen of black shale formation (below Lisburne); 20 feet exposed.

27 D. Specimen of Neruokpuk schist, 200 yards below 27 C.

29. Creek on east side of the river a mile inside of Franklin Mountains. At fault in black shale formation.

29 A. Limestone below the fault contact with black shale formation. This horizon is more than halfway down in the limestone.

29 C. Limestone conformably above the black shale formation; within a few hundred feet of the base of the formation.

Fossils from lower part of Lisburne limestone, Canning River region, Alaska.

Collection 7137. Locality 25:
Zaphrentis sp.
Lithostrotion junceum small var.
    basaltiforme?
Lithostrotion irregulare?
    affine?
    sp.

Collection 7137a. Locality 25:
Lithostrotion junceum?

Collection 7137b. Locality possibly 25:
Zaphrentis sp.
Lithostrotion aff. L. basaltiforme.
Fenestella sp.
Spirifer aff. S. striatus var. attenuatus.

Collection 7129. Locality 25 or 26:
Syringopora geniculata?

Collection 7138. Locality 26 A:
Zaphrentis aff. Z. ovidos Salter?
Syringopora geniculata Phillips?
Lithostrotion junceum Fleming?
    junceum small var.
    basaltiforme?
    portlocki?
    irregulare?
    affine?
Fenestella sp.
Hemitrypa sp.

Collection 7138a. Locality 26 X:
Lithostrotion martini?
Zaphrentis sp.
Fenestella sp.
Productus giganteus.
    aff. undatus.
    sp.
Camarotoechia? sp.
Spirifer aff. S. striatus var. attenuatus.
    pinguis.
    ovalis.
Bellerophon sp.
Phillipsia sp.

Collection 7125. Locality 29 A:
Syringopora reticulata?
Lithostrotion basaltiforme?
    sp.

Collection 7125a. Locality 29C ?:
Zaphrentis sp.
Lithostrotion portlocki?
Productus aff. P. giganteus?
Spirifer aff. S. striatus var. attenuatus.

Collection 7130. Canning River wash.
Lithostrotion portlocki?

Collection 7130a. Hulahula River wash:
Syringopora geniculata?

Collection 7130b. No label:
Syringopora reticulata?
    geniculata.
Zaphrentis sp.
Lithostrotion irregulare?
    aranea?

Fossils from upper part of Lisburne limestone, Canning River region, Alaska.

Collection 7135. Locality 1B:
Conularia sp.
Chonetes aff. C. hardrensis
Productus sp. (cora group).
    semireticulatus?
Dielasma aff. D. formosum?

Spirifer aff. S. striatus var. attenuatus.
aff. S. pellensis.
Cliothyridina? sp.
Composita aff. C. trinuclea.
Eumetria aff. E. vera.
Myalina sp.
Collection 7135a. Locality 1-1A?:
Fenestella sp.
Batostomella? 2 sp.
Stenopora? sp.
Streptorhynchus? sp.
Dielasma sp.
Spirifer aff. S. striatus var. attenuatus.
aff. S. grandicostatus?
sp.
Spiriferina aff. S. octoplicata.
Composita? sp.
Myalina sp.
Collection 7123. Locality 5A:
Fenestella sp.
Polypora sp.
Derbya? sp.
Chonetes aff. C. hardrensis.
Productus aff. P. ovatus.
semireticulatus.
Spirifer aff. S. striatus var. attenuatus.
aff. S. pellensis.
Collection 7123a. Locality 5B:
Fenestella sp.
Pustula aff. P. elegans.
Spirifer aff. S. striatus var. attenuatus.
Collection 7131. Locality 5C:
Fenestella sp.
Polypora sp.
Collection 7123b. Locality 5D:
Fistulipora sp.
Stenopora sp.
Rhipidomella aff. R. michelini.
Schuchertella? sp.
Chonetes aff. C. hardrensis.
Productus semireticulatus.
aff. P. sublevis.
aff. P. scabriculus.
sp.
Strophalosia? sp.
Rhynchopora sp.
Dielasma? sp.
Spirifer aff. S. striatus var. attenuatus.
aff. S. duplicicostus.
Syringothyris? sp.
Reticularia lineata?
Streblopteria? sp.
Collection 7128. Locality 8:
Zaphrentis sp.
Schuchertella? sp.
Productus semireticulatus.
Eumetria aff. E. vera.
Collection 7126a. Locality 12A?:
Spirifer aff. S. striatus var. attenuatus.
aff. S. duplicicostus?
Composita? sp.
Eumetria aff. E. vera.
Collection 7124. Locality 12B:
Derbya? sp.
Chonetes aff. C. hardrensis.
Productus semireticulatus.
Dielasma sp.
Collection 7126. Locality 12C:
Syringopora? sp.
Zaphrentis sp.
Productus semireticulatus.
Collection 7136. Locality 16:
Fenestella sp.
Dielasma aff. D. hastatum.
Spirifer sp.
Cliothyridina aff. C. sublamellosa.
Composita aff. C. trinuclea.
Aviculipecten? sp.
Phillipsia sp.
Collection 7132. Locality 19E:
Productus aff. P. sublevis or timanicus.
Collection 7127. Locality 23:
Crinoid.

The paleontologic evidence, as I interpret it, agrees closely with your interpretation of the geology. Two or three points, however, invite comment. There are two distinct faunas, corresponding to your two formations, the lower a limestone and the upper the Sadlerochit sandstone, but each formation presents two faunal facies. As is indicated in your memoranda relating to the collection, the lower part of the limestone consists of dark coral-bearing limestones and the upper part of light siliceous limestones. Corresponding to these lithologic differences there is a rather strong difference in faunal facies; the lower fauna is rich in *Lithostrotion, Zaphrentis, Syringopora,* and other corals, whereas the upper fauna consists largely of brachiopods and bryozoans. In order to divide the collections from the limestone in a broad way according to these distinctions, I would place in the lower fauna lots 7125, 7125a, 7129, 7130, 7130a, 7130b, 7137, 7137a, 7137b, 7138, and 7138a, and in the higher fauna I would place lots 7123, 7123a, 7123b, 7124, 7126, 7126a, 7127, 7128, 7131, 7132, 7135, 7135a, and 7136.

As to geologic age and correlation you have already, I believe, correlated the limestone with the Lisburne limestone. In a general way this is borne out by the paleontologic evidence, except that the evidence does not show whether they are exactly equivalent—one formation containing no more and no less than the other. Your fossils from the limestone seem to me to indicate an upper Mississippian age, the difference in facies between the upper and lower faunas probably not indicating any important difference in time. At least I am not ready to call the upper fauna Pennsylvanian. In this connection I may note that the Lisburne limestone has at its base a fauna and flora, indicating lower Carboniferous (Mississippian), and that nothing comparable has come to hand from the limestone in the Canning River region.

CORRELATION.

Schrader[1] gave the name Lisburne to a light-gray limestone, with subordinate shale and

[1] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 62-67, 1906.

dark limestone, with a thickness of 3,000 feet, which occurred on Anaktuvuk River. He correlated it with an apparently identical limestone at Cape Lisburne. The age was first determined as Devonian by Schuchert, but Girty, in discussing Collier's report[1] upon the Cape Lisburne region, placed it in the Mississippian.

Kindle's sections 14 and 15, at Cape Thompson, show about 5,000 feet of gray limestone underlain by 400 feet of black and buff limestones.[2] The fossils in both members are of Mississippian age. Kindle's beds, 14*c* and 14*d*, are correlated with the lower part of the writer's Lisburne and his beds 15*a* and 15*b* with the upper part. He states that the beds included in 15*b* do not contain fossils and may continue up into the Pennsylvanian. Possibly the upper part of beds 15*b* may be the equivalent of the writer's Sadlerochit formation.

Collier's Carboniferous section at Cape Lisburne has been discussed above by Martin. His upper formation is the Lisburne, without doubt. The middle formation, after excluding the Triassic portion, probably is the equivalent of the black shale formation of the Canning River section.

Schrader's Fickett series[3] is called Carboniferous from the evidence of fossils found in the river gravels. At that time the Lisburne was thought to be Devonian, and the Fickett was separated from it, but as the Lisburne is now known to be Carboniferous also there is, in the writer's opinion, no reason for separating the fossiliferous portion of the Fickett from the Lisburne. From Schrader's description this portion of the Fickett is in no way dissimilar from the Lisburne.

> Besides the above-mentioned rocks, light-gray and dark or black limestones, apparently belonging to this series, but not met in place along the route traversed, were sighted and studied through the field glass. * * * These limestones, judging from the resemblance to the specimens found in the stream gravels, are the mother rock of the fossils occurring so abundantly in the streams.[4]

In the writer's opinion, this part of the Fickett should be transferred to the Lisburne.

[1] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 25, 1906.

[2] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 522–528, 1909.

[3] Schrader, F. C., op. cit., pp. 67–72.

[4] Idem, p. 69.

Schrader[5] has another limestone formation, the Skajit, which consists of about 4,000 feet of heavy bedded crystalline limestone and mica schist and was assigned to the "Upper Silurian," from the supposed stratigraphic relations and from the evidence of a single shell, determined by Schuchert to be of any age from "Upper Silurian to Lower Carboniferous." Schrader puts the Skajit under the Totsen (Silurian) schists, but Brooks[6] states that the evidence may equally well be interpreted that the Skajit is over the Totsen.

In response to a request of P. S. Smith, of the United States Geological Survey, for a redetermination of the age of the single specimen of the Skajit fauna, E. M. Kindle made the following reply:

> The alteration of the rock has so completely destroyed the original texture of the shell that we have no basis for determining the genus or species represented by the rather poorly defined outline of a portion of one valve. * * * I should say that any attempt to refer the specimen to any one of three or four different genera can rank little better than a guess. So far as I can see, this specimen affords no definite evidence as to whether the rocks involved should be referred to the Silurian, Devonian, or Carboniferous.

From the evidence advanced by Schrader there seems to be no reason for separating the limestone of the Skajit from the Lisburne. Smith[7] is also of the opinion that the Skajit may be a metamorphosed phase of the Lisburne.

Smith[8] describes two Carboniferous formations from the Noatak-Kobuk region. They have similar faunas but are divided into the Noatak sandstone and the Lisburne limestone by their lithology. Smith regards the fossil evidence as pointing to Mississippian age for both of the formations, and says that his Lisburne limestone is the same as that of Schrader.

Maddren reports orally that on the 141st meridian there are two belts of fossiliferous limestones of Carboniferous age. His preliminary section shows 2,000 feet of limestone with shaly beds. This limestone contains fossils similar to those of the Lisburne formation.

[5] Idem, pp. 56–58.

[6] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 215, 1916.

[7] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 65–66, 1913.

[8] Idem, pp. 69–78.

Over this limestone there are about a thousand feet of beds, consisting of sandstone at the bottom and thin limestone and limy shales at the top. This he calls the *Schwagerina* zone. Then come a thousand feet of light-gray limestone with an Artinskian fauna.

O'Neill[1] mentions that black massive limestone, mostly changed to marble, occurs repeatedly for 8 miles at least on Firth River, near the 141st meridian. This limestone is probably a metamorphosed phase of the Lisburne.

SADLEROCHIT SANDSTONE (PENNSYLVANIAN).

CHARACTER AND OCCURRENCE.

The Sadlerochit formation, consisting of about 300 feet of light sandstone or dark quartzite, overlies the Lisburne limestone with conformable contact and underlies the Shublik formation with unknown contact but with parallel bedding. It occurs chiefly as a blanket formation on top of the limestone at the southern slopes of the three outlying anticlines. Wherever this formation occurs the topography is characteristic. The blanket layer of sandstone, which originally covered the whole southern slope of the Sadlerochit Mountains, has been cut through at short intervals by streams, so that the sandstone now occurs in wedges bounded by cliffs. A characteristic exposure is shown in figure 7.

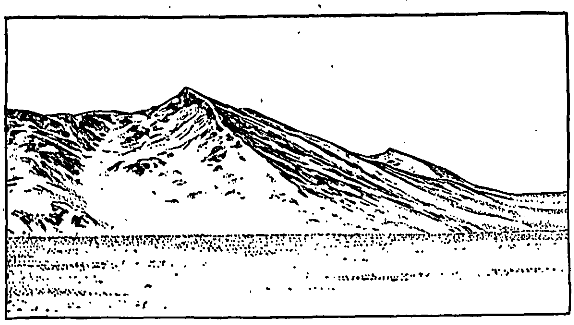


FIGURE 7.—A typical occurrence of the Sadlerochit sandstone, Ignek Valley. After a photograph.

In the Sadlerochit Mountains the formation is a light-colored, heavy bedded, fine sandstone, which weathers dark brown. Fresh surfaces may show wavy reddish lines or specks of the same color. At the west end of these mountains the rock is locally yellow or even reddish. At the west end of Shublik Mountains, the sandstone is much the same as it was farther north. There are a few thin shaly layers which contained scanty fossils (the middle part of the Sadlerochit mentioned below by Girty), and near the top of the formation, there are a few slightly conglomeratic layers. The rock here weathers out into thin slabs, and locally it weathers into cobblestones.

On the south side of the Shublik Mountains the light sandstone has given place to a dark quartzite. It there weathers to brownish red. The characteristic exposures occur in a series of hogbacks along the foot of the mountains and the rock does not form a blanket layer over the limestone. Small patches of the formation were seen in the Third Range at both ends, but there did not seem to be much near the middle. At the north front of the Franklin Mountains, at the rock gorge of the Canning, there are vertical beds of the Sadlerochit, but within these mountains only distant glimpses were seen of rocks that are probably sandstones infolded in the top of the limestone.

Near Lake Schrader on Sadlerochit River the sandstone or quartzite is so mingled with the younger beds by the greater deformation that the existence of the formation in this area was not ascertained. On the Okpilak the Sadlerochit formation was not identified in the dark complex above the limestone, but dark quartzite float containing Sadlerochit fossils was found in the streams flowing from its probable position.

The lower contact has been described as conformable with the Lisburne of Mississippian age. The upper contact was nowhere found. At several places on Canning River there are Triassic outcrops within a few hundred feet of the Sadlerochit sandstone, but the areas were so disturbed that the relations were not clearly made out. At the east end of the outside belt of mountains, at Camp 263 Creek on the southern side, the Carboniferous and Mesozoic rocks have a monoclinal structure. Here Triassic rocks were found, 300 feet in section, above the highest Carboniferous sandstone beds. The bedding of both formations was parallel, so that no unconformity is indicated.

[1] O'Neill, J. J., Canadian Arctic Expedition, 1914: Canada Geol. Survey Summary Rept., 1914, p. 114, 1915.

AGE.

The Sadlerochit sandstone is abundantly fossiliferous only at the lower contact. A few pelecypods were found in the body of the sandstone in only two localities. Mr. Girty's report is given below.

Fossil localities of the Sadlerochit sandstone, Canning River, Alaska.

7. On the top of the ridge forming the southwest corner of the Sadlerochit Range near the cliff of Sadlerochit sandstone. This locality is at or near the contact between the Sadlerochit and the Lisburne.

7 A. Dark-brown sandy rock. Abundant white casts of fossils were picked up along the shattered outcrop. None in place. Thickness 10 feet.

7 B. Yellowish sandstone conformably above 7 A. Grades into 7 A, and perhaps the fossils are mixed. Only a few feet thick.

7 C. Fine yellow-gray sandstone, 100 feet thick.

7 D. Nearly the same horizon and 150 feet west of 7 A.

Below 7 A is about 2,000 feet of Lisburne limestone and above 7 C is 300 feet of Sadlerochit sandstone.

9 A. Southeast corner of Red Hill, Ignek Creek. Gray sandstone.

11. North side of creek running west from Mount Copleston.

11 A. Near top of formation.

11 B. On hillside and about same horizon, 300 yards from 11 A.

14. Shublik Springs, close to Lisburne contact.

16. Stream wash from north side of Shublik Mountains.

19. Bluff on stream flowing from the north side of Shublik Mountains toward the west end of the "Third Range." Inside of hogback at contact with limestone.

19 A. Fine dark quartzite, 100 feet thick; no fossils.

19 B. Shaly bed, 10 feet thick. Fossils at contact with 19 C.

19 C. Hard dark quartzite, 60 feet thick. Fossils absent or rare.

19 D. Rock similar to that of 19 C, 30 feet thick, but fossils abundant.

Talus, 30 feet.

19 E. Gray Lisburne limestone; crinoid stems and a few fossils.

19 V (=B?). Shaly beds on opposite side of creek, 10 feet thick.

19 X (=C?). Hard quartzite, 6 feet thick.

19 Y (=C?). A shaly layer 8 inches wide next to X.

Fossils from basal part of the Sadlerochit sandstone, Canning River, Alaska.

Collection 7117b. Locality 7 A:

Productus aff. P. aagardi.
 aff. P. mexicanus.
 sp.
Spiriferella aff. S. saranae.
Aviculipecten sp.
 sp.

Collection 7117. Locality 7 B:

Productus irginae?
 multistriatus?
 cora?
 n. sp. aff. P. timanicus.
Marginifera involuta?
Camarophoria mutabilis?
Spiriferella aff. S. saranae.
 aff. S. cameratus.
Martinia? sp.
Reticularia? n. sp.
Squamularia perplexa?
Aviculipecten (Streblopteria?) sp.

Collection 7117a. Locality 7 D:

Zaphrentis sp.
Orthothetina sp.
Productus irginae?
 aagardi?
 koninckianus?
 aff. P. gruenewaldti.
 aff. P. horridus.
 aff. P. timanicus.
 aff. P. inflatus?
 aff. P. mammatus?
Rhynchopora aff. P. nikitini.
Spirifer aff. S. cameratus.
 lyra?
Spiriferella aff. S. saranae.
Aviculipecten sp.

Collection 7122. Locality 14:

Streptorhynchus? sp.
Spirifer aff. S. rectangulus.

Collection 7119. Locality 16:

Streptorhynchus? sp.
Productus aff. P. mammatus.
Rhynchopora aff. R. nikitini.
Spirifer aff. S. rectangulus.
 aff. S. marcoui.

Collection 7118. Locality 19 B:

Productus sp.
Camarophoria aff. C. mutabilis.

Collection 7118a. Locality 19 C:

Productus aff. P. timanicus.

Collection 7118b. Locality 19 D:

Productus mammatus?
 gruenewaldti?
 aff. P. timanicus.
Spirifer aff. S. rectangulus.
Pleurotomaria? sp.
Bellerophon sp.
Streptorhynchus? sp.

Collection 7118c. Locality 19 V:

Cliothyridina sp.

Collection 7132a. Locality 19 Y:

Spirifer? sp.

Collection 7120. Locality?:

Productus aff. P. timanicus.
 aff. P. multistriatus.
 aff. P. mammatus.
 sp.
Spirifer sp.
Aviculipecten sp.

Fossils from middle part of Sadlerochit sandstone, Canning River region, Alaska.

Collection 7133. Locality 9 A:
Bakewellia? sp.
Schizodus? sp.
Collection 7121a. Locality 11 A?:
Aviculipecten? sp.
Schizodus? sp.
Bakewellia? sp.
Collection 7121. Locality 11 B:
A few small gastropods and pelecypods, all undetermined.

The collections from the Sadlerochit sandstone also show two phases which may be more significant than those of the underlying Lisburne limestone. The principal fauna of the Sadlerochit is composed of brachiopods and is rich in *Productus*, *Spirifer*, and other forms. A few collections, however, contain none of these species but show a pelecypod facies, which is so meager and so ambiguous that I can not positively claim it for the Paleozoic at all. This facies occurs in lots 7121, 7121a, and 7133. The typical Sadlerochit brachiopod fauna is found in lots 7117, 7117a, 7117b, 7118, 7118a, 7118b, 7118c, 7119, 7120, 7122, and 7132b, the accuracy of each assignment depending on the variety and character of the fauna. It should be noted that lots 7117, 7117a, and 7117b, which occupy a stratigraphic position intermediate between the underlying limestone and the typical Sadlerochit, belong paleontologically distinctly with the Sadlerochit fauna; also lot 7132, which is referred to the limestone, might very well be Sadlerochit so far as the single *Productus* in the collection affords a clue. * * *

The Sadlerochit shows a marked faunal change from the limestone below. I correlate it with the Gschelian zone of the Uralian section of eastern Russia. The group of small collections showing a pelecypod facies that are included in the Sadlerochit, as I have already stated, present a marked contrast with the brachiopod fauna to which the preceding statements refer. These three faunas are too small and too poorly preserved to be significant.

The typical Sadlerochit fauna occurs at the contact with the Lisburne and may run down into the Lisburne. With regard to the American equivalent of the Gschelian, Girty, in a report upon Maddren's fossils from the 141st meridian, makes the following remarks in a letter written more than a year previous to the above report upon the writer's fossils:

The correlations with the Russian section are credited to Dr. Olaf Holtedahl, who is studying the Spitzbergen faunas and has also examined the Russian collections at St. Petersburg. * * * These correlations with the Russian section differ somewhat from those previously made by me and are doubtless more accurate. I have called the Artinskian horizon, which correlates with the Nation River formation, Gschelian, * * * a term which Dr. Holtedahl tells me is no longer used by the Russian geologists. * * * The Artinskian is by many European geologists included in the Permian, but Dr. Holtedahl classes it with the Carboniferous (our Pennsylvanian).

According to Girty's report upon the writer's fossils and to his remarks just quoted, the age of the Sadlerochit sandstone is Pennsylvanian. To which part of the Russian section the fauna belongs, whether to the *Schwagerina* zone or to the Artinskian, the writer is unable to state.

CORRELATION.

Kindle[1] at Cape Thompson found "a section which passes without structural complications from the fossiliferous Carboniferous limestones to the top of the highest beds exposed in the vicinity." This section, No. 15, contains two lithologic divisions—*a* and *b*, light-gray limestone; *c*, *d*, *e*, black shales, limestone, and argillite. The portion marked *d* contains Triassic fossils, and as *c* is essentially similar it is also put in the Triassic. This leaves *b*, 2,000 feet of unfossiliferous limestone, between the Triassic, and *a*, the 3,000 feet of known Lisburne limestone. Thus at Cape Thompson there is a wide interval between the Lisburne limestone and the Triassic rocks, in which an equivalent of the Sadlerochit formation may occur.

Neither Collier at Cape Lisburne nor Schrader on the 152d meridian found any rocks which can be grouped with the Sadlerochit. In Maddren's section on the 141st meridian he has 1,000 feet of limestone with Artinskian fossils. This is the nearest equivalent to the fauna of the Canning River region that has been found in the Arctic Mountains.

In O'Neill's section[2] on Firth River there are several sandstones and quartzites which overlie the limestone. They amount to 400 or 500 feet in thickness, and though they are lithologically different from the Sadlerochit they may be its equivalent.

MESOZOIC SEDIMENTARY ROCKS.

SHUBLIK FORMATION (UPPER TRIASSIC).

CHARACTER AND OCCURRENCE.

The Shublik formation, which consists of about 500 feet of dark limestone, shale, and sandstone, overlies the Pennsylvanian Sadle-

[1] Kindle, E. M., The section at Cape Thompson: Am. Jour. Sci., 4th ser., vol. 28, p. 526, 1909.
[2] O'Neill, J. J., op. cit., p. 114.

rochit sandstone and underlies the Lower Jurassic Kingak shale. Neither the upper nor the lower contact has been found, but the dip of the three formations seems to be the same. As a rule the Shublik is easily separated from the next older rocks by the abrupt change in color from light in the Carboniferous rocks to nearly black in the Triassic rocks, but the younger Kingak shales are so similar to those of the Shublik formation that the determination of the dividing line between these formations must rest upon paleontologic evidence.

The Shublik formation as a whole is less resistant than the Paleozoic rocks and has apparently been eroded from the elevated parts of the country, so that now it is found only along the northern front of the Franklin Mountains. It occurs chiefly in the outlying structural valleys. The type locality is at Shublik Island on Canning River, at the southwest corner of the Shublik Mountains, where the formation was first discovered. This locality, however, is not favorable for study, for the exposures are complicated and scattered. South of the east end of the Sadlerochit Mountains, where the rocks have a monoclinal structure, the relations are much more simple. In this locality several southward-flowing creeks show exposures across the strike. The entire section, including the contacts, was not revealed in the single cut examined, on Camp 263 Creek, exposures of the Shublik formation fairly complete sections could be made out by extending the field of study to similar streams farther to the west.

The section on Camp 263 Creek is shown below. The thickness was determined by estimation and by pacing distances along the creek bed, which is cut perpendicular to a monoclinal dip of about 20°.

Triassic section on Camp 263 Creek.

	Feet.
1. Unexposed, probably soft shales	800
2. Scattered exposures of dark limestone, some shaly beds	80
3. Unexposed, probably soft rocks	140
4. Dark calcareous sandstone, conglomeratic (?)	30
5. Unexposed, probably soft rocks	300
	1,350

The lower sandstone member is apparently calcareous, and the grains stand out so as to be rough to the touch in weathered specimens. Darker pebble-like markings are so numerous as to give the rock a mottled appearance. This sandstone with its characteristic markings was identified in nearly every Triassic locality from Okpilak River to the Canning. On the top of Red Hill at the west end of the Sadlerochit Mountains this sandstone member outcrops in a low rounded ridge that rises perhaps 10 feet above the general level, somewhat after the manner of a lateral moraine. Here the thickness could not be ascertained, owing to the shattered condition of the rock, but it was estimated to be less than 30 feet. On Okpilak River no sandstone was found in place, but talus blocks of dark sandstone with darker pebble-like markings undoubtedly belonged to this phase of the Shublik.

The limestone member is very dark, in places almost black. The greatest exposed thickness was about 100 feet. There are heavy beds about a foot thick and shaly beds made up almost entirely of flattened *Pseudomonotis* or *Halobia* shells. Slabs composed of such shells have been found in every limestone outcrop from Okpilak River to Canning River, and also have been brought in by natives from Sagavanirktok River, 50 miles west of the Canning. Another peculiarity of this limestone, by which it may be identified in the field, is that in nearly every outcrop there are beds which contain numerous small brachiopods, chiefly *Terebratula* and *Rhynchonella*, in the form of white or polished black casts.

The section above the limestone was not exposed on Camp 263 Creek, but less than 40 miles to the west, at localities 21 and 22, on Ikiokpaurak Creek, a tributary to the Canning, more than 100 feet of black shale is exposed above the limestone. Triassic fossils were collected from the lower 25 feet of these shales, but the upper portion was so masked by a disintegrated talus that no search was made there. These shales could not be separated lithologically from those of the Kingak formation, found elsewhere.

In the only measured section, that on Camp 263 Creek, but there is every probability that were found about 250 feet apart vertically, which is a minimum thickness. The strata were not exposed for 800 feet above and 300 feet below this exposure, so that 1,300 feet is the maximum possible thickness.

Mr. J. J. O'Neill, the geologist with the Canadian Arctic Expedition, which wintered at Collinson Point in 1913–14, made a brief winter trip up Sadlerochit River. A good section of Mesozoic rocks was found in the gap where the river cuts through the east end of the third range. The following section was furnished by Mr. O'Neill:

Section near east end of Third Range, Sadlerochit River.

	Feet.
1. Dark-gray sandstone, no conglomerate, abundant fossils	200
2. Dark-gray sandstone, with dark pebbles and fossils	10
3. Thin-bedded sandstone, darker than the beds above	100
4. Massive sandstone with basal conglomerate	20
Unconformity:	
5. Dark shale	100+
	430

The fossils and rock specimens from this section were examined by the writer. Without doubt they come from the Shublik formation. O'Neill seems to have found the lower part of the formation, as there are no limestones in his section. With allowance for a difference in estimation of thickness, his section, which is given above, and the writer's are similar. O'Neill's No. 1 corresponds to the writer's No. 3, No. 2 to No. 4, and Nos. 3, 4, and 5 to No. 5.

The contacts of the Shublik formation with the older and younger rocks were not found. At Camp 263 Creek there are only 300 feet of beds unexposed between the Upper Triassic and the Carboniferous, and the dips are conformable. Although there may have been vertical movements between the two periods there could not have been any notable mountain building at the close of the Paleozoic era. The nearest Jurassic rocks, 800 feet above the Triassic, have a greater dip, yet as the dip increases progressively within the Jurassic rocks no unconformity is indicated between the two systems.

The Shublik formation partakes in the general deformation of the mountains, but as it is composed of softer rocks it is locally more closely folded than the older formations.

AGE.

Only one fossil was found in the lower sandstone member of the Shublik formation, a *Cardium* (at locality 6), which was not sufficiently characteristic to determine the horizon. In the overlying limestone and shales fossils are abundant, and they have been gathered from many localities of this rather thin formation, so that a fairly representative collection has probably been secured.

T. W. Stanton has made the following determinations of the invertebrates. Vertebrate remains, consisting of a few pieces of bone, probably from a rib, were found at localities 30 and 115.

Locality 6. Canning River, near top of Red Hill. Isolated outcrop of dark sandstone; 10 feet exposed.
Cardium? sp.
Not sufficient to determine horizon.

Locality 13. Canning River. Float.
Rhynchonella sp.
Aviculipecten sp.
Natica? sp.
Probably Triassic.

Locality 15. Canning River. Outcrop across creek from camp 150.
Rhynchonella sp.
Probably Triassic.

Locality 17. Bluff on Canning River, half a mile above camp 152, on north side of Ikiakpaurak Creek. Large pelecypods, nearly all perpendicular to bedding planes. All collected along top of anticline within 1 or 2 feet of the same bed. Hard dark limestone, 50 feet exposed.
Rhynchonella sp.
Terebratula 2 sp.
Spiriferina sp.
Pecten sp.
Lima? sp. (large form; several specimens).
Avicula sp.
Gervillia sp.
Nucula? sp.
Megalodon? sp.
Pleurotomaria sp.
Probably Triassic. The brachiopods suggest a fauna closely related to the somewhat doubtful Triassic fauna collected near the mouth of Nation River on the Yukon.

Locality 18. Canning River. Isolated outcrop of limestone at base of hogback 2 miles east of camp 152, on north side of creek.
Rhynchonella sp.

Halobia sp. cf. H. superba Mojsisovics.
Megalodon? sp.
Pleurotomaria? sp.
Triassic.

Locality 21. Bluff on Canning River, on south side of Ikiakpaurak Valley, a mile above camp 152. Chiefly black shales that crumble when handled. Some harder layers contained fossils that could be saved. About 100 feet exposed. Fossils collected from bottom of exposure.

Terebratula sp.
Spiriferina sp.
Halobia sp. cf. H. superba Mojsisovics.
Pseudomonotis sp.
Triassic.

Locality 22. Half a mile east of locality 21, on the south side of Canning River. About 35 feet of dark limestone overlain by 100 feet of soft black shale. The bottom of locality 21 and the top of the limestone of locality 22 fall nearly into line.

Locality 22A. Fossils from the top of the limestone.

Rhynchonella sp.
Spiriferina? sp.
Aviculipecten sp.
Triassic.

Locality 22C. Fossils from 1 to 3 feet of black shale, 30 feet above locality 22A.

Rhynchonella sp.
Halobia sp. cf. H. superba Mojsisovics.
Triassic.

Talus block at locality 22C.

Rhynchonella sp.
Rhynchonella? sp.
Gryphaea? sp.
Pseudomonotis subcircularis (Gabb)?
Triassic.

Locality 30. Canning River. Cut on Camp 149 Creek, half a mile above camp. More than 100 feet of dark limestone exposed.

Rhynchonella sp.
Bone fragments.

Locality 30A. Top of exposure.

Halobia sp. cf. H. superba Mojsisovics.

Locality 30B. Talus below locality 30A.

Rhynchonella sp.
Spiriferina sp.
Gryphaea? sp.
Lima sp.
Halobia sp. cf. H. superba Mojsisovics.
Pseudomonotis subcircularis Gabb.
Avicula sp.
Megalodon? sp.
Atractites? sp.

Locality 30C. Bottom of exposure.

Halobia sp.

All the collections from locality 30 are Triassic.

Locality 115. Sadlerochit River. Camp 263 Creek, near the mountains.

115B. Dark limestone, 12 feet exposed, about 80 feet below the probable top of the limestone member of the formation.

Rhynchonella 2 sp.
Gryphaea? sp.
Halobia sp. cf. H. superba Mojsisovics.
Cardium? sp.
Undetermined small gastropods.
Clionites? sp.
Atractites? sp.
Bone fragment.
Triassic.

Hulahula River, fishing place at edge of mountains. Fossils collected in winter from scattered outcrops along the river.

Rhynchonella sp.
Spiriferina sp.
Lima? sp., small fragments.
Gervillia? sp., very small specimen.
Pleurotomaria sp.
Clionites? sp.
Atractites? sp.
Triassic.

Shublik Falls, Canning River. Fossils collected in winter from scattered outcrops along the river.

Rhynchonella sp.
Gryphaea?? sp.
Probably Triassic.

Sagavanirktok River; slab collected by natives.

Pseudomonotis subcircularis (Gabb).
Triassic.

Black Island, Canning River, near Shublik Falls.

Pseudomonotis? sp.
Probably Triassic.

CORRELATION.

Martin has shown in his discussion of Collier's Cape Lisburne section (see p. 107) that both Collier and Kindle found Triassic fossils at the west end of the Arctic Mountains. Schrader does not seem to have found any Triassic rocks on the 152d meridian, but Smith[1] found Triassic float in the Noatak-Kobuk region. Maddren[2] reports Triassic fossils from the international boundary. O'Neill[3] gives a section on Firth River, which is not far east of the boundary line, in which there are some dark limestones and conglomeratic sandstones near the horizon where the Triassic should occur. He speaks of the resemblance of the section to that in the Canning River region, so it is probable that the Triassic is represented on the Firth also.

[1] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 79–80, 1913.

[2] Maddren, A. G., Geologic investigations along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 18–19, 1912.

[3] O'Neill, J. J., Canadian Arctic Expedition: Canada Geol. Survey Summary Rept., 1914, p. 114, 1915.

KINGAK SHALE (LOWER JURASSIC).

CHARACTER AND OCCURRENCE.

The Kingak shale, which consists of about 4,000 feet of black shales, overlies the Shublik formation of Triassic age and probably underlies the Ignek formation of Jurassic(?) age. It is apparently conformable in bedding with the Shublik formation, but nothing is known of the upper contact. The formation name is confined to the shales which contain the fauna that is listed below. The Kingak shale has been identified at only one locality, Kingak Cliff, near camp 263, at the southeast end of Sadlerochit Mountains.

Near camp 263 (localities 110, 114) there is a great exposure of the Kingak shale in apparently undisturbed sequence. There are outcrops along the creeks on the north side, in both banks of Sadlerochit River, and in the creeks on the south side. Camp 263 Creek, on the north side of the river, reveals a nearly continuous exposure of about 1,500 feet of the lower part of the formation, followed by a break of perhaps 1,000 feet. This break is succeeded by about 500 feet more of beds exposed in the north bank of the river. Then follows an interruption of a few hundred yards at the river, but the formation appears again on the south side and can be traced to the top of a hill about 1,000 feet high.

On the north side of the river, where detailed examination was made, the shales are nearly black, thin-bedded, and friable. There are many concretions both in spheroidal form and in beds half a foot thick. Many of these concretions contain pyrite. Fossils are abundantly distributed throughout this part of the formation, but only those from the concretions were collected, on account of the difficulty of transporting fragile specimens. Ammonites are a noticeable element in this fauna. No pebbles were found in these shales, in which respect they differ from the Ignek shale. There was little likelihood that any member of hard sandstone would have been unexposed.

On the south side of the river the shales in the river bluffs are black, but on the hillsides above they are a dirty green. On the top of the hill mentioned above the shales are capped by a dark harder rock that was considered to be the lowest sandstone member of the Ignek formation. In the rolling upland basin south of the river several outcrops show harder rock that also overlies black shales. No red beds were seen anywhere in this area.

The structure here appears to be monoclinal. The dip at the bottom was about 30°, and increases to 50° at the river, but apparently decreases again near the top of the formation. The thickness across this section is about 4,000 feet, but as there are no horizons by which faulting could easily be noted, the beds may have been duplicated by this agency.

A small outcrop of black shale was observed in winter at a small island called Black Island, in Canning River, opposite Mount Copleston. A single fossil, which is probably Triassic, was found there. The next summer a native boy, who had visited the island after the snow had disappeared, brought out a slab containing crinoid remains, which he had found there. The age of this crinoid is Jurassic, about the same as that of the Kingak fauna found at camp 263 (locality 114). As this crinoid came from some distance west of the west end of the plunging anticline which forms Shublik Mountains, it is in the probable location of the Kingak shale. The outcrop is much too far vertically above the nearest Sadlerochit strata to be Triassic.

AGE.

T. W. Stanton has identified the following fossils, except the crinoid, which was identified by Frank Springer:

Black Island, in Canning River, opposite Mount Copleston. Small exposure of black shales. Specimen collected by native.

Pentacrinus cf. P. subangularis Miller.

Although this material is not sufficient for any accurate specific determination or description, there is enough to show that it clearly belongs to the true *Pentacrinus* (=*Extracrinus* Austin of De Loriol, P. H. Carpenter and other authors) of the Lower Jurassic of England and continental Europe, and is of the type of *P. subangularis* Miller, from the Middle Liassic of Lyme-Regis, England, and Boll, Holzmaden, and other localities in Wurttemberg, Germany. In default of more perfect specimens it may be referred to that species. * * *

The material from Black Island, Canning River, brought in by Mr. Leffingwell * * * is of great interest. It consists of part of a set of arms belonging to a very large individual in exquisite preservation. The matrix and mode of deposition are very similar to those of the *Pentacrinus* beds at Lyme-Regis, and the condition of the specimen indicates that it was part of a large colony in which many individuals were embedded together. * * *

So far as I know these remains of *Pentacrinus* are the first that have been found in American rocks, with the exception of isolated stem joints, and it is interesting to note that a specimen of the same genus and type has recently been found in the Dutch East Indies, thus showing the great geographic range of this form.

Locality 110. Bluff on the north side of Sadlerochit River, trending northeast from camp 258. Friable black shales, containing concretions of pyrite.

Inoceramus sp. related to I. lucifer Eichwald.
Harpoceras whiteavesi (White).
Harpoceras sp.
Jurassic.

Locality 114. Sadlerochit River. Black shales, containing concretions on Camp 263 Creek.

Locality 114A. Half a mile up the creek from camp, fossils mostly from concretions at foot of exposure. This locality is about half a mile down the creek from the Triassic locality 115A, and about 800 feet above that locality in the section.

Inoceramus sp. same as at locality 110.
Hammatoceras sp. cf. Ammonites (Lillia) howelli White, which according to Pompeckj is a Hammatoceras.

Locality 114B. Two hundred to three hundred yards below camp on north side of Sadlerochit River, 1,500± feet above 114A, and about the same distance below locality 110.

Inoceramus sp. related to I. lucifer Eichwald.

The collections from localities 110 and 114 all belong to a single fauna, and the ammonites indicate that the horizon represented is probably about the same as that of the exposures on Kialagvik Bay, Alaska Peninsula, which have yielded an ammonite fauna described by White and referred to the Lower Jurassic (upper Lias) by Hyatt and Pompeckj. Unfortunately the stratigraphy on Kialagvik Bay has not been studied, and nothing is known of the relations of the ammonite-bearing beds there to the Jurassic formations, so well developed elsewhere on the Alaska Peninsula, that have already been described. The collections from localities 110 and 114 show nothing in common with the collection from locality 3.

CORRELATION.

Maddren[1] found on the 141st meridian a crinoid bed composed of fragments of the same *Pentacrinus* which is described above by Springer. The rocks associated with this crinoid bed were so intimately associated with those of the Triassic that they could not be separated. No other occurrence of Lower Jurassic formations in the Arctic Mountains is known to the writer, but possibly some of the shales and slates found by O'Neill[2] on the Firth may be the equivalent of the Kingak.

[1] Oral communication.

IGNEK FORMATION (JURASSIC?).

CHARACTER AND OCCURRENCE.

The Ignek formation consists of about 2,500 feet of black shales with coal or "red beds," and subordinate sandstone members. It probably overlies the Kingak shale, of Lower Jurassic age. No younger Mesozoic rocks were found in the region. The formation occurs at both ends of the Sadlerochit Mountains and probably along the northern front, but it has not been identified elsewhere. The type locality is on the south side of Red Hill, in the Ignek Valley, at the west end of these mountains.

In this locality for about a mile along the south side of the plunging anticline there are scattered exposures. The curving strike of the rocks makes an acute angle with the line of the exposure, and the dip is in many places nearly in the plane of the exposure, so that it was difficult to ascertain the thickness. The section along the south side of Red Hill is as follows, the thickness being roughly estimated:

Jurassic (?) section on the south side of Red Hill.

	Feet.
Blue-gray, fine-grained sandstone	200
Black shales, with red bed near the top; fauna of locality 3	1,500
Unexposed	400
Gray sandstone, weathering yellow	100
Unexposed	400
	2,600

Below the lower unexposed 400 feet there was an outcrop of dark mottled Triassic sandstone. This outcrop lies some distance from the face of the hill, and its dip could not be ascertained. Its position in the section was estimated by extrapolating the curving strike.

The lowest exposure, 100 feet of dark sandstone, contained a few scattered, water-rounded pebbles, the largest 2 inches in diameter. It could not be confounded with the Triassic sandstone, nor with the Sadlerochit sandstone. The scattered pebbles differentiate it from both

[2] O'Neill, J. J., op. cit., p. 114.

these rocks, and its color is intermediate between their colors. No fossils were found in this lowest sandstone.

The shales are exposed nearly continuously along a steep bank for about a mile. They are black and very friable, and contain a few rounded concretions, the largest of which are 3 feet in diameter. No concretionary beds were noted. Waterworn pebbles 2 inches in diameter are sparingly scattered throughout the portions examined. Flattened pelecypods are abundant, but the rock is so friable that difficulty was experienced in securing unbroken specimens. A few unflattened shells were found in the concretions. Locality 3, where the collections were made, is about half a mile to the west of the sandstone, which outcrops at the east end of the long bluff on the south side of Red Hill. About half a mile farther west are the "red beds," which are described below. Thus, unless faulting has occurred within the shales, locality 3 lies at about the middle of the black shale member of the Ignek formation.

At the west end of this exposure and near the top of the section there are red beds, which have been produced by coal beds that have been burnt. These highly colored beds stand out in strong contrast to the black shales on the face of the cut, and they can be followed on the upper surface of the hill in a low curving ridge of shattered orange and yellow rock. In the river bank the central part of these beds consists of a crumpled complex of ash and brightly colored rock. On both sides of this complex the shales have been hardened and colored also. There can be no doubt that coal was formerly present there, and that the present aspect of the beds is due to the burning of this coal. In addition to the evidence from the ash and the bright color, the effect of heat is shown in the local disappearance of the limestone in the glacial drift, which overlies similar red beds at the head of Marsh Creek. The native name of the stream which cut Red Hill is Ignek, meaning "fire." The natives have assured the writer that these red beds were still smoking when their ancestors came into the country, not many years ago.

At a short but unmeasured distance above the red beds the shales are succeeded by about 200 feet of blue-gray sandstone. No fossils were found in this sandstone nor were scattered pebbles noticed. Above this sandstone the rocks are not exposed.

These coal-bearing black Ignek shales differ from the black Kingak shales in containing scattered pebbles and in the presence of sandstone members. They also have an entirely different fauna. In the field the two formations were considered to be identical, but a careful review of the evidence makes it advisable to separate them. At Camp 263 Creek a thick formation of black shales probably capped with sandstone overlies the Shublik formation. At Red Hill a thick series of black shales similarly capped with sandstone also overlies the Shublik formation. The presence of a hard sandstone member at the bottom of the Red Hill section and its probable absence at camp 263 was a disturbing element in the correlation of the two localities, although it does not make the correlation uncertain.

The Kingak fossils were collected from several horizons between approximately 500 and 2,500 feet above the Shublik formation at camp 263, and the Ignek fossils, from about 1,500 feet above the Shublik formation at Red Hill. It is probable that there are two shale formations with distinct faunas. It is held that most of the Kingak formation has been cut out at Red Hill by faulting, so that now there is a distance of only 400 feet between the Shublik and Ignek formations, and in this gap a portion of the Kingak formation may occur. Additional evidence of such faulting is found in the red beds, which were observed from a distance to occur 5 or 6 miles up Ignek Valley from Red Hill. These red beds are almost in contact with the Sadlerochit sandstone at the southern foot of the Sadlerochit Mountains, where it seems that not only the Shublik and Kingak formations have been cut out but also nearly the whole of the Ignek formation.

Near the head of Marsh Creek, which flows northward from a point near the east end of the Sadlerochit Mountains, there is an area in which red beds, black shales, and sandstones occur in rather complicated relations. In the high bluff on the west side of the creek there is an exposure of red, orange, yellow, green, and bluish shales, masked by a disintegrated talus through which little of the structure can be seen. Near the north end of the exposure these shales are capped by a dark sandstone whose thickness could not be ascertained. On the east side of the river for a mile or so there are similar highly colored exposures but no sandstone capping. No fossils were found there, but from the lithologic similarity this locality is correlated with the upper part of the Ignek formation of Red Hill. Red beds were also observed from a distance to occur close to the northern foot of the mountains near the head of Katakturuk River.

On the east side of the creek and opposite the red beds there is a small exposure of sandstone from which fossils were collected (locality 117). It was impossible to correlate this outcrop with the others in the neighborhood, but it was considered in the field to be probably the same as that which capped the red beds.

Half a mile above this exposure, around the bend in the creek, there is a complicated area of sandstones and black shales whose relation to the red shales and sandstone just described was not made out. There has been thrust faulting upward from the southeast in a plane parallel to the strike of the beds, and there are probably one or more faults at right angles to the strike of this thrust fault, so that the beds are duplicated in a confusing manner. From an elevated outlook the outcrops of the sandstones seem to be grouped in threes, so that there are probably three sandstone members, perhaps 50 to 100 feet thick, separated by about the same thickness of shales.

Fossils were collected from the first outcrop of dark sandstone on the right bank of the creek (locality 118A). They were confined to a rusty layer in the sandstone. Blocks of fine conglomerate were seen in the talus, but none in place. A few scattered pebbles were noticed in the sandstone. Above the sandstone on the same side of the creek there are perhaps 50 feet of dark, soft mudstone, containing fragments possibly of algae. There are numerous yellow-stained bands a foot thick and also scattered pebbles. Above the mudstones there is another outcrop of about 50 feet of heavy bedded sandstone, succeeded by shales. The outcrops of sandstone on either side of the creek are in echelon and thus indicate a fault along the river bed. The bends on the southwest side are displaced from 100 to 200 feet to the northwest, relatively to those on the opposite side.

A conglomerate bed a foot thick was found at the bottom of one of the sandstone outcrops on the southwest side of the creek. This bed is composed almost entirely of pebbles, the largest of which are 1½ inches in diameter, much larger than those of the talus blocks mentioned above. The pebbles are well rounded and chiefly of white quartz and dark or black chert. The rock fractures without the breaking of many of the pebbles, but along the joint planes the pebbles are evenly cleaved.

About half a mile south of the sandstone and shale exposures just described, at the point where Marsh Creek flows northward out of the mountains, there is a good exposure of the rocks which here overlie the Lisburne limestone. Several hundred feet of vertically dipping rocks are exposed in a nearly continuous section, but the sequence is not the same as that found elsewhere. The limestone is succeeded above by an interval of about 30 feet in which no beds are exposed. This interval is followed by about 200 feet of blue-gray shales, with red-stained sandy beds less than 3 feet thick. There are also fine reddish seams in the shales, in places as many as three to a foot. Above the shales there is about 150 feet of sandstone. The northernmost and what is apparently the top bed of this sandstone is conglomeratic, and the pebbles, chiefly of quartz, attain a maximum diameter of 1½ inches. The sandstone grades through shaly beds, containing scattered pebbles, into a formation of black shales that carry thin rusty beds from 5 to 10 feet apart. Then comes an exposure of about a third of a mile of black shales, which dip steeply to the south. Beyond these shales but separated from them by an unexposed area comes the area of southeastward-dipping shales and sandstones described above.

No fossils were found in this series of rocks at the base of the mountains, and if the writer's examination had been confined to this section alone there would have been little hesitation in calling it an undisturbed sequence of the post-Lisburne rocks. When the sequence found in other places is taken into consideration it will be seen that there must have been complicated folding and faulting at the head of Marsh Creek, by which the present relations of the beds have been brought about.

The Sadlerochit sandstone, about 300 feet thick, is typically in such close contact with the Lisburne limestone that no great thickness of shales could have escaped notice. The actual contact was observed on the south side of the Shublik Mountains, where the two formations graded together within a short distance. Fossils of the two formations were collected only 30 feet apart at locality 19. No conglomerate was anywhere found in the Sadlerochit sandstone. In the normal sequence the sandstone and limestone of the Shublik formation there is a wide area of unexposed and probably soft rocks, which are capped by a dark sandstone. There is room between the sandstones for the Shublik and Kingak formations. The upper sandstone is considered to be the lowest member of the Ignek formation. The section seems to be the same as that on Camp 263 Creek, a few miles south, on the opposite side of the Sadlerochit Mountains.

A sketch of the area around the head of Marsh Creek and sections showing its structure are given in figure 8.

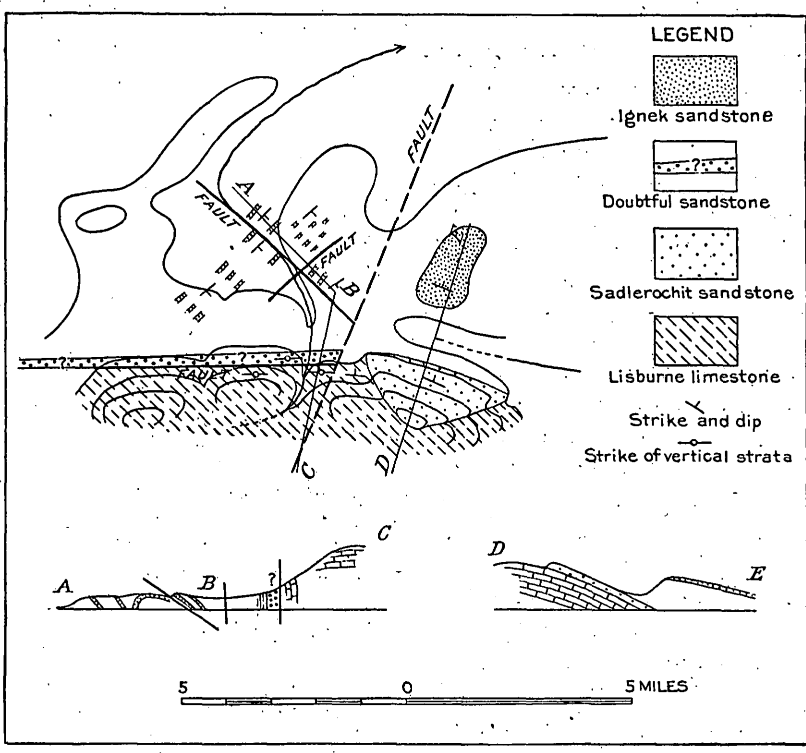


FIGURE 8.—Outcrops of the rocks and structure at the head of Marsh Creek.

should occur about 300 feet above the Sadlerochit sandstone, yet in the exposure of shales above this doubtful sandstone no outcrops of harder rocks were noted, and they could hardly have escaped notice had they existed. Consequently it is believed that the upper part of the Ignek formation has been brought into conformable dip with the Lisburne limestone by faulting, and that probably the beds have been overturned, so that the youngest lie next to this limestone.

A mile or so east of this puzzling locality the normal sequence seems to hold. The Lisburne limestone is capped by the Sadlerochit sandstone as usual, and above this sandstone

On the west side of Canning River, opposite Mount Copleston, there are three or four outcrops of sandstones that dip southward at high angles and are separated from one another by unexposed areas, which probably represent softer rocks. The sandstones strike eastward, and are apparently on the south side of the plunging west end of the Shublik anticline. They are apparently several thousand feet higher in the section than the Paleozoic rocks on the east side of the river. Fossils were collected from the second outcrop from the south at a point where about a hundred feet of beds are exposed. The rock is a hard, fine, blue-gray sandstone, somewhat shattered but apparently heavy bedded. There are a few thin horizons with numerous white and gray quartz pebbles. The fossils were collected from a conspicuous rusty bed on the south side near the water's edge. Slabs were broken off which were formed almost entirely of the matted fossils of several species. These sandstones (locality 100) were considered in the field to be correlated with those of the Ignek formation found near the head of Marsh Creek (localities 117 and 118), and the paleontologic evidence bears out this inference.

AGE.

The Ignek formation is considered, chiefly from stratigraphic reasons, to be younger than the Kingak shale. The relations of the beds are apparently undisturbed at camp 263, and there the Kingak formation, of Lower Jurassic age, closely succeeds the Triassic. At Red Hill the Ignek formation succeeds the Triassic, but, as has been shown, a considerable thickness of rocks probably has been cut out by faulting.

If it were not for the sandstone which underlies the Ignek shales at Red Hill, the writer would consider that the two shale formations grade together, and that the sandstone (?) which caps the Kingak section at camp 263 is the same as that which caps the Ignek section at Red Hill. Although this suggested relation may prove to be the actual one upon detailed examination, the best evidence at hand indicates that the Ignek formation begins with the lowest sandstone at Red Hill, and that this sandstone and the sandstone (?) at the top of the section at camp 263 are probably the same.

The several sandstone and shale members described at the head of Marsh Creek and the sandstones from the west side of the Canning, together with the fauna at locations 100, 117, and 118, were not found in determinable relations to the typical Ignek shale of Red Hill (locality 3), but as they could hardly have been present below these shales without being discovered they are considered to be younger. In the field they were considered to overlie immediately the red beds at the top of the Ignek shale, but there was not conclusive evidence of this relation. The red beds are capped by sandstone, but whether this sandstone is the lowermost member of the group of sandstones is uncertain.

The Ignek formation is typically the black shale formation which contains coal at Red Hill and has the fauna found at locality 3. The sandstones and black shales, which probably overlie the typical Ignek shale, were grouped with the Ignek formation, for no definite stratigraphic or faunal break could be found.

T. W. Stanton has identified the following invertebrates of the Ignek formation, and F. H. Knowlton has reported upon the fossil wood.

Locality 3. Canning River, bluff on south side of "Red Hill," Ignek Valley, about half a mile east of red beds. A very friable black shale. Several hundred feet exposed. Contains a few rounded concretions less than 3 feet in diameter.

Terebratula? sp.
Spiriferina? sp.
Pecten sp.
Lima? sp.
Modiola sp.; fragment.
Inoceramus?? sp.; small imprint.
Nucula sp.
Leda sp.
Yoldia sp.
Astarte sp.
Pholadomya? sp.; young shell.
Pleuromya? sp.
Goniomya? sp.; fragment.
Undetermined pelecypods of two or more genera.
Burtinella sp.

This rather poorly preserved collection is puzzling because of its lack of relationship to any other Alaskan fauna known to me, and because of the absence of characteristic types. It is probably Mesozoic and may be Jurassic.

Locality 100. Canning River. Bluff on the west side of the river opposite Shublik Island. The second outcrop of sandstone north. Fossils very abundant in a rusty band a few inches thick and not found elsewhere. Exposure of about 100 feet of fine blue-gray sandstone.

Astarte sp.
Cyprina? sp.
Homomya sp.
Dentalium??
Pleurotomaria? sp.
Natica sp.
Belemnites? sp. represented by imperfectly preserved specimens which appear to be the phragmacones of large belemnoids.

This puzzling collection of fairly well preserved Mollusca is presumably of Jurassic age, but it seems to have no species in common with any of the known Jurassic or other Mesozoic faunas of Alaska.

Locality 117. Exposure 50 yards above camp 266 on east side of Marsh Creek.

Astarte sp.; same as at locality 100.
Pleuromya sp.

Locality 118A. Bluff on northeast side of Marsh Creek a mile above camp 266 at first good exposure of sandstone. Fossils from a rusty band.

Astarte sp. same as at localities 100 and 117.

Localities 117 and 118A are probably Jurassic, and their horizon is nearly the same as that at locality 100.

F. H. Knowlton gives the following report on the fossil wood:

Locality 3. Canning River, bluff on south side of Red Hill, Ignek Valley, about half a mile east of red beds.

Fragments of fossil wood.

I have examined thin sections of this material and find it to be coniferous wood with unusually small wood cells or tracheids. In the radial section the pits on the tracheids are found to be nearly circular in outline and disposed in a single vertical row. The pores or slits in the pits could not be made out with certainty, nor could markings or pits of any kind be noted on the lateral walls of the medullary rays.

In the tangential section the medullary rays are seen to be arranged in a single series, usually comprising 2 to 4 cells, though in places there is only one and rarely there may be 6 or 7.

I do not find any characters which would mark this wood as unmistakably of Paleozoic age, and to the best of my knowledge and belief it is Mesozoic. It is probably to be best regarded as a species of Araucarioxylon.

CORRELATION.

As Stanton finds the fauna of the Ignek formation to be different from any other in Alaska no correlation can be made from the marine portion of the formation. Schrader[1] and Collier[2] both describe a "Jura-Cretaceous" formation which contains coal. This is the Jurassic Corwin formation of the Cape Lisburne region.

PALEOZOIC AND MESOZOIC IGNEOUS ROCKS.

GREENSTONES.

DIABASE AND BASALT.

Character and occurrence.—At the first creek that flows out of the west end of Shublik Mountains into Ignek Valley there are outcrops of igneous rock, which cap the limestone on both sides of the creek. A second outcrop occurs several hundred feet below, near the level of the stream. The upper outcrops show a mass of chocolate-colored rock, about 800 feet thick, which lies apparently conformably to the bedding of the Lisburne limestone. The portion of this rock on the west side of the creek is only a few hundred yards long, but on the east side the rock extends for a mile along the northern face of the mountains. A lens-shaped area of light-colored talus within this area of chocolate-colored rock was considered to be limestone.

From the aspect of the neighborhood the upper igneous mass must be several hundred feet below the top of the Lisburne limestone.

Specimens of the lower igneous rock were obtained, but none of the upper rock. The lower rock, which was cut by the creek, when viewed from a distance resembled the upper rock in its chocolate color. Its relations with the overlying limestone were concealed by talus, and the bottom was not exposed above the creek. As an overturned fold or fault occurs at the front of the mountains, the lower bed is considered to be a continuation of the upper one. Close inspection showed that much of the rock was a finely crystalline dark greenstone. This rock has been determined under the microscope to be a diabase.

No bedding planes were observed. The rock was massive and jointed in three directions. A hand specimen shows a groundmass of diabase, which incloses much fine breccia of a chocolate-colored chertlike rock that may be a glass. The largest piece of this glass (?) is 2 inches across and is traversed by a set of parallel joints, a quarter of an inch apart, which do not pass into the groundmass. The same hand specimen shows many oval amygdules, the largest a quarter of an inch in diameter, filled with chlorite. Another specimen contains chocolate-colored glass (?) that is brecciated and filled with epidote through which later quartz veinlets run in different directions.

Although the upper mass of this greenstone was thought to be intrusive from the apparently included limestone, the evidence from the lower mass is that it at least was extrusive.

A rock that resembles in every way the one just described is exposed near the east end of Sadlerochit Mountains, in Itkilyariak Valley.

[1] Op. cit., pp. 72–74. [2] Op. cit., pp. 27–30.

It forms a chocolate-colored mass about 300 feet thick which apparently lies conformably within the Lisburne limestone that is exposed in a northward-facing fault scarp. Among the stream gravels there are specimens of greenstone, apparently identical with the rock of the western exposures.

No other exposures of similar greenstones were noted, nor was any float seen in the streams.

A determination of two of the specimens of the greenstone exposed at the west end of Shublik Mountains was made by J. B. Mertie, of the United States Geological Survey, whose report is here given. L 31 B is a specimen of the groundmass, and L 31 A is a specimen that shows the amygdaloidal phase.

Greenstones from the west end of Shublik Mountains.

L-31-B. Diabase. Texture: Ophitic fabric. Constituents: Augite, labradorite (largely sericitized), iron oxides, and chlorite (secondary) spherulites.

L-31-A. Amygdaloidal basalt. Texture: Interstitial fabric. Constituents: Labradorite, augite, iron oxides, and much basaltic glass.

The amygdules are filled in the centers with a grass-green chlorite that is more or less pleochroic. The outer borders of the cavities are composed also of chloritic material, greenish-yellow in color, but without pleochroism. In a few of the cavities rounded grains of garnet appear, surrounded by chlorite; spherulitic plagioclase (oligoclase?) also occurs in one cavity of the chlorite. The basaltic glass is locally intensified around the amygdules, which indicates definitely the primary origin of the amygdules in the form of vesicles.

Age.—This extrusive greenstone occurs near the middle of the Lisburne limestone, which is of Mississippian age.

Maddren has brought back specimens of greenstone from the one hundred and forty-first meridian which greatly resemble the greenstones described above and are associated in unknown relations with limestone. Smith [1] describes greenstones from the Noatak-Kobuk region and discusses their existence in neighboring areas. His conclusion is that they are of Paleozoic age and probably older than the Carboniferous. Under the head of "Early effusives and intrusives," [2] he mentions gabbros, and amygdaloids, tuffs, and volcanic agglomerates of andesitic or dioritic composition and texture. The age of these rocks is considered to be Mesozoic, probably in the middle rather than in the early part of that era, and certainly older than the Upper Cretaceous.

[1] Smith, P. S., op. cit., pp. 107–109.
[2] Idem, pp. 109–112.

BASALT.

Character and occurrence.—Another greenstone of quite different appearance was found in the rock canyon on Hulahula River at the edge of the mountains. There is at that place an exposure about 2 miles in length of a very hard fine-grained green rock. This portion of the river was hurriedly traversed, and the only observations entered in the notebook are that the rock is massive and jointed, and in places shows slight indications of bedding and folding. Near the south side it becomes somewhat fissile and is fractured, in some places showing a slaty cleavage. Some purplish phases were noted. The bottom is not exposed, and the top is not visible from the canyon floor. At least 300 feet was the estimate of the thickness. In the mountain on the west side of the canyon the Lisburne limestone lies much above the level of the greenstone, so that the probable position of the greenstone is well down in or below the limestone. Mr. Mertie has examined this greenstone under the microscope and makes the following report:

Greenstone from the canyon of Hulahula River.

LH 1. Basalt. Texture: Interstitial fabric, very fine grained. Constituents: Augite, very small crystals of feldspar (plagioclase), altered, a little quartz, secondary chlorite, etc.

Age.—Though this greenstone is so different in appearance from that of the Shublik Mountains, the microscopic examination shows them to be similar. As the greenstone occurs in a somewhat similar position with reference to the Lisburne limestone, it may be part of the same flow that was extruded in Mississippian time a little farther to the west.

GRANITE.

Character and occurrence.—The granite occurs in a roughly circular area about 15 miles in diameter, between Hulahula and Jago rivers. Okpilak River heads a short distance behind the granite and flows through its central part. The granite and the hardened schist south of it form the Romanzof Mountains, which rise about 3,000 feet above the rest of the Arctic Mountains and reach a total elevation of 9,000 feet above the sea.

Numerous specimens of the granite were collected, but as they were too heavy for summer transportation they were cached, with the intention of sledding them out during the winter. The writer was not able to go after them personally, so he asked a native to bring them out. The cache was found, but the spermophiles had eaten all the bags and labels, leaving only a pile of broken rock, which the man did not think worth the trouble of transportation.

The granite, as the rock is assumed to be, is coarse grained and light gray in color. Locally it has a bluish tinge, but no red or pink phases were seen. Near the contacts with the other formations the feldspars are as much as 1½ inches across, giving a porphyritic aspect to the rock. A few quartz veins occur along joint planes. In one place there was a vein 30 feet wide filled with soft white and yellow material (gouge?) so impregnated with pyrite as to be perceptibly heavy in hand specimens. Elsewhere pyrite was scattered in small crystals throughout the rock.

On the south the granite is in contact with a gneiss(?), which is believed to be a hardened phase of the Neruokpuk schist. The bedding and schistosity of the gneiss are parallel to the contact, which is nearly vertical at the forks, and change in direction with the contact where it makes a sharp bend a mile or so up the east fork. The feldspar crystals seem flattened near this contact, but the granite seems otherwise unaltered. No stringers of granite were noticed in the gneiss, nor blocks of gneiss in the granite.

The northern contact against the Lisburne limestone is apparently conformable with the bedding of this overlying formation. A creek runs along the contact on the east side of the Okpilak, and the actual contact was not found. Outcrops of limestone and granite occur within 30 feet of each other on opposite sides of the creek. The granite is fissile and yellow there, and though the limestone is on the whole more crystalline than elsewhere and has lost all its fossils except crinoid disks it does not seem greatly altered near the contact. No stringers of granite were seen within the limestone nor any limestone within the granite. The limestone here is only about a third as thick as elsewhere.

Structure.—The granite is affected by a persistent set of joints throughout the exposure on Okpilak River. The dominant plane ranges as a rule between N. 70° W. and N. 60° W. (true) in strike, though one measurement gave N. 35° W. The dip of this joint plane ranges between 50° NE. and 75° SW. The second plane strikes between N. 52° E. and N. 30° E. and dips between 70° and 90° NW. The third joint plane, near the forks, strikes parallel to the second, but the dip is 5° to 50° E., in many places curving. These joints are spaced 1 to 15 feet apart and divide the rock into parallelopipeds whose sides range in length within these limits. Wherever the slope of the mountain side is parallel with the plane of the third joint, as is common on the steep west side of the valley, the blocks slide off as fast as they are loosened, exposing large smooth surfaces of granite. These joints give rise to "saw teeth" on the ridges.

Age.—It has been shown above that the Lisburne limestone was not greatly altered, even near the contact; at least not more than might be accounted for by the deformation which took place during the period of mountain building. No positive evidence of intrusion, such as intermingling of granite and limestone at the contact, was found. There was also no evidence of depositional unconformity, such as would be expected between a limestone and a naked mass of coarse-grained granite. The black shale which underlies the limestones elsewhere in the Arctic Mountains is thus lacking. More than half the thickness of the limestone also seems to be lacking near the granite. On balancing the evidence it seem probable that the granite was intruded after the limestone was laid down. This conclusion makes the lower limit for the age of the granite post-Mississippian.

The rocks above the limestone were so crumpled and metamorphosed that their structure could not be made out. Triassic talus was found in this complicated area within 4 or 5 miles of the granite, but no definite upper limit to the age of the granite was found, except that it was intruded prior to the cycle of erosion which produced the present drainage system.

Smith[1] in discussing the granites of the Noatak-Kobuk region, regards them as younger than the greenstones. He says that they

> were formed probably in the Mesozoic and certainly between the known Devonian or Carboniferous and the known Upper Cretaceous sediments. * * * The most widespread period of volcanism in Alaska appears to have been in the Jurassic and it seems more than likely that these granites were intruded during that general period.

Maddren reports orally the existence of gray granites of unknown age near the 141st meridian.

CENOZOIC DEPOSITS.

SANDSTONE ON CANNING RIVER (TERTIARY?).

In a river cut bank on the east side of the Canning, 4 or 5 miles north of Sadlerochit Mountains, there is an exposure of coarse gray sandstone, which dips gently away from the mountains. There seem to be remains of plants in this rock, but no recognizable fossils were found. This sandstone is different from anything in the region and is considered to be younger than Jurassic and older than Pliocene. It somewhat resembles Schrader's lower Colville[2] and so is more likely to be Tertiary than Mesozoic.

SANDSTONE AT PEARD BAY (TERTIARY?).

CHARACTER AND OCCURRENCE.

In sailing along the high bank that runs from Barrow southwestward for about 40 miles two outcrops of rock were seen, and the southern one was examined. This locality is at the extreme end of the high bank, where an outlier is cut off by a small valley. The rock is a gray-green sandstone, fairly hard in fresh exposures, but when weathered it can be crushed between the fingers. The bedding is massive, but the rock disintegrates into thin flakes. Locally there is cross-bedding. There are irregularly spaced joints, but these do not seem to fall into any distinct joint systems. No fossils were found, but there are fairly abundant cylindrical holes that appear to indicate the existence of animal life. The largest holes are 6 inches long and half an inch in diameter. Some of them are curved longitudinally; others have helical (?) markings on the walls.

This exposure commences on the northeast side of the small valley, and beyond a concealed interval of a hundred yards or so it can be followed to the southwest end of the outlying bank. The total length of the exposure is about a mile. The rock rises gently above the beach sands, and after reaching a maximum elevation of 10 feet falls as gradually until it is again lost beneath the beach.

The bedding is horizontal and undisturbed. The upper surface is horizontal and parallel with the bedding, within the limits of measurement at any one place, though of course the upper surface follows a gentle curve from end to end. Few contacts were found free from the mud which was slumping down from above, and no irregularities of the surface were seen at these places. The writer was unable to determine whether this outcrop was a gentle anticline whose upper surface was undisturbed by erosion or a gentle undulation in a base-leveled plain.

AGE.

As no fossils were found in this sandstone at Peard Bay, its age can only be estimated. The upper contact of the sandstone is everywhere against the horizontal unconsolidated mud shales, which are thought to be Pleistocene. There is an evident unconformity in texture. As the surface of the coastal plain shows no increase in height over the sandstone, the Pleistocene deposits may be considered to preserve the same horizontality here as elsewhere along the 40 miles of exposures in the high bank. The sandstone rises at least 10 feet into these shales, so that it must be unconformable in structure also. Thus an interval is indicated between the deposition of the sandstone and the Pleistocene shales.

The nearest known rock exposures are at the coal beds of Wainwright Inlet, about 40 miles to the southwest. Schrader, who examined an outcrop near Wainwright, found it to be of "dense earthy-colored or dark-gray, soft impure limestone or calcareous shale, and hard gray sandstone of medium grain, all interbedded with dull-bluish softer shale."[3] The

[1] Op. cit., pp. 112–114.

[2] Op. cit., pp. 82–83.

[3] Schrader, F. C., op. cit., p. 73.

age is considered to be late Jurassic or early Cretaceous from plant remains.

This sandstone in no way resembles the rocks of Wainwright Inlet nor any of the Mesozoic rocks found by the writer along the front of the Arctic Range. A Tertiary age is regarded as most probable. The absence of scattered pebbles is considered to be significant in separating it from the Pliocene shale of Camden Bay. If the presence of these pebbles is correctly interpreted as indicating an Arctic climate, it is not probable that the sandstone of Peard Bay, if it were of Pliocene age, would be entirely free from them.

SHALE NEAR COLLINSON POINT (PLIOCENE).

CHARACTER AND OCCURRENCE.

These shales have been found only near the northern edge of the Anaktuvuk Plateau in the type localty at Carter Creek, and at Katakturuk River. Carter Creek, near the point where it enters the Arctic Ocean, about 2 miles east of Collinson Point, flows through an east and west valley. On the north side of this valley, within the space of a mile, there are several exposures of the formation, which there consists of neutral-tinted soft shales. There are a few thin bands of harder sandy shale and also a few layers in which occur rounded concretions a few feet in diameter. As a rule the outcrops have broken down into mud, but in a few places the bedding could be made out. Black chert pebbles were occasionally seen in place, and they are abundantly distributed over the face of the outcrop, in some places being concentrated into rows along the strike. Small boulders are also scattered over the face of the outcrop, some of them striated. These boulders probably belong to the overlying gravels rather than to the Pliocene shales.

In addition to the stones there were also large crystals scattered upon the surface of the outcrops. These crystals were of two forms—single four-sided crystals tapering from the middle toward each end, and clusters of such pointed crystals. The single crystals were usually 4 to 6 inches long, but those in clusters were much smaller. They have been determined by Waldemar T. Schaller, of the United States Geological Survey, to be calcite pseudomorphs after celestite.

Fossil wood was also found upon the surface, mostly in fragments, but one specimen was excellently preserved. Fossil shells were collected from the surface where the shattered concretions were abundant. A few were broken out of the harder rock of the concretions.

The thickness of the rock in this exposure is less than 200 feet, but as outcrops of a similar appearance were visible a mile or so farther south the formation may be rather thick—a thousand feet or more.

About 10 miles from the coast, upon the west bank of Katakturuk River, there is a continuous exposure of shales in a cut bank. These shales are soft, so that a badland topography is developed in the face of the bank. In color they range from blue-gray to greenish. There are a few thin bands of harder material and also disklike concretions, the largest of which are 6 feet in greatest diameter. Black chert pebbles are numerous, but there are no crystals. A few fragments of petrified wood were found, some of it partly carbonized, but no fossil shells were seen.

On the opposite side of the river from the locality just mentioned, about 2 miles nearer the coast, at the first creek which enters the river upstream from the coast, there is an outcrop of shales containing a 6-foot bed of moderately hard, coarse, gray sandstone. This sandstone is cross-bedded and contains scattered chert pebbles and one or two conglomeratic bands of fine gravel. There are also many disklike coal pebbles, the largest of which are 2 inches in diameter. These pebbles in one place are so abundant that they form a conglomeratic band a couple of inches wide. The coal is a black lignite, which G. C. Martin, of the United States Geological Survey, states is similar to the Tertiary coal of Cook Inlet.

This sandstone bed is about 6 feet thick and is underlain by about 100 feet of exposed shales, which are similar in character to those just described. No fossils were found.

STRUCTURE.

The structure of the shale is monoclinal in the three localities in which it has been found. The strikes are all about northeast and the dips are toward the ocean. At Carter Creek the dip was estimated at 15° to 20°; on the east side of Katakturuk River, at 25° to 30°, and on the west side at 40°. The strikes at the three localities fall nearly into one line upon the map, so all the shales are grouped into one formation.

AGE.

W. H. Dall, of the United States Geological Survey, has made the following determinations of the fossils collected at Carter Creek. The first two collections were made in 1912; the rest in 1914. Locality 200 A is the same as No. 7068 (Carter Creek, A). Locality 200 B is probably the same as No. 7070 (Carter Creek, C). Dall states that the age is Pliocene, resembling that of the Nome beaches. "The number of undoubtedly new forms precludes the fauna being regarded as Pleistocene: Moreover, the Pleistocene fauna is more Arctic in character." The Pliocene fossils "indicate a temperature similar to that of the present Aleutian Islands."

Pliocene fossils from the shales at Carter Creek.

Location 200 A.
Astarte arctica Gray (fragments).
Venericardia alaskana Dall (fragment).
Macoma calcarea Gmelin (cast).
Tachyrhynchus sp.? (cast).
Dentalium sp. (cast).
Balanus sp. (fragment).

Location 200 B.
Macoma calcarea Gmelin.
Tellina sp.
Astarte borealis Schumacher (fragment).
Astarte arctica Gray? (fragment).
Astarte rollandi Bern.? (cast).
Chrysodomus sp.? (internal cast).
Cardium grönlandicum Fabricius? (fragment).
Balanus sp. (fragment).

7068. Carter Creek, A.
Astarte n. sp.? (fragment).
Saxicava cf. S. arctica Linné.
Nucula sp. near mirifica Dall.
Admete? cf. A. regina Dall.
Bela? sp. (fragment).
Buccinum sp.? (fragment).
Balanus rugosus Wood.

7069. Carter Creek, B. Eighty feet below A and 100 yards to the east.
Astarte n. sp.
Admete cf. A. regina Dall.

7070. Carter Creek, C. One hundred feet below B and 200 yards to the east.
Cyrtodaria n. sp. near C. siliqua Daudin.
Leda sp. cf. L. frigida Torell.
Astarte sp. (fragment).
Cadulus n. sp.
Turris (Antiplanes) sp.? (fragment).
Amauropsis cf. A. islandicus Gmelin.
Cryptonatica sp. cf. C. clausa Broderip and Sowerby.

CORRELATION.

The upper part of Schrader's Colville series[1] contains fossils which have been identified by Dall as Pliocene: The upper part of the Colville is practically free from indurated rock and consists of "beds of fine gray, slate-colored, or ash-colored calcareous silts, containing faunal remains." The thickness where observed was 40 to 50 feet. The only species in common with the shales at Collinson Point is *Saxicava arctica*. These two Pliocene formations, less than 150 miles apart, are correlated with one another, even though the fauna of Collinson Point is more similar to that of Nome. A list of species found in the beaches at Nome is given by Moffit.[2]

No other Pliocene formations from northern Alaska are known to the writer. O'Neill[3] reports fossils from the upland north of the mountains on Firth River. These may prove to be Pliocene.

UPLAND GRAVELS (PLEISTOCENE).

CHARACTER AND OCCURRENCE.

The upland gravels form a superficial deposit upon the Anaktuvuk Plateau, confined, as far as the writer's observations go, to an area south of Camden Bay. They have their greatest development on Katakturuk River, whose banks as a rule show good exposures. A few miles from the coast a level-topped bank begins on the east side of the river and runs several miles southward. Near the southern end it attains a height of approximately 100 feet. On the west side of the river, near the end of the eastern bank, a similar bank runs 2 or 3 miles farther south. Both these banks are capped with a horizontal bed of coarse gravels, which is exposed through a vertical distance of 20 feet and has a maximum possible thickness of 40 feet. The material is coarse and increases in size to the south. At the end of the eastern bank, where the maximum size was 18 inches, there are many stones over a foot in diameter. The material is of local derivation, as far as could be seen, but no limestone was found.

Under the gravels there are exposures of highly dipping shales which are considered to

[1] Schrader, F. C., op. cit., pp. 81–83.
[2] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, pp. 45–47, 1913.
[3] O'Neill, J. J., op. cit., p. 113.

be of Pliocene age. The exact contact was concealed by the slumping gravels, but it must be a nearly horizontal plane.

On the east side of the river, opposite the southern end of the west bank, there is a flat-topped, gravel-capped bluff about 120 feet high. Here the material is much coarser than in the lower portions of the river. There are many boulders more than 1½ feet in diameter, and one was found that was 2½ feet in diameter. The cobblestones are well rounded, but the boulders are only slightly rounded. No striae were seen after a careful search. The material is mostly sandstone that was probably derived from the Sadlerochit formation. There is also much limestone, probably Lisburne limestone, which was not found in the other exposures. The thickness of the deposit is about 25 feet.

The top of the hill slopes gently down to the edge of the gravels, and then breaks sharply down to form the bluff. The ground near the edge of the bluff is covered with gravel, but none was seen upon the higher part of the hill, so that a deposit of 20 to 40 feet of soft material is considered to overlie the gravels. With a field glass outcrops of gravels could be seen in horizontal patches somewhat below the tops of the gently rolling hills in the vicinity. The evidence is strong that perhaps 40 feet of this material overlies the gravels.

Deposits of boulders at the head of Marsh Creek are possibly derived from glacial drift. These boulders may have originated in the same manner as the gravels, but the evidence is in favor of a glacial origin. In the same valley, about 8 miles below its head, there is a conspicuous flat-topped bluff that rises about 100 feet above the creek bed. This bluff is capped with a bed of gravels about 30 feet thick, but the underlying material is concealed by slumping. The deposit consists of boulders, the largest of which are 2½ feet in diameter, in a matrix of sandy clay. It resembles glacial drift. The boulders are almost all of sandstone, although a few small ones of cherty limestone were found. Those composed of sandstone are polished, and one has markings running in two directions which were thought to be glacial striae.

Before the gravels had been investigated in other areas this deposit was considered to be glacial. If glacial, it could have been deposited only during a stage of glaciation earlier than that during which the other moraines of the region were laid down. The chief points of difference between this deposit and the moraines are the lack of glacial topography and the small limestone content. After finding boulders of equal size at an even greater distance from the mountains on the Katakturuk, and after finding striae elsewhere among the gravels, this deposit on Marsh Creek has been correlated with the nonglacial gravels.

On Marsh Creek, 4 or 5 miles from the coast, a blanket deposit of gravels several hundred feet long upon the east bank was studied through field glasses. The cobbles were probably less than a foot in diameter.

The crest of the ridge which separates the lower portion of Carter Creek from Sadlerochit River is capped in at least three places by a bed of gravels. Only the northernmost one was examined; the others were observed with field glasses. The northernmost deposit lies on top of the slope that leads up from the beach, about 4 miles east of Collinson Point. It is about 2 miles from the beach and lies at an elevation of approximately 250 feet. The gravels occupy an area about 100 yards long by 30 yards wide, and their relief above the hilltop is slight. The pebbles are less than 6 inches in diameter and of local origin as far as noted. After a careful search no striae were found.

All these gravels occur in nearly horizontal beds upon or near the top of the upland. Two other areas are described below in which they have a different aspect and possibly a different origin.

Near the ocean Carter Creek turns sharply west for a mile or so and then sharply to the north again to its mouth. On the north side of the east and west part of the creek abundant waterworn stones are scattered over the brow of the hill and over the Pliocene shales exposed in its face. Some of the stones lie upon narrow ridges of naked shales where a slight displacement would have caused them to roll down on either side. The larger boulders, most of which are less than a foot in diameter, are chiefly of sandstone; only one limestone boulder was found. Several large flints, one of which is 16 to 18 inches in diameter, were found embedded in the disintegrated shales. There is no conspicuous impurity in the material. The stones are well rounded, the flints showing the marks of severe pounding in the moonlike fractures, such as are seen in agate marbles. When these gravels were first examined in 1912 several cobbles, the largest 8 inches in diameter, were found to be definitely striated. Two or three of them were cached in a prominent place. In 1914 these cobbles were reexamined and were noted to be "subangular, waterworn stones, with striae on one side."

As neighboring gravel deposits were found at an altitude about 150 feet above these beds, the gravels just described may have been let down from a general blanket layer as the country was lowered by erosion. Their much greater size in comparison with those found at the greater altitude makes this origin somewhat doubtful. Also the stones found upon the narrow shale ridges would have difficulty in keeping their insecure position while the top of the ridge was lowered about 20 to 30 feet below the general elevation of the bank. On the other hand, no stones were seen in place except black chert pebbles, but it is not impossible that some of these may have weathered out of the shales.

On the northern slope of the Anaktuvuk Plateau, 3 or 4 miles south of Collinson Point, on the west side of Marsh Creek, there are two linear deposits of gravel running east and west, at an elevation of 200 to 250 feet above sea. The northern deposit covers the brow of the upland where it slopes down to the coastal plain. The gravels extend 50 to 100 feet down the slopes with a slight hummocky topography. The deposit strikes roughly east and west, and can be traced with glasses for 2 or 3 miles. Although the strike is nearly in a straight line, the altitude is not constant, for the gravels undulate with the surface of the hill through a vertical range of perhaps a hundred feet. Where they dip into depressions they are thicker than elsewhere.

The second deposit is about a quarter of a mile to the south and about 50 feet higher. It comprises a moraine-like ridge of gravel which runs in almost a straight line parallel to the first for nearly a mile along the crest of the hill. It is 15 to 30 feet wide and rises 3 to 12 feet above the gentle slope of the hill. There is scarcely any local relief to the top of the ridge, but from end to end it may vary as much as 50 feet in altitude. The material is well rounded; stones from 4 to 6 inches in diameter are common, and a very few reach a diameter of a foot. This gravel ridge has such a resemblance to an esker that it would be called one in a region of known glacial deposits.

Schrader[1] describes several gravel deposits on Anaktuvuk River. About 50 miles from the mountains, in several places the bluffs are capped by 10 to 40 feet of sand and gravel. Some of the pebbles approach the size of boulderlets, and even boulders. Schrader is of the opinion that these gravels are of glacial outwash origin.

ORIGIN.

Three hypotheses concerning the origin of these linear deposits have been entertained: (1) That they are remnants of a blanket deposit; (2) that they are elevated beaches; (3) that they are outcrops of vertically dipping conglomerate beds in the Pliocene shales.

(1) If these ridges are remnants of a general deposit their linear form can not be accounted for.

(2) The ridges have every aspect of raised beaches, except the most important, which is horizontality. Instead of lying in a horizontal plane and following the horizontal contours of the surface, they lie in a vertical plane and follow the vertical undulations. It does not seem probable that an originally horizontal beach could have been let down into the present position of these gravels as the country was eroded.

(3) If these ridges are considered to be outcrops of vertically dipping conglomerate beds in the Pliocene shales, many of the difficulties of interpretation disappear. Their linear form, vertical undulations, and increase in thickness in gullies are easily understood. As there are difficulties in ascribing their source to Pliocene conglomerates, if there are many gravels of a later age in the vicinity, the origin of these two linear deposits is left for future investigation.

[1] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 87–88, 1904.

The gravels, with the exception of those in the ridges last described, occur in a blanket layer over much of the upland in the area south of Camden Bay. The size of the stones increases toward the mountains and apparently the thickness of the deposit also. Nowhere has any conspicuous variation in these gravels been observed. It is fairly certain that they were spread out over the surface of the ground before the present cycle of erosion had attacked the Anaktuvuk Plateau. Whether they were laid down under the ocean or were spread out by rivers after the land had emerged has not been determined, although their general aspect is more in keeping with the writer's idea of subaerial deposition.

AGE.

The gravels lie upon upturned and eroded Pliocene beds. Time must have elapsed during the deformation and planation of these beds before the gravel could have been deposited. Although sufficient evidence to determine in what part of the Pliocene epoch the shales were deposited has not been gained from the fossils collected, it seems safe to say that this epoch must have been entirely consumed in the deposition of a thick series of beds, their deformation, and planation. The age of the gravels is therefore put as post-Pliocene.

It is shown below that there is strong evidence for believing the Flaxman formation to be of Wisconsin age. As no foreign material was found among the gravels—certainly none of the conspicuous components of the Flaxman formation—the gravels could not have been laid down under the ocean during Wisconsin time. If the gravels are a subaerial deposit, as seems most likely, the evidence from the material is negative. From the great amount of erosion in the area covered by them, their age must be much greater than Wisconsin, so they are thought to have been deposited in early Pleistocene time.

The few striations noted among the gravels point to the action of ice, either glacial or moving river or sea ice. A cold climate is thus postulated. If the gravels were the outwash of an early glacial stage, a very few boulders might be expected to retain their striations even after being transported by streams. This seems to be the best hypothesis as to their origin.

GLACIAL DEPOSITS (PLEISTOCENE).

In each of the four larger valleys examined by the writer definite evidence of the former existence of large glaciers was found. Schrader[1] has reported traces of Pleistocene glaciation in the Arctic Mountains, along the 152d meridian, and Maddren[2] along the 141st meridian, so it seems probable that the northern slopes of these mountains were generally glaciated in former times. In the region under discussion most of the higher peaks still contain remnants of the ice.

OKPILAK RIVER.

Of the four river valleys examined the valley of the Okpilak is the most strongly marked by glaciation. Although the glacier was probably not more than 40 miles long, it was able to carve a deep trough in the hard granite of the Romanzof Mountains.

The area about the head of the west fork is at present so deeply covered by snow and ice that no evidence was gained as to the depth to which the ice formerly filled it. If the upper limit of the ice, as determined farther downstream, is taken as a criterion it seems probable that the ice completely filled the area around the headwaters or even rose above the highest elevations as an ice cap. At the bend where the existing glacier turns from north to northeast the upper limit of glaciation can be made out by the rough alinement of the tops of the truncated spurs. This alinement is very irregular, owing to the action of the cliff glaciers, which has continued from the period of maximum glaciation until the present day. The evidence is that at the bend of the west fork the ice filled the valley to a height of about 2,000 feet above the present floor. There the highest peaks, perhaps ice capped also, rose about a thousand feet above the level of the ice. At the point where the two forks join, the ice was nearly 3,000 feet thick, but from this point the thickness diminished until at the edge of the mountains the ice barely overflowed upon the surface of the Anaktuvuk Plateau, which lies about 1,500 feet above the river bed. If the writer is correct in locating the outermost moraines at the northern edge of the upland the ice sheet extended only 10 or 12 miles be-

[1] Schrader, F. C., op. cit., p. 84.
[2] Oral communication.

yond the mountains, being confined, as far as could be determined, within the shallow valley. The lower end was less than 1,500 feet above sea level.

The valley of the west fork, which is cut in schist, is not U-shaped. In many places the slopes are covered with talus and the bottom is filled with drift, talus slumps, and alluvial cones, so that its glaciated aspect is lost. The east fork, though smaller, is more strongly marked. Below the forks, in the granite, the valley shows evidence of strong ice action. All the minor irregularities have been smoothed out, leaving a deep trough, which extends nearly to the terminal area outside of the mountains. In looking up and down the valley one can scarcely see the narrow breaks where the lateral streams enter. The contours seem to run without interruption. Just below the forks the trough is about 3,000 feet deep, with slopes locally as steep as 50°, above which gentler slopes lead up to the summits. The rock floor is there about half a mile wide. Farther north the floor widens and the slopes of the trough are somewhat more gentle.

Throughout the glaciated area only two lateral valleys were observed to be in adjustment with the main valley, and these contained large glaciers. The lower parts of all the other valleys have been cut off by glaciation, but instead of ending in the air they have built alluvial cones out on the flat floor, so that the streams now have a graded path to the river. Several of the cones rise to an altitude of 500 feet above the river. To compute the actual amount of deepening of the main valley the preglacial gradients of the truncated valleys must be extrapolated to the middle of the river floor, and the amount of postglacial filling on this floor must also be considered. Such evidence as the writer was able to gather points to a minimum deepening of the Okpilak Valley of 300 feet, which is much less than its heavily glaciated aspect had led him to expect.

Beyond the fresh moraines at the ends of the existing glaciers no heavy body of drift was found within the mountains. The slopes are too steep to afford lodgment, and what was left upon the floor has been buried under the alluvial filling. On the west side of Okpilak River, near the north front of the mountains, a bench of drift extends for a mile at an elevation of about 150 feet above the bed of the river. A little farther north, at the edge of the mountains, where the till deposit is marked on the geologic map (Pl. II, in pocket), the innermost of a series of five or six recessional moraines swings out from the west side of the valley and rises higher above the valley floor, running with a fairly well defined hummocky crest to the river, where it has an inside height of 150 feet. East of the river it fades out into a wide area of characteristic terminal morainic topography of low relief.

The other recessional moraines repeat the same features in swinging out from the west side as ridges and in flattening out on the east. They become fainter and more deeply buried by the gravels toward the outside of the belt.

Within the area in which the ice completely filled the valley and spread over the surface of the upland, at the front of the mountains, the outer limit of glaciation is definitely indicated on the west side, where it was examined. This limit is marked by a series of discontinuous windrows of drift, which in few places reach a height of 30 feet and in general form only a veneer of granite and schist boulders upon the sedimentary beds. The highest drift was found 1,500 feet above the river bed. No lateral moraines could be seen upon the opposite side of the river with the aid of powerful field glasses.

There does not seem to be any definite terminal moraine exposed on this river. The drift shows in patches here and there above the gravels, and finally disappears, near the northern front of the upland.

The drift upon the valley floor is characterized by the smallness of the boulders in comparison with those of the drift upon the elevations. Upon the floor boulders 3 feet in diameter are rare, but on the higher levels those more than 10 feet in diameter are common. The largest boulder observed stood 15 to 20 feet out of the ground upon an alluvial cone at the edge of the mountains. It could not have been deposited in that place by the ice, but must have rolled down from above. Nearly all the boulders are of granite.

No terraces of older gravels were noticed within the mountains, where the present alluvial filling has probably buried the original glacial outwash; but among the recessional moraines there are older gravels, which are exposed in places to a depth of 60 feet. These gravels swing out from the west side of the valley and curve toward the river with the moraines. They are higher than the gravel flooring within the moraines, and so must have been deposited before the ice uncovered the inner area. No doubt they were deposited by lateral drainage contemporaneously with the moraines.

Locally on the east and west forks, and continuously for 4 or 5 miles below the forks, the river has cut a postglacial canyon 10 to 40 feet deep in the rock floor. The two side streams which are in adjustment with the river also have cut shallow postglacial canyons.

HULAHULA RIVER.

The greater part of Hulahula River was hurriedly traversed in the winter, and therefore but few details as to the extent of former glaciation are known.

Although a heavy stream of ice must have flowed from the southern slopes of the Romanzof Mountains and down the northeast fork of the river, it is probable that the main body of ice came over the divide from the south. The valley leading from the divide is large, and it is reported to be connected with the Chandalar drainage by a wide pass. A coarse-grained greenstone boulder was found a few miles up this valley. The country rock here is a schist, and the natives do not know of any greenstones in the vicinity. The most probable source of this boulder is south of the divide.

The evidence of ice action is not marked near the forks, and the upper limit of glaciation was not determined. The lower slopes, however, are sufficiently smoothed to indicate the former existence of a considerable body of ice at that place. About halfway to the northern edge of the mountains ice action is more strongly in evidence, and the upper limit of glaciation on the west side is shown by truncated spurs (Pl. XXIV, *B*, p. 166), which indicate that the thickness of the ice here may have been about 1,500 feet. On the east side, however, the ice coming down from the higher Romanzof Mountains seems to have overridden the tops of the slopes which are visible from the river floor.

It is very probable that the Hulahula Glacier pushed over the low pass that leads to the glacial lakes on Sadlerochit River, joined the glacier of that river, and deflected it toward the northwest. The great amount of granite in the drift of the Sadlerochit Glacier can have its source only in the Romanzof Mountains, and the most favorable path for the granite to have followed to the Sadlerochit Valley is through the pass mentioned.

Beyond the face of the mountains the glacier probably filled the wide valley nearly to the top of the level-crested ridges, which rise more than a thousand feet on both sides. Scattered over the surface of the snow-covered slopes were many short ridges that were thought to be composed of drift when viewed from a distance. Those examined were all of drift, but those more distant may have been outcrops of rock. The glacier pushed at least as far south as the east end of the Sadlerochit Mountains, where heavy deposits of till are exposed along the river banks.

The length of the glacier from the divide to its terminus was about 75 miles, but if the writer is correct in believing that the center of flow was south of the divide, the total length was somewhat greater. The altitude of the lower end was not determined, but it can not have been more than 700 or 800 feet above the sea.

Most of the lateral valleys are at grade with the main valley, and there is a considerable filling of gravels, so that it is difficult to make an estimate of the amount of glacial erosion. It must be small in comparison with that of the Okpilak. The writer was unable to determine whether the hard greenstone dam at the edge of the mountains, through which the river has cut a canyon 200 or 300 feet deep, extends entirely across the valley, or whether there is a preglacial channel which is blocked with drift. If there is no such channel, the softer rocks upstream from the greenstone must have been cut down to their present level by glacial action.

Near the northern edge of the Anaktuvuk Plateau the river banks for a distance of a few miles show heavy deposits of till. Exposures of till 20 to 30 feet thick are common, and the adjacent slopes contain scattered boulders to an elevation of about 100 feet above the river. Although the deposit of till is heavy, the topography is not what would be expected in an area of terminal moraines. Instead of the usual knob and kettle character of surface, the gently rolling upland is in general fairly mature. Near the top of the slopes on the east side of the river a few scattered patches of drift are the only evidence of glaciation. One definite ridge on the opposite slope appeared to be a short remnant of a lateral moraine, but it may have been a rock outcrop.

Till was noticed in both terminal and lateral moraines in the area just within the canyon at the entrance to the mountains. These recessional moraines were not examined in detail. In this same locality there were well-marked gravel terraces at levels of approximately 10, 20, and 80 feet. These terraces are perhaps due to successive stages in the erosion of the greenstone dam across the river below. Besides these terraces very few deposits of older gravels were noted. Patches of gravel were seen in the canyon up to elevations of perhaps 60 feet and just beyond the face of the mountains, at the mouth of the stream coming in from the east side, there are gravel banks 50 feet high.

Both forks of the river have postglacial channels cut in schists, 20 to 40 feet in depth and about 100 feet in maximum width. The main river flows for the most part over gravels, but on the sides of meanders there are local rock cuts 10 to 20 feet deep. The canyon, a sharp notch cut into a somewhat flat floor of hard greenstone, was estimated to have a depth of more than 200 feet, but all of this may not be due to postglacial erosion. As the gravel terraces rise to about 80 feet above the canyon, that height may possibly represent the amount of cutting since glacial time.

SADLEROCHIT RIVER.

During the period of maximum glaciation one of the largest glaciers of the region occupied the Sadlerochit basin. The evidence is strong that the whole upland behind the Sadlerochit Mountains was filled with ice, which was confluent with that of the Hulahula and the Canning. The high gathering ground has many existing glaciers and one or two ice caps, so that at the maximum stage the whole area around the headwaters was probably filled with ice and only the highest peaks emerged above it. As the writer's observations terminated at the head of the upper lake, nothing is known of the ice above that point. The upper limit of the ice is difficult to determine at Lake Schrader, for the numerous glaciers that came down from Mount Chamberlin complicate the situation. Still, an idea of the elevation of the surface of the ice may be gained from the truncated spurs. This elevation is about 2,000 feet above the surface of the lake, and to this must be added the unknown depth of the lake. Beyond the face of the Franklin Mountains the ice coming out of the valleys joined and spread over the upland basin behind the Sadlerochit Mountains. It has been mentioned that part of the ice of the Hulahula basin pushed across the low divide east of the lakes to join that on the Sadlerochit.

The open divide between this river and Ikiakpuk Valley, which leads to the Canning, is estimated to be only 400 or 500 feet above Sadlerochit River. That the ice was at least 1,200 feet thick is shown by the presence of two foreign boulders on the top of the isolated mountain close to the southwest end of Lake Peters. The altitude of this mountain is about 700 feet above the divide to the Canning, only 3 miles to the west. The direction of flow was probably toward the Canning, as the floor of the Sadlerochit is there considerably above that of the Canning.

The divide between Ikiakpaurak Valley and the Sadlerochit is also reported to be open and low, so that ice may have pushed over into the head of this valley, but if so it probably did not reach as far as the Canning.

The Sadlerochit Glacier reached at least as far north as the southern slopes of the Sadlerochit Mountains. In the basin of Camp 263 Creek, which flows southward out of these mountains just east of Sunset Pass, there are granite and schist boulders, the largest of which are 3 feet in diameter, in the creek bed and on the slopes up to an elevation of 60 feet above the stream. Either a tongue of ice pushed up this creek or a small lake was formed by a glacial dam and the boulders floated on icebergs to their present location. No deposits of till were seen there.

No foreign boulders were seen on the south slopes of the mountains near Sunset Pass.

The lateral glacial drainage may have swept all the drift away as it was deposited. A small amount of drift was found near the river at the mouth of Camp 263 Creek.

How far the ice pushed downstream around the east end of the Sadlerochit Mountains is not known. No foreign boulders were seen in Itkilyariak Valley, so the ice is not thought to have pushed across the divide at Sunset Pass, which now lies 700 feet above the river.

The Sadlerochit glacier was perhaps 50 miles in length, and its maximum width was 15 miles. Its area may have been as much as 400 square miles. The maximum observed thickness reached by the ice was over 2,000 feet, and the lower end of the glacier was perhaps 1,000 feet above sea level.

The probable terminal moraine area, which is near the east end of Sadlerochit Mountains, was not examined. No evidence of heavy glacial deposits was found on the north side of the river behind these mountains. Several miles south of the river, upon the rolling upland, numerous large boulders are scattered over the surface of the tundra, but there is very little suggestion of glacial topography. Boulders 15 feet in diameter were not uncommon, those of granite being numerous. Several smooth ridges 30 to 50 feet high lead down the slopes of the Lake Fork from each side. These ridges have much the aspect of erosion slopes, except that they are parallel and pitch downstream. In places boulder dumps, most of which are close to the river, show that these ridges are lateral recessional moraines. Closer to the lakes, a few ponds, piles of boulders, and gravel cones give a more definite glacial topography. The granite, which was conspicuous nearer the main river, disappears as the lakes are approached.

In the first part of a journey across the upland from the east end of Shublik Mountains to Lake Peters very little evidence of glaciation was seen, except some large boulders scattered over the smoothly rolling tundra. The first area which showed definitely glacial topography was in the valley of the stream that flows from the gap west of the isolated mountain south of Lake Peters. Here several black boulder-strewn ridges of drift pitched down the valley, marking the stages of retreat of a tongue of ice which pushed through the gap above. This same black area of fresh moraines continues over the ridge on the east side of the stream and spreads out northeast of the mountain and down into the head of the open valley beyond. This black rocky morainic area is in strong contrast to the tundra-covered upland outside of it. It has a kettle and knob topography of low relief. Where it was examined, it has a definite outside limit, which is unusual in the region.

The evident outlet of the lake was dry, even before the spring floods had ceased; and the waters of this fork must escape by subflow under a heavy glacial dam into the valley which heads north of the lake. (See p. 57.) The thickness of the drift must here be several hundred feet.

There is a conspicuous development of gravel terraces on the main river for several miles above the mouth of the Lake Fork. The highest terrace, estimated to be 80 feet above the river, is well developed on both sides of the river, and in places is nearly a mile wide. Benches have been cut into this terrace at approximately 40, 20, 10, and 5 feet above the river. Of these benches that at 20 feet is perhaps the best developed. There can be little doubt that these terraces were formed by outwash during the retreat of the glacier.

In the open pass leading from the basin of Camp 263 Creek, west of Sunset Pass, to Itkilyariak Creek there is a broad, even-crested ridge about a quarter of a mile long, curving from northeast to east, which leads up and over the low divide. The slopes are very gentle and rise about 20 feet above the floor on each side. The ridge is composed of cobblestones, but boulders a foot in diameter occur sparingly. The material is mostly local limestone, but there is also a small amount of foreign rock. The ridge has the aspect of an esker, but it seems improbable that the ice pushed over this divide into Itkilyariak Creek. No drift or foreign boulders were found anywhere in this valley.

The Sadlerochit Glacier must have filled the eastern end of Ignek Valley, so that the drainage was ponded. The outlet may have been westward into Katakturuk River or between the ice front and the southern slopes of Sadlerochit Mountains until it escaped through Camp 263 Creek into Itkilyariak Valley. The absence of granite boulders in Itkilyariak Valley, however, is remarkable if the Sadlerochit Glacier had an outlet there. There is so little drainage in this valley at present that there can not have been much alluvial filling since glacial time. The stream is sometimes dry even in June.

In postglacial time Sadlerochit River has been occupied chiefly in cleaning out the deep outwash filling, but it has made many cuts against the soft shales on both sides. No definite postglacial gorges were noticed.

CANNING RIVER.

Although a glacier perhaps 100 miles long is believed to have occupied the valley of Canning River, the evidence is not striking except near the forks. The writer's observations did not extend above this point, but as low passes are reported to exist at the head of both forks it is probable that the ice of the Canning was confluent with that of the Chandalar. North of the Franklin Mountains the glacier was joined by a heavy stream coming down Ikiakpuk Valley, probably an overflow from the Sadlerochit Glacier. Neither Ikiakpaurak Valley nor Ignek Valley seem to have contained ice. At the west end of Sadlerochit Mountains the ice rose nearly to the top of Red Hill, about 1,000 feet above the river. From this point northward scattered deposits of drift were noted as far as the front of the Anaktuvuk Plateau. The ice was probably confined on the west by the high ridge on that side, but it spread out somewhat over the lower upland on the east side. No definite outer margin to the glacial deposits on this side could be seen from elevated stations in the mountains.

Near the forks, to judge from the truncated spurs, the thickness approached 1,500 feet, but in the open basin just below the evidence shows that it was not over 1,000 feet. The lower slopes of the isolated hill which blocks the creek coming in from the east were strongly marked by ice, and there were foreign boulders on the sides. All evidence of ice action ceased near the top of the hill, which is estimated to be about 1,000 feet above the river. The notch on the corner of the mountain on the east side of the river, about 7 miles below the forks, which is thought to have been cut by lateral glacial drainage, is also about 1,000 feet above the river.

North of the mountains the high ridge on the west side of the valley shows patches of dark material that have the aspect of short lateral moraines, but there, as on the Hulahula, it is uncertain whether the patches are composed of drift or rock. The same thickness of ice—1,000 feet—was apparently maintained there also, and as far as Red Hill, where the next definite evidence was gained. Beyond this point there was no evidence to show the thickness reached by the glacier, except that it overflowed the bluff on the east side as far as the northern edge of the upland. The minimum thickness necessary for this was only about 100 feet.

At the forks, as shown in Plate XV, *A* (p. 58), both valleys are U-shaped, with the floors freed from all obstructions. Below the forks the spurs on the west side have been truncated (Pl. XXIV, *A*, p. 166), but the valley loses its glacial aspect. There is a roche moutonnée in the foreground of Plate XV, *A*, which shows plucking. At the edge of the Franklin Mountains the western slopes show some glacial cutting, and the rock floor is strongly marked.

The two valleys which enter from the east a short distance above and below the forks show well-developed troughs. The contours seem to run uninterruptedly from end to end when the valleys are viewed from the main river. Ikiakpuk Valley does not show conspicuous evidences of glaciation, yet there is evidence that a heavy stream of ice came down from the Sadlerochit Glacier. The writer's investigations were confined to the lower few miles of Ikiakpuk Valley. There he found moraines which marked the end of a tongue of ice that filled this valley after the ice of the Canning had retreated from the area. The general aspect of Ikiakpaurak and Ignek valleys is the same as that of Ikiakpuk Valley, but the absence of drift makes it probable that these valleys contained no ice.

No evidence was obtained as to the probable amount of glacial erosion on the Canning. Within the Franklin Mountains near the forks all irregularities have been removed from the bottom of the valley. A few miles below, at the bend to the north, there is the roche moutonnée mentioned above, which lies well out toward the middle of the valley floor. A couple of glacially sculptured hillocks of rock show above the gravel filling on the west side of the river near that place (Pl. XX, *C*, p. 158). North of the Franklin Mountains the erosion must have been very slight. Not only do the valley walls fail to show severe glacial erosion but there are islands composed of soft shale and sandstone in the river bed.

At the junction of the upland with the coastal plain, about 20 miles from the ocean, in the bluff on the east side of the river, about 40 feet of till is exposed, and boulders are scattered sparingly over the surface of the adjacent upland. On the north edge of the upland, a mile east of the river, there is a conical mound which rises 20 to 30 feet above the general level of the country, on which there are numerous boulders, the largest of which are 3 feet in diameter. At the foot of the mound there is a depression occupied by a pond. Here we have an isolated knob and kettle. From this mound a few similar patches of drift can be seen scattered over the tundra upland and also several small ponds. The general character of the upland is there, as elsewhere, gently rolling, without any suggestion of a glacial topography except at the isolated piles of boulders.

Several cuts in the east bank above this locality show exposures of till from 10 to 20 feet thick, and there were no exposures of rock, so that there is probably an area at the northern edge of the upland underlain by till. The outside limit of the till deposit is indefinite, except at the north, where it ends at the commencement of the coastal plain, and on the west, where it ends at the river.

Between this area of till and the west end of Sadlerochit Mountains there were scattered boulders on the top of the bluff on the east side of the river. About halfway to the mountains on the west side and close to the river there is an apparently deep pond, which may occupy a kettle.

On top of Red Hill there are scattered boulders and a few dumps 10 to 20 feet high, but no continuous moraines. While the snow was still on the ground these patches seemed to have a fairly definite trend, running from a point near the bottom of the hill on the southeast side, up the side, and swinging to the north over the top of the hill. As no glacial material was found east of this line it is tentatively regarded as the limit of maximum glaciation. No drift was observed in Ignek Valley and only a few patches at the western foot of Shublik Mountains. At the southwest corner of these mountains, at the entrance to Ikiakpaurak Valley, two well-defined ridges curve around from the east about 300 feet above the river. The upper ridge forms a bench against the mountain slopes and is separated from the lower one by a depression 50 feet deep. At the place where Shublik Springs has cut a trench through these moraines there are many boulders exposed. It is not known whether these moraines mark a recessional stage of glaciation or whether at the maximum the ice stood out from the mountain slopes at this corner.

The next extensive deposits are on the flat at the west end of the Third Range of mountains. Here is an evident recessional moraine of a tongue of ice which came down Ikiakpuk Valley. A crescentic ridge swings out from a continuation of the end of the Third Range and curves southwest and south to the north bank of Ikiakpuk Creek. On the south side it runs southeast toward the foot of the Franklin Mountains. This ridge is over half a mile long and locally rises nearly 100 feet above the alluvial flat to the west and about 30 feet above the area which it incloses. A gap has been cut through the ridge, apparently by glacial drainage at the time of the deposition. The material is mostly of small size, boulders 2 feet in diameter being rare. At the river bluffs there are exposures of till which extend to the river bed, so that the thickness must be more than 100 feet.

On the north side of Ikiakpaurak Valley, opposite this moraine, no evidence of glaciation was found. Within the Franklin Mountains there were only a few scattered deposits of till, the chief one lying on the east side of the river and 2 or 3 miles above the rock canyon at the edge of the mountains.

The Canning Valley within the Franklin Mountains is floored for the first 6 to 8 miles with gravels, which rise to an elevation of 40 feet above the river bed. On the west side, near the edge of the mountains, there is a flat nearly a mile wide, but on the east side there is only a narrow bench along the base of the mountains. Several gravel mounds rise above this flat. The largest mound, which is 30 feet high, was composed of stones, the largest of which are 6 inches in diameter. North of the mountains the flat on the west side of the river continues for several miles at the base of the upland slopes.

A heavy deposit of gravel runs out from the valley which enters Ignek Valley on the south side near the west end of Shublik Mountains. The uppermost level is about 30 feet, and there are three lower terraces. The material is very coarse. Boulders 2 feet or less in diameter, mostly of limestone, were seen. These gravels have to a great extent been cleaned out of the lower end of Ignek Valley, but on the south side, along the base of the mountains, the 30-foot level is maintained in a bench half a mile wide, nearly to the Canning. A corresponding gravel bank rises out of the flat on the north side of the stream and ends half a mile below, abreast of the flat just mentioned. On the same side of the creek, a mile above, there is a hummocky deposit of material, which from a distance appeared to be gravel. It is 100 yards long and about 20 feet high and may be a slumped remnant of the old gravel terrace.

North of Sadlerochit Mountains, terraces were observed on both sides of the river, but they were not investigated. The most noticeable one, perhaps 15 feet high, fills the flat between the river and the hills on the west side near the northern edge of the upland and after extending a few miles beyond the upland fades out into the coastal plain.

The notch at the corner of the mountains a few miles below the forks was probably cut by lateral glacial drainage. The elevation is about at the upper limit of ice shown elsewhere in the neighborhood. The cut is steep and narrow, about 300 yards long and more than 200 feet deep (Pl. XV, *B*, p. 58). The bottom is full of talus, so that the real depth could not be ascertained. This gorge seems to be rather a cut in the mountain side than the result of a displacement of a block, for the bedding is parallel to that of the mountain. There is a second notch at the same locality, perhaps 25 feet deep, at an elevation of 500 feet above the river.

No other evidence of lateral glacial drainage was noted between this notch and the terraces leading out from the west end of the Shublik Mountains into Ignek Valley. These heavy gravels were probably deposited by a glacial stream which cut through the low pass in the west end of these mountains. This route was not examined, but the divide can hardly be more than 400 or 500 feet above Ikiakpaurak Valley.

In the gap between Red Hill and Sadlerochit Mountains the divide is only 70 or 80 feet above Ignek Creek and there are here two or three rock canyons which are not at present occupied by streams. If the limit of the ice is correctly placed at the top of Red Hill, lateral glacial drainage as well as the ponded waters of Ignek Creek would find an easy outlet over this divide into Tamayariak Creek. Near the point where this creek empties into the Canning the writer crossed a wide expanse of coarse gravels with stream lines. These probably represent glacial outwash through the gap behind Red Hill.

The west fork of the Canning is reported to have several rock canyons 50 feet or more deep, through which it is impossible to go on foot. The streams on the east side near the forks have cut rock canyons 20 to 30 feet deep. The rock gorge at the edge of Franklin Mountains is perhaps 60 feet deep and a couple of hundred yards wide; it is cut in limestone and quartzite.

MARSH CREEK.

The north side of Sadlerochit Mountains in the neighborhood of Marsh Creek does not have a glaciated aspect, though there is a deposit at the foot of these mountains which seems to be of glacial origin. The top of the isolated hill about 2 miles west of the point where the creek flows out of the mountains is apparently covered with till. The boulders, some of which are 2 feet in diameter, are chiefly of limestone and the others are of sandstone; both varieties are of local origin. The elevation of this deposit is 300 or 400 feet above the creek bed.

A mile or so to the northeast the top of the ridge that lies on the west side of the creek is covered by a boulder deposit, which runs for half a mile along the bank like a lateral moraine. This deposit is about 100 feet wide and rises 20 to 30 feet above the general level of the top of the ridge. The material is chiefly limestone and sandstone. The largest limestone boulders are 2 feet in diameter, but the sandstone boulders are mostly small. One boulder had markings which might have been either glacial striae or slickensides. The exposures in the bluff showed Ignek shales immediately beneath this supposed drift.

On the opposite side of the creek the surface of the upland was sprinkled with small subangular boulders of sandstone. No striae were found. The absence of limestone is probably due to calcining by the heat of the burning coal beds of the Ignek formation. This feature was also noticed locally on top of the bluff just described.

As noted under the heading "Upland gravels" (p. 130), the Anaktuvuk Plateau north of the east end of the Sadlerochit Mountains is generally covered by a bed of outwash. The material ranges in size from cobblestones near the coast to boulders 2 feet in diameter near the mountains. Some faint striae were found on these gravels. Although the driftlike deposits at the head of Marsh Creek, described above, may belong to the upland gravels, their much fresher appearance and their topography points to a glacial origin.

EXTENT AND CHARACTER OF PLEISTOCENE GLACIATION.

No evidence was seen of any former ice cap which covered more than individual peaks, except in the Romanzof Mountains. Here the area about the headwaters of the Okpilak and smaller areas around the heads of the lateral streams may have been completely buried under ice. Neither is there any evidence of a piedmont glacier outside of the Arctic Mountains, as suggested by Schrader[1] for the Colville region, where the glaciers deployed from the mountains with a thickness sufficient to cover the Anaktuvuk to a depth of 800 to 1,000 feet.[2]

With the exception of the granite boulders derived from the Romanzof Mountains, the drift is characterized by the smallness of its material. Few boulders of other materials exceed 2 feet in diameter and many of the fresher moraines show none larger than 1 foot. The till as seen in the few good exposures has the same general appearance as that in the western mountains of the United States. The matrix is light in color, not the blue-gray that is common in the younger boulder clay of the Mississippi Valley.

Striae are not common on surface boulders. If striae had been cut on the limestones they would soon have been lost by weathering. The limestone gravels of the fresh river bars are smooth to the touch, but by the time the bars have been covered with vegetation the limestone has become roughened or pitted. The glacial boulders of the mountains are in strong contrast to those of the Flaxman formation with respect to striations. The limestones of the Flaxman formation are beautifully marked, and even the crystalline boulders have minor flutings.

The bedrock of the mountains is also in general free from striae. Even on the roche moutonnée shown in Plate XV, *A* (p. 58), there are none. The granite shows a few markings, but nothing approaching fluting was observed.

No deposits of definitely older drift were found, but some of the material of the upland gravels may be of glacial origin. If so, an earlier ice sheet is postulated.

The gradual disappearance of the scattered patches of till in the terminal area of Okpilak River has been mentioned. Those patches probably represent the higher portions of a body of drift which is buried by later outwash. On Hulahula River there was a heavy body of drift with a nonglacial topography. Patches of drift were scattered over the surface here and there. The terminal area of the Sadlerochit Glacier was not investigated, but in the upland basin there are also isolated patches of drift and boulders are scattered over the smooth tundra-covered slopes of a heavy deposit of till. The Canning, at the northern edge of the upland, shows similar features.

These deposits of terminal drift have every appearance of equal age and probably represent the deposits of the same period of glaciation.

Marked recessional moraines were noted on each of the four larger rivers. They were all characterized by fresh glacial topography, in great contrast with the drift areas outside of them. The approximate ratio of maximum length of the glaciers, as shown by the outermost deposits, to that at the recessional moraines, is as follows: Okpilak, 4:3; Hulahula,

[1] Schrader, F. C., op. cit., p. 91.
[2] Idem, p. 86.

3:2; Sadlerochit, 5:3. The recessional moraine on the Canning was not formed by the main ice sheet but by a lateral feeder in Ikiakpuk Valley. These fresh moraines are correlated together as marking the same stage of glaciation.

As far as the evidence goes, the ice may have either retreated gradually to the place where the recessional moraines are found and halted there long enough to deposit a considerable amount of drift, or it may have retreated to a point within these moraines and then may have advanced again. The topography of the isolated patches of surface drift in the terminal areas is not greatly different from that in the recessional areas, so that both of the drift areas were probably deposited during a single ice advance and retreat.

The exposures of drift in the river banks do not differ markedly from those of Wisconsin drift in the mountains of the western United States, but they should not be correlated on account of their unweathered aspect alone. The till of the northern region is at present frozen, and unless the climate has been much warmer in the past, it has been frozen ever since its deposition.

The postglacial erosion in the Arctic Mountains, as shown by rock gorges, is about the same as in the Rocky Mountains farther south. The weathering of the mountain slopes is also about the same. In the granite trough of the Okpilak slopes of 50° still exist, and in other areas the slopes are covered with talus.

The only feature in which the Arctic glacial topography differs from that of Wisconsin age in the United States is the surface aspect of the outermost till deposits. Instead of the boulder-covered knob and kettle topography, there is a gently undulating tundra plain, which here and there shows a boulder, a knob, or a kettle. The writer has tried four hypotheses to account for this peculiarity: (1) The irregularities may have been filled in with peat, leaving only the highest knobs exposed. (2) The irregularities may have been similarly filled with outwash. (3) The till may be of pre-Wisconsin age. (4) The till may have been deposited under water.

No doubt vegetation has done some filling, but there are so many unburied boulders on the surface that such filling can not amount to much. Outwash may very well have buried the moraines on the floor of the Okpilak, but such a postglacial covering could not have been spread over the upland, in which there are valleys more than 100 feet deep. If such filling had occurred the resulting topography would be unmistakable. The isolated knobs, ponds, and surface boulders can hardly have lasted since pre-Wisconsin times, but the general aspect of the surface of the deposits is in keeping with such an age.

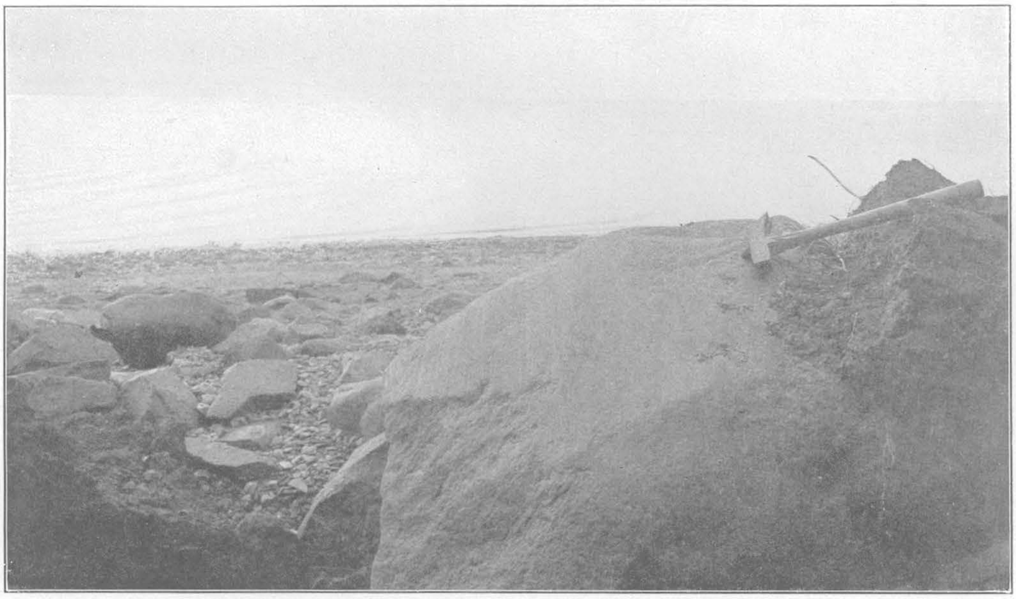
If the till was laid down under water, the present aspect of the desposits might be accounted for. The writer has never seen definitely water-laid glacial deposits elsewhere, nor has he found descriptions of them in the literature, so he can not discuss the probability that the till in this region was deposited under water. Such a great depression of the land as would bring the ocean nearly to the mountains needs strong corroborative evidence before being advanced as probable. The only evidence that the writer can present is that the sea level was not greatly different in Wisconsin time from that of to-day. If the ocean had reached the ends of the glaciers, icebergs would have transported material along the coast and foreign material would have been deposited on the area overlain by water. No foreign material was observed anywhere, and such rocks as granite could hardly have escaped notice. Also the peculiar distribution of the Flaxman formation, which is considered to be of Wisconsin age, points to a nearly constant sea level since Wisconsin time.

The outside areas of till most probably were deposited during Wisconsin time, but under conditions that gave them a topography different from that which is usually found in the United States for moraines of this age.

FLAXMAN FORMATION (PLEISTOCENE).

The Flaxman formation is defined as a deposit of foreign glacial till, possibly containing glacial ice, scattered along the Arctic coast line of America. Individual boulders of this formation are spoken of as Flaxman boulders. The formation is named from Flaxman Island, where it is well exposed.

A. WEST SHORE OF FLAXMAN ISLAND, SHOWING GLACIAL BOULDERS ON THE BEACH.



B. STRIATED GREENSTONE, FLAXMAN FORMATION.

C. STRIATED LIMESTONE. FLAXMAN FORMATION.

CHARACTER.

The till is composed of clay, boulders, gravels, and sands, in proportions similar to those of the ground moraines in the United States. The clay is dark blue-gray in color where it is found free from mixtures of muck and sand.

The boulders are the most noticeable content of the till. They are very striking when concentrated along the beach under a retreating bank, where they may be so abundant as to cover the ground or even to form piles of rock. Many of them have the characteristic outlines of glacial boulders, but others are angular and shattered by the frost. The largest ones are at least 10 feet in diameter, but most of them are less than 2 feet. A 4-foot boulder is an exception (Pl. XVI, *A* and *B*; fig. 9).

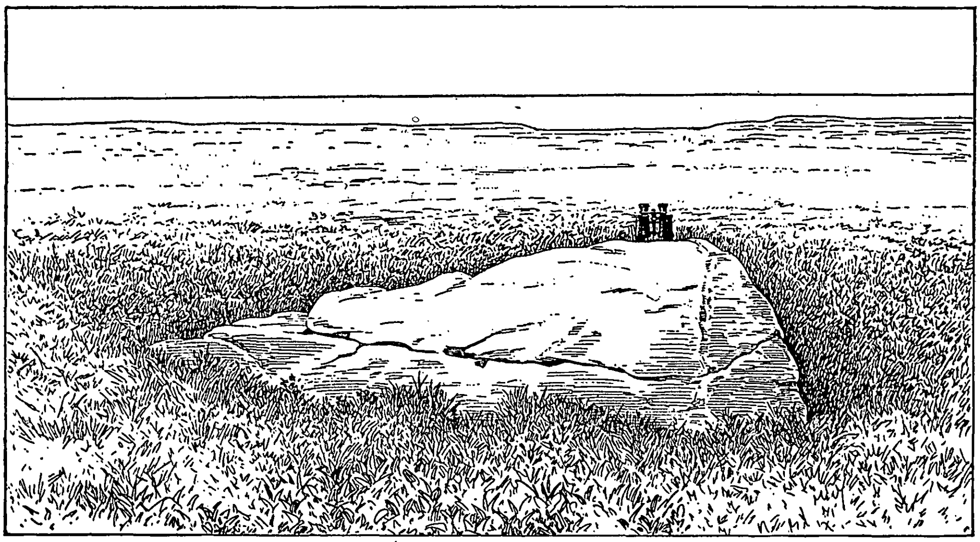


FIGURE 9.—Boulder on the surface of Flaxman Island.

The variety of rocks is also striking. The most conspicuous, in both color and abundance, are the quartzites, which are pink, red, and purple and commonly banded, cross-bedded, or conglomeratic. Dark greenstones are also very abundant, but not so noticeable as the pink and red granites. The limestones are mostly light-colored.

Boulders of all kinds and sizes, with the possible exception of the granites, are striated, and many of them are planed off. The limestones, as usual, show this feature in a more pronounced fashion than the other rocks. Every indication of strong glacial action is given by these boulders. (See Pl. XVI, *B* and *C*.)

Descriptions of some of the conspicuous crystalline rocks, by J. B. Mertie, jr., of the United States Geological Survey, are appended. Although the beach was carefully examined for fossiliferous limestone, only one specimen was found. The report on the fossils from this rock has not been received.

Microscopic character of boulders and pebbles of igneous rocks in the Flaxman formation.

No. (8–11) A L 1. Coarse-grained quartz diabase. Texture: Ophitic fabric. Constituents: Augite, altering to uralite (fibrous); uralite, in places spherulitic; some femic mineral, possibly biotite, completely altered to talc(?); plagioclase, centers labradorite, rims more acidic; alteration product, sericite; quartz here and there intergrown graphically with feldspar; a little apatite.

A fine example of uralitization of pyroxene.

No. (8–11) A L 2. Diabase. Texture: Ophitic fabric. Constituents: Augite, altering to chlorite; plagioclase, much sericitized, probably labradorite; iron oxides; a little apatite.

Prehnite(?), secondary.

No. (8–11) A L 3. Hornblende granite. Texture: Hypidiomorphic granular. Constituents: Oligoclase, altered in large part; microcline (fresh); quartz; some quartz and potash feldspar graphically intergrown; hornblende; a little biotite; beautiful rutile needles penetrate the biotite and divide it into triangles; apatite and titanite; chlorite (secondary).

Evidently a soda-rich granite, for the acid plagioclase probably exceeds the microcline in amount. To be regarded as an intermediate type between the Rapakiwi granite and the normal granitic type.

No. (8–11) A L 4. Granite (biotite). Texture: Hypidiomorphic granular. Constituents: Oligoclase, very largely altered, but commonly surrounded by a very narrow rim of unaltered or secondary feldspar;

microcline, quite fresh; quartz; biotite (somewhat chloritized); muscovite; apatite.

A peculiar type of granite. The acid plagioclase, as in specimen No. 3, is more plentiful than the microcline. Probably rich in soda. Related to Rapakiwi type of granite.

No. (8–11) A L 5. Biotite granite. Texture: Hypidiomorphic granular. Constituents: Oligoclase, largely altered; microcline, less abundant than oligoclase; quartz; biotite, somewhat chloritized; a little muscovite; apatite.

No. (8–11) A L 6. Basalt. Texture: Intersertal fabric; considerable glass; docrystalline. Constituents: Augite; plagioclase laths, too much altered for exact determination; black glass.

No. (8–11) A L 7. Diabase. Texture: Ophitic fabric. Constituents: Augite; plagioclase, altered to chloritic products and sericite; a little glass.

The Flaxman formation presents a striking contrast to the glacial deposits of the Arctic Mountains to the south. None of the Flaxman rocks are known to exist in the interior, either in moraines or in place. The till of the inland region is composed chiefly of sandstones, limestones, and metamorphic rocks, none of which have been identified in the Flaxman formation. Striae are rare inland but abundant on the Flaxman boulders along the coast.

The view was long held that the whole of Flaxman Island was underlain by a sheet of ice, which, as it had till upon it and was granulated, must be glacier ice. Later insight into the character of ground ice in general and into that of the island in particular has caused the writer not only to abandon the idea of a continuous sheet of ice but to doubt whether any of the ice is glacial. As wedge-shaped masses of ice grow in place in the ground, the presence of till above such ice shows that the till is older than and not contemporaneous with or younger than the ice. Also the wedge-shaped masses of ice are granulated, so as to resemble glacier or snow ice.

Although most of the ice seen in the good exposures on the north side of the island in the summer of 1914 was in the form of wedges, there were complicated exposures that did not seem to have this structure. Also there were two places where the ice showed structures which can not be explained by the growth of wedges. One of these resembled a shear zone.

The structure revealed in the excavation of the ice cellar on the island presents some features which may favor a glacial origin for the ice in that spot. The site of the ice house was in the middle of one of the elevated polygon blocks described under the heading "Ground ice wedges" (p. 205). The excavation was about 4 feet in diameter at the top but broadens out to 8 feet or more at the bottom. The depth was about 9 feet. At the bottom niches were cut 4 feet deep into three of the sides, giving a maximum length of about 16 feet and a width of 12 feet. With the exception of a foot or two of clay at the top and a few inclusions of earth the excavation revealed solid ice. The sailors who dug the cellar in 1907, while the writer was absent, reported that they met with sand at the bottom.

A specimen of the ice from the walls of the cellar was allowed to lie in the shade. It soon showed polygonal grains about half an inch in diameter. Numerous minute air bubbles were somewhat evenly distributed throughout the specimen. The ice walls of the cellar showed markings of two kinds—whitish vertical lines from concentration of air bubbles, and wavy inclined lines formed by dustlike inclusions in the ice. That these lines were the intersections of planes with the surface of the walls could be seen at the corners of the cellar.

Near the bottom of the cellar there were several small inclusions of very fine sand.

The greatest width of the ice wedges in the region is about 10 feet near the top, and not over 6 or 7 feet at a depth of 9 feet. The ice house exposes at least 12 feet of ice in its narrowest dimension. The wedges of ice surround polygonal blocks of ground which are free from ice, but the cellar is constructed in the middle of such a polygonal block and should show no ice of wedge-shaped structure. Either the wedges have here grown into contact to form a solid sheet of ice, such as is found in the New Siberian Islands, or the ice is of an entirely different origin.

The granulation is not in itself indicative of an origin either in ice or in snow, for the wedge-shaped masses of ice may also be granular. The small size of the granules is in keeping with what has been said of glacier ice in cold climates. The wavy planes of dustlike inclusions are strongly suggestive of an origin in snow, and their presence in the wedge-shaped masses can not be accounted for; the vertical arrangement of air bubbles, however, is a characteristic of wedge-shaped ice. The inclusions of sand point strongly toward glacial origin, as such pockets would hardly occur in other ice, according to present knowledge. The material in this sand, as determined by J. B. Mertie, jr., is quartz and chloritized feldspar in about equal amounts. Such sand may very well have originated out of the material of the Flaxman formation and so is not in opposition to a glacial origin. Had it been composed of material from the country rocks, a glacial source would be impossible.

The question whether any of the ground ice in areas containing the Flaxman till is of glacial origin must be left open, but on the whole the evidence favors the view that there may be some glacial ice.

OCCURRENCE.

The Flaxman formation as a whole, its content of possible glacial ice excepted, forms a thin surface layer. In the type locality, at Flaxman Island, it is broken up by wedges of ground ice and intermingled with muck and peat, so that its original distribution is uncertain. The boulder clay is not abundant and is scarcely 3 feet thick in the maximum exposure. The boulders are mostly superficial. One was seen embedded in the ground at a depth of 2 feet and two embedded in the ice itself. Sands and scattered pebbles of Flaxman origin have been seen to depths of 12 feet below the surface of the tundra.

At Heald Point Flaxman till underlies about 12 feet of silt. The exposure showed only 2 or 3 feet of blue clay containing boulders. Nearly all the other localities revealed nothing but boulders scattered over the surface of the tundra or else concentrated in numbers along the beach. Isolated boulders may be observed almost anywhere along the beaches and occasionally upon the tundra.

The coast east of Barter Island was traversed only in winter. A few greenstone boulders were observed protruding through the snow which covered the beach near Demarcation Point. A. G. Maddren, of the United States Geological Survey, who visited this locality as geologist with the International Boundary Commission in the summer of 1912, reports that there are boulders not only upon the beach but upon the tundra as well. They were confined to a belt about 200 yards in width along the coast and were not at any place more than 25 feet above sea level. Mr. Maddren is of the opinion that they may have been shoved up on the tundra by the sea ice. After looking over the hand specimens collected by the writer in the type locality at Flaxman Island Mr. Maddren is of the opinion that similar specimens could be found at Demarcation Point.

From Martin Point westward the whole coast line, except in the delta islands and a few shallow bays, was traversed on foot as far as Oliktok, at the eastern side of the Colville delta. From Oliktok to a point about 40 miles beyond Point Barrow probably more than half of the coast line has been closely examined, either on foot or from a small boat along the beach.

A single greenstone boulder about 2½ feet in diameter lies on the spit which joins Manning Point with the mainland. Another greenstone boulder, 2 feet in diameter, is nearly buried in the flat on the south side of Barter Island. There is also a boulder lying about a foot below the surface of the water near the southwest corner of this flat. Flaxman boulders occur in some numbers along the foot of the high bank that runs for a mile or so to the west of Collinson Point. No boulders were seen on the tundra and none in the bank.

Franklin mentions an island lying between Collinson Point and Konganevik which he named "Boulder Island." Collinson also mentions it, and it is still upon the maps, though it has now been cut away. A shoal, however, still marks its former location. There can be no doubt that the boulders were of the Flaxman formation.

From Konganevik to Brownlow Point, a distance of about 20 miles, the tundra contains scattered boulders in a belt about a mile wide. They are also numerous along the beach, and a few large ones lie in the water some distance from the land. The area occupied by the boulders is generally of greater elevation than the land behind it, especially between the two mouths of Canning River. In crossing the tundra about 5 miles from the shore and parallel with this belt no boulders were seen. Flaxman Island, about 3½ miles long and nearly a mile wide, falls in line with this belt.

A few scattered boulders were seen upon the mainland beach between Flaxman Island and Bullen Point but none upon the tundra. A few boulders lie on the beach just beyond Bullen Point and one on top of a 6-foot bank. On a point of the mainland southeast of Tigvariak Island there are abundant boulders along the beach and a few on the surface of the tundra. On Tigvariak Island the Flaxman formation is typically developed; boulders as large as 6 feet in diameter occur on the tundra, and there are many along the beach. The beach wash is reddish. There are a few boulders along the foot of the bank east of Kadleroshilik River but none upon the tundra.

Foggy Island seems to be mostly covered with the Flaxman formation. The writer has visited only the northern end, where numerous boulders were observed upon the tundra as well as upon the beach. Reports both by Stefánsson and by natives show that the same is true of the southern end of the island.

At Heald Point, as already mentioned, a bed of till underlies about 10 feet of silt. A small sand island about a mile northwest of Heald Point contains a block of tundra which is about 40 yards in diameter and from 4 to 5 feet high. There are numerous large boulders upon the tundra, upon the beach, and in the water. About 3 miles southwest of Heald Point, in what appeared in winter to be the bottom of a drained pond, many boulders were seen sticking up through the snow.

At Point Storkersen, on the west side of Prudhoe Bay, there are many boulders along the beach for about half a mile, but none were seen upon the tundra. The source of these boulders may have been in an underlying till bed, as at Heald Point, but as the banks were slumped at the time of examination this could not be verified. In the estuary of Fawn Creek greenstones and granites were seen both in the water and upon the tundra 5 or 6 feet above it, but there was not enough foreign material to give the characteristic reddish tinge to the beach sands. The exposed material in the banks showed the usual sandy loam with black and buff chert pebbles. From this estuary along the beach to the southwest toward the mouth of Kuparuk River boulders were fairly abundant, and in one place numerous, but none were seen on the tundra.

The mainland between Kuparuk River and Oliktok revealed no boulders in the portion which was examined. At Cottle and Bodfish islands of the Jones Islands there were a few boulders on the beach and in the water. The surface material of these islands is local. Leavitt Island has no boulders on the north side, but natives report a few on the opposite beach. At Oliktok there are a few small boulders on the beach, and some Flaxman material in the beach wash.

Boulders must be rare between Oliktok and Point Barrow, else the writer would have seen some of them during his several trips along this coast. There is an unpublished account of one in Schrader's notebooks of his trip down Colville River in 1901. It was a striated and grooved boulder of mountain quartzite over a foot in diameter in the estuary of a small creek west of camp August 18, in the head of Harrison Bay, west of Colville River. Although Schrader describes it as "mountain quartzite," there can be no doubt that such a glacial boulder belongs to the Flaxman formation. The prospector Arey has reported a large crystalline boulder embedded in the tundra at Cape Simpson, near the asphaltum mound. This report is confirmed by Stefánsson. (See p. 149.) Another, a greenstone of large size, is said by Arey to lie in the water near the east side of Dease Inlet, about 4 miles south of Point Tangent. Dease and Simpson saw the same boulder in 1837. (See p. 75.) Natives have reported that there are a few small boulders on the tundra near Barrow. This report is also confirmed by Stefánsson. There is a noticeable amount of Flaxman material in the beach wash at Barrow.

The Flaxman formation is a deposit of glacial till of foreign origin. It is confined to the coast line and rarely extends a mile inland. It is not continuous along the coast but occurs in patches. Typical deposits occur near the mouths of Canning, Shaviovik, and Sagavanirktok rivers, but the coast between these localities is nearly free from the formation.

ORIGIN.

As an evident glacial deposit was found near the mouth of Canning River, the writer at first thought the source of the material was in the mountains that are visible to the south. Later investigation, however, showed that there is neither any source for the material in these mountains nor is there any evidence that the inland glaciers came within 20 miles of the coast. The absence of foreign material in the glacial deposits of the mountains prohibits such a hypothesis, even if a possible source of the boulders could be found. The same objection holds against transportation of the foreign material to the coast by an ice sheet of an earlier glacial epoch.

As a possible origin for the formation is not found on the land, it is necessary to look for one in the sea. The only workable hypothesis is that the foreign material was brought into its present location either by an ice sheet that extended over the Arctic Ocean or by floating icebergs. It seems scarcely possible that an ice sheet could have extended along the coast of Alaska without leaving conspicuous marks of its presence. The material was probably transported by icebergs.

A glacier that entered the Arctic Ocean from a region which contains the rocks found in the Flaxman formation may have carried the material to the sea. Bergs are supposed to have broken off the end of the glacier and to have floated along the north shore of Alaska, dropping boulders and till upon the bottom of the ocean and perhaps grounding permanently here and there. The grounded berg gradually wasted away until a deposit of drift was left to mark its place. Possibly some of the original ice has remained until the present day as ground ice.

Flaxman, Tigvariak, and Foggy islands are suggestive of such grounded icebergs, two of them being even higher than the mainland behind them. The boulder-covered area between the two mouths of Canning River strongly suggests an island which lay across the former mouth of the river. The angular bend of the east mouth against the higher Flaxman area is significant. The long, narrow point of land at Konganevik is separated from the mainland by a belt of tundra much lower than the land on either side, much as if an island had been connected with the mainland. Boulder Island of Franklin is another illustration of the same feature.

The Flaxman formation is found at a maximum elevation of 25 feet above the present sea level; consequently the land has been elevated at least that amount, if the material was dropped from floating bergs. The probable amount is much greater, for the smallest berg capable of floating the largest boulders would draw many feet of water. A berg bearing sufficient material to make a notable deposit of drift would probably draw 200 or 300 feet. If the material was concentrated upon the top of a grounded berg, so that some of the ice was preserved, as may possibly have occurred, the process is difficult to conceive. It is improbable that any ice could exist for a great length of time under the ocean, even if covered by a considerable layer of earth. Consequently the top of the berg must have remained above sea level while the berg was melting away. This relation necessitates a rapid lowering of the ocean. The difficulties encountered in this view make it very unlikely that there is any glacial ice in the Flaxman formation, although the field evidence favors its existence.

Most probably the moving bergs scattered material over the bottom and the grounded bergs made local deposits of some thickness as they melted or broke up under the action of the waves.

A single berg as large as Flaxman Island is not extraordinary in comparison with those of the Antarctic Ocean, but it is not necessary to postulate a single berg of such size; several might lodge in one neighborhood and their deposits become fairly continuous. A single smaller berg might spread deposits over a considerable distance as it gradually melted and was forced along the shore by winds and currents.

The chief weakness of this hypothesis is that it does not take account of the even surface of the tundra and the presence of boulders only half buried in its surface. Flaxman Island, although it is in general a level plain, has a surface relief of 10 to 20 feet. At the eastern end peat beds at least 8 feet in thickness show that the modern even surface is not the original one. Thus the objection offered by the slight relief of the formation is not vital.

So many boulders exist upon the surface of the formation that they can hardly have been deposited upon the sea bottom. They would probably have been buried before the land was elevated, unless the elevation took place suddenly. If they were transported upon the top of a grounded iceberg, which melted without total submergence of the drift upon its surface, their present position is accounted for.

Although some of the boulders scattered along the beaches may have been transported by sea ice, the probability that they were so transported is not strong. Most of the beach boulders were probably left behind by retreating tundra banks. In the fall of 1907 a single gale cut away a small tundra block in the spit on the north side of Flaxman Island, leaving several boulders on the beach. Had the former presence of similar boulders been unknown one might think that they had been transported by ice.

The question whether the boulders found upon the tundra were shoved up from the sea bottom by the ice has been raised in discussion with Maddren. It is improbable that the sea ice at present ever mounts more than a couple of hundred feet upon the land even where a gentle slope allows an easy path. (See p. 173.) In pushing upon the land with a force sufficient to move large boulders the ice would also shove up other material and leave a hummocky topography of greater relief than the size of any of the boulders observed in the region. Any subsequent smoothing of these irregularities by filling in with peat or other material would probably cover most of the boulders contained in the material.

Even if all the boulders had been shoved up from the sea bottom they must have been transported from some other region and dropped along the coast. Under this view the boulders must have been transported to the ocean by glaciers and then picked up and carried along the coast by sea ice, but this does not simplify matters.

SOURCE OF THE MATERIAL.

It is widely accepted that ice from the Keewatin Glacier moved northward into the Arctic Ocean and even reached the islands of the Arctic Archipelago. Camsell[1] finds evidence that the west side of Mackenzie River near Fort McPherson was covered by an ice sheet that moved northward toward the ocean. On the top of Mount Goodenough (latitude 67° 55′, longitude 135° 45′), at an elevation of 3,000 feet above sea level and only 60 miles from it, he found boulders. McConnell[2] states that "the ice from the Archean gathering grounds to the east poured westward through the gaps and passes in the eastern flanking ranges of the Rocky Mountains until it reached the barrier formed by the main axial range, and unable to pass this was deflected to the northwest in a stream approximating 1,500 feet in depth down the valley of the Mackenzie and thence out to sea." In the same report Archean granite is frequently mentioned in describing the drift of the Mackenzie Valley.

The ice sheet of the last glaciation of the northwestern part of Canada thus affords a source for the foreign glacial material found on the neighboring Alaskan shore. From the great Archean gathering grounds a large assortment of boulders might be picked up. Whether the sources of the rocks found in the Flaxman formation exist in the Keewatin area must be left for future investigation.

AGE.

As the Flaxman formation is confined to a narrow belt of rapidly retreating shore line, its existence above sea level must have been short. If it was formerly below sea level, the period of submergence must also have been short, else the boulders would have been buried by marine deposits. All the evidence from the field thus points to the youth of this formation.

The most probable source is in the area covered by the continental ice cap that radiated from the Keewatin region. From the youth of the Flaxman formation it must be ascribed to the last advance of the continental ice—the Wisconsin. Even with an age as great as this it is hard to account for the present aspect of the formation.

If a Wisconsin age is accepted, it follows that portions at least of the coastal plain were submerged during this time. This submergence did not reach inland to the area occupied by the local moraines while they were being formed, for there is no foreign material near them. If the aspect of the inland drift should indicate deposition under the ocean during the

[1] Camsell, Charles, Report on the Peel River and tributaries, Yukon and Mackenzie: Canada Geol. Survey Ann. Rept. for 1904, vol. 16, pp. 39–40 CC, 1906.

[2] McConnell, R. G., Report on an exploration in the Yukon and Mackenzie basins, N. W. T.: Canada Geol. Survey Ann. Rept. for 1888–89, new ser., vol. 4, p. 27 D, 1890.

last period of glaciation, it would follow that there was an emergence of the land between this time and the time of deposition of the Flaxman formation. That is, the local glaciers would have reached their maximum and have started to retreat before the Keewatin Glacier began to discharge icebergs into the Arctic Ocean.

LITERATURE.

Under the heading "History of exploration" (pp. 69–87), the narratives of Franklin, Collinson, and Dease and Simpson have been abstracted. Franklin and Collinson mention Boulder Island in Camden Bay, and Dease and Simpson the boulder in Dease Inlet.

Brooks[1] gives a report by the prospector, Marsh, on the north shore of Alaska, in which he says:

> Till is found along the bays of the coast line. The most prominent points consist of large boulders, rough masses of rock, chiefly granites, diorites, and heavy sands, all foreign to the vicinity.

On the basis of a day's examination of the type locality in the fall of 1906 the writer published a report in which the glacial origin of the formation was brought out but in which many statements were made which further observation shows to be erroneous.[2] The ice was thought to underlie the whole island and to be entirely of glacial origin. Later studies showed that the ice occurs chiefly in isolated patches, and is mostly in wedge-shaped masses. The source of the glacier was ascribed to the mountains of the mainland, but this is seen to be impossible.

Stefánsson,[3] in reviewing the writer's article, doubts the glacial origin of the ice. His statement that he saw the base of the ice exposed and that the ice was nowhere over 4 feet thick must be the result of misinterpretation of the exposures. Almost any good exposure shows more than 4 feet and many more than 10 feet. The same author refers in a later publication to the boulders along the coast.[4]

> Excepting in river deltas proper, there is not a 5-mile stretch without boulders between * * * Gwydyr Bay * * * and Herschel Island. * * * There are boulders at Cape Simpson and at various points between the cape and the Colville. Natives say there are boulders here and there inland from Point Barrow. These boulders range in size from a man's head to the dimensions of a large wagonload of hay and are of varied structure. * * * Boulders seem especially frequent along the high-cut banks, leading one to suppose that they are about equally distributed along the various parts of the shore line.

SANDS AND MUDS NEAR POINT BARROW (PLEISTOCENE).

CHARACTER AND OCCURRENCE.

In the long bank that runs 40 to 50 miles southwest of the village of Barrow there is an exposure of the formations that underlie the coastal plain. Although this bank is not in the region to which the writer's studies were chiefly confined, he had two opportunities for examination while ice blocked the entrance to the Arctic coast. The bank begins at the village and runs with hardly a break to the lower end of Peard Bay. The top is even throughout, and the maximum height is nearly 50 feet.

The lower part of the exposure is composed of blue-black mud shales and the upper part of greenish-yellow sands. The contact between the two members was concealed by slumping, but distant views showed that it ran in a horizontal line about the middle of the bank from end to end. In a few fresh exposures the shales appeared to be homogeneous, and lines of black chert and pebbles of coal showed that the bedding of the sand was horizontal.

AGE.

No fossils were found in the shales, but locally the sands contained numerous shells, mostly of a single species. Collections made from two localities were submitted to W. H. Dall, who says that those from the first locality (15 miles from Barrow) are Pleistocene but that those from the second locality (40 miles from Barrow) might be Pliocene, like the Pliocene fossils of Colville River.

Fossils from sands near Point Barrow.

Peard Bay. From talus below bluff on coast 15 miles southwest of Barrow.
Macoma calcarea Gmelin (fragment).

[1] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, p. 261, 1906.
[2] Leffingwell, E. de K., Flaxman Island, a glacial remnant: Jour. Geology, vol. 16, pp. 56–63, 1908.
[3] Stefánsson, Vilhjálmur, Underground ice sheets of the Arctic tundra: Am. Geog. Soc. Bull., vol. 40, pp. 176–177, 1908.
[4] Stefánsson, Vilhjálmur, Notes from the Arctic: Am. Geog. Soc. Bull., vol. 42, pp. 460–461, 1910.

Astarte arctica Gray (1 valve).
Venericardia alaskana Dall (valves).
In place, same locality.
Venericardia alaskana Dall (valves).
Balanus sp. (worn fragment).
7067. Peard Bay, 40 miles southwest of Barrow.
Astarte cf. A. bennetti Dall.
Astarte n. sp.
Astarte borealis Schumacher.
Venericardia alaskana Dall.

The upper surface is not even, but the irregularities have been so filled in with peat, muck, and turf that the ground is quite level. The lower contact is unconformable against the sandstones of Peard Bay.

CORRELATION.

Schrader,[1] under the name Gubik sand (in the writer's opinion properly spelled Kupik), describes a formation believed to be Pleistocene, which is a superficial deposit of brownish sand or loam, 10 to 15 feet thick, that overlies Tertiary rocks on the Colville and also occurs along the coast to the west. He says:

> 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 of an inch in diameter were found. * * * The deposit as a rule is structureless or without stratification planes. * * * It is here named the Gubik sand, after the Eskimo name of Colville River.

GRAVEL MOUNDS (PLEISTOCENE AND RECENT).

CHARACTER AND OCCURRENCE.

Where the coastal plain is wide isolated mounds scattered over the level surface of the tundra are common. East of Shaviovik River they are scarce, but to the west they are abundant. From a single triangulation station near Shaviovik River pointings were made upon about 30 mounds within an arc of 140°, and many more were noted outside this arc. South of the Jones Islands they were sufficiently numerous to give the sky line an undulatory appearance. A half dozen large mounds near the coast serve as landmarks for the mariner.

Most of these mounds are in the form of gentle domes less than 40 feet high. Only one of them, the largest, was measured by aneroid; the height of the rest was estimated, and this the writer has found difficult to do accurately in such a featureless region. Any prominence stands out so conspicuously that there is a tendency toward overestimation. There are many mounds 25 feet high, and a few 50 or 60 feet. The only mound that greatly exceeds this latter altitude has a measured height of 230 feet above the plain. Although most of them have rounded tops and slopes of less than 15°, a very few are steep-sided and have an angular break at a somewhat level top.

Only a few of the most readily accessible mounds were examined, and most of these in winter in connection with triangulation. Wherever the character of the material could be ascertained it was found to be either coarse gravel or else the usual coastal material of mud, sand, and small pebbles. On a few mounds there was a capping of silt.

The writer's examination of the area east of Barter Island was confined to a single trip in winter, most of which was made in thick weather and in moonlight, and no mounds were seen. Maddren reports a few mounds, less than 15 feet high, upon the banks of Clarence River at the boundary line. He states[1] that some of them, which were exposed by river cutting, contained ice underlying the gravels and appeared to be the result of uplift by hydraulic pressure. This process is discussed below under the heading "Ground ice." Natives report a flat-topped ridge back of Griffin Point, which may be a gravel mound.

Between Barter Island and Okpilak River, near the coast, there are three or four mounds, probably less than 25 feet high. These are reported by natives and by the prospector Arey to be composed of earth. None were seen between this area and Konganevik, on the west side of Camden Bay. A few miles south of the Konganevik there is a single low mound almost surrounded by lakes.

There are possibly three or four mounds between Canning and Shaviovik rivers; west of the Shaviovik they are abundant. The first conspicuous mound is that on which the triangulation station called Shav is located. This mound is a gentle dome that is estimated to be 80 feet in height. It is oval in ground plan.

[1] Schrader, F. C., and Peters, W. J., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, p. 93, 1904.

[1] Oral communication.

The greatest diameter, about 200 yards, trends east-northeast, the direction of the prevailing winds. Three rolling depressions cut across the top in the same direction and have a relief of about 3 feet. The top of the mound, which to a great extent is free from snow, had numerous waterworn stones scattered over it. A hole was made perhaps a foot deep, and the material thus exposed consisted of gravel and a very little fine material in the interstices. The gravels were coarse, the largest stones reaching 4 inches in diameter. The material is believed to be of local derivation; certainly no conspicuously foreign element was seen. Black chert pebbles are abundant in it.

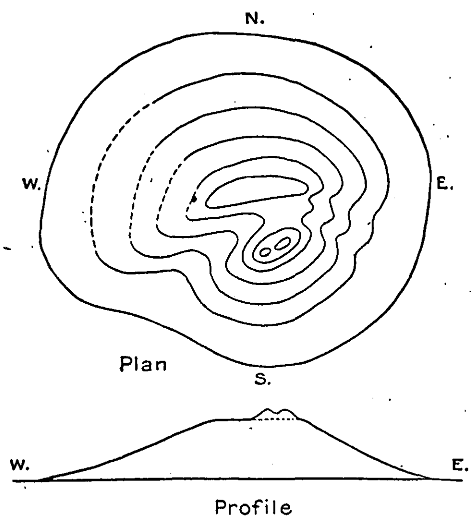


FIGURE 10.—Plan and profile of Kadleroshilik mound.

About 12 miles up Kadleroshilik Creek, and close to the east side of the stream, is the largest mound recorded. It was measured by aneroid to rise 230 feet above the plain and 380 feet above sea level. In ground plan this mound is roughly circular. The slopes are 15° to 20° on the north but even steeper on the southeast side. The top is divided by a flat-bottomed col about 20 feet deep that trends about east and west. On the north side of the col there is a flat-topped ridge about a hundred feet long. On the south side there is a shorter ridge which has two conelike peaks that rise perhaps 30 feet above the col, so that they are visible above the northern ridge when the mound is viewed from the coast (fig. 10). The symmetry of the mound is broken by the rounded depression which forms the col and leads down to the plain on both sides. A rough map of the mound was sketched from the top, and in camp the next day this sketch was filled in while the details were fresh in mind (fig. 10).

At the time of the writer's visit the sides were mostly covered with snow, but there were a few bare spots which revealed gravels 2 or 3 inches in diameter. The cones were bare on top and had many waterworn stones, the largest 14 inches in greatest dimensions. Many were larger than 6 inches. No foreign material was noticed. Five holes, 1 to 1½ feet deep, were dug in erecting a signal. The material was coarse gravel, and the holes could be dug by loosening it with the blunt end of an ax. There was scarcely any fine material present.

The general aspect of this mound is that of an upheaved crust of ground which had split across the middle.

From Shaviovik River westward to Oliktok mounds are visible from nearly all parts of the coast, and there was scarcely any triangulation station upon such mounds from which a score of others might not be counted.

Two of the stations were upon mounds which were peculiarly associated with lines of drainage. The Kuparuk mound, east of Gwydyr Bay, is at the head of an estuary about a mile long. The banks are about 15 feet high near the mound, but shortly above it they vanish, and the stream flows almost upon the surface of the tundra. The Thetis mound, near Oliktok, lies upon a level platform between two open and nearly dry valleys. These valleys head a short distance behind the mound but have been excavated nearly to sea level abreast of it, and their banks are over 10 feet high. They empty into an estuary, which has the appearance of a drowned valley.

Only two other large mounds were visited. Of these the first, Return mound, is about 8 miles from the coast and close to the east bank of Kuparuk River. It is about 50 feet high and has steep sides and a somewhat flat top. The material on top was gravel, as usual; the largest pebbles were about 3 inches in diameter. The Beechey mound, south of the Jones Islands, may be 60 feet high. The gravels contain material not identified in the mountains to the east. One of the conspicuous new elements was a conglomeratic quartzite, which may very well have come from the vicinity of

Kuparuk River. Schrader described such formations upon the Colville.

A great many mounds are visible south of Beechey mound. Native boys say that they occur inland along Kuparuk River for four days' travel with packs, which may be estimated at 60 miles.

Between the Colville and Point Barrow only two mounds were seen from the coast. These mounds are gentle domes, perhaps 30 feet high, at Cape Simpson. They were not examined, and reports are conflicting as to whether they are asphaltum or gravel mounds. Between Barrow and Cape Lisburne the coast was observed from ships and no mounds were seen.

Richardson, in the appendix to Franklin's narrative,[1] was the first to describe such mounds:

> The whole coast line from Cape Bathurst to the mouth of the Mackenzie, and the islands skirting it, * * * present a great similarity in outline and structure. They consist of extensive sandy flats, from which there arise abruptly hills of an obtuse conical form from 100 to 200 feet above the general level. * * * There is a coating of black vegetable earth, from 6 inches to a foot in thickness, covering these sandy hummocks, and some of the escarped sides appeared black, which was probably caused by soil washed from the summit.
>
> It is possible that the whole of these eminences may at some distant period have been formed by the drifting of movable sands.

Of one of these mounds Richardson[2] says:

> This hill rose from the boggy ground in a conical form to the height of about 100 feet. * * * On ascending the hill I found it hollow, like the crater of a volcano, in which, about 15 feet below its brim, stood an apparently deep lake of very clear and sweet water. The interior beach of this curious pond was formed of fine clean gravel, and the hill itself apparently consisted of sand and gravel with a coating of earth. From its summit I saw many similar heights to the eastward and southward.

They are considered by Richardson to be remnants of sand formations. The conical effect is from sea wash at high tide.[3]

Schrader[4] has described similar mounds on the flats east of Colville River, above the delta, as follows:

> The monotony of the waste is somewhat relieved by occasional low mounds. * * * These are composed, in part at least, of gravel and sand. Some of them rise as much as 40 feet above the flats. In shape they are low and rounded. * * * Perhaps the most plausible hypothesis is that they are remnants of beds belonging to the Tertiary Colville series, which, chancing to be capped with some hard stratum, were not worn by the river to the level of the flats.

Smith[5] describes mounds on the Mission Lowland of Noatak River as follows:

> Here and there rounded hills one-half mile in diameter at the base rise 100 to 300 feet above the general surface of this plain. They are symmetrical in shape, and, although irregularly distributed over the plain, suggest, when viewed from a distance, giant haystacks. None of these was examined at close range, but they are apparently gravel mounds similar to those near the mouth of the Colville.

Mendenhall[6] reports abundant sand and gravel prominences rising 30 to 40 feet above the general level of the Fish River lowland. "They are interpreted as remnants of a slightly higher level generally destroyed by the meandering of the stream."

There are a number of hills in the delta of the Mackenzie noted on Harrison's map[7] as conspicuous landmarks. He describes them as follows:

> All about this coast line, between the delta of the Mackenzie and Cape Brown, there are great numbers of such hills, and from their appearance I should certainly have taken them to be of volcanic origin, but it appears from Sir John Richardson, who examined one of them in the summer time, that their formation is of gravel and mud. They rise in some instances to a height of 200 feet, and * * * the abrupt angle they form with the plain is particularly interesting.

One was examined by Harrison in winter. He found a pond upon the top and was informed by natives that these mounds were sure places wherein to find fresh water during the summer.

Dr. R. M. Anderson, in the scientific appendix to Stefánsson's narrative,[8] also mentions the mounds of the same region as follows:

> A conspicuous feature of the country east of the Mackenzie, * * * are large rounded hills of mud

[1] Franklin, John, Narrative of a second expedition to the shores of the Polar Sea, p. 301, Philadelphia, 1828.

[2] Richardson, John, Arctic searching expeditions, vol. 1, pp. 249–250, 1851.

[3] Idem, p. 247.

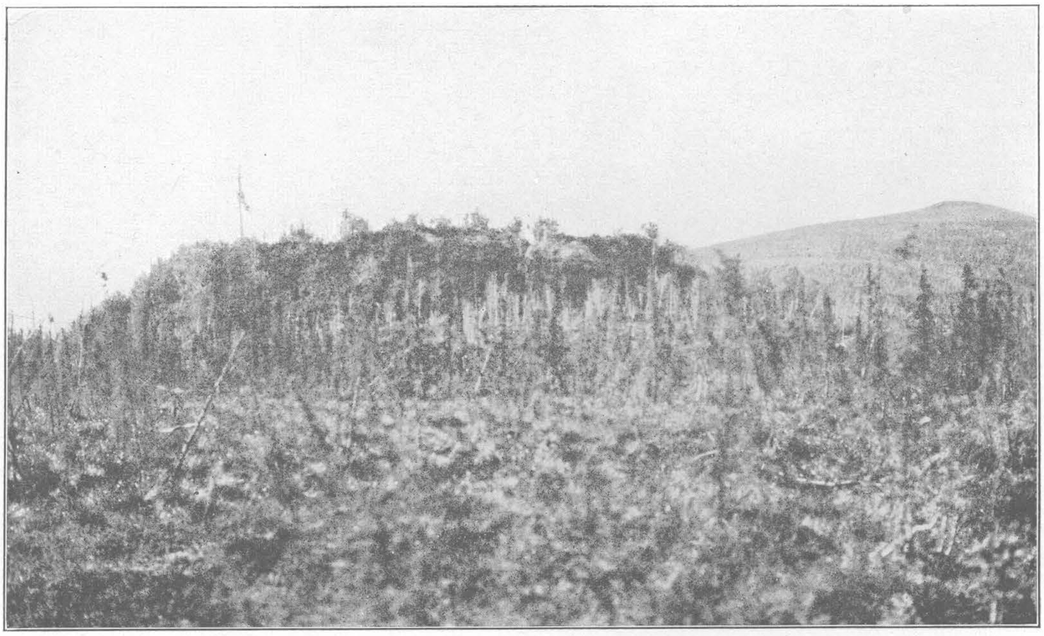
[4] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, p. 94, 1904.

[5] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 28, 1913.

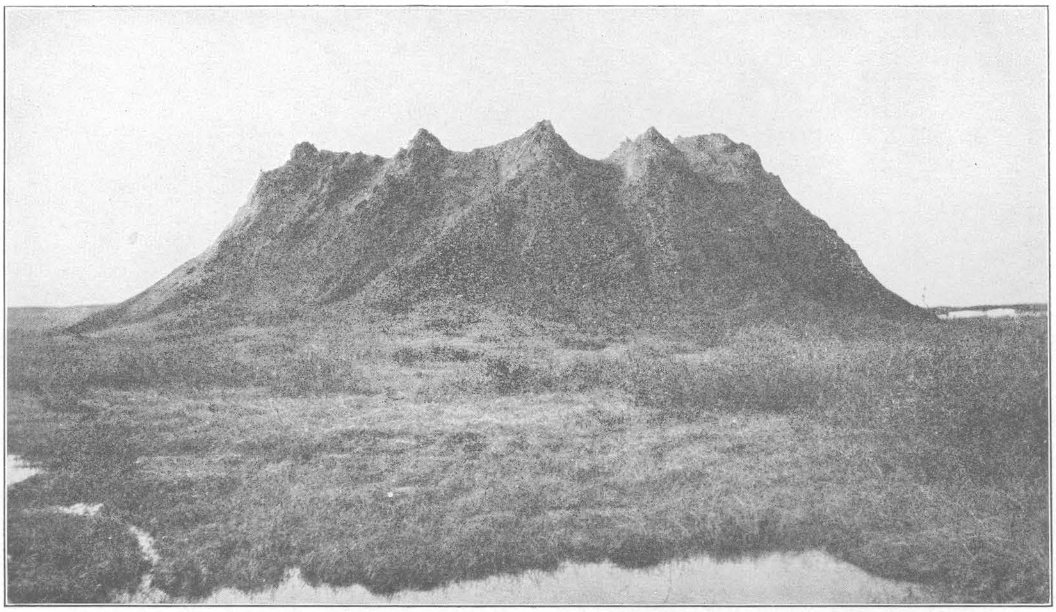
[6] Mendenhall, W. C., A reconnaissance of the Norton Bay region, Alaska: U. S. Geol. Survey Special Pub., p. 207, 1901.

[7] Harrison, A. H., In search of a Polar continent, pp. 196–197, London, 1908.

[8] Stefánsson, Vilhjálmur, My life among the Eskimo, pp. 438–439, New York, 1913.



A. MOUND ON MAIN CREEK, RUBY DISTRICT, ALASKA.



B. MUD VOLCANO NEAR CAPE PARRY.

Photograph by Stefánsson. Courtesy of Harper's Magazine.

or clay rising 50 to 125 feet in height from the flat plain surrounding. These hills * * * are sometimes hemispherical, with either smooth or furrowed sides, and sometimes in the shape of a truncated cone with a crater in the center like an extinct volcano. One of the most typical "mud volcanoes" of this type is situated on the flat plain at the base of the Parry Peninsula between Langdon Bay and Darnley Bay—a landmark for many miles. In summer this crater has a pool of water in its bottom.[1]

There is a distant photograph of this mound in the same book. A closer view of the mound, published in one of Stefánsson's magazine articles,[2] is reproduced in Plate XVII, *B*. Of this mound Stefánsson[3] has given the following details:

I never measured the height of it, but as I remember it it can not be much over a hundred feet. It rises from a typical level tundra land, although some rolling hills are only half a mile away to the south. * * * The formation is similar, apparently, to that shown in the cut banks on the north coast of Alaska, some of the upper strata being composed of peat.

In conversation with the writer Stefánsson stated that old natives have noted changes in the appearance of the mounds, even an increase in size during a lifetime.

During the season of 1915 George L. Harrington, of the United States Geological Survey, investigated several mounds in the Ruby mining district of the lower Yukon. He has furnished the writer the following description and accompanying photograph (Pl. XVII, *A*):

In the Ruby district there are numerous isolated mounds on the gentle slopes of the wide valleys, generally near the stream. Many of these mounds are characterized by a good growth of deciduous trees, which serves to give them greater prominence by the contrast of the arboreal color and at the same time emphasizes the difference between the soil of the mounds and the adjoining slopes, as the birch and aspen particularly favor the warmer, well-drained soils. One of the largest mounds is in the valley of Little Dome Creek. Others are on upper Poorman and Glacier creeks, and it seems probable that a mound on the west side of Tamarack Creek is of similar character. The mound that shows the best development is in the valley of Main Creek about 5½ miles southwest of Deadman Hill. It is about 75 to 100 yards long and rises about 25 feet above the general slope. It is oval in outline and there is a spoon-shaped depression 10 feet deep in the top. This depression has an outlet to the northeast up the slope, from which a small stream of water was flowing in July, though there had been no rains for two days. The mound is composed of fine sand or silt and both its outer and inner slopes are steep, so that it rises abruptly from the poorly drained, moss-covered slope on which it lies. This slope has a grade of about one-half per cent. From the dumps of several old prospect holes near by it seemed reasonable to assume a depth to bedrock of at least 50 feet, and fine material, similar to that composing the mound, appears to comprise half this thickness, whereas the lower half is made up of gravels.

The origin of these mounds is not clear and in this area proof was not at hand to determine it. Some of the mounds seemed possibly to be remnants of an older valley filling, but if so, evidence of its former presence other than these rather widely isolated mounds should have been found.

ORIGIN.

These mounds are scattered haphazard over level plains in areas where the ground is permanently frozen. They may be composed either of gravel or mud. Most of them are rounded domes, but a few have depressions in the top which may contain water. In altitude they may reach to 250 feet. The material is considered to be local. As a rule the large mounds have coarser material than the small ones.

In seeking for a theory of their formation, the following working hypotheses were entertained:

1. Destructional—that they are erosion remnants left as monadnocks upon a peneplain.

2. Constructional—(*a*) that they are glacial deposits; (*b*) that they were formed by hydraulic pressure.

The first hypothesis, that of Richardson, Schrader, and Mendenhall, presents many difficulties when applied to the Arctic Coastal Plain. If the planation had been by river action, working in a region of fairly homogeneous material, the remnants would never take the present aspect of symmetrical mounds irregularly distributed. At least some suggestion of the former drainage system would be shown. If the mounds were centers of resistant material, such as igneous intrusions, the problem would be simpler, but no consolidated material has been seen anywhere in the area over which the mounds are distributed. While the coastal plain was being cut down at least 250 feet and reduced to a plain, the upland, which is composed of scarcely more resistant

[1] Stefánsson, Vilhjálmur, My life among the Eskimo, opp. p. 140, New York, 1913.
[2] Stefánsson, Vilhjálmur, Harper's Mag., April, 1913.
[3] Personal communication.

material, would surely show a more advanced state of erosion than we now find.

These objections apply even more strongly to planation by submergence beneath the sea, for the coastal mounds would have been reduced long before the country behind them was reached by the waves.

The second hypothesis, that they are glacial deposits or kames, would account for the main facts, but there is no evidence of any such extensive glaciation. None of the glaciers left recognizable deposits within 20 miles of the ocean, even where the mountains come nearest the coast. There are mounds on the Colville which are nearly 150 miles from mountains that contained only local glaciers. A glacial origin is not within the limits of possibility.

The third hypothesis, that the mounds are the result of hydraulic pressure, was suggested by the ice domes that are found upon the rivers in winter. These domes are described under the heading "Aufeis" (p. 158). In the fall of the year the shallow places freeze solid to the bottom, thus restricting the flow. Hydraulic pressure is then exerted against the ice, so that it is bulged up into domes or ridges.

The formation of the gravel mounds would proceed under this hypothesis as follows: The coastal plain slopes seaward. If it is composed of pervious material in general, any water entering the ground in the higher portions of the plain will either come to the surface in springs nearer the coast or be carried underground to the ocean. At the beginning of the Arctic climate, if the coastal plain was already in existence, or upon the emergence of the plain from the sea, if this took place under such a climate, the ground became frozen progressively downward. This freezing formed an impervious layer over a tilted water-bearing stratum, giving rise to conditions favorable to artesian wells. As soon as the downward freezing interfered with the flow of the ground water, hydraulic pressure was set up. This pressure may have acted so slowly as to bulge up and fracture the frozen crust locally without any great outflow of water, or it may have occurred suddenly with a great outflow of water which carried up material from the underlying beds. The coarser material may have been deposited at the outlet of the spring, thus building up a mound. As the ground froze more deeply, the ground circulation was restricted or even shut off from the mounds, so that in the Alaskan region, at least, no springs are at present associated with the mounds. The frozen layer also became too strong to be affected by any hydraulic pressure which might exist in the area, so that no new mounds could be formed.

It was not expected that the early stages of mounds formed in this way would be found, for they probably came into existence when the cold climate began. That mounds recently formed, and even in process of formation, occur in the area east of the Mackenzie has been shown in the literature. The photograph by Stefánsson (Pl. XVII, *B*, p. 152) shows a mound which can be interpreted as having very recently been shoved up by pressure from beneath it. Such a jagged sky line can be but a temporary feature of unconsolidated material. Unless new growth restores the mound, it will not be many years before the outline becomes rounded. Probably the crater will exist for a few centuries, but even that should disappear before the mound is flattened out by erosion.

The mounds near the Mackenzie are reported by Richardson and Harrison to contain craters, so that they are fairly recent also.

The earliest stage upon the north Alaskan coast is seen in the Kadleroshilik mound, which has the appearance of a bulging and fracturing of frozen ground. Instead of symmetrical fracturing, as in the mounds east of the Mackenzie, this mound was fractured across the middle, so that no crater was formed. The two conelike peaks upon the south side are considered to be remnants of a rugged summit.

Some field evidence points toward a large outflow of water from some of the mounds. The Kuparuk mound is closely associated with a stream cut of notable size for the Coastal Plain. There is very little water at present in this creek, which flows on the surface of the tundra a short distance beyond the mound. The same is true of the Thetis mound. Whether this association is by chance or is the result of outflow from the mound must be left an open question.

If lakes are found to be also associated peculiarly with the mounds, as is a possibility, they might be accounted for in this manner. The outflow from the mounds in winter would form a deposit of aufeis in the neighborhood. If at the same time material was being carried out by the springs this would be spread out over the ice and incorporated with it. During the activity of the spring a heavy deposit of ice might be built up. Upon the extinction of the spring the ice would waste away until sufficient material was concentrated upon its surface to preserve it. Irregularities in the amount of material would cause irregularities in the amount of melting and depressions containing ponds would be formed.

Thus the hypothesis of formation by hydraulic pressure from below is in best accordance with the character and occurrence of these mounds.

COASTAL SANDS (PLEISTOCENE AND RECENT).

CHARACTER AND OCCURRENCE.

In addition to the coastal formations described above, a great variety of other deposits are exposed in the cut banks, such as sand, silt, clay, muck, peat, and mud. These are separated by their elevated position from the evidently recent beach deposits. There are few banks higher than 15 feet along the northern coast; 30 feet is the maximum. As these banks are mostly slumped, they seldom afford good exposures, yet there is probably sand underlying the superficial muck along most of the coast. Between Kuparuk River and Oliktok, both on the mainland and the Jones Islands, there were many exposures showing 6 to 8 feet of blue-gray and yellow sandy loam. The bedding where visible was horizontal. Small rounded chert pebbles are scattered throughout the sand, black chert being conspicuous. Scattered exposures of similar sands were noted all along the coast to the east as far as Barter Island. Here a dirty yellowish sand, containing pebbles, was exposed in the 30-foot cut bank on the north side of the island.

AGE.

No fossils were found in the coastal formations east of Barrow. These sands underlie the Coastal Plain, which is considered to have risen after the close of the Pleistocene, so the age of most of the sands is probably Pleistocene. Post-Pleistocene warping may have locally brought up Recent deposits, so that the age of the sands is placed at Pleistocene and Recent.

PEAT, MUCK, AND COASTAL SILTS (PLEISTOCENE AND RECENT).

Peat is not extensively developed in this region. A few small lenses or beds were observed in the banks of the rivers. On the coast isolated exposures of peat attain a maximum thickness of 10 feet.

The term "muck" is loosely used by miners to cover any dark muddy deposit, even silts or clays. Typical muck contains vegetable remains and varies from a mass of peaty detritus to a black mud. The surface of the tundra is to a great extent underlain by muck, but no great thickness of it has been observed along the northern coast. In many places it is confined to a layer not over a foot in thickness, but it may be as much as 8 feet. Brooks[1] states that muck may be "a subaerial accumulation, due in part to the decay of vegetable matter, in part to the deposition of silts during the rainy season." Moffit,[2] from extended studies at Nome, is of the opinion that muck may accumulate under water. The writer is inclined to think that most of the muck along the northern coast has been so formed. Recently drained ponds commonly show muck deposited over the bottom, some of which, however, may have been derived by erosion of the banks. Shallow ponds commonly contain growing vegetation. As this decays the ponds become filled and a muck deposit is formed.

Silt is exposed in the deltas of most of the rivers to a maximum thickness of about 30 feet. It occurs both in horizontal beds and in dunes. The dunes, which are evidently of recent formation, are separately discussed. (See p. 163.) The silts are composed of nearly homogeneous fine sand, as a rule of a gray color. No pebbles were ever seen in place or scattered over the surface of silt deposits. There was no resemblance to loess in any of the exposures examined.

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[1] Brooks, A. H., The Kougarok region, Alaska: U. S. Geol. Survey Bull. 314, p. 168, 1907.

[2] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, pp. 49–51, 1913.

In the islands of the Okpilak-Hulahula delta silts which are apparently water-laid are exposed to a thickness of 8 feet. Sadlerochit River empties through a low flat, where exposures are only a few feet thick. The east mouth of the Canning breaks through high banks of the Flaxman formation and flows directly into the ocean. The silts here are probably wind blown. Off the western mouth of the Canning there are several silt islands some distance from the shore. The bedding is horizontal and the islands seem to be remnants of a former delta plain whose surface was 5 to 10 feet above the present sea level. Shaviovik River has one or two silt islands at the mouth, but they were not examined. The banks on either side of the river were grass-grown so that the material could not be ascertained.

The most conspicuous development of silt is in the delta of Sagavanirktok River. With the exception of Foggy Island, all of the numerous islands seem to be composed of silt. Howe Island, which is estimated to be 30 feet high at the eastern end, has good exposures in the cut banks, which show horizontally bedded silts. At Heald Point, at the west side of the delta, about 10 feet of silts overlie the Flaxman formation.

The Kuparuk delta has a few silt islands, but whether they are of aqueous or eolian origin is uncertain. On the west side of the Colville delta there are several silt islands 5 to 15 feet high. The material resembles that of the coast to the east.

Most of the horizontally bedded silts were probably deposited under water. If they were built up by wind-blown material the usual cross-bedding should be conspicuous and strata of turf should be seen within the silts. The 10 feet of silt above the Flaxman formation at Heald Point shows that here the uplift occurred some time after the maximum of Wisconsin glaciation.

GLACIAL DEPOSITS (RECENT).

OKPILAK RIVER.

The higher peaks of the Romanzof Mountains are so covered with ice and snow as to be conspicuous from all directions, but on account of the rugged character of the country the number of glaciers could not be ascertained. From the valley floor only the ends of the larger glaciers can be seen, except in the more open portion of the west fork of Okpilak River. Besides the main glacier of the west fork, which may be 10 miles long, at least four others were observed which were more than 3 miles long. It is probable that there are a dozen of this length, and several scores of small cliff glaciers.

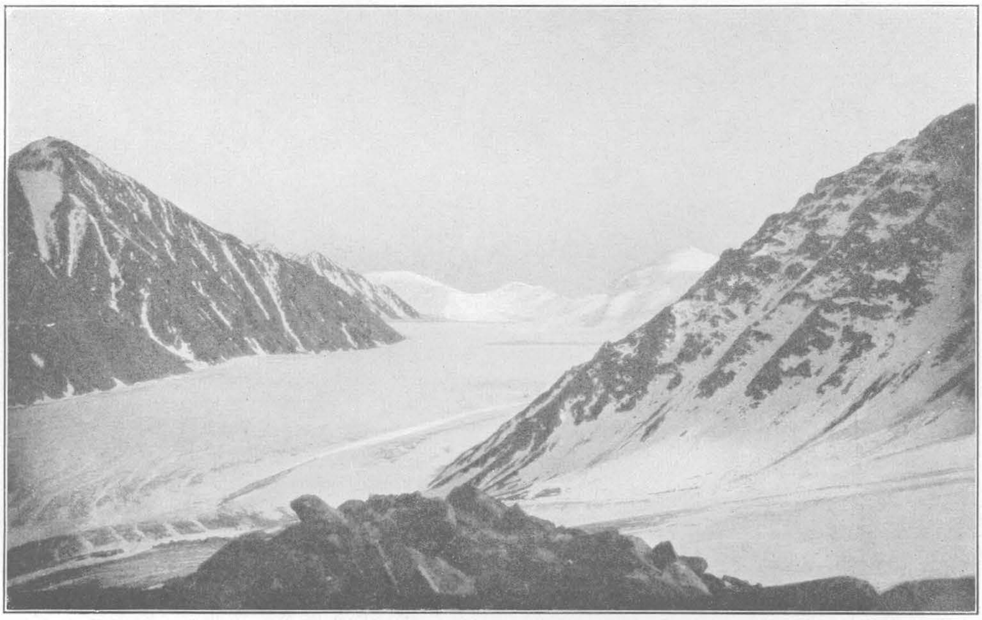
As the glacier at the head of the west fork is the only large one in the region and is believed to be unique in the Arctic Mountains, it was examined in some detail (Pl. XVIII, *A* and *B*). The lower part only was accessible in June, for the part above the bend was so covered with snow that it was impassable without snowshoes.

The total length is perhaps 10 miles and the average width a mile, so that, excluding the ice-capped summits, the area of this glacier is about 10 square miles. The thickness of the ice was not determined. It probably exceeds 200 feet near the lower end. An idea of the thickness may be obtained from Plate XIX, *A*.

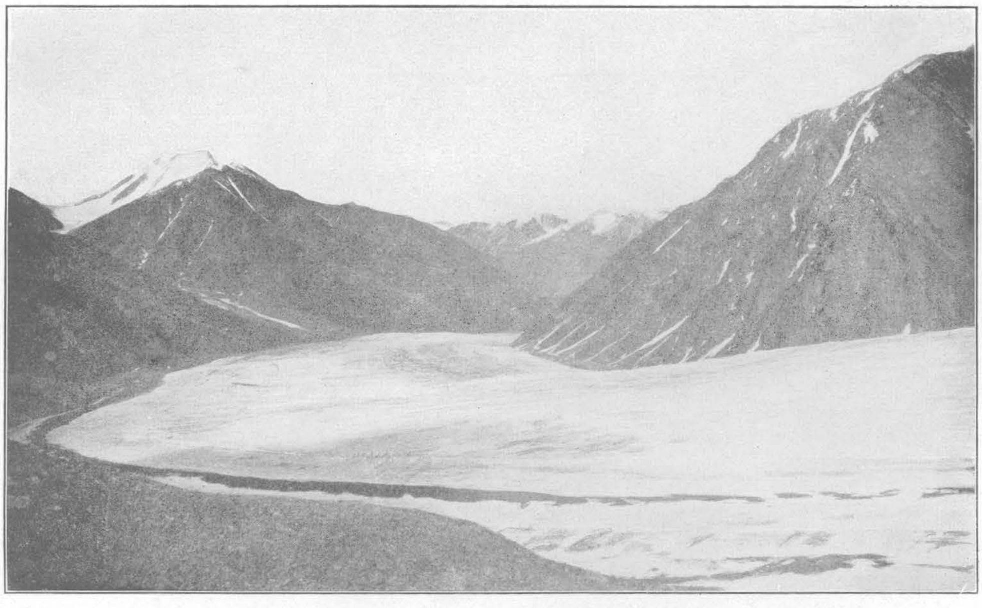
The end of the glacier was so covered with drift that no determination of the profile of the ice was possible. The sides as a rule grade into the lateral moraines or rest against the mountain sides, but in the few clear places the sides of the ice were observed to be steeply convex. For the first mile above the drift-covered end the surface is very even and of clean unbroken ice. Above this part is a sharp rise with numerous open crevasses for a few hundred yards, beyond which the apparently unbroken surface of the glacier continues in a gentle incline to the limit of vision.

The end and the adjacent sides of the ice grade into terminal and lateral morainic areas which have apparently been abandoned. Close inspection shows that many of the hummocks are of thinly veneered ice. Stream cuts also reveal much ice in these areas, so that most of the drift is still epiglacial. There is a single linear moraine on the surface of the clear ice, which may be observed in Plate XVIII, *B*. A few dust wells and narrow discolored bands are the only other interruptions to the clear blue ice in the lower portion of this glacier.

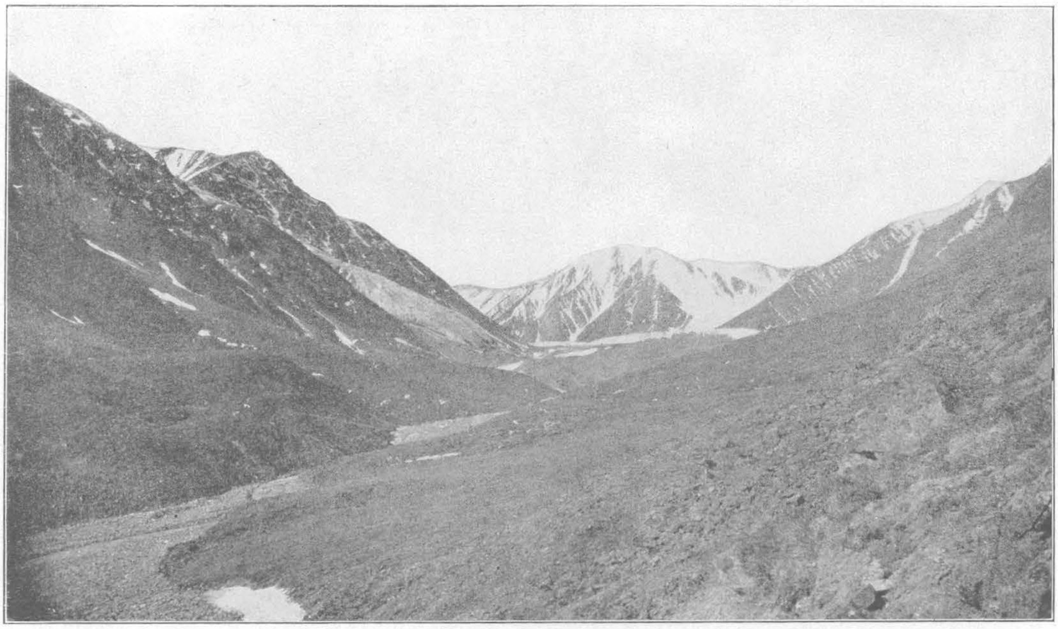
There are many small streams on the surface of the lower part. The largest ones, perhaps 2 feet across and twice as deep, flow along the



A. UPPER END OF OKPILAK GLACIER.

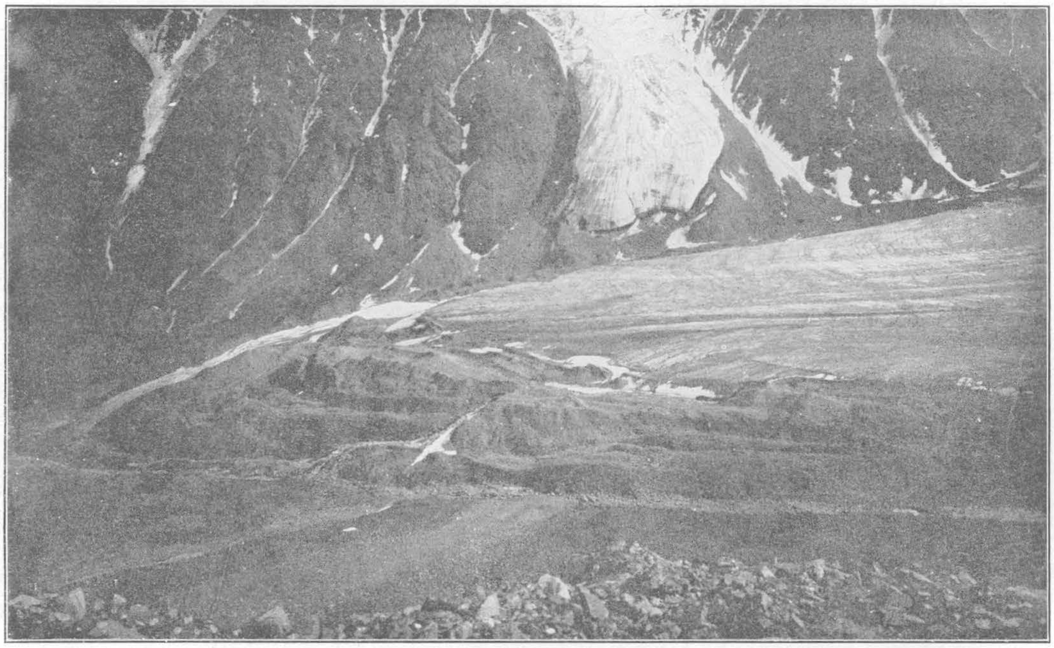


B. CENTRAL PART OF OKPILAK GLACIER.



A. WEST FORK OF OKPILAK RIVER.

Lower end of the glacier in the distance.



B. LOWER END OF OKPILAK GLACIER.

median line toward the end. The others flow down the lateral slopes. Many of these streams disappear into crevasses.

There was drainage along both borders of the ice, but it was more marked on the left side. Above the mouth of the last feeder on this side there is a pond which is dammed by the inflowing ice stream, and below it there are a few ponds between the rock walls and ice or behind moraines. The lateral stream flows over a boulder-filled bed, in many places cutting deeply into the margin of the glacier. At one place where the lateral drift is exceptionally heavy, the stream disappears down an ice tunnel and comes to light again beyond this drift dam. Near the end of the glacier there are several abandoned channels which mark the former course of the stream. They are chiefly cut through drift, but in several places through rock. The largest of these rock canyons was about 15 feet deep and 5 feet wide. Such cuts seem remarkable for a small stream during the time the ice was stationary at one particular level.

No observations were made as to the rate of motion of the ice, but there was strong evidence that the ice was moving. The linear surface moraine mentioned above consists of a belt of till 50 to 100 feet wide and 3 to 20 feet high. The marginal portions of the moraine are covered with clean boulders lying in stable positions, but along the crest there is a continuous line of mud and mud-covered stones lying in unstable positions. Some of the flat slabs of schist were standing on edge or even canted over, so that they resembled the ice blocks in a newly formed pressure ridge in the Arctic Ocean. It seems that the middle of the glacier is shearing past the marginal ice.

The lower end of the glacier grades into an area containing drift-covered ice (Pl. XIX, *B*). There is no drift separated from the end of the glacier, so that the ice as a whole can not have recently retreated to any noticeable degree, but neither is there any evidence that the ice has recently advanced. As much of the drift-covered marginal ice is at a higher level than the general surface of the glacier, this surface has recently become lower.

Plate XX, *B*, shows a small hanging glacier in the neighborhood of the one just described. The ice is very clear, except the basal 6 feet, which is black with débris. The lower end of another glacier is shown in Plate XX, *A*. It ends in a perpendicular face 30 to 40 feet high and is also composed of clean ice, except for a vertical distance of a few feet at the bottom. It seems to have recently overriden its own terminal dump. There are a couple of larger glaciers in the neighborhood which are shown on the map (Pl. I, in pocket). They have retreated entirely within their valleys, leaving areas of abandoned moraines.

HULAHULA RIVER.

During the time of the writer's visit the mountains of the Hulahula were covered with snow, so that any small glaciers that may have existed near the headwaters were not seen. As the northeast fork heads back against the Romanzof Mountains, it probably receives ice from their southern slopes. The streams which flow into the river from the east also head in these mountains and so may contain glaciers. The streams which head near Mount Chamberlin on the west side probably also have glaciers.

SADLEROCHIT RIVER.

No glaciers were observed to reach the floors of the main branches of the Sadlerochit, but the head of the Lake Fork is possibly filled with ice. A side glacier was observed to reach nearly to the floor, at the limit of vision from the upper lake. There are many other small glaciers and even ice caps where lodgment is found. Mount Chamberlin is almost entirely ice covered, but the lower limit of the ice was not ascertained in more than one place. The thickness of the ice cap can be made out on the northeast side, where a perpendicular cliff of ice rises perhaps 50 feet above the rock face. Small glaciers radiate from this ice cap into the valleys which head against the mountain. Probably none of them is much over a mile in length.

CANNING RIVER.

One or two distant cliff glaciers were observed among the mountains on the east side of the east fork of Canning River. As the area around the headwaters is reported to be more open and even rolling, there can hardly be much ice in that locality. Mount Salisbury, which reaches an altitude of about 7,000 feet on the west side of the river, has an ice cap and may discharge small glaciers into the Canning drainage.

OTHER AREAS.

Several glaciers can be seen from the coast to flow from the northeast corner of the Romanzof Mountains into the Jago drainage. The prospector Arey, who partly explored the Jago, reports that there are many other glaciers farther upstream on the west side. Aichillik River is reported by the natives to have many small cliff glaciers, but none are reported from the Turner. Maddren[1] observed none near the international boundary. Very little is known of the region between the Canning and the Colville. Arey, who traversed the Sagavanirktok in winter, reports that he saw no living glaciers. Schrader[2] does not mention any along the 152d meridian. Smith[3] reports a few glaciers at the headwaters of the Noatak and Koyukuk. None of them is more than a couple of miles long. No other glaciers are known by the writer to exist on the southern slopes of the Arctic Mountains.

AUFEIS (RECENT).

The heavy deposits of ice that are formed over the flood plains of Arctic rivers have been described in many of the recent reports upon Alaska. Middendorff, however, first described and explained this phenomenon in the middle of the last century, after several years of observation in northern Siberia.[4] The writer can add very little either to his description or his explanation.

Deposits of this kind of ice are called "glaciers" by miners and even by some geologists. "Flood ice" has also been used, but does not convey the proper impression. Middendorff introduced the term aufeis, and the writer has adopted it for this report.

The process of formation of aufeis is as follows: During the winter the flow of the rivers is locally impeded by the formation of anchor and frazil ice,[5] or the shoal places may freeze solidly to the bottom. The water coming from the upper stretches of the river, being thus impeded, will rise and flood the adjacent land. When the river is entirely frozen over, as is the rule in the Arctic, the hydraulic pressure is sufficient to bulge up and fracture the ice at weak places. The escaping water is soon coated with ice, and the flow is gradually restricted by freezing, until sufficient hydraulic pressure is set up to enable the water to burst through again. This flooding and freezing goes on all winter, or at least until the winter flow of water is so reduced that it can pass through the gravels beneath the ice. Thus a deposit of ice may be built up, much after the manner of an alluvial deposit.

If the winter flow is sufficient the aufeis may reach a considerable thickness, so that it may override the ordinary banks of the river and spread out over the whole flood plain. The greatest deposit seen by the writer was about a mile wide and 3 or 4 miles long. The thickness in the last part of June was about 12 feet.

In autumn the river is covered with thick ice before the flow is retarded sufficiently to set up hydraulic pressure. Acting under this pressure the water forces up the domes and ridges of ice, which are a conspicuous feature of aufeis deposits. These elevations are as a rule less than 10 feet high; about 15 feet is the maximum. As a rule their shape is oblong, though ridges over a hundred feet long have been noted. There is invariably a fracture along the crest of the mounds, whence water occasionally flows. The writer has never seen these mounds in the process of formation, but early in November the Canning was dotted with them. The natives say that they have seen them rising early in the autumn, accompanied by an outflow of water. The prospector Arey confirms this report.

After this first process of formation of the mounds the water escapes more quietly. As soon as the newly flooded area is frozen over hydraulic pressure is again set up, but it has only a few inches of ice to fracture. Consequently there is but slight disturbance of the surface.

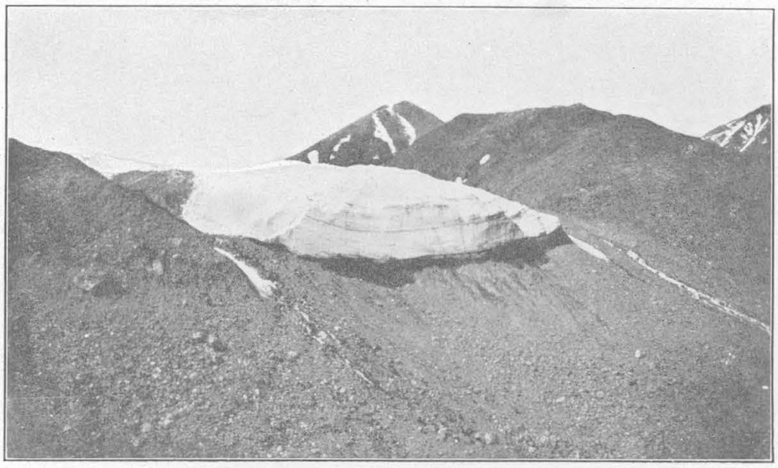
[1] Oral communication.

[2] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, 1904.

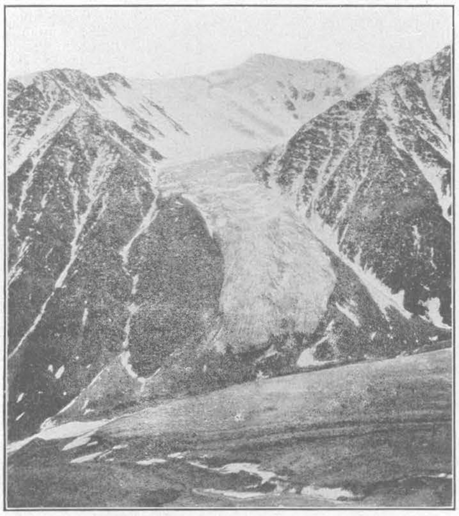
[3] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 32, 1913.

[4] Middendorff, A. T. von, Sibirische Reise, Band 4, Theil 1, pp. 439–457, 1859.

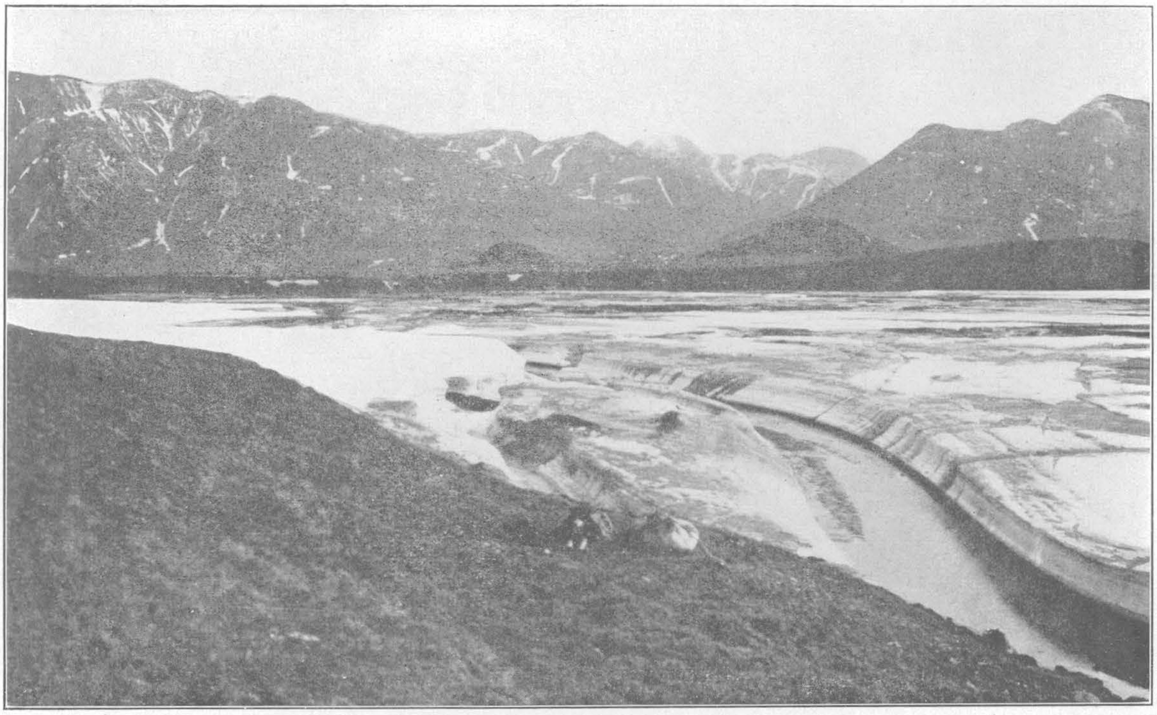
[5] Barnes, H. T., The formation of ice, London and New York, 1906.



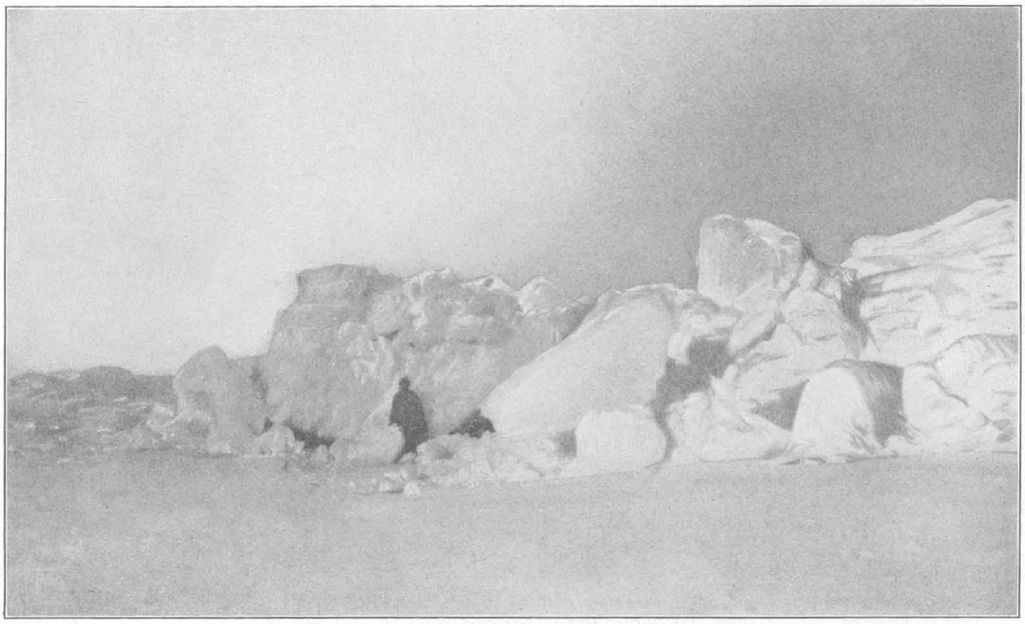
A. SMALL GLACIER ON OKPILAK RIVER.



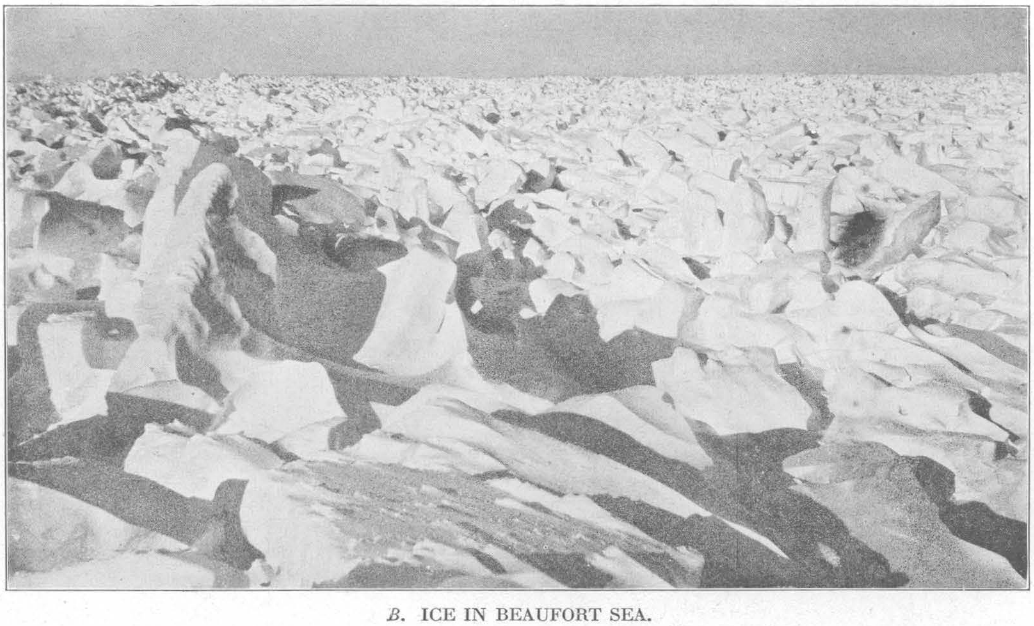
B. HANGING GLACIER ON OKPILAK RIVER.



C. AUFEIS ON CANNING RIVER IN JUNE, 1908.



A. PRESSURE RIDGE, BEAUFORT SEA.



B. ICE IN BEAUFORT SEA.

With the advent of warm weather the flooding waters, no longer freezing, cover the whole deposit of aufeis. Soon the drainage is concentrated into troughs, which have been melted along the lines of greatest flow. As these troughs are cut downward those most favorably situated grow at the expense of the neighboring streams, until by the time the actual river bed is reached the water is concentrated into one or two streams flowing at the bottom of ice canyons. Abandoned channels upon the aufeis of the Canning are shown in Plate XX, *C*.

The ice is gradually undermined by the river, so that large blocks break off with loud reports and fall into the water. Navigation at this time would be very dangerous, for there is danger from falling ice and of being swept under the ice by the current. All of the ice within reach of the river is cut out before the summer is over, but that upon the high bars may remain until September or may possibly last over a second winter. By the 1st of July the aufeis of the Canning was removed from the stretch north of the mountains; a week earlier that near the forks was almost intact. The mounds often remain some weeks after the thinner deposits have melted away.

Okpilak River contained very little aufeis. There was a steep valley train of ice that had been built out a couple of hundred yards from the lower end of the West Fork Glacier. A similar deposit floored the bottom of a valley that stretches eastward from Mount Michelson. At the time of the writer's visit the Hulahula had two areas of aufeis outside of the mountains, and within the mountains as far as the forks most of its floor was covered with ice. Sadlerochit River had one area of aufeis north of the mountains, but above this there were only a few patches confined to the side streams. On the Canning aufeis occurs nearly everywhere from the forks to the coast, the greatest development being near the forks and below Shublik Springs.

SEA ICE (RECENT).

In addition to the ordinary ice of the Arctic Ocean, which has been so often described in reports of explorations in the polar regions, there is a form which is to a great extent peculiar to Beaufort Sea. This form is called "old ice," from the lack of a better term. After a few notes upon the ice in general, the "old ice" will be discussed at some length.

PRESSURE RIDGES.

When the moving floes meet obstructions they are completely shattered (Pl. XXI, *B*) or their edges are crushed up into ridges composed of brecciated ice (Pl. XXI, *A*). The ridges may be piled upon the beach or may be formed anywhere over the surface of the ocean. Many reports mention ridges 50 to 100 feet high, but in the six years which the writer has spent on the shores of Arctic Alaska nothing approaching this maximum has been seen. The same is true of the ice seen during a previous expedition to Franz Josef Land. On sled trips and on shipboard the writer has spent nearly a year in the ice pack, and the shore ice has been observed during numerous journeys along the beach. The height of the largest ridges was estimated as carefully as possible. No ridges were seen which averaged more than 20 feet in height, and very few pinnacles which reached more than 30 feet.

Whaling captains have reported ice ridges 60 to 70 feet high from the same region in which the writer has traveled. Stefánsson[1] also reports an ice ridge 60 feet high.

CONGLOMERATIC ICE.

When one floe grinds along another the irregular edges of the floes are soon reduced, so that the motion takes place along a nearly straight line. The blocks of ice are gradually ground into small fragments, so that a mixture of boulders of ice in a groundmass of white slush is formed along the line separating the moving and stationary ice. When the floes separate, the ice conglomerate is often left with a vertical wall to mark the former plane of motion. This kind of ice has been observed only near the shore, where the relative motion of the floes is much greater than it is at a distance from the land.

LAMINATED ICE.

Several small flat floes were observed to be composed of ice showing parallel horizontal

[1] Stefánsson, Vilhjálmur, Notes from the Arctic: Am. Geog. Soc. Bull., vol. 42, pp. 460–461, 1910.

lines. This kind of ice is formed by the telescoping of thin sheets of ice. As the resistance to the motion of a layer of ice becomes great the thin ice fractures and a new layer is shoved up, so that a notable thickness of laminated ice may thus be built up. Cracks across pressure ridges sometimes show the lower slopes of the ridges to be laminated. Individual laminations often extend into the brecciated area.

Nansen[1] describes and illustrates such ice.

> When it was broken across, the blue showed a marked stratified formation, recalling the stratification of glaciers. * * * In several places the strata were bent and broken. * * * In spite of the bending of the strata the surface of the ice and snow remained smooth. It was evidently the result of horizontal pressure in the ice at the time of packing. It was especially noticeable at one place near a huge mound formed during the last pressure.

It is not clear whether he means that the structure was the result of horizontal pressure upon homogeneous ice or whether it resulted from telescoping thin sheets, but the former seems more probable.

OLD ICE.

Scattered among the flat floes and the masses of angular blocks of ice, which are evidently of recent origin, there are other floes of a very different appearance (Pl. XXII, *A*). These "old ice" floes have an undulating surface and the color is blue, in contrast to the greenish color of the new ice. The old ice contains no perceptible salt above the water line. These floes are very thick as a rule and may be miles in extent. The highest ridge that came under the writer's observation rises about 25 feet above a platform which is 6 feet above sea level. If the sides were perpendicular, the total thickness of this floe would be about 100 feet.

The term "paleocrystic ice" has been used in describing these undulating blue floes. As first applied to the ice east of Greenland, it refers to flat floes that have attained a great thickness through several years of freezing. As the term paleocrystic ice is inapplicable and no new name suggests itself, the ice under discussion is called by the local name "old ice."

[1] Nansen, Fridtjof, Farthest north, vol. 1, pp. 401–402, New York, 1897.

The floes of old ice vary in abundance from year to year and are always a subordinate element near the coast. After the open seasons of 1910 and 1911 only one small piece of blue ice was seen near the shore, but after the icy season of 1913 blue ice was abundant. The writer's record covers only observations made along the coast between Icy Cape and Herschel Island and those made during a sled trip a hundred miles northward from the mouth of the Colville. Old ice was seen along the north shore and for about 40 miles southwest of Barrow. On the sled trip the old ice was much more abundant at the farthest point reached than it was near land, but it never exceeded 1 per cent of the total amount of ice.

The writer has made no attempt to go through the literature of Arctic exploration in quest of observations upon the ice. A few narratives have been examined in which he remembered that old ice had been described. Parry, on the first of his famous Arctic voyages, was blocked by very heavy ice between Melville and Banks islands, on the eastern side of Beaufort Sea. There is no doubt that old ice was a large component of this barrier. He says:[2]

> An immense floe was covered with large hummocks, giving its upper surface the appearance of hill and dale. The thickness of the floe at its nearest edge was 6 or 7 feet above the sea, * * * but the hummocks were many of them at least 15 to 25 feet above the sea. * * * It was the opinion of Lieut. Beechey * * * that it very much resembled the ice met with at Spitzbergen, * * * but it was very much heavier than any they had seen there.

Elsewhere he says:[3]

> The ice to the west and southwest was as solid and compact to all appearance as so much land, to which, indeed, the surface of many of the fields, from the kind of hill and dale I have before endeavored to describe, bore no imperfect resemblance.

The ice about 200 miles east of the above locality had a very different aspect.

> The ice along which we continued to sail this day was composed of floes remarkable for their great extent and continuity. * * * Their height above sea was not generally more than 12 inches and their surface as smooth and even as a bowling green, forming in both these respects a striking contrast to the ice to which we had lately been accustomed more westerly.[4]

[2] Parry, W. E., Journal of a voyage for the discovery of the Northwest Passage in 1819–20, p. 205, Philadelphia, 1821.

[3] Idem, p. 214.

[4] Idem, p. 225.

A. OLD ICE IN BEAUFORT SEA.

B. ICE IN BEAUFORT SEA.

McClure's voyage took him along the north shore of Alaska and Canada and the west and north sides of Banks Island. Somewhere near the international boundary line they met ice

of stupendous thickness and in extensive floes, some 7 or 8 miles in length; * * * the surface of it was not flat, such as we see it in Baffin's Strait and the adjacent seas; but rugged with the accumulated snow, frost, and thaws of centuries.[1]

From the north end of Prince of Wales Strait, east of Banks Island, the ice was seen to be very heavy.

Great hills and dales of blue crystalline sea-ice rolled on before them in the direction of Melville Island.[2]

At the northwest corner of Banks Island

the pack was of the same fearful description as that they had encountered in the offing of the Mackenzie River during the previous autumn. The surface of the floes resembled rolling hills, some of them 100 feet from base to summit, and the edge of this wonderful oceanic ice rose in places from the water as high as the *Investigator's* lower yards.[3]

During Nansen's drift and sledge journey over the Arctic Ocean he recorded a few occurrences of old ice. It could hardly have been abundant, else he would have mentioned it more frequently. The sledding on these floes is so much easier than over the usual brecciated fields, that detours are made to reach them. Some of the ice seen by Nansen was

unusually massive with high hummocks, so that it looked like undulating country covered with snow. This was undoubtedly very old ice which had drifted in the Polar Sea for a long time on its way from the Siberian Sea to the east coast of Greenland. * * * High hummocks and mounds are thus formed [by pressure] which summer after summer are partially melted by the rays of the sun and again in the winter covered with great drifts of snow.[4]

Stockton records a "very large, long hummocky floe, at least 10 miles in length, several miles in breadth, and aground in 80 feet of water,"[5] off Cross Island, about 70 miles west of Camden Bay. The writer, during a voyage to Franz Josef Land which included about 400 miles of navigation in the vicinity of ice, could not have seen any such remarkable floes without remembering them. Neither could Mikkelsen, who was on the same expedition, recall seeing any. He was quite positive also that he saw none during a previous expedition to the east coast of Greenland. The writer recalls reading of a single floe on the west side of Greenland, which was so remarkable as to call for extended description. It was undoubtedly composed of old ice.

The references given above are sufficient to show that old ice is abundant in Beaufort Sea and rare or absent elsewhere. The motion of the ice from the north shore of Alaska westward and then northwestward across the pole toward Greenland is well established by the drifts of the *Karluk*, the *Jeannette*, and the *Fram*. The old ice floes are caught in this drift and should be expected along the course of these ships. It is surprising that Nansen did not see more of them.

The old ice differs from ordinary ice in being many times as thick as the flat floes and in having smooth surface undulations of solid blue ice instead of the piles of angular green blocks which compose the recently brecciated floes. It is very different in aspect from any icebergs ever recorded. A glacial origin is very improbable.

Both McClure and Nansen agree in calling it very old sea ice, and that is the conclusion to which all the whalers have come. Nansen's explanation that the old floes are the result of long thawing of the surface of heavy brecciated areas accounts for all the known facts. There is an abundant supply of heavy masses of broken ice, and when sufficient time has elapsed, the jagged surface of these floes becomes rounded by thawing. Snowdrifts help in filling in the irregularities, but they must play a subordinate part. The salt drains out of sea ice when the temperature reaches 0° C., so that blue fresh-water ice is left.

The writer has not been able to trace all the stages between fresh pressure ridges and old blue floes. The ice floes observed by him were without exception evidently very young or very old. Grounded ridges, known to have been exposed to one summer's thawing, become somewhat smooth in outline, but the ice is still white. A few subangular protuberances have

[1] McClure, Robert, Discovery of the Northwest Passage, edited by Sherard Osborn, 2d ed., p. 84, London, 1857.
[2] Idem, p. 139.
[3] Idem, p. 207.
[4] Nansen, Fridtjof, Farthest north, vol. 2, p. 140, New York, 1897.
[5] Stockton, C. H., Arctic cruise of the U. S. S. *Thetis*: Nat. Geog. Mag., vol. 2, p. 185, 1890.

been observed in the old blue floes. Several times the outlines of angular blocks could be made out, where the structure of the old ice was revealed in recent fractures or in the bottom of surface pools. The contrast between recently brecciated ice and old ice is seen in Plate XXII, *B*.

There is not much information from which to estimate the time necessary for the formation of old ice. From the effect of a single summer the writer would place the time at a few years; certainly not centuries, as McClure believed. If the new ridges among which the drift of the *Fram* began had become changed during the three years that the drift lasted to anything approaching the old blue ice, the fact could not have escaped notice and description. We must therefore conclude that three years is far from a sufficient time for the formation of old ice. The maximum limit is of course dependent upon the duration of the Arctic climate, which is probably to be reckoned in thousands of years. From the slight amount of evidence obtainable the writer considers that 20 years is the least time in which old ice can be formed.

The old ice, so far as known, is confined to Beaufort Sea or to floes that have probably drifted out of this sea. The drift toward the west is so constant that no ice formed in this sea could be more than a very few years old. The old ice must come from somewhere in the east where the ice is exposed to great pressures and yet prevented from being quickly swept away by the general drift. There must be a small outlet from this region, through which the old floes can escape into Beaufort Sea. There is no source possible in the Amundsen Sea, between Canada and Banks Island, nor in Melville Sound to the north, where, as stated above, Parry found the ice to be predominantly in flat floes.

The greatest amount of old ice on record is southwest of Prince Patrick Island, where it remained near shore even against heavy winds. This lack of movement suggests a land barrier to the west, where Harris has placed a neck of his hypothetical Arctic land (p. 59). Thus the most probable gathering ground for the old ice is to the north and west of Prince Patrick Island, in an area sufficiently large for the development of great ice pressure, and which is nearly cut off from Beaufort Sea. The existence of a land barrier is more likely than that the ice is kept out of the general drift by a local eddy of the current. The chief outlet from this gathering ground is thought to be southward along the shores of Banks Island. This outlet must be small in comparison to the area in which the old ice is formed.

Harris[1] mentions the existence of the old ice of Beaufort Sea in his discussion of the supposed land. Mikkelsen[2] also mentions it in several places. They both hold that the old ice has its origin in Beaufort Sea.

In the writer's opinion the distribution of the old ice strongly supports the evidence drawn from the tides of the existence of land in this region.

DEPOSITS OF ERODED MATERIAL (RECENT).

Talus.—From expressions like "shattered by the intense action of the Arctic frost," used in descriptions of Arctic rocks, one would expect to find talus very extensively developed in the Arctic Mountains, but there seemed to be no difference between the slopes of these mountains and those of the higher mountains of lower latitudes. The chief work of frost is at the change from above to below the freezing point, and as the mountains of temperate regions are more frequently exposed to this change the shattering should be less in the Arctic. For a great part of the year the temperature is permanently below freezing, and the sun is either low or absent, so that the rocks are not warmed by absorption. In summer the daily range is not great, for the sun is above the horizon continuously.

On Okpilak River the talus, in addition to lying at the usual angle, commonly takes bench-like forms, whose general aspect is that of slumping rather than that of a steady flow as described by Capps.[3] The fronts of the benches as a rule are steep, and the tops are uneven and commonly slope downward toward the mountain side. Undoubtedly there is ice among the

[1] Harris, R. A., Arctic tides: U. S. Coast and Geodetic Survey, p. 91, 1911; Indications of land in the vicinity of the North Pole: Nat. Geog. Mag., vol. 15, p. 257, 1904.

[2] Mikkelsen, Ejnar, Conquering the Arctic ice, pp. 13–15, 226, 438, London and Philadelphia, 1909.

[3] Capps, S. R., Rock glaciers in Alaska: Jour. Geology, vol. 18, pp. 359–375, 1910.

talus blocks, but the deposits do not seem to be of sufficient magnitude to flow as a body. The low ground temperature, even in the summer, may interfere with such a flow.

Alluvial fans.—Large alluvial fans have been built out from the hanging valleys of Okpilak River. The largest reach an elevation of about 600 feet above the river flat and extend with slopes as high as 17° out to the middle of the valley, in many places deflecting the river.

Levees.—The drainage lines upon the alluvial fans are generally in the form of levees. Some of these troughs are built to a height of 10 feet above the general level of the fan. The material in the banks of the levees is remarkable in size. Boulders 6 feet in diameter are common, and one was noted to be at least 15 feet.

River gravels.—All the larger rivers flow among fresh gravel bars and have a flood plain of older gravels. The material is coarse, even near slack water at the coast. Okpilak River, near the edge of the mountains, has a gravel filling nearly a mile wide and probably 200 feet deep.

Coastal silts.—All the larger rivers have deposits of silt in the slack water near the coast. Mud flats are being built out also. Most of these flats are less than a mile wide; those on Sagavanirktok River, however, may be twice this width. It is impossible to see land from a small boat off the Colville delta in places where the water is only a foot deep.

Silt dunes line the western banks of the delta channels. They are locally very numerous, but hardly any of them rise more than 15 feet above the ground upon which they are built.

Coastal sands and gravels.—Wherever waves have access to the shore, the usual beach deposits of sand and gravel are formed. Many spits are built out from the land, and some of them are prolonged into barrier reefs many miles in length. The material of these sands, when derived from the Flaxman formation, is entirely foreign to the country and has misled prospectors as to the probable country formations. Magnetite, "ruby sand," and granite are among the constituents, and these are considered to indicate a region favorable for prospecting.

GENERAL STRUCTURE OF THE REGION.

ARCTIC MOUNTAIN SYSTEM.

The structure of that part of the Arctic Mountains which is considered in this report has been produced chiefly by folding and thrust faulting of Paleozoic rocks along nearly east and west lines. Some Mesozoic rocks are also involved in this folding. Many of the folds are sharply overturned toward the north and faulted along the axis. The upward movement of all east and west faults came from the south.

Schrader's section[1] along the 152d meridian shows the same general structure near the northern boundary of the Arctic Mountains. Maddren's section along the 141st meridian, which is not published, shows the same east and west folding and faulting, but the deformation has been more intense than in the areas farther west.

FRANKLIN MOUNTAINS.

Canning River.—At the forks of the Canning the Lisburne limestone overlies the Neruokpuk schist in a relationship which is probably due to thrust faulting from the south. The limestone and schist both dip monoclinally toward the south, but at different angles, that of the schist being about 30° and that of the limestone half as much. The limestone, which lies north of the schist in fault contact, has a synclinal structure for the first few miles, and then there is a gap containing crumpled rocks whose structure could not be made out. This complicated area has been left blank on the geologic map and section (Pl. II). The limestone immediately north of it, though in general of monoclinal structure, has minor plications and even infolding. Underlying this area of limestone, and probably in conformable relations to the limestone, are the black shales of Mississippian or Devonian age, which are closely crumpled and even slaty. These shales are brought up by faulting against the limestone, which here forms the northern scarp of the mountains. The frontal belt of limestone has a sharp fold, as shown in Plate XXIII. At the place where

[1] Schrader, F. C., op. cit., pl. 3.

the photograph was taken there does not seem to have been faulting along the crest of the upward fold, but the aspect of the front of the mountains is that of a fault scarp.

Sadlerochit River.—At the glacial lakes of the Sadlerochit the steeply southward-dipping schists end against the narrow belt of perpendicularly dipping limestone in relations that are probably due to faults. North of the limestone the younger beds are so much disturbed that their structure was not made out.

Hulahula River.—On the Hulahula thrust faulting is thought to have brought the upper schist belt into contact with the upper limestone belt, and to have thrown this limestone, with its underlying Mississippian or Devonian shales, up against the lower schist belt. The rest of the river was hurriedly traversed in bad weather, so that little of the structure of the rocks along it was noted. On the east side of the river, abreast of the granite, the structure is probably very complicated.

Okpilak River.—Above the forks of the Okpilak there are vertical or steeply southward-dipping beds of a rock that was considered to be a more highly altered phase of the Neruokpuk schist. The granite, which runs from the forks nearly to the north edge of the mountains, is conspicuously jointed in two or three planes. Veins of softer material are common along the chief joints. At its northern edge the granite is overlain by closely folded and shattered limestone, which in general dips northward. The younger beds north of the limestone are so crumpled and shattered that their structure could not be made out. The northern front of the mountains at this locality does not appear to be determined by a fault.

OUTLYING MOUNTAINS.

Third Range.—The narrow belt of mountains known as the Third Range is separated from the Franklin Mountains by Ikiakpuk Valley. It is formed by a sharp-crested fold, which is steeply overturned toward the north. The apex of the fold had been eroded away near the west end of the range, and no signs of displacement could be made out within the homogeneous limestone. The western end of this fold seems to plunge downward toward the Canning, but the eastern termination is indefinite. If the isolated ridge at the Hulahula, which falls into line with the Third Range, is a part of the same fold, then cross folding must have occurred, for the west side of that ridge dips toward the west.

Ikiakpuk Valley has been formed by the removal of the soft Mesozoic rocks from the syncline between the Franklin Mountains and the Third Range.

Shublik Mountains.—Only the western end of the Shublik Mountains was examined. There the limestone beds rise from the south and extend nearly horizontally to the northern front, where they abruptly give way to vertical beds. There the apex of the fold is so sharp that fracturing must have taken place and probably faulting also. These mountains are terminated at the Canning by plunging on the north and by cross-faulting on the south. The eastern end, as observed from a distance, seemed to plunge.

Ikiakpaurak Valley is also structural, but instead of an apparent open syncline, as in Ikiakpuk Valley, there is an evident synclinorium of two or three folds.

Sadlerochit Mountains.—The structure at the narrow west end of the Sadlerochit Mountains is similar to that of the two other ranges; a monocline on the south changes into nearly horizontal beds over the top and ends vertically on the north. That there was faulting along the apex of the overturned fold is shown by a zone of breccia between the horizontal and vertical beds.

In the section exposed near the eastern end of these mountains at Itkilyariak Valley the structure is much the same. A fault within the limestone belt is perhaps the continuation of the one at the western front. The eastern front does not end in a fault scarp but in northward-dipping beds.

The west end of the fold plunges down under the Mesozoic rocks of Red Hill and the east end, as observed from a distance, seems to plunge also.

ANAKTUVUK PLATEAU.

In the few exposures along the rivers, the Mesozoic and Tertiary rocks that form the Anaktuvuk Plateau are seen to be deformed, but not to such an extent as the Paleozoic rocks of the mountains. Highly dipping beds on the west side of the Canning opposite Shublik

DOUBLE FOLD AT NORTHERN FRONT OF FRANKLIN MOUNTAINS, CANNING RIVER.

Mountains probably mark the prolongation of this plunging anticline. North of Sadlerochit Mountains there are gentle folds and near the coast there are northward-dipping beds. At the head of Marsh Creek there is an area of complicated structure produced by faulting in two or three directions, so that the Mesozoic and Paleozoic formations have been brought into relations which are not understood. On Okpilak River the formations are very closely crumpled.

COASTAL PLAIN.

The beds that form the surface of the coastal plain are nearly horizontal and are apparently disturbed only by the work of frost. The writer was unable to determine whether or not the beds that form Barter Island are deformed, but it is probable that they dip away on all sides from this dome.

HISTORICAL GEOLOGY.

The earliest event recorded in the Canning River region is the deposition of the material out of which the quartzite schist was formed. Following this deposition there was a period of deformation in which the sediments were changed into schists. Evidence as to the early succeeding periods is lacking in this region, but in other areas there was uplift, accompanied by mountain building and followed by erosion.[1]

No fossiliferous deposits of pre-Carboniferous age were found in the region under discussion, but as Devonian deposits have been reported elsewhere in the Arctic Mountains,[2] we are justified in attempting to outline the history of these mountains since the Devonian period. At the close of the Devonian the land emerged above the sea sufficiently to allow the growth of the plants in the earliest Mississippian. About the time of deposition of the Mountain limestone of Europe, the land sank sufficiently to allow the deposition of a great thickness of limestone over much of the area now occupied by the Arctic Mountains. Locally the conditions were favorable for the formation of the sandstone. During the middle of this period there were extrusions of greenstones.

About the close of the Mississippian epoch there was an abrupt change from the formation of limestone to that of sandstone in the Canning River region, but elsewhere either limestones or shales were deposited. The close resemblance of the Alaskan Carboniferous fauna to the European points to an uninterrupted path for migration between the two regions.

The history of Arctic Alaska during late Pennsylvanian, Permian, and Lower and Middle Triassic times is unknown. Either there was little deposition during this interval or else the deposits have been eroded away, for there are only 300 feet of beds in the Canning River region and 600 feet near Cape Lisburne that represent the deposits of that time. Whatever may have been the history, it is certain that at the close of the Paleozoic era no deformation took place.

The Upper Triassic was an epoch of deposition of dark sandstone, shale, and limestone over much of Arctic Alaska. During the close of this epoch no deformation took place in the Canning River region, and the deposition was either continuous or was interrupted for only a brief time before the deposits of the Lower Jurassic were formed. During the Jurassic period the land was elevated sufficiently for the formation of coal beds. The sandstones with basal conglomerate mark several oscillations at about sea level.

Smith[3] states that in the Kobuk-Noatak region there was a period of mountain building after the close of the Triassic, after which erosion removed material to form new deposits. In the Canning River region the bedding of all the formations from Mississippian to Jurassic is approximately parallel, so that no great amount of deformation could have taken place there.

The definite pre-Tertiary history of the region ends with the Jurassic, but deposition took place elsewhere in Lower Cretaceous time and was followed by deformation, uplift, and erosion. Deposition again commenced in the Upper Cretaceous and probably extended into the Eocene.[3]

[1] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, p. 122, 1913.

[2] Idem, pp. 68–69.

[3] Smith, P. S., op. cit., p. 123.

Some time after this late Mesozoic and perhaps Eocene deposition the rocks in the area now occupied by the Arctic Mountains were deformed into nearly their present structure. This deformation was formerly believed to have occurred at the same time as that of the Rocky Mountains in the United States and Canada, and the Arctic Mountains were thought to be a continuation of the Rocky Mountains. Smith concludes that there was no stratigraphic break between the Mesozoic and the Tertiary.

In the Canning River region the only evidence is that the deformation took place between Jurassic and Pleistocene time. After this deformation and uplift erosion began. If the Endicott Plateau was formed by base leveling the Arctic Mountain area must have been above the sea during much of the Tertiary.

During this period of erosion there was deposition over the area north of the mountains. The full history of this sedimentation is not known, but in the Colville region there are indications of a temporary emergence of the land during the Pliocene, whereas during the same period in the Canning region shales were deposited. This deposition was followed by deformation and uplift of the Pliocene beds, and probably of the whole mountain area.

This deformation and uplift was followed by a period of erosion, during which the soft Mesozoic and Tertiary beds were leveled off and the mountains reduced nearly to their present topography. This period of erosion is believed to have lasted during much of Pleistocene time. At the same time sediments were being laid down under the area now occupied by the coastal plain. Then came an uplift of the Anaktuvuk Plateau, with the accompanying erosion of the present valleys by rivers which flowed out from the already established mountain drainage system. There may have been a pause in this uplift, during which the margin of the ocean was at the northern front of the upland, for the topographic break there may be the result of wave erosion. Later the uplift was continued until the coastal plain was brought nearly into its present position, which probably occurred shortly before the Wisconsin stage of glaciation.

While the Wisconsin ice sheet lay over Canada and the northern United States, the Arctic Mountains were also glaciated. All the major valleys were filled with ice from 1,000 to 3,000 feet thick, and ice tongues pushed to a distance of several miles beyond the north front of the mountains. The Keewatin ice sheet advanced from Canada into the Arctic Ocean; icebergs broke off and drifted along the Alaskan shore, dropping foreign boulders and till, and perhaps grounding permanently on the mud flats near the mouths of rivers. Since that time a slight uplift has raised many of the boulders above the sea, and there have been minor uplifts and subsidences all along the coast line.

GEOMORPHOLOGY.

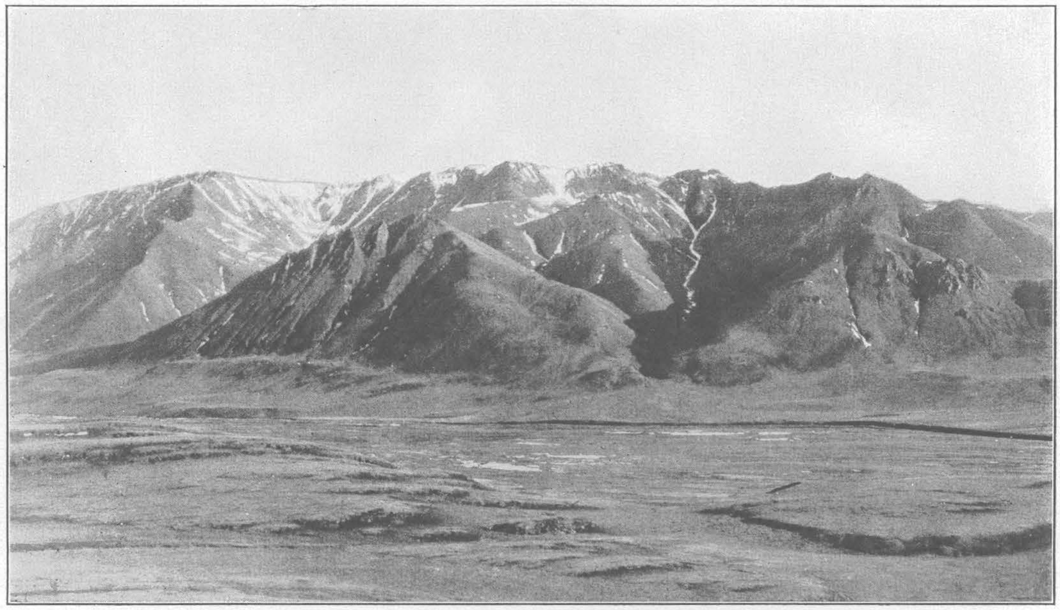
ARCTIC MOUNTAINS.

The Arctic Mountains received their present structure from deformation which took place near the close of the Mesozoic era but whether in late Mesozoic or early Tertiary is not yet certain. After this deformation the mountains were subjected to erosion until the softer Mesozoic beds had, so far as known, been removed from their summits, and considerable erosion had taken place in the harder rocks of the Paleozoic. According to the generally accepted belief, most of Alaska was in post-Cretaceous times reduced to base-level.[1] The Arctic Mountains in particular are thought by Schrader[2] to have been planed off, and he has introduced the term Endicott Plateau for the peneplain.

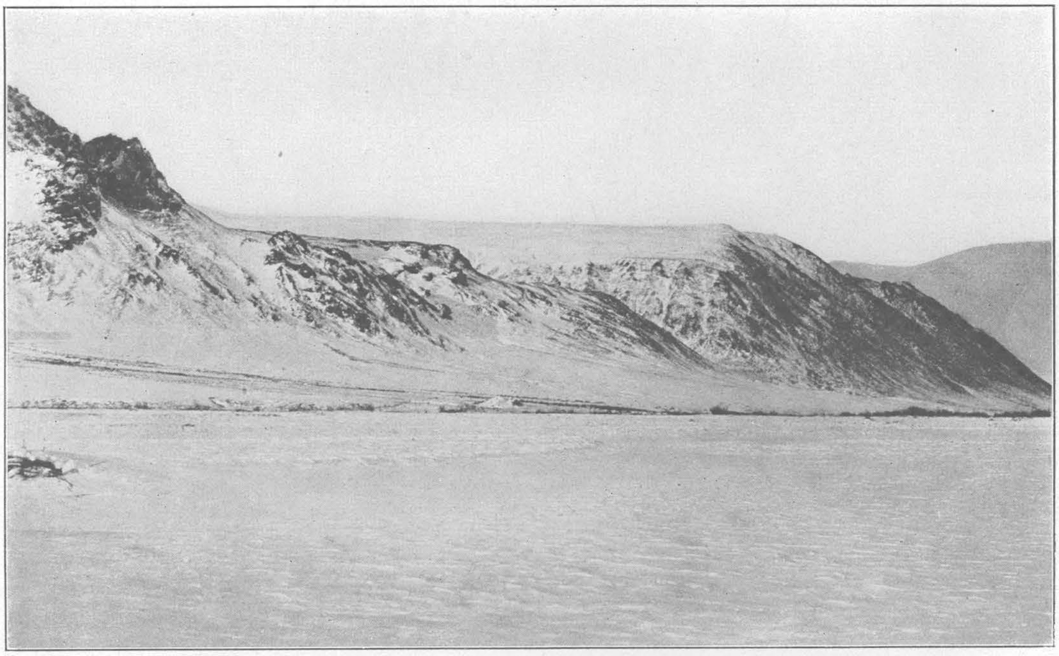
In the Canning River region, with the exception of the Romanzof Mountains, there is the same general accordance of summits which Schrader observed farther west. As the writer knew of the views of Brooks and Schrader upon the subject, and was not aware of the change of attitude of many geologists toward postulating peneplains over every area of accordant summits upon this evidence alone, he considered it a settled matter while in the field that the Arctic Mountains had been carved out of an elevated plateau of erosion. In consequence of this opinion a careful watch was not kept for evidence which might have a bearing upon the question.

As the burden of proof now seems to lie upon one who postulates an uplifted peneplain

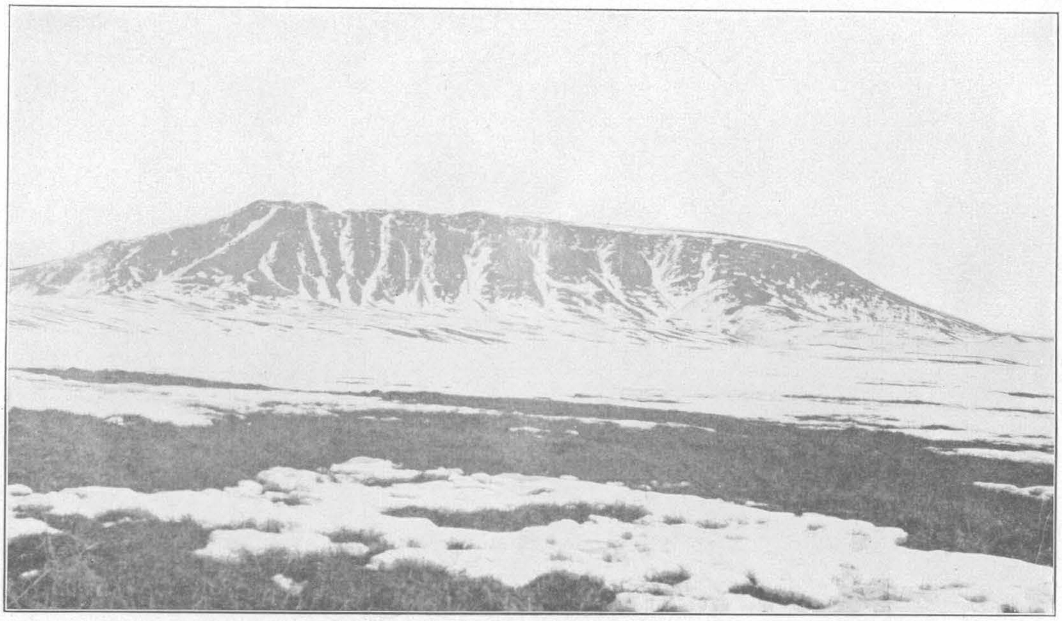
[1] Brooks, A. H., The geography and geology of Alaska: U. S. Geol. Survey Prof. Paper 45, pp. 286-290, 1906.
[2] Schrader, F. C., op. cit., pp. 42-43.



A. EVEN SKY LINE, FRANKLIN MOUNTAINS, CANNING RIVER.



B. FLAT-TOPPED AREA IN FRANKLIN MOUNTAINS, HULAHULA RIVER.



A. LEVEL-CRESTED RIDGE SEVERAL HUNDRED FEET BELOW THE SUMMIT LEVEL OF THE ARCTIC MOUNTAINS, CANNING RIVER.

B. SEA ICE MOUNTING BEACH, FLAXMAN ISLAND.

in a rugged mountainous area, the writer will present a few observations, and leave the question open as to the ancient plateau feature of the Arctic Mountains.

The topographic map (Pl. I, in pocket) is not sufficiently accurate in its elevations to show the apparent accordance of summits, but Schrader's illustrations[1] bring this out very clearly. A plain which included the summits in the region under study would lie about 6,000 feet above sea level.

Locally somewhat flat-topped areas rise to the same level as the peaks and ridges (Pl. XXIV, *A* and *B*). Plate XII (p. 51), a view taken at the northern front of the Romanzof Mountains, shows a flat-topped area sloping toward the east. This area is underlain by deformed Paleozoic and Mesozoic rocks and is very suggestive of peneplanation.

One who sees peneplanation in every flat-topped area in the mountains will probably be able to make out a second and lower stage of erosion in the shoulders of some of the peaks. This feature is well illustrated at the west end of the Shublik Mountains. Here there is a well-defined bench 600 to 800 feet below Mount Copleston. Plate XXV, *A*, shows a flat-topped ridge in which the gently southward dipping beds end against the nearly horizontal top of the ridge. These shoulders occur so generally that they are strong evidence of a halt in the uplift of the mountains.

In discussing the development of a possible peneplain over the Arctic Mountains the drainage system must also be considered. Within the Franklin Mountains the rivers flow across the folds and faults with very little deviation from their northward course. Although the three outlying ranges have to a great extent been avoided, the Sadlerochit cuts across the east end of the Third Range, and there is good evidence that it formerly ran through the east end of the Sadlerochit Mountains. There is a gap through the west end of the Shublik Mountains through which the Canning is thought to have formerly flowed, and a corresponding gap behind Red Hill, at the west end of the Sadlerochit Mountains.

Such a drainage system should have originated on a northward-tilted flat surface. There are three possible hypotheses to be considered. According to the first hypothesis, at the end of Mesozoic or early Tertiary sedimentation, the land was uplifted and tilted toward the north. The drainage was then established in rather closely spaced, northward-flowing rivers. Then came the folding and faulting, which produced the present structure of the mountains. This deformation came on so slowly that the drainage was not diverted but kept its course across the growing faults and folds. Under this hypothesis the present accordance of summits must be accounted for by other processes than planation by the sea or the rivers.

The second hypothesis is that the mountains were deformed and elevated and reduced nearly to sea level again. The peneplain was then elevated and tilted to the north and the ancient rivers were rejuvenated. Under this hypothesis the rivers should show some signs of the previous cycle of erosion, such as complete adjustment to rock structure. It is shown just above that the present drainage is not completely adjusted, and that it was much less so earlier in the present cycle. When the supposed river planation had proceeded to a degree sufficient to bring the summits within their present accordance, such closely spaced parallel rivers would hardly persist. Some meandering over the ancient plain is to be expected.

The third hypothesis is that after the mountains had been deformed and uplifted they were reduced to a peneplain over which the sea encroached. Sediments were laid down, and when the marine plain was uplifted the rivers flowed in straight lines toward the north. The new rivers intrenched themselves in the horizontal homogeneous rocks, and when they had cut down to the old deformed rocks they kept their courses across the structural lines. Under this hypothesis all the facts known to the writer are accounted for.

The Romanzof Mountains, which are composed of granite, show a similar accordance of summits, and a plain may be recognized at an elevation of about 3,000 feet above the Endicott Plateau, as Schrader terms it. (See Pl. XII, p. 51.) The Romanzof Plateau may have been the result of marine, fluvial, or subaerial planation, for all that the writer could tell. If of marine or fluvial origin it must be

[1] Schrader, F. C., op. cit., pl. 7.

older than the Endicott Plateau, provided that is of the same origin. If both plateaus are the result of subaerial planation the different levels may be the result of the difference of hardness in the rocks.

ANAKTUVUK PLATEAU.

The writer can not say whether the Arctic Mountains had ever been base-leveled, chiefly because he did not find sufficient areas of the supposed peneplain. With regard to the Anaktuvuk Plateau there does not seem to be any uncertainty, for throughout most of the upland the ancient surface still persists over beveled-off folds and tilted beds. The even-crested ridges that lead out from the mountains on most of the rivers show this plateau feature (Pl. XIII, *A* and *B*, p. 52).

The Anaktuvuk Plateau nearly everywhere in the Canning River region ends against the fault or sharp fold which forms the northern scarp of the Arctic Mountains. This relation was also observed near the Colville by Schrader.[1] With only such simple relations to consider there is no reason for separating the Endicott and Anaktuvuk plateaus, as Brooks[2] has brought out. They might represent one period of erosion, and their present relations might have resulted by differential uplift along the northern scarp of the mountains. In the upland basin behind the east end of Sadlerochit Mountains, however, the relations are such that the two levels can not be the result of differential uplift of a single plain. The Anaktuvuk Plateau occurs on both sides of these mountains and around the outliers of the other minor ranges.

Brooks[3] suggests that the level of the Anaktuvuk Plateau may pass below the undisturbed Pliocene beds found by Schrader on the Colville, and that the plateau is thus pre-Pliocene in age. In the Canning River region, where Pliocene beds are tilted and beveled off, the evidence indicates that it is post-Pliocene. Near the coast at the upper end of Camden Bay, where the beveled Pliocene beds were found, the Anaktuvuk Plateau has lost a good deal of its plateau feature, but no break could be seen between this area and the more evident plateau behind it. Unless there were two levels of planation which fell so closely into line that no break was observed, the whole upland was planed off in post-Pliocene time.

Whether the planation of the upland was marine or fluvial or whether the sea encroached upon the plain after fluvial planation is not at present known. A deposit of wash material overlies the beveled Pliocene beds and has been described under the heading "Upland gravels" (p. 130), but whether it is marine or fluvial the writer is unable to say. O'Neill[4] gives the following description of the upland which fronts the Arctic Mountains near the international boundary:

> The section on the Firth River showed a peneplained surface over which is spread a mantle of stratified muds, sands, and gravels. Fossils were obtained from the folded rocks below and from the overlying loose material, so that a limiting range will be obtained for the age of erosion.

On the next page these overlying stratified deposits in the section along the Firth are considered to be "apparently a river deposit, or formed under flood-plain conditions."

At the close of the period of erosion, during which the soft Mesozoic and Tertiary rocks were reduced to a peneplain, there was an uplift accompanied by northward tilting, which brought the Anaktuvuk Plateau nearly into its present position. In many places the outer margin of the upland suggests that faulting took place during the uplift. The plateau ends in a north and south scarp at Sadlerochit River. On the Canning the upland is higher on the west side than on the east. Thus there seems to be a tilted block lying between the two rivers.

As the valleys in the upland near the base of the mountains seem in general to be more mature than they are near the coast, the tilting probably took place gradually. By the time the last glaciers, probably of Wisconsin age, pushed out of the mountains, the upland had been brought practically into its present state of erosion, for the ice flowed in preglacial valleys.

COASTAL PLAIN.

While the Anaktuvuk Plateau was being base-leveled in early Pleistocene time, sediments were being laid down over the area

[1] Schrader, F. C., op. cit., p. 45.
[2] Brooks, A. H., op. cit., pp. 288, 290.
[3] Idem, p. 275.

[4] O'Neill, J. J., Canadian Arctic expedition: Canada Geol. Survey Summary Rept. for 1914, pp. 113–114, 1915.

now occupied by the coastal plain, and in late Pleistocene or early Recent time this plain was elevated nearly into its present position. Very little deformation took place during the elevation. There are local domes at Barter Island and Herschel Island which rise 60 and 500 feet above the coastal plain, but although these domes reveal Pleistocene formations, it is not known whether their deformation took place at the end of the Pliocene or in the Pleistocene.

At present the rivers have graded courses almost at the surface of the coastal plain, so that the amount of erosion is nearly balanced by the deposition. The Okpilak seems to have locally built up the plain by outwash during the last stage of glaciation.

The evidence as to the time of emergence of the coastal plain is slight. The few fossils from the sands at Point Barrow are said by Dall to be Pleistocene and Pliocene. The absence of Flaxman boulders from the coastal plain, except along the seaward edge, points strongly to a pre-Wisconsin age for the whole plain. Peat deposits 8 to 10 feet thick point, according to Capps,[1] to an age at the coast greater than 2,000 years. The evidence from ice wedges indicates that the age of the seaward edge of the coastal plain is not more than 1,000 or 2,000 years, but this evidence is founded upon very weak grounds. The evidence from the great amount of material transported along the coast by waves and currents is that the coastal plain has been at about its present position for a very long time. The barrier islands that extend nearly 50 miles west of Flaxman Island are composed of material washed out of the Flaxman formation. This work must have required a long period, for the only known source is at Flaxman Island and east of that place.

COAST LINE.

DEVELOPMENT.

The coast line took approximately its present position at the end of the uplifting of the coastal plain. The waves have modified it, however, by cutting against the shores in some places and by building it up in others. The result is that now the coast is marked by low banks, sand spits, and barrier beaches and islands. To these the rivers have added their deltas.

There are evidences of minor undulations in the coast line since it took nearly its present position. At Barter Island there are faint beaches and wave-cut scarps above the reach of modern waves. Where the west bank of the island fades out upon the southern flat an old sand and gravel beach runs along the foot of the bank and then runs south over the flat, nearly parallel to the present beach line and about 4 feet above it. Between this old beach and the shore there is a flat about a hundred yards wide and slightly lower than the crest of the beach. The driftwood along this beach is very rotten, logs 2 feet in diameter being incorporated into the soil. To judge from the state of this wood in comparison with the wood of old Eskimo houses, the time of deposition must have been several hundred years ago. No rise of tide sufficient to flood this beach was experienced during the nine summers of the writer's observations.

Half a mile northwest of the same bank there is a bench 50 to 100 feet wide, cut into the western side of the island at an elevation of about 6 feet above the 4-foot flat which fringes the coast at this place. At the place where the high bank on the east side of the island swings in upon the southern flat it fades out into a grassy slope, upon which an elevated bench can be traced for about a mile by scattered scarps which have not yet been obliterated.

The evidence is that Barter Island formerly stood about 9 feet lower than at present. At the point where the coastal plain abuts against the front of the upland, 4 miles east of Collinson Point, there are a few dark patches, which were considered to mark an old wave scarp. The elevation was estimated at 15 feet.

The deltas of many of the rivers have silt islands whose level surface is well above the present reach of flood tide. The maximum elevation is about 25 feet, at Howe Island, at the edge of the Sagavanirktok Delta.

In addition to the foregoing evidences of slight uplift of the coast, there is an accompanying evidence of depression, so that a slight vertical undulation of the shore line is indicated. A few miles west of Oliktok the mouth of a small

[1] Capps, S. R., Age of the last great glaciation of Alaska: Washington Acad. Sci. Jour., vol. 5, pp. 108–115, 1915.

creek is drowned for several hundred yards. The western arm could not be waded, but the creek which emptied into it could be stepped across. Fawn Creek, east of Gwydyr Bay, has an estuary nearly a mile long, up which a boat may be taken. Perhaps the best illustration of a drowned valley is in the meandering estuary which runs 2 or 3 miles inland behind Konganevik, on the west side of Camden Bay.

RECENT CHANGES.

The maps of the early explorers are on such a small scale that it is necessary to depend to a great extent upon the narratives in discussing changes of the coast line in historic time.

Franklin mentions an Eskimo encampment on a sand island near Sadlerochit River in 1826. To-day there are only some islets nearly awash at this place, upon which it would be unsafe to camp. Boulder Island and its neighbor in Camden Bay have been entirely cut away. Collinson saw these islands in 1854, and old natives have reported that they had seen them many years ago. On the writer's map (Pl. V, in pocket) shoals are marked near the former locality of Boulder Island. The string of sand islands which ran west from Boulder Island are represented now by only one or two bars.

It is evident from the difficulty which Franklin experienced in going inside of Flaxman Island that the channel was formerly different. During the years 1906 to 1914 there was not less than 9 feet of water close to the east end of the island, and at the southeast spit there were 3 fathoms within 50 feet of the beach. Flaxman Island is described as 4 miles long, 2 miles wide, and about 50 feet high. The length was not greatly different from that of to-day, but the breadth seems formerly to have been much greater. It is now not over a mile wide, and nowhere is it over 25 feet high. The shape on Franklin's map is different also, as there is a convex shore line on the northern side, whereas the modern shore line is straight. It seems safe to say that at least half a mile has been cut away from the northern side since 1826.

In addition to the evidence from Franklin's narrative of the greater size of Flaxman Island in former times, there is evidence on the island itself. There are drainage lines leading toward the south side which have been beheaded at the bank which fronts the ocean. From the aspect of the lines the inference was drawn that a greater area has been cut away than exists at present.

In 1837 Dease and Simpson stated that there was a passage inside of the tundra island which they named Cape Halkett. At present this passage is closed by a spit which runs out from the mainland. The reefs west of Cape Halkett are now replaced by sand bars.

Cape Simpson, according to the narrative of Dease and Simpson and as shown on their map (fig. 5, p. 74), was a sharp point projecting a mile or so into Smith Bay. This point has been cut away, so that it is now impossible to locate the place where the name was applied. The maps of the coast line at Point Drew and Cape Simpson, as drawn by both Dease and Simpson in 1837 and by Maguire (figs. 5, p. 74, and 6, p. 81) in 1853, are so similar that there can not be any doubt of their general accuracy. When these maps are compared with the writer's map (Pl. III) the amount of erosion at these places becomes apparent.

The dimensions of the deer pond near Point Drew, as well as the shape of this point as it appears on Dease and Simpson's map (fig. 5, p. 74), show that a considerable amount of the land has been cut off by the waves since 1837. The lake is stated to have been 4 miles inland; at present it is not more than 2 miles.

With the exception of the changes mentioned the coast line seems to be about the same as it was nearly a century ago. Most of the names given by Franklin and by Dease and Simpson can be confidently located upon the writer's map.

There is very good evidence that some parts of the coast line have been stationary for centuries. On the sand spit running east from the north end of Barter Island there are Eskimo ruins which must be very old. The same is true of Arey Island. The woodwork of the houses is decayed even under the ground, so that there is simply a mound of gravel to mark the location of a former gravel-covered driftwood hut. There are huts with the framework still standing at Collinson Point, yet none of the living natives knew who formerly inhabited them. Collinson mentions passing several huts on a shingle point in 1854, probably those on Collinson Point. The age of the older huts near Barter Island must be many times that of those at Collinson Point.

In addition to the evidence from the ancient houses, there is the evidence from the vegetation on the sand spits and islands. It seems certain that moss and grass require many years to secure a foothold upon gravel and sand, yet many of the larger islands are covered by such vegetation. Although the beacon on Cross Island was erected before Stockton's visit in 1889, the gravel is still bare around its base.

RATE OF EROSION.

That the coast is locally being cut back is evident from the numerous fresh banks. The rate of retreat of the shore probably varies with the nearness of the sea ice to the shore. The blocks that break off after being undercut may remain at the foot of the bank to protect it for several seasons. Consequently observations must be carried over a period of several years to ascertain the rate of retreat at any place.

During a single gale lasting two or three days a tundra islet in the sand spit on the north side of Flaxman Island was cut entirely away. The dimensions of this islet were approximately 50 feet long, 30 feet wide, and 5 feet high. The prospector Arey dug an ice cellar in 1901 at Brownlow Point, east of Flaxman Island. It is reported to have been a hundred yards from the beach. In the summer of 1907 the sea had cut the shore back so that this ice house was exposed in the bank. Allowing for a generous overestimation of the distance a rate of more than 30 feet a year is indicated for the retreat of the coast at this place.

If Flaxman Island has been cut back half a mile since 1827, an annual retreat of 30 feet is indicated. At Point Drew the rate may be over a hundred feet and at Cape Simpson about the same. These localities, however, are exceptional.

During the open season of 1911, all the exposed parts of the coast were affected by the waves. During the next summer all the banks were lined with the blocks which had broken off. In 1914 some of these blocks were still in existence. An average retreat of 10 feet for all the cliffs on the north shore is estimated for the summer of 1911, but as scarcely any retreat occurred between 1911 and 1914, the average retreat must have been less than 4 feet.

The writer regrets that he did not place a line of stakes near the north side of the island when he first arrived, so that the amount of erosion might have been measured between 1906 and 1914. In 1914 the boulder shown in figure 9 (p. 143) was found by pacing to be 55 yards from the top of the bank. It is of light-colored granite, about 5 feet long, and lies on the tundra about a mile from the northeast corner of the island. At the same time there were two abandoned native huts near the base of the spit north of the writer's house, which were 5 and 42 yards, respectively, from the northern bank. The northernmost one was formerly inhabited by a native named Wixrak and the other by one named Kaurnaurak.

The writer's large-scale map of Flaxman Island (Pl. V, in pocket) is thought to be sufficiently accurate to show changes of hundreds of feet, so that a resurvey at a distant date will give a fair value of the rate of retreat of the shore. The other portions of the map vary in accuracy, but near triangulation points on the coast any changes of 50 feet ought to be revealed. Unfortunately many of the stations are so near to cliffs that they will be washed away before any use will be made of them. A sufficient number, however, may be recovered after a long period, for the purpose of comparing the writer's shore line with a new survey.

DRAINAGE.

Okpilak River.—The Okpilak seems to have had an orderly development, flowing out of the granite area and running to the coast with no apparent interruptions. Its floor at the edge of the mountains is so much higher than that of the Hulahula that eventual capture of the Okpilak by the Hulahula is probable. Already the head of a side stream from the Hulahula has reached to the edge of the main Okpilak Valley and has even visibly captured some of its drainage. This is shown in Pl. XII (p. 51), where small drainage lines run diagonally downward toward the left of the view, where the Okpilak lies. This area slopes to the left, and formerly the drainage all ran into the Okpilak. Recently the head of the valley in the foreground has cut across this

Okpilak drainage and has captured it for the Hulahula.

Hulahula River.—From the forks northward the Hulahula seems to have had an orderly development; south of the forks there is some indication of piracy. The northeast fork (not within the area mapped) heads on the south side of the Romanzof Mountains and flows southwest. At the forks it turns abruptly west into the northward-flowing main river. The valley of the south fork, which falls in line with that of the northeast fork, appears much too large for the short stream which it carries. There is reported to be a wide, low pass at the head of the south fork, and then an abrupt descent into the Chandalar drainage. Thus it seems probable that the northeast fork flowed southward into the Chandalar but was captured by the Hulahula, which had the advantage of a much shorter distance to the ocean.

The hard greenstone which blocks the Hulahula at the edge of the mountains may delay the downcutting so much that a side stream from the Sadlerochit will eat back through the soft Mesozoic shales which probably underlie the gap south of this greenstone area. A still more favorable place for capture is at the east end of the Sadlerochit Mountains, where Sadlerochit River is fast reducing the narrow neck of soft upland which still separates the two rivers.

Sadlerochit River.—There is good evidence that the Sadlerochit formerly flowed through the large truncated valley now occupied by Itkilyariak Creek. This valley, as can be seen on the topographic map, is beyond all question much too large to have been carved by the creek, which often is dry as early as June. The present elevation of Sunset Pass is about 700 feet above Sadlerochit River.

Canning River.—Possibly the Canning flowed across the western ends of the Shublik and Sadlerochit mountains, for there is a gap in each range which can be accounted for in no other way. The lateral streams on the east side of the Canning show adjustment to rock structure. Ignek, Cache, and Eagle creeks all flow in structural valleys where downfolds lowered the soft Mesozoic rocks.

PRESENT ACTIVITIES.

Some of the activities by which the features of the region are being modified are here outlined, especially the work of sea ice.

WORK OF WATER.

Although the action of running water nearly ceases during eight or nine months of the year, a given amount of annual precipitation, in running off during the brief summer, probably has a greater erosive effect than it would have if the flow were spread out over the whole year.

The frozen state of the ground probably reduces alluvial bank cutting to a considerable degree. Slow cutting may go on as the ice in the freshly exposed soil melts, but in times of flood, when the greatest amount of erosion of banks takes place in temperate regions, the frozen ground can not be rapidly cut away. Thus Arctic rivers may be expected to change their meanders more slowly than those of warmer regions.

Russell[1] has pointed out that the frozen state of the ground delays surface erosion, also that cold water has small dissolving power, and that vegetation decays slowly and so may retard drainage and favor deposition.

The ocean also is quiescent during most of the year, but during the open season it does not, by increased work, make up for the lost time, as the rivers probably do. On the contrary, the floating cakes of ice cut down the waves, so that their effect upon the Arctic coast is very small in comparison with those of other regions. The nearness of the ice pack to shore is of course the controlling factor in the work of the waves. On the average the pack is within sight of the land the whole summer, and sometimes it is so close that no noticeable waves can be formed. Occasionally the pack recedes a great distance, so that waves of considerable size may be formed during onshore gales. In 1911 and 1912, from reports by captains of whaling ships, the ice was more than 100 miles from land. Certainly a tremendous sea rolled in at times from the ocean, overwashing islands and spits which had not been disturbed for a

[1] Russell, I. C., Surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 128–129, 1889.

very long period. In one such season more work is probably done on the coast than in 50 ordinary years.

WORK OF INLAND ICE.

The snowfall is so small that its work as snow is almost negligible. The native sheep hunters report that avalanches sometimes occur, but they can not be frequent, else the writer would have observed them. The living glaciers probably do at least as much work as those of warmer regions of an equal amount of precipitation. The motion may be slower, but the ice is thicker.

The deposits of aufeis (described on p. 158) upon the flood plains of the rivers have little effect upon the development of the topography, except that the channel is likely to be shifted more frequently. The water flowing over this flood-plain deposit of ice may concentrate and cut a channel through the ice which may not at all coincide with the river bed beneath. This superimposed drainage may intrench itself into the frozen ground before the old channel is free from ice.

WORK OF SEA ICE.

The ice pack is often driven violently against the land, and thus is a factor in the development of the shore line. There is also a shoreward pressure from the expansion of landlocked bodies of ice, and this is sometimes true on the open shores, when heavy grounded ridges prevent expansion seaward.

During a period of warm, calm weather one July the ice on the north side of Flaxman Island was shoved up on the beach. Plate XXV, *B* (p. 167), shows an early stage of the movement of the ice which locally overrode the beach 15 to 20 feet. About 3 miles from land the sea ice was so firmly anchored to the bottom by heavy ridges that during the heavy pressures of the winter the shore ice was not disturbed. Although there may have been some motion of the ice toward the beach as it expanded during the gradual advent of spring, no evidence of this was found. The whole visible motion occurred in a few hot days after the sea ice had reached the approximately stable temperature of summer. It seems to the writer that the expansion of this ice can not be due to a rise of temperature, for the amount of expansion—about one one-thousandth—seems far too great. The explanation may lie in the regelation of the snow water as it soaked down into the cold sea ice.

There are rather exaggerated accounts of the pressure of the moving sea ice against the shore. When the shore is formed by a steep bank the ice will bring solidly up against the bank and will then buckle and fracture at some weak place. This buckling and fracturing is very apt to occur near the beach. The ice moves steadily shoreward and thus piles up sometimes to a height of 30 to 40 feet. If the bank is low, the ice blocks may form an incline over which an unbroken sheet of ice may mount to override the bank. but this is very exceptional.

Where the shore rises gently from the sea level, as on sand spits and islands, the tongues of ice may mount in an unbroken sheet many feet upon the land. Then, as the resistance to such movement becomes great, the ice may buckle and fracture near the shore line, and a new tongue be shoved up over the first one until a great pile of ice is built up on the beach. The greatest distance of movement of ice over the beach with which the writer is acquainted is at the village of Barrow. Here the ice is reported to have once reached a building which is estimated to be nearly 200 feet from the water's edge. The ice pressure against the west side of Point Barrow is by far the greatest on the Arctic shore of Alaska, and it is probably as great as anywhere in the world.

East of Point Barrow the motion of the ice is chiefly along the land, so that notable pressure is exerted only upon salients in the coast line. Evidence of former pressure upon the beach was infrequently seen, and in no place did such evidence extend more than 100 feet from the ocean.

Collier[1] reports that the school-teacher at St. Lawrence Island, in Bering Sea, was in fear of the destruction of the buildings, which stood half a mile from the sea. This fear was groundless, however, for there are many native huts much closer to the beach than the schoolhouse, and if anyone is acquainted with the behavior of the ice pack an Eskimo is.

[1] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, p. 34, 1906.

The distances which the ice is stated to have reached in shoving up on the shore do not represent a uniform advance of the ice over the whole beach line. Where the maximum advance is 200 feet the average distance may not be 20 feet. Even on the west side of Point Barrow the ice does not shove up on the beach every year, and east of this point such pressures are still less common.

In moving shoreward the ice carries material from the sea bottom up on the beach. When the ice melts this material is left behind, so that the effect of the ice pressure is to build up the shore at the expense of the sea bottom. As the ice advances only short distances, except on gently sloping beaches, most of the material transported is within easy reach of the waves of the next summer. The piles of gravel, or turf and gravel, formed in this way, have been observed to reach a height of perhaps 15 feet, but a brief examination shows that the bulk of the material is ice. As the protective mantle is of pervious material the ice will melt out before many years, leaving an area of hummocky topography, in which the relief is not more than 5 or 6 feet.

If the ice remains near the coast all summer, as frequently happens, the waves may not be able to remove the evidence of the previous winter's pressure. During such summers many piles of gravel may be observed along the beach. On the other hand, during open seasons the waves quickly obliterate most of the gravel piles that have accumulated since the last open season.

In a very few places the pressure may have carried the material beyond the reach of the waves, and there the piles of gravel and turf will remain indefinitely unless the shore is cut back so that the waves can reach them. There was only one place along the north shore of Alaska where the writer observed a deposit of material that had been carried notably beyond the reach of the waves. This locality was on the east side of Camden Bay, perhaps 4 miles east of Collinson Point, at which place for several hundred yards there was an area of disturbed gravel, turf, and driftwood which reached in places more than 100 feet from the water's edge. Here and there along the sand islands and spits isolated heaps of gravel are the only evidence of former pressures. In Plate XXV, *B* (p. 167), is shown a pile of gravel which is representative of the ordinary pressures that occur on the north shore of Alaska.

Any estimate as to the amount of material moved landward by the ice can only be vague. Probably more work is done by the waves during half an hour of an autumn gale than is done by the ice during a whole winter. During a single open season probably more material is moved by the waves and currents than is moved by the ice during 50 years.

Where heavy cakes of ice ground in deep water they force up ridges of material, which, as they are not within reach of the waves, may remain a long time. Currents also probably deposit more material in the eddies caused by the grounded cakes of ice, thus building up the bottom. This grounding of heavy ice may play an important part in the formation of shoals.

Pressure ridges sometimes dam up the outlets of small creeks, thus producing a local flooding. The occurrence of fresh driftwood some distance above sea level in small coastal gullies and lagoons may be explained in this manner.

In moving over the beach the ice may produce striations upon the beach gravels. After a careful search in several places the writer found two or three beach stones with faint scratches upon them. They can not be mistaken for glaciated stones, although some of the scratches are parallel. The stones evidently have been rounded first and then slightly abraded.

During the spring the ice along the beach, unless protected by heavy snowdrifts, melts some time before the ice off the shore is broken up, so that there is ordinarily a narrow lane of water between the ice and the shore, even while it is possible to travel over the sea ice. Consequently, when the ice finally breaks away from the shore, it does not leave a general ice foot as in higher latitudes. Only on the north side of high banks, where the snow is late in melting, is anything seen that approaches an ice foot.

As the ice in contact with the beach melts away as a rule before the pack moves there is very little chance that beach material may be picked up and transported by the sea ice. Where heavy snowdrifts protect the ice, conditions are somewhat more favorable for transportation. In such places the ice usually breaks off at the tide crack between the floating and the land-fast ice. The land-fast ice may later break from the beach and possibly carry some beach material with it.

Vegetation, silt, sand, and gravel may be blown out upon the ice. Boulders and mud may slump down on the ice under high banks. (See Pl. XXVI, *B*, p. 202.) Gravel, sand, turf, and driftwood may be carried out on the ice by spring floods of rivers or by the small coastal lagoons after breaking through their barrier beaches. All such material, except boulders, is often observed upon the sea ice. Collinson[1] reports three stones the size of a man's head upon the ice 10 miles from land, near Point Tangent (30 miles east of Point Barrow).

Material included in the bottom of the ice when it breaks from the land is probably not carried far before it is melted out, but that on the surface of the ice has every chance of being transported to a distance. As the ice melts the material will be scattered over the bottom of the ocean. The resulting formation may be characterized by a groundmass of fine water-laid material with stones scattered through it. As the deposition of ice-borne material is periodic, the pebbles may be more abundant in particular horizons of the formation. They may even locally form a thin bed.

The retreat of the pack from the shore during diagonally onshore winds deserves notice. There is some force which keeps the ice together as a body, even though the effect of the wind is to scatter it. The eddy currents set up along the edge of a drifting pack probably act so as to pull the loose pieces toward the main body of ice. The writer when stationed upon grounded ice, separated from the moving pack by a narrow lane of water, has observed loose cakes traveling at least a mile an hour in an opposite direction to the main drift, against a strong wind. These cakes would sweep into bays in the edge of the moving pack and become lodged and then follow the general drift with the wind.

A great amount of water must be dragged along by the uneven lower side of the ice pack, and the disturbed ocean level must be restored by a countercurrent. There seems to be a component of this current toward the sides of the pack, by which the loose cakes within its scope are gathered into the main body. The cakes beyond the reach of the eddies are drifted away by the wind, so that as a rule the edge of the main ice pack is quite definite.

WORK OF WIND.

Although high winds are frequent, they cause no marked amount of erosion. In a few places, especially in cols in the mountains, the wind has cut the turf partly away. The finer material is locally swept from the beach deposits, leaving a concentration of coarse stones on the surface. In the winter hard snowdrifts are cut to pieces by the wind.

Nor does there seem to be any notable amount of material, excepting snow, transported by the wind. The fine snow at low temperatures is picked up by winds blowing 15 miles an hour and swept along within a few inches of the ground. As the wind increases in velocity the drifting snow rises higher, until at 25 miles an hour the snow is drifting higher than a man's head. Heavy gales carry the snow several hundred feet into the air. Many times the air was so full of drifting snow that at a distance of a hundred feet only the topmasts of a schooner could be seen. During one or two gales, when the wind was estimated to be more than 60 miles in velocity, it was at times impossible to see a 6-foot post only 20 feet from the window of the house, and dark objects on the ground within 6 feet of the window were frequently obscured.

Such forms of vegetation as occur upon the tundra are broken off and carried by the wind to great distances, but the total amount of such material must be very small.

The mud flats of rivers afford a supply of silt, which is picked up by the wind. It does not seem to be carried far, for most of the silt dunes are confined to the immediate banks of rivers. The writer has observed discolored snowdrifts about 5 miles in the lee of a silt-dune area, but the total amount of silt transported more than a few hundred yards is very small. There are unburied boulders which must have been upon the surface of the tundra a very long time.

No sand drifts more than a foot or so high were observed. The tundra in the immediate

[1] Collinson, Richard, Proceedings of the *Enterprise*: Roy. Geog. Soc. Jour., vol. 25, p. 197, 1855.

lee of a wide sand beach may have sand scattered over it for a hundred feet but not enough to cover the grass. Either the sand is too coarse to drift readily or the supply is too scanty for the formation of large sand dunes. As the climate is very damp, there may be very little dry sand during any particular high wind. The writer has observed scattered grains of sand upon the sea ice as much as 3 miles from any possible source. Stones half an inch in greatest diameter have been observed on the sea ice a mile from their probable source. They were scattered in a wide belt in the lee of a sand spit.

WORK OF FROST.

There is a tendency to postulate a greater shattering action of frost upon the rocks of the Arctic than upon those of warmer regions, but the writer was unable to note any difference in this respect between the general aspect of the Arctic Mountains and the higher mountains of the United States. Smooth glaciated slopes of granite occur on Okpilak River, and the amount of talus in general is not striking. As the chief work of frost upon the rocks is accomplished through alternate freezing and thawing, it would seem that high latitudes are not favorable for this. During seven months of the year the temperature at sea level is permanently below freezing. At high altitudes the period is probably somewhat longer. During most of this time the sun is low or absent, so that the rocks are seldom warmed to the thawing point. In summer when the temperature on the mountain tops may be near freezing there are not the usual great alternations of temperature from day to night.

The ground ice of the north shore of Alaska occurs chiefly as a network of vertical wedges which inclose polygonal blocks of the tundra formation. (See p. 205.) The ice wedges are accompanied by two kinds of surface topography—shallow depressions, which surround elevated polygonal blocks, or two parallel ridges, which surround depressed blocks.

In addition to the disturbance of the surface produced by the formation of wedges of ground ice, the material in the ground for several yards in depth is deformed by the lateral pressure exerted by the growing wedges. The most striking development is seen in the upturning of muck beds and the squeezing up of lower layers of sand along the sides of the wedges. Accompanying this displacement of material there must be a general slight elevation of the surface of the ground to make place for the intruding ice. A possibly extreme example of this work is seen in the New Siberian Islands, where there are indications that ground ice wedges have grown into contact at their upper portions. After this contact was formed the ice kept increasing by upward growth until the surface of the ground had been elevated several yards.

On the coastal plain and elsewhere in the Arctic there are isolated mounds which have probably been raised by hydraulic pressure of ground water upon a layer of frozen ground.

Högbom [1] has recently brought out an article upon the work of frost in which he gives a bibliography of 150 publications. He has devoted much space to the description and explanation of the surface markings of unconsolidated deposits, and he illustrates some polygonally divided areas of the tundra of Spitzbergen.[2] Similar areas in the same region are described by Holmsen as being underlain by ground ice, and as is shown under the discussion of ground ice (p. 205) there is every reason to regard these polygonal markings as due to ice wedges.

CRITERIA OF ARCTIC CLIMATES.

Some of the natural forces which are at work on the north shore of Alaska produce effects which may remain for a long period. If the climate should become milder, evidence might still be found of the former Arctic climate. Below are presented some of the lines of evidence that appear to be of importance.

Glacial drift is by no means indicative of an Arctic climate, nor is the reverse true, that the absence of drift denotes the absence of such a climate. The amount of precipitation is so largely the controlling factor that the degree of cold can not be estimated unless the other factor is known.

Striations upon stones may be produced not only by glacial action but by moving river and

[1] Högbom, Bertil, Ueber die geologische Bedeutung des Frostes: Geol. Inst. Upsala Bull., vol. 12, pp. 257–390, 1914.

[2] Idem, fig. 28; also Einige Illustrationen zu den geologischen Wirkungen des Frostes auf Spitzbergen: Geol. Inst. Upsala Bull., vol. 9, fig. 8, p. 56, 1910.

sea ice, and it has been suggested that stones entangled in the roots of drifting trees may produce or receive striations. The polishing and striation of stones embodied in the banks of Alaskan rivers is thus described by Russell:[1] "Many of the stones * * * are so similar to glacial pebbles that if removed from their normal positions to a glaciated region, even the most acute observer would attribute their markings to glacial action." The striation of beach stones by the motion of sea ice as described above (p. 174) is a very rare feature. The striations produced by floating trees must be almost negligible in amount. The striations of river pebbles may of course be formed in temperate climates, but those found upon ocean beaches indicate a climate which approaches that found in the Arctic to-day.

Scattered boulders or pebbles in a deposit of fine material may have originated in several ways. The most obvious method is by dropping from floating ice. Stones enmeshed in the roots of recently fallen trees may also be transported and dropped upon the bottom of bodies of water. Barrell[2] points out that pebbles may be transported a great distance by the wind. The presence of scattered stones in finer formations is mentioned by Davis as an evidence of cold climate.[3] Boulders may be dropped from icebergs in such temperate regions as the North Atlantic, however, and are not necessarily evidence of cold climate.

If the climate of northern Alaska should become so mild that the ground no longer remained frozen, there would be evidences of the former cold climate in areas where wedges of ground ice had been developed. At first the coastal plain would be covered with a network of deep gullies, such as are seen to-day where the ice has been cut out near high banks. Slumping of the thawed ground would smooth the contours, and vegetation would, perhaps, fill up the depressions. The most striking condition would probably be the penetration of surface formations down into the hollow left by the melting ice. Smith[4] describes some features of the Nome ground deposits which may in part have originated in this manner:

> A series of ramifying streaks of a black peaty material cut in irregular directions across the layers of sand and gravel. * * * When first examined it was believed that they represented cracks which had been subsequently filled by material from the surface. * * * In the light of more careful study, however, such an interpretation seems inadequate, for many of the seams taper off toward the top as well as toward the bottom, so that a connection with the surface is not indicated.

The presence of gravel mounds outside of glaciated areas, if the theory proposed for their origin is found to be correct, is definite evidence of a climate sufficiently severe to bring about a frozen state of the ground. So far as the writer knows, nothing similar to these mounds has ever been reported outside of areas affected by such a climate. The formation of kames at the immediate front of an ice sheet is well understood. If the region in front of the ice were subjected to an Arctic climate, gravel mounds might be found at a distance beyond the line of maximum extension of the ice and be mistaken for kames. It is thus seen that piles of gravel do not necessarily mark the exact front of the ice.

Modern deposits of aufeis upon the flood plains of northern rivers do not seem to leave any permanent marks upon the topography. Under favorable circumstances, however, such as along the front of a continental glacier, a wide belt of aufeis and outwash might be built up. Upon the melting out of the ice with the advent of a warmer climate the surface of the resulting outwash plain would probably form gentle undulations instead of a dead level. Accumulations of coarse material might take place at the bottom of canyons melted into the aufeis, and these deposits would resemble eskers leading out from the former ice front.

Where the sea ice has shoved material far up on the land the resulting hummocky topography might remain through a change of climate. Even if it were generally buried by growth of the surface, exposures would reveal a disturbed area of beach formations.

[1] Russell, I. C., Surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 117-120, 1889.

[2] Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, p. 283, 1908.

[3] Davis, W. M., Antarctic geology and polar climates: Am. Philos. Soc. Proc., vol. 49, pp. 200-202, 1910.

[4] Smith, P. S., Recent developments in southern Seward Peninsula: U. S. Geol. Survey Bull. 379, p. 272, 1909.

MINERAL RESOURCES.

POSSIBILITIES OF DEVELOPMENT.

As will be evident from the narrative of the expedition, there was no time for detailed search for mineral deposits. The writer had, however, the advantage of association with the prospector Arey, who had lived in the country many years and had himself prospected the region here described. The general conditions of isolation, climate, and transportation are such that even if parts of the Canning River region are mineral bearing the chances for their development are not favorable, and it is not likely that they will attract the prospector.

A few fine flakes of gold constitute the only definite evidence of any occurrence of valuable minerals within the region here described. A seepage of petroleum and some outcrops of coal have been found in the western part of the Arctic slope region. These discoveries will be referred to below. It is possible that the formations in which these mineral fuels occur underlie part of the Canning River region, but of this there is no direct evidence.

PLACER GOLD.

Hardly a trace of gold was found in the gravels of any of the streams except in those of Okpilak River. Here the prospector Arey reports the discovery of some fine particles of gold. Another prospector is also said to have found alluvial gold on this stream. The Okpilak has its source in a region of metamorphic rocks and intrusive granite, a geologic condition generally considered favorable for auriferous mineralization. It is probable, therefore, that the alluvial gold above described was derived from these metamorphic rocks. These rocks occur in a belt that trends eastward (p. 103) in the southern part of the Canning River region and seem to be the only rocks in the region that are likely to contain gold deposits. An auriferous quartz vein is reported to have been found in the Canning River valley but was not sufficiently attractive as a mining venture to warrant its being staked.

Even if gold placers were found in this region, the adverse climatic conditions, the remoteness of the field, and the absence of fuel except on the coast would hardly justify development unless the deposits were extraordinarily rich. The evidence at hand does not indicate any intense mineralization, and therefore it is unlikely that rich placers have been formed.

COAL.

Although no coal in place was found within the region studied, there is every probability that it occurs on the rivers west of the Canning. The red beds in the Ignek formation have been described as marking the location of former coal beds. The natives report coal on Shaviovik and Sagavanirktok rivers, and Schrader found it on the Colville. The writer has seen brown lignite in an ancient Eskimo house at Barter Island.

PETROLEUM.

At Cape Simpson, on the west side of Smith Bay, there are two conspicuous mounds. The writer has been informed by natives that the northern mound contained a petroleum residue, but, according to information furnished by Stefánsson, this residue is contained in a pool a few hundred yards from the mound. A sample was secured from a keg of the material collected by natives in the employ of Mr. C. D. Brower, of Barrow. It resembles axle grease. An analysis by David T. Day is given below. The deposit is near the seashore, and the natives say that a considerable amount could easily be dug out with spades.

Composition of petroleum residue from Cape Simpson, Alaska.

Water and soluble matter	22
Alcoholic extract (resins and some oil)	8
Naphtha extract:	
Light oil	12
Heavy oil	16
Benzol extract (asphaltic material)	11
Clay and vegetable fiber	29
	98

Natives report another petroleum mound between Humphry Point and Aichillik River, near the coast. According to current reports, an oil seepage has been discovered in northern Alaska near Wainwright Inlet, about 100 miles southwest of Point Barrow.[1] If this report is

[1] Brooks, A. H., The Alaska mining industry in 1915: U. S. Geol. Survey Bull. 642, p. 35, 1916.

confirmed, it indicates that there may be an oil field between Wainwright Inlet and Smith Bay. These oil-bearing rocks may also occur in other parts of the Arctic slope region. Even if an oil pool were found in this northern region, there is serious doubt of its availability under present conditions, though it might be regarded as a part of the ultimate oil reserves that would some time be developed.

AMBER.

Though the writer has never personally found any amber, he has seen the natives pick up a few pieces a quarter of an inch in diameter from the protected beaches between Harrison and Smith bays. In the collection of Eskimo gear belonging to Mr. C. D. Brower, of Barrow, there were several carved pieces of amber perhaps an inch in diameter. The writer is not absolutely certain that the substance was amber, for no specimens were procured, but the transparent yellow substance could hardly be mistaken.

GROUND ICE.

INTRODUCTION.

The ground in Arctic and sub-Arctic regions, as is well known, is permanently frozen to great depths and thaws to a depth of only a few feet in summer. Many observers have reported the presence of more or less clear ice within the frozen ground and have advanced theories as to its formation. During the nine summers spent by the writer on the north Alaskan coast, exposures of ground ice were examined at every opportunity. In constructing the map the entire coast was traversed on foot, with the exception of the river deltas and a few shallow bays. The coast was examined both on sled and boat trips outside the mapped area, so that few stretches between Martin Point and Point Barrow were not visited.

During the first seven summers, although many exposures were examined and described in notebooks, no insight was gained into the formation of most of the coastal ground ice. During the winter of 1912–13 the American literature was examined, but no theories were found which would fit the conditions. During the writer's last trip to the Arctic exceptionally good exposures gave details which had previously escaped notice, and he was able to construct a theory of the formation of ground ice which not only applies to the north coast of Alaska but seems also to apply to other regions.

The chief difficulty in the study of the tundra formation arises from the poor exposures. As the ground is composed of material consolidated only by frost, a short exposure to the summer air causes slumping and consequent masking of the details. Only where wave or river action has undermined the face of a bank, so that large blocks break off, are good exposures formed. When slumping has taken place erroneous conclusions may be drawn as to the distribution of the ice, for scattered outcrops may be interpreted as exposed parts of a single bed.

The upper surface of the ground ice is usually only a foot or two under the surface of the tundra. Consequently, in an area in which discontinuous bodies of ice are separated by masses of muck and other material there will be the least amount of material for slumping exactly where the ice occurs. The ice melts back under the overhanging turf, forming a cave, and at either side the muck slumps and masks the whole face of the bank. Thus, wherever the actual surface of the bank is exposed, ice is apt to be seen, and observers are lead to believe that a continuous body of ice underlies the whole area.

In addition to the erroneous impression as to lateral extent, the conclusions as to thickness are also often faulty. A winter's snowdrift against the foot of a bank may be covered by slumping and be later exposed, apparently showing a thickness of ice only limited by the height of the bank. The same may be true of river or sea ice. An illustration is given of an apparently continuous bed of heavy ice which the writer examined carefully for a quarter of a mile, before learning its true nature (figs. 11 and 12, p. 180).

The waves had undercut this bank the summer before, making a long low cave, perhaps 10 feet deep. During the following winter this cave had been flooded at high tide and partly filled with ice. Early in the summer the face of the bank had been masked by slumping, leaving only a few glimpses of true ground ice under the turf. Shortly before the time of observation the lower part of the bank had been washed clear of débris, exposing the continuous layer of new sea ice. This layer appeared to be ground ice, when considered in

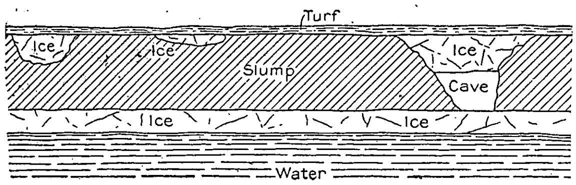


FIGURE 11.—Exposure of a bank showing an apparently continuous thick bed of ice.

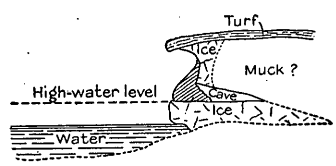


FIGURE 12.—Structure of the bank shown in figure 11.

connection with the scattered exposures of undoubted ground ice above it. Luckily the cave was exposed to view at one point, so that the mistake in interpretation could be corrected.

DEFINITION OF GROUND ICE.

The term "ground ice" is used to denote bodies of more or less clear ice in permanently frozen ground. Deposits which are evidently only temporary features are excluded under this definition, and the term is not applied to deposits which seem to be on top of the ground. Stagnant earth-covered glaciers appear to fall about in the dividing line of this definition. If their glacial origin is evident, they would be excluded. The lower end of the Malaspina Glacier might be called ground ice if nothing were known of its connection with the living glacier. Any glacial ice embodied in the flat Arctic tundra, as there may be at Flaxman Island, must be included in any definition. Ice in caves and under talus in regions of unfrozen ground is excluded.

Synonymous with ground ice are the terms subsoil ice, underground ice, subterranean ice, fossil ice, stone ice, bodeneis, ureis, and jordbundsis. The word glacier is used by miners to denote both ground ice and frozen ground, and at least one scientist has adopted this loose terminology.

The terms ice beds, ice sheets, and ice cliffs, as a rule, refer to ground ice. Anchor ice on the beds of northern rivers is often called ground ice, but in the more exact descriptions the term anchor ice is used.

Frozen ground is called eisboden and taele. The term ground frost relates to this phenomenon. In speaking of the depth of frost the depth of permanently frozen ground is meant.

DISTRIBUTION OF PERMANENTLY FROZEN GROUND.

As the existence of ground ice is theoretically possible wherever the ground is permanently frozen the horizontal and vertical distribution of frozen ground will be discussed in the following pages.

HORIZONTAL DISTRIBUTION OF FROZEN GROUND.

If nothing prevented the free access of air to the surface of the ground their mean annual temperatures should be equal. The annual variations of temperature are ordinarily perceptible to a depth of about 50 feet. In order that the ground may be permanently frozen the mean regional temperature must be sufficiently below freezing to offset the gradient of increasing ground temperatures to a point below the limit of annual change of temperature. This gradient is subject to such complications from the alternately frozen and unfrozen state of the ground that it can only be assumed to be within the ordinary limits of less than a hundred feet per degree Celsius, so that the mean annual temperature of the air need be less than 1° C. below freezing in order to bring about permanently frozen ground. The line limiting the distribution will thus follow closely the isothermic line for 0° C.

Several influences, however, disturb this theoretical distribution, all tending to raise the temperature of the ground above that of the air. In summer the absorption of the sun's rays by the ground is in excess of the radiation, for the isotherm of 0° C. runs through high latitudes, where the days are much longer than the nights. Where the ground is shaded, of course, both absorption and radiation are hindered.

The presence of water has a great influence upon the distribution of ground frost. Obviously the ground can not freeze downward under a body of water of a depth greater than the annual thickness of ice. The ground may freeze under small bodies of water by lateral conduction from the cold ground which surrounds the water, but this can not take place in large lakes. Near the southern limit of frozen ground a very small lake may keep the ground underneath it unfrozen, and it is doubtful whether a lake half a mile in diameter would have frozen ground under its center, even where the frost limit is in general at a depth of 1,000 feet.

Flowing water, either on the surface or in the ground, also plays an important part in the distribution of ground temperatures, as it tends to raise the temperature of the ground in cold regions. In porous soils the water warmed at the surface may carry down the higher surface temperatures much faster than they can penetrate by simple conduction. The effect of the penetration of surface waters into the ground is shown by Callendar and McLeod.[1] After a heavy rain, the temperature at 10 inches in the ground was raised 4° F. in two days.

It is well known that, in placer mining in regions where the ground as a rule is deeply frozen, there are unfrozen areas among the gravels. Moffit[2] mentions this fact in describing the Nome region.

> In general the gravel * * * is frozen from top to bottom, but in places there is no frost. These unfrozen areas are distributed irregularly, and their presence has never been satisfactorily explained. * * * Thawed ground is in some places overlain by frozen ground, and in one or two places is known to be underlain by it also. The presence of thawed gravel appears to be due in part, at least, to the circulation of water through the ground. * * *

In winter snow forms an insulating layer which retards the penetration of the cold wave. The importance of this insulation is emphasized by Callendar and McLeod[3] as follows:

> With respect to the buried thermometers the most remarkable feature of the curves is the extreme steadiness of the temperature throughout the winter. This is due to the protective effect of the snow covering, and is followed by an extremely rapid rise as soon as the snow disappears and the ground is thawed. * * * That the annual mean temperature of the soil is nearly 5° F. above the mean temperature of the air is probably due to the protective effect of the snow during the winter months.

These disturbing influences are sufficient to prevent the formation of permanently frozen ground under standing bodies of water, and to a less extent where the ground circulation is strong. Such localities are exceptions in the general distribution, which is chiefly influenced by the combined effect of the summer's absorption of radiant heat and the winter's insulation by snow. There is a lack of information as to mean annual temperatures at the southern limit of ground frost. Holmsen,[4] after searching the literature for data upon the subject, concludes that where the mean annual temperature is below —4° to —6° C., the ground is as a rule frozen and may contain ground ice. This estimate seems to the writer to be as accurate for ordinary soils as can be made at present.

VERTICAL DISTRIBUTION OF FROZEN GROUND.

ANNUALLY THAWED LAYER.

Above the permanently frozen ground there is everywhere a layer which is alternately frozen and thawed each year. The thickness of this layer, though primarily dependent upon the warmth of the summer, is yet so greatly influenced by the nature of the soil that it is quite variable. Porous gravels and sand will thaw many times as deep as muck or clay. Moss-carpeted forest-covered areas may thaw only a few inches while neighboring bare gravel bars are thawing many feet. In most of the areas in which ground ice is recorded the limit of seasonal thawing is less than 6 or 7 feet, less than 3 feet being the rule.

[1] Callendar, H. L., and McLeod, C. H., Soil temperatures: Roy. Soc. Canada Proc. and Trans., 2d ser., vol. 2, sec. 3, p. 111, 1896.

[2] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, pp. 116–117, 1913.

[3] Callendar, H. L., and McLeod, C. H., op. cit., pp. 109–110.

[4] Holmsen, Gunnar, Spitzbergens jordbundsis: Norske Geog. Selskaps Aarbok, vol. 24, pp. 112–132, 1912–13.

CONDITIONS AFFECTING THE DEPTH OF FROST.

In the theoretic discussion of the penetration of frost into the ground only the effects of temperature, time, thermal diffusivity, and the water content of the soil are taken into account. The depth increases in a complicated ratio, directly with time and diffusivity and inversely with the temperature and water content. By means of these constants it is possible to calculate the depth to which the ground will freeze if not disturbed by other influences. The constants are difficult to ascertain, the surface temperature being the only one which can be easily determined with any accuracy. It is necessary to assume different values of the other constants and calculate the depths accordingly. This is discussed under the heading, "Age of frozen ground" (p. 187).

It has been shown that the ground is not uniformly frozen, even where low temperatures prevail. The differences in the diffusivity of the ground will have some effect in bringing about this variation of depth, but the chief factor is probably the circulation of ground water, which may greatly interfere with and even prevent the freezing of the ground. The presence of salts in the ground water will raise the limit to which the freezing takes place. This is not an important feature but may be expected near the seashore. It is to be noted that unfrozen brine seeped into the bottom of the shaft at Barrow,[1] where the temperature was —12° F.

The most favorable condition for the penetration of frost to the limits set by the temperature, time, diffusivity, and water content of the soil is found in impervious soil well away from any bodies of water. A flat region where the ground circulation is stagnant is favorable even when the soil is not impervious.

As illustrating the irregularity of ground temperatures and consequently the depth of frost, the observations recorded by Middendorff[2] in the neighborhood of the Schergin shaft are of importance. The table below shows the ground temperatures at different localities and those of the Schergin shaft at the nearest date.

[1] Ray, P. H., International polar expedition to Point Barrow, Alaska, pp. 338–339, U. S. War Dept., 1885.

[2] Middendorff, A. T. von, Sibirische Reise, Band 1, Theil 1, pp. 112–116, 1848.

Comparison of ground temperatures (° Réaumur) in the vicinity of the Schergin shaft.

Locality.	Date.	Depth of 7 feet.	Depth of 15 feet.	Depth of 50 feet.
		°R.	°R.	°R.
Borloch shaft	Apr. 5	−15.7	....	....
Schergin shaft	...do....	−15.1	....	....
Schilov	June 18	− 2.6	−4.0	−3.1
Schergin shaft	June 21	− 6.8	−8.8	−6.6
Mangan	May 23	− 6.1	−5.9	−3.3
Schergin shaft	...do....	− 9.0	−9.6	−6.6
Leontjov	June 19	− 3.7	−4.9	....
Schergin shaft	June 18	− 6.8	−8.8	....

The Borloch shaft was a few paces from the Schergin shaft and the other localities were probably within 5 miles, so that the air temperatures could not have been greatly different. The higher ground temperatures at these places may be best explained as being the result of the warming of the ground by surface waters. No other reason seems at all adequate, although heavier banks of snow and also increased sunshine against slopes may have had their effect.

RECORDED DEPTHS.

The greatest measured depth of frozen ground with which the writer is acquainted is 384 feet in the Schergin shaft at Yakutsk, Siberia. The temperature at the bottom was —3° C., which, from the gradient of temperature, indicates a total depth of frost of about 650 feet, as is described below.

In Alaska a shaft has been sunk 320 feet on Smallwood Creek in the Fairbanks mining district,[3] which did not penetrate below the frozen ground.[4] In the same district there are several shafts reaching about 200 feet, some of which are stated to be entirely in frozen ground.[5]

In the Nome district Moffit[6] reports a shaft 230 feet in gravels. No statement is given as to the depth of frost, but in Mr. Collier's field notebook of 1903 we find that unfrozen ground was reached at 90 feet in this shaft.

[3] Brooks, A. H., The mining industry in 1907: U. S. Geol. Survey Bull. 345, p. 42, 1908.

[4] Brooks, A. H., oral communication.

[5] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, pp. 102, 121–122, 1913.

[6] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, p. 39, 1913.

In the Koyukuk region a shaft has been sunk 335 feet into the ground, and a pipe was driven 30 feet deeper, making a total depth of 365 feet.[1] The writer has been informed by Mr. Maddren that the limit of frost was not reached. Several other shafts from 135 to 180 feet deep were sunk in the same region, all in frozen ground.

Tyrrell[2] reports that the ground in the Klondike region is frozen to a depth of about 200 feet.

In Spitzbergen a tunnel of a coal mine on Advent Bay is reported to run 500 to 1,000 meters into the mountain side. The end of it may lie 100 to 200 meters below the surface of the ground.[3] The temperature at the inner end of the shaft was —4.5° C. It is unfortunate that more accurate data are not available, for this seems to be one of the deepest records of the penetration of ground frost.

In Arctic Alaska, outside of the mining district, the writer finds only one record of excavation—that made by Ray at Point Barrow in 1881–82. This was only a shallow hole 37 feet deep. The frozen layer may have been penetrated, for brine flowed into the bottom of the shaft; but as the water did not rise many feet it is more likely that a pocket of brine had been tapped. The temperature at the bottom of the shaft (12° F.) shows that the frost must penetrate many feet deeper.

DEPTHS DEDUCED FROM GROUND TEMPERATURES.

The depth of frost is of both scientific and practical importance. In placer mining regions frozen ground is so much cheaper to work, chiefly on account of the absence of water in the shafts, that this consolidation of the gravels is almost a necessity. Thawed areas are avoided as much as possible, and if such ground is met with in excavation it is sometimes necessary to form bulkheads against it by artificial refrigeration. In placer regions the porous gravels are so influenced by ground circulation that the depth of frost is very irregular. Practical tests in the field are more decisive than scientific deductions from the phenomenon in general.

The large operators bore prospect holes, which of course settle the question as to the state of the ground. Where this can not be done, observations of ground temperatures as the shaft is sunk will throw some light upon the probable distance to which the ground is frozen. The ordinary method of excavation, however, is by thawing the ground, which would invalidate any observations of temperature unless the work were stopped long enough to sink thermometers deeply into the bottom of the shaft each time the thawed material is removed.

As regards scientific utility, temperature observations in frozen ground are of importance for deducing the time during which the region has been subjected to a cold climate. For this calculation it is necessary to know the depth of frost, the mean annual temperature of the ground at any depth, the diffusivity of the soil, and its water content. In the localities mentioned above the depth of frost has not been definitely determined, with the possible exception of the Klondike. By extrapolation of the curves of ground temperature a probable depth can be obtained for any given shaft, and by using the gradients found in this way, the depth in other regions may be roughly estimated.

As the annual disturbances are noticeable to a depth of about 50 feet, any observations above that depth must be carried on over a whole year, so that the mean temperature may be determined. Below this depth single careful observations at 50-foot intervals are sufficient to establish the gradient.

There are no records of such observations of ground temperature from the deep shafts in the mining regions of Alaska, and none could be expected under the method of excavation. At Barrow, where the shaft reached only 37 feet, the observations were confined to single readings as the work progressed, and consequently they are valueless. The observations at the bottom, which were constant for several months, give a value which, with an assumed gradient, will give the depth of frost. The observations taken at other stations of the international polar expeditions are confined to the upper 4 or 5 feet of the ground, and consequently they throw little light upon the gradient.

[1] Maddren, A. G., The Koyukuk-Chandalar region, Alaska: U. S. Geol. Survey Bull. 532, p. 92, 1913.
[2] Tyrrell, J. B., A peculiar artesian well in the Klondike: Eng. and Min. Jour., vol. 75, p. 188, 1903.
[3] Holmsen, Gunnar, op. cit., pp. 32–33.

Middendorff[1] gives observations from many stations in Siberia, but they were mostly taken during short periods and within the zone of annual change. In the deep Schergin shaft, however, they were carried on over a whole year at various levels clear to the bottom. These are the only observations in deeply frozen ground which are known to the writer to be of sufficient accuracy for deducing the constants needed in calculating both the thickness of the frozen layer and also the duration of the cold climate.

SCHERGIN SHAFT.[2]

GROUND TEMPERATURES.

In 1828 Schergin sank a shaft about 100 feet into the frozen ground at Yakutsk, latitude 62°, in Siberia, in the hope of finding a water supply for the village. Having given up the work at that depth he was persuaded by Baron Wrangell to renew the excavation with the object of determining the depth of frost. At a depth of over 380 feet the attempt was abandoned. Recommendations were made that the Academy of Sciences of St. Petersburg should finance the completion of the shaft. They decided that careful ground temperature observations should first be undertaken in order to establish the gradient and consequently the depth at which the shaft would probably reach unfrozen ground.

During the years 1844 to 1846 Middendorff carried out a series of observations in this shaft, which, as far as the writer is aware, are unique in affording data as to the temperature of ground frozen to a great depth. Holes were bored 7 feet horizontally into the walls of the shaft at depths of 7, 15, 20, 50, 100, 150, 200, 250, 300, 350, and 382 feet. In each of these holes two thermometers were placed, 1 and 7 feet, respectively, from the surface of the wall. All these thermometers were read one to five times each month, from November, 1844, to November, 1845, and for three or four months in 1846.

The readings, in degrees Réaumur, are given in Middendorff's report.[3] The outer thermometers, at a distance of 1 foot from the shaft wall, are of course greatly influenced by the temperature of the air in the shaft. Those at 7 feet must feel this influence also. The maximum difference of temperature shown by the outer and inner thermometers is about 5.5° C., near the top of the shaft; at the bottom it is only a small fraction of a degree. The mean differences for the year run from —1.8° C. at 50 feet to +0.04° C. at the bottom. The sign of the upper 200 feet is minus, and from that depth to the bottom is plus.[4] That is, the thermometers nearest the shaft are colder in the upper half of the shaft and warmer in the lower half.

The cause of the colder temperatures shown by the outer thermometers near the top of the shaft is ascribed by Middendorff[5] to the transmission of outside temperatures through the column of air in the shaft. If the covering of the shaft formed a perfect insulation convection currents would tend to equalize the temperature of the air from top to bottom, so that the upper portion would be warmer than the walls and the bottom colder. If the outer air temperatures could penetrate the shaft either by conduction through the covering or by air currents the effect would be much greater in winter, when the colder outside air would sink into the shaft. The warm air of summer would remain at the top of the shaft. The observations show that this cooling effect is felt as far as 200 feet. That the temperature of the walls in the lower half of the shaft is warmer than that of the ground surrounding the shaft, as shown by the observations, is contrary to what would be expected if convection had free scope. One would be inclined to think that the general air circulation was shut off at about 200 feet, so that the lower portion of the shaft had a circulation of its own; but as the observer was lowered in a bucket the shaft must have been open throughout.

The effect of this difference in temperature is to cool the ground around the upper half of the shaft. Middendorff finds a difference of 0.5° R. between his own observations at 50 feet and those taken 15 years earlier at the same depth.

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[1] Middendorff, A. T. von, op. cit., pp. 85–175.
[2] Idem, pp. 92–175.
[3] Idem, p. 110.
[4] Idem, pp. 149–154.
[5] Idem, p. 155.

With observations at only two distances from the walls of the shaft, it is impossible to draw a curve which will represent the variation of temperature with the distance from which, by extrapolation, the true ground temperature could be calculated at each depth. The curve will be asymptotic, so that the temperatures 7 feet from the walls will not differ greatly from the true ground temperatures, even in the upper portion. The main effect will be to increase slightly the gradient when the mean temperatures are considered and to disturb the amplitudes and phases of the yearly variations. For the purposes of discussion the temperatures at 7 feet from the walls will be taken as the true ground temperatures, as more accurate determinations are lacking.

Section exposed in the Schergin shaft.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Black mold, becoming more and more sandy	14	14
Fine sand	18	32
Clay	3	35
Sand	34	69
Sandy clay with vegetable remains	3	72
Limestone	1	73
Fine sand	7	80
Limestone	1	81
Gray sandstone, with pyrite and lignite (Braunkohle)	23	104
A layer of ash.		
Clay and sand, some thin layers of limestone and sandstone	280	384

[a] Middendorff, A. T. von, op. cit., p. 96.

Monthly temperatures (°Réaumur) in the upper portion of the Schergin shaft.[a]

Month.	Depth of 7 feet.	Depth of 15 feet.	Depth of 20 feet.	Depth of 50 feet.
	°	°	°	°
January	−12.9	− 7.0	− 6.8	−6.6
February	−16.1	− 9.1	− 7.7	−6.6
March	−16.8	−10.5	− 9.1	−6.7
April	−14.5	−11.1	− 9.8	−6.6
May	−11.0?	−10.3?	−10.0?	−6.6?
June	− 7.5	− 9.5	− 9.8	−6.6
July	− 5.7	− 8.6	− 8.8	−6.7
August	− 4.6	− 7.6	− 8.1	−6.7
September	− 4.1	− 6.8	− 7.6	−6.6
October	− 3.2	− 6.0	− 6.9	−6.6
November	− 3.4	− 5.6	− 6.4	−6.5
December	− 7.3	− 5.4	− 6.2	−6.4

[a] Middendorff, A. T. von, op. cit., pp. 111, 134.

Mean temperatures of the Schergin shaft.[a]

Depth.		Temperature.	
Feet.	Meters.	Réaumur.	Celsius (centigrade).
		°	°
7	2.1	−8.94	−11.2
15	4.6	−8.13	−10.2
20	6.1	−8.12	−10.2
50	15.2	−6.61	− 8.3
100	30.5	−5.22	− 6.5
150	45.7	−4.64	− 5.8
200	61.0	−3.88	− 4.8
250	76.2	−3.34	− 4.2
300	91.4	−3.11	− 3.9
350	106.7	−2.73	− 3.4
382	116.4	−2.40	− 3.0
(680	207.3	0.0	0.0)

[a] Middendorff, A. T. von, op. cit., p. 174.

The mean temperatures at the different depths have been plotted and a curve drawn through them (fig. 14, p. 189). The curve shows that the temperatures change rapidly at first and then much more slowly. The first 50 feet and the last 200 have nearly constant gradients of 4.4 and 30.8 meters, respectively, per degree Celsius. Between these two straight portions of the curve the gradient changes from depth to depth in an orderly manner. As the ground is frozen, the circulation of ground water can not be the cause of the difference in gradient in the two portions. The diffusivity of the ground can hardly vary greatly enough to cause the observed effect. Any variations of the diffusivity due to the presence of different kinds of rocks ought to produce angular variations in the curve. The possible cooling of the upper portion of the shaft by penetration of the outer air can hardly amount to more than the half degree observed by Middendorff, but the curve indicates a lowering of about 5° C. for the temperature of the surface ground. The most favorable hypothesis seems to be that the mean temperature of the air has been lowered about 5° C. in comparatively recent times.

DEPTH OF FROST.

If the curve from 7 to 50 feet is prolonged, it will reach 0° C. at about 170 feet; the curve from 200 to 382 will reach it at about 680 feet. If the excavation had stopped at 50 feet, there would have been every reason for expecting to reach the frost limit at less than 200 feet. The gradient is so constant for the lower 180 feet of the shaft that we should be justified in placing the limit of frost at about 680 feet. Middendorff's calculations[1] place it at 612 feet, with 670 feet as a maximum. Dr. Peter[2] assumes that the gradient becomes progressively lower and calculates that 1,000 feet is the depth of frost.

The effect of the weight of the overlying ground will be to depress the freezing point of water. Consequently the depths given above must be corrected for this effect. If the specific gravity of the frozen ground is taken as 2, the pressure at 650 feet is equal to $39.6\frac{Kg}{C^2}$. According to Tammann[3] it requires about $138\frac{Kg}{C^2}$ to depress the freezing point 1° C. From this we find that water freezes at —0.29° C. at a depth of 650 feet, which, with a gradient of 100 feet per degree, will make a difference of about 30 feet in the depth calculated for 0.0° C. A final result of about 650 feet of frozen ground is thus indicated by the observations in the Schergin shaft. The average gradient for this depth is about 18 meters per degree Celsius.

Recently it has been found that Schergin observed the temperature of the bottom of the shaft as the digging progressed. His observations differ so greatly from Middendorff's that one is disposed to question their accuracy, yet they are supported by a single observation made by Adolph Erman, who visited Yakutsk while the shaft was being excavated. Middendorff also supports them in a remark relative to a cooling effect noticed in the 15 years that had elapsed between the digging of the shaft and the time of his observations. Below are the ground temperatures observed by Schergin, according to Von Baer[4] and Erman.[5]

[1] Middendorff, A. T. von, op. cit., p. 157.
[2] Idem, p. 175.
[3] Hess, H., Die Gletscher, p. 24, Braunschweig, 1904.
[4] Von Baer, K. E., On the ground ice or frozen soil of Siberia: Roy. Geog. Soc. London Jour., vol. 8, pp. 210–213, 1838.
[5] Erman, Adolph, On the temperature of the earth in Siberia: Franklin Inst. Jour., new ser., vol. 23, pp. 110–123, 1839; Travels in Siberia, vol. 2, pp. 366–369, 1848.

Temperatures in the Schergin shaft, according to Schergin.

Depth.		Temperatures.	
Feet.	Meters.	Réaumur.	Celsius (centigrade).
		°	°
(?)	(?)	−6.0	−7.5
77	25	−5.5	−6.9
119	36	−4.0	−5.0
217	66	−2.0	−2.5
305	93	−1.5	−1.9
350	106	−0.5	−0.6
382	116	−0.5	−0.6

Erman personally observed that when the shaft was 50 feet deep the temperature of the bottom was —6° R. (—7.5° C.). As soon as a lump of frozen earth was brought to the surface the thermometer was plunged into it. The temperature of the different lumps was found to vary but slightly from that given above. Erman states also that the mean air temperature at Yakutsk in 1827 was —5.9° R. (—7.4° C.).

According to Schergin[6] the temperature "at some feet below the surface" was —7.5 C., and at 77 feet it was —6.9° C. This is in agreement with Erman's observation of —7.5° C. at 50 feet. In 1845 Middendorff found —8.2° C. at 50 feet, and he states that 15 years earlier the temperature was 0.6° C. higher, which gives —7.6° at the time when the earlier observations were made.

Thus for a depth of 50 feet the three observers are in accord. Below this point, as shown in figure 14 (p. 189), Schergin's temperatures are much higher than those of Middendorff. As might be expected from the manner in which they were observed, Schergin's temperatures do not fall into an even curve, but the greatest departure is not more than half a degree. Below the depth to which the annual variations of the temperature of the air are felt, about 50 feet, the true temperatures of the ground ought to be revealed by single observations in the bottom of the shaft as the excavations proceeded, as was the method used by Schergin.

[6] Von Baer, K. E., op. cit.

If Schergin's observations of ground temperature are approximately correct, Middendorff's observations represent the temperature after the ground around the shaft had been exposed for 15 years to the much colder air temperatures. The depth of frost would thus be about 400 feet, instead of nearly 700 feet, as deduced from Middendorff's observations. The gradient would be 53 feet or 17 meters per degree Celsius.

On the other hand, Middendorff must have been acquainted with Schergin's observations, and if he had considered them reliable he would undoubtedly have drawn attention to the cooling of the lower part of the shaft.

Erman states that the mean annual temperature of the air at Yakutsk was −7.4° C. in 1827, and Middendorff gives −12.2° C. for 1845. A lowering of the temperature of about this amount was deduced from the shape of Middendorff's curve, but as the cooling of the shaft may have disturbed the original distribution of ground temperature, all the deductions from it are thrown into doubt.

POINT BARROW SHAFT.

The observations taken by Ray [1] at Barrow, Alaska, were made in a crude manner, yet they show that a constant temperature was reached at about 37 feet. No readings were made at different depths over an extended period, so that no curves can be drawn to show the penetration of the cold. Work was commenced on the shaft in December, 1881, and continued until February, 1884. The temperatures were ascertained by burying a thermometer at the bottom of the shaft every night and reading it in the morning. In the upper part of the shaft the air temperatures obviously had great effect upon those indicated by the thermometer. This is shown by the great rise in temperature at nearly the same depth between April and November, 1882, when the change was from 8.5° to 17.5° F. After the shaft was completed, the temperature of the air at the bottom was read once each day and found to be constant at 12° F.

At a depth of 50 feet in the Schergin shaft the temperature of the thermometer which was sunk 1 foot into the wall averaged about 2° R. lower than the one sunk 7 feet, whose readings were taken to represent the true ground temperatures. On the other hand, at the bottom of the 380-foot shaft the two thermometers indicated about the same degree. Inasmuch as the bottom temperature on the Barrow shaft was constant over a long period, it is improbable that varying temperature of the outside air had any effect at that depth, so that the recorded temperature of 12° F. (−11.1° C.) may be taken to represent the mean ground temperature at 37 feet.

Nothing is known of the temperature gradient at the Barrow shaft. Two assumptions have been made: (1) That the gradient is constant and equal to that in the lower part of the Schergin shaft, which gives a depth of frozen ground of 1,140 feet, omitting the corrections for the freezing point of water, and (2) that the gradient decreases downward with an average of 18 meters per degree Celsius, which gives 600 feet.

AGE OF FROZEN GROUND.

Three hypotheses have been suggested as to the origin of the deep freezing of the ground in the Arctic regions. Russell [2] came to the conclusion that deposition and freezing went on at the same time, so that the present thickness of the frozen layer is the result of successive additions of frozen material. Brooks [3] has suggested that the frozen ground of the Yukon Valley is the result of a colder Pleistocene climate, and that at present the ground is thawing. The third and usual hypothesis is that the ground has been frozen to the present depth under temperatures which now prevail.

At the request of Russell,[4] Prof. R. S. Woodward calculated the depth to which the cold surface temperatures would reach after different lengths of time. In doing this he was forced to assume various constants for the equation which represents the change of temperature. His conclusion is that the freezing of even the deepest stratum of ice reported in the Arctic regions might have resulted directly

[1] Ray, P. H., International polar expedition to Point Barrow, Alaska, pp. 338–339, U. S. War Dept., 1885.

[2] Russell, I. C., Surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 129–130, 1889.

[3] Brooks, A. H., communication. See also Antimony deposits of Alaska: U. S. Geol. Survey Bull. 649, p. 27, 1916.

[4] Russell, I. C., op. cit., pp. 130–132.

from a mean annual temperature no lower than that which now prevails in northern Alaska.

In Woodward's discussion two of the assumptions have such a controlling effect upon the deduced length of the cold period that the writer has thought it advisable to repeat the calculations with data which may be nearer the truth.

Woodward assumes the value of the diffusivity of the earth's crust which was used by Kelvin in calculating the age of the earth. This diffusivity was derived from observations on trap rock, sand, and sandstone. In the region under discussion the diffusivity of frozen ground would probably be different from that found by Kelvin for sand and rocks. In examining the records of ground temperatures in the Schergin shaft it was found that they were presented in such a manner that the diffusivity of the frozen ground might be calculated. These calculations are given below (pp. 191–194).

Woodward's second assumption is that at the time when the cold climate was initiated the ground had a uniform temperature for a depth of a couple of thousand feet. This assumption is certainly not correct at present, nor has it been since the history of the earth began. In one of the latest calculations of the age of the earth an initial gradient of downwardly increasing temperatures is assumed.[1] As the ground temperatures could not have been uniform, it seemed advisable to make the calculations with assumed initial gradients. By this method it is found that the initial gradient is the controlling factor, so that the duration of the Arctic climate is indeterminate.

It is necessary also to assume that the surface of the ground has been at a constant temperature since the beginning of the cold climate. The change to modern conditions probably took place gradually, rather than suddenly. This fact will not affect the total depth to which the cold is felt, but it will decrease the depth to which the ground is frozen in a given time.

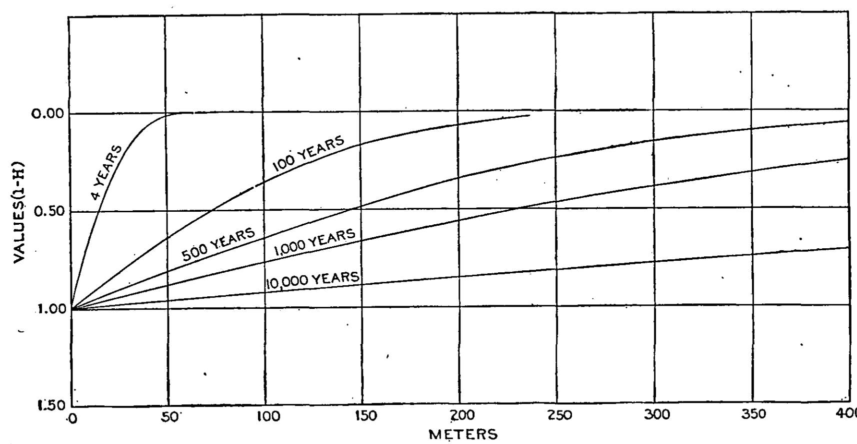


FIGURE 13.—Curves showing the relation of $1-H$ and depth for different times.

According to Woodward's notation, the fall of temperatures at points within the ground is expressed as follows:

$$u_0 - u = u_0\left(1 - \frac{2}{\sqrt{\pi}}\int_0^{\frac{x}{2a\sqrt{t}}} e^{-z^2}dz\right)$$

Where—

u_0=the excess of the original temperature of the surface of the ground over the new constant temperature.

u=the temperature of the earth at a depth x at any time t after the initial epoch.

a^2=the diffusivity of the ground=59.6 in meter-year units (derived below from the Schergin shaft).

It is convenient to write $u_0-u=E$, so that E is the excess of temperature of any point in the ground over the constant temperature of the surface. Then if the integral be represented by H

$$E=u_0(1-H)$$

[1] Becker, G. F., Age of a cooling globe in which the initial temperature increases directly as the distance from the surface: Science, new ser., vol. 27, pp. 227–233, 1908.

The values of the integral have been tabulated under the form

$$\frac{2}{\sqrt{\pi}}\int_0^t e^{-t^2}dt$$

so that it is a simple matter to make the required calculations with the aid of a slide rule.[1] The following table gives the values of $1-H$. These values are shown graphically in figure 13.

The depth to which any change of surface temperature will penetrate depends only upon the diffusivity and the time. To get the actual distribution of temperature the value of $1-H$ must be multiplied by u_0, which is the initial excess. Any change of the temperature of the surface of the earth, with the assumed diffusivity, will be felt at 50 meters in four years and at 250 meters in 100 years. The distance varies as the square root of the time. The effect of a variation of the diffusivity is the same as of a variation of the time, so that if a new diffusivity of one-half the above value is used, the distribution of temperature will be the same as found above for half the time.

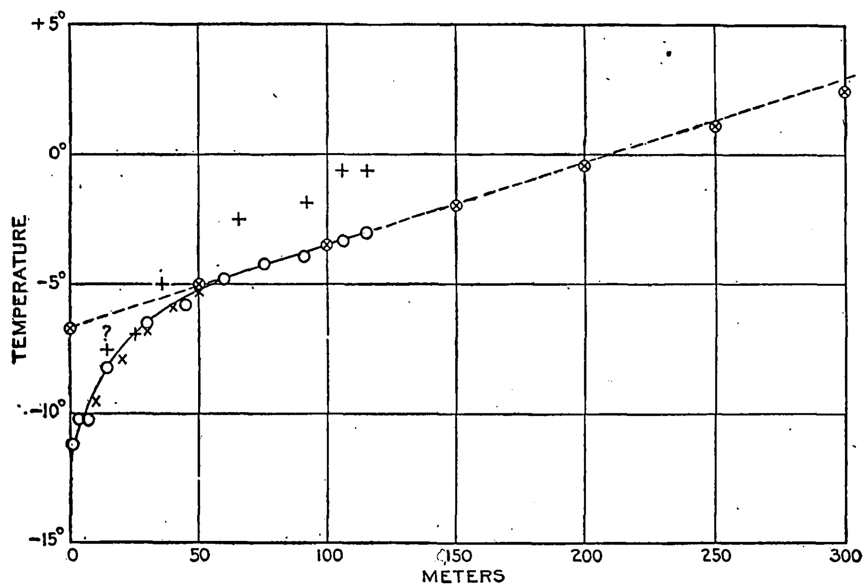


FIGURE 14.—Curves showing variation of temperature with depth in the Schergin shaft. Solid line is drawn through observed temperatures. Broken line is prolongation of lower part of curve. ○ = Recorded temperatures in the shaft, according to Middendorff; + = recorded temperatures in the shaft, according to Schergin; × = 4-year curve with original gradient of 31.2 meters per degree Celsius; ⊗ = 1,000-year curve with original gradient of 58.8 meters per degree Celsius.

Values of 1 – H for different times and depths.

Depth (meters).	Time from initial epoch.				
	4 years.	100 years.	500 years.	1,000 years.	10,000 years.
0	1.00	1.00	1.00	1.00	1.00
10	.65	....	....	....	....
20	.37	....	....	....	....
30	.18	....	....	....	....
40	.08	....	....	....	....
50	.02	.65	.81	.88	....
75	....	.49	....	....	....
100	....	.36	.64	.77	.93
125	....	.25	....	....	....
150	....	.17	.48	.66	....
175	....	.11	....	....	....
200	....	.07	.35	.56	.85
250	....	....	.24	.47	....
300	....	....	.16	.38	.78
400	....	....	.06	.25	.71
500	....	....	.02	.12	.65

[1] Burgess, James, Roy. Soc. Edinburgh Trans., vol. 39, pp. 257–321, 1896–1899.

For the depth that is on record in frozen ground (115 meters) the distribution for 500 years and less is in a curved line and for 1,000 years and more in practically a straight line.

The plotted temperatures of the Schergin shaft (fig. 14) follow a curve for about 60 meters and then proceed in a straight line. In comparing the Schergin curve with the curves of $1-H$, we may draw the inference that the straight portion of the Schergin curve was produced during a long period, when the temperature of the surface of the ground stood about –6.7° C., and that the curved portion was produced by a recent lowering of the surface temperature to –11.6° C., a fall of 4.9° C.

To consider first the distribution of temperature in the upper 60 meters of the Schergin shaft. Here there is a definite original gradient of 1°=31.2 meters—that of the lower part of the shaft. u_0=4.9°.

Becker[1] has shown that in addition to the integral which is represented above by H there is another term CX, where C is a constant temperature gradient. In Woodward's calculations C=0, and the temperature of the ground was uniform. The complete equation of the distribution of temperature is then

$$E=u_0(1-H)+CX.$$

When the gradient of the lower portion of the Schergin curve is taken and u_0=4.9°, the 4-year curve closely approximates the distribution of temperature in the upper part of the Schergin shaft. The values given in the table below have been plotted by the sign × in figure 14. If a curve were drawn for 3½ years, the values would more nearly coincide.

Distribution of temperature after four years.

[Initial gradient of 1°=31.2 meters.]

Depths (meters).	$u_0(1-H)$.	Original gradient.	Resulting temperature.
	°C.	°C.	°C.
0	4.9	−6.7	−11.6
10	3.1	−6.4	− 9.5
20	1.8	−6.1	− 7.9
30	0.9	−5.7	− 6.6
40	0.4	−5.4	− 5.8
50	0.1	−5.1	− 5.2

The changes which furnished the data for this calculation for the effect of four years of lower temperature upon the upper portion of the Schergin shaft took place entirely in frozen ground, which was assumed to have a constant diffusivity. In attempting to ascertain from the lower part of the curve the time required to freeze the ground to its probable depth of 210 meters, an entirely new factor must be considered—the heat liberated by the freezing of the moisture in the ground. The effect of the moisture will be taken up separately and the temperature distribution will first be considered under the supposition that the ground is free from moisture.

The prolongation of the straight portion of the Schergin curve reaches the surface at −6.7°. To find the time since the ground began to freeze, the original surface temperature is taken as 0°, so that u_0=6.7°. If the curves of u_0 $(1-H)$ are plotted along with the Schergin curve, those of 500 years and older fall below the straight portion of the Schergin curve. Consequently all the curves of 500 years and older may be reduced to that of the Schergin curve by assuming an appropriate initial temperature gradient. The temperatures for 500 years follow a slightly curved line, so that they can not be brought into coincidence, but those of 1,000 years and older follow a straight line and may be made to coincide with the straight portion of the Schergin curve. The 1,000-year curve coincides as far as 150 meters but begins to depart at 200 meters. The greater the period the deeper will the coincidence follow. As nothing is known of the ground temperatures below 115 meters, it follows that the present distribution of ground temperatures in the Schergin shaft may have come about during a thousand years or more of a climate which kept the surface of the ground at −6.7° C., and which in the last four years had reduced the surface temperatures to −11.6° C. Of course, this calculation neglects the freezing of the moisture in the ground.

The table below represents the 1,000-year curve, with an assumed initial gradient of 1°=58.8 meters. The resulting temperatures are plotted in figure 14. A table is also given for a period of 10,000 years, with an initial gradient of 1°=36.6 meters. These temperatures are not plotted, but it can be seen that they are approximately on the same straight line. It is obvious that there is no upper limit to the age of the frozen ground found in this manner. If the original gradient is assumed to be parallel to that of the lower part of the Schergin curve, the age will be infinitely great.

Distribution of temperature after 1,000 years.

[Initial gradient of 1° C.=58.8 meters.]

Depths (meters).	$u_0(1-H)$.	Initial gradient.	Resulting temperature.
	°C.	°C.	°C.
0	−6.7	0.0	−6.7
50	−5.9	+ .8	−5.1
100	−5.2	+1.7	−3.5
150	−4.4	+2.5	−1.9
200	−3.8	+3.4	− .4
250	−3.1	+4.2	+1.1
300	−2.5	+5.0	+2.5

[1] Op. cit.

Distribution of temperature after 10,000 years.

[Initial gradient of 1° C.=36.6 meters.]

Depth (meters).	$u_0(1-H)$.	Initial gradient.	Resulting temperature.
	°C.	°C.	°C.
0	−6.7	0.0	−6.7
100	−6.2	+2.6	−3.6
200	−5.7	+5.3	−0.4
300	−5.2	+7.9	+2.7

If the ground contains moisture, the freezing of the water will liberate its latent heat. This will add notably to the amount of heat that must flow toward the surface as the temperature of the ground is lowered. In the freezing of clear water about 160 times as much heat is released as there is in lowering an equivalent thickness of ice 1° in temperature. It is difficult to ascertain the proportion of latent heat to that liberated in lowering the temperature of the frozen ground 1°. The diffusivity is known but not the heat capacity. If the capacity is about the same as that of ice there will be 16 times as much heat liberated in the freezing of ground which has 10 per cent of moisture.

It is beyond the writer's mathematical ability to introduce this factor into the equation which represents the flow of heat. The effect of this additional heat from the freezing of the moisture will be greatly to delay the downward freezing. The time required for freezing to a given depth may be several times that for dry soil. The curve which represents the resulting distribution of temperature will be compound, with an approach toward horizontality where the temperature is 0°, for at this point the liberation of latent heat delays the downward progression of the cold wave. From this consideration the depth of frost in the Schergin shaft is expected to be somewhat greater than that indicated by prolonging the curve in a straight line.

In order to determine more accurately the age of the frozen ground the ground temperature must be ascertained to greater depths than the cold wave has penetrated. The data will indicate the original gradient, and the period of cold may be found in the manner in which it has been found for the upper 60 meters of the Schergin curve. The effect of the moisture in the ground may be treated mathematically or be found experimentally after the method of Callendar and McLeod.[1] Their curves of soil temperatures are almost stationary during the winter months and the resulting diffusivities are very small, probably because of the protective action of the snow and the dryness of the soil, but perhaps in part because of the retardation of the cold wave by the freezing of the moisture.

New values of the diffusivity of various kinds of frozen ground are also desirable. These may be secured after the method of Callendar and McLeod much more easily than by Middendorff's method in the Schergin shaft.

The ground temperatures of the Schergin shaft may have resulted from a surface temperature of −6.7° C. that was maintained at least a thousand years. The freezing of the moisture in the ground would at least double this period. No maximum length of the cold period can be fixed with the data at hand.

It has been mentioned that the observations made by Schergin during the excavation of the shaft differed greatly from those found by Middendorff 15 years later. The ground had probably been cooled by the penetration of the colder outside temperatures to the bottom of the shaft, and any deductions from the distribution of temperature in the shaft are consequently thrown into doubt. There was a recent lowering of the mean annual temperature, however, as has been deduced from the shape of the curve.

DIFFUSIVITY OF FROZEN GROUND.

Thomson[2] states the law of diffusivity as follows:

> If the temperature of any point of an infinite plane, in a solid extending indefinitely in all directions, be subjected to a simple harmonic vibration the temperature throughout the solid on each side of this plane will follow everywhere according to the simple har-

[1] Callendar, H. L., and McLeod, C. H., Soil temperatures: Roy. Soc. Canada Proc. and Trans., vol. 1, sec. 3, pp. 63–83, 1895; vol. 2, sec. 3, pp. 109–117, 1896.

[2] Thomson, William, On the reduction of underground temperatures: Roy. Soc. Edinburgh Trans., vol. 22, p. 410, 1860.

monic law, with epochs retarded equally and with amplitudes diminished in a constant proportion for equal augmentations of distance. The retardation of epoch expressed in circular measure (arc divided by radius) is equal to the diminution of the Naperian logarithm of the amplitude, and the amount of each per unit distance is equal to $\sqrt{\frac{\pi c}{Tk}}$, if c denotes the capacity for heat of a unit bulk of the substance and k is its conductivity.

As the observed temperatures at any depth do not vary exactly according to the simple harmonic law, they are analyzed and expressed by a series of simple harmonic functions according to the principle laid down by Fourier. The form to which the temperature at each depth is reduced is thus given by Everett:[1]

$$v=A_0+P_1 \sin\left(2\pi\frac{t}{T}+E_1\right)+P_2 \sin\left(4\pi\frac{t}{T}+E_2\right)$$
$$+ \text{---------------} +P_n \sin\left(2n\frac{t}{T}+E_n\right)$$

where v = the temperature at any time;

$\frac{t}{T}$ = the fraction of the fundamental period;

P = the amplitude;

E = the phase;

n = number of the term.

It is shown by Everett[2] that

$$\frac{\Delta \cdot E_n}{x}=\sqrt{n\frac{\pi c}{Tk}}=\frac{\Delta \cdot \log_e P_n}{x}$$

where x = difference in depth between any two thermometers.

$\Delta \cdot E_n$ = retardation in phase between any two thermometers expressed in radians.

$\Delta \cdot \log_e P_n$ = diminution of Naperian logarithm of the amplitude shown by any two thermometers.

$\frac{k}{c}$ = diffusivity of the soil—that is, k = conductivity and c = thermal capacity.

[1] Everett, J. D., On a method of reducing observations of underground temperatures: Roy. Soc. Edinburgh Trans., vol. 22, p. 430, 1860.

[2] Idem, pp. 438–439.

The equation for expressing the temperature at any depth converges so rapidly that only the three first terms are necessary[3]—those with the constants P_1, E_1, and P_2, E_2.

The ground-temperature observations in the Schergin shaft were analyzed by Dr. Peters and expressed according to the form given above.[4] Consequently the amplitude and phases can be taken directly from these equations, with the saving of a great deal of calculation. The first three terms only are given for the depths of 7, 15, and 20 feet.

For 7 feet, $v=-8°.935-6°.645 \sin (n\ 30°+359°\ 15')-1°.801 \sin (n\ 60°+305°\ 48')$

15 feet, $v=-8°.131-2°.643 \sin (n\ 30°+314°\ 01')-0.591 \sin (n\ 60°+259°\ 36')$

20 feet, $v=-8°.118-1°.861 \sin (n\ 30°+293°\ 50')-0°.289 \sin (n\ 60°+214°\ 58')$

The month is the unit of time used in calculating the temperatures, and n is the number of the month, beginning with January. Here $n\ 30°=2\pi\frac{t}{T}$, where T= a whole year and $t=n$ months, or $\frac{n}{12}$ years. The temperatures are expressed in Réaumur and Celsius (centigrade) degrees and the depths in English feet. From the above equations the following constants are derived:

Constants of temperatures and depth.

Depth (feet).	Réaumur.		Celsius (centigrade).		Arc.		Radians.	
	P_1	P_2	P_1	P_2	E_1	E_2	E_1	E_2
	°	°	°	°	°	°		
7	−6.64	−1.80	−8.30	−2.25	359	305	6.25	5.32
15	−2.64	− .59	−3.30	− .74	314	260	5.48	4.54
20	−1.86	− .29	−2.32	− .36	294	215	5.13	3.75

In order to ascertain the retardation in phase and diminution in amplitude, the constants of different depths are compared.

[3] Idem, p. 431.

[4] Middendorff, A. T. von, Sibirische Reise, Band 1, Theil 1, p. 169, 1848.

Comparison of constants of different depths.

Annual term.

Depth (feet).	Thickness (feet).	Ratio of amplitudes.	$\Delta \log_e P_1$	$\sqrt{\frac{\pi c}{Tk}}$	ΔE_1	$\sqrt{\frac{\pi c}{Tk}}$
7 and 15	8	$\frac{-8.30}{-3.30}=2.51$	0.916	0.114	0.77	0.096
15 and 20	5	$\frac{-3.30}{-2.32}=1.42$	.351	.070	.35	.070
7 and 20	13	$\frac{-8.30}{-2.32}=3.58$	1.275	.098	1.12	.086

Semiannual term.

Depth (feet).	Thickness (feet).	Ratio of amplitudes.	$\Delta \log_e P_2$	$\sqrt{2\frac{\pi c}{Tk}}$	$\sqrt{\frac{\pi c}{Tk}}$	ΔE_2	$\sqrt{2\frac{\pi c}{Tk}}$	$\sqrt{\frac{\pi c}{Tk}}$
7 and 15	8	$\frac{-2.25}{-0.74}=3.04$	1.112	0.138	0.091	0.78	0.098	0.070
15 and 20	5	$\frac{-0.74}{-0.36}=2.06$	.724	.145	.104	.79	.158	.113
7 and 20	13	$\frac{-2.25}{-0.36}=6.75$	1.910	.147	.105	1.57	.121	.086

Comparison of the values of $\sqrt{\frac{\pi c}{Tk}}$.

Depth (feet).	Annual term.		Semiannual term.		Mean.
	Amplitude.	Phase.	Amplitude.	Phase.	
7 and 15	0.114	0.096	0.091	0.070	0.093
15 and 20	.070	.070	.104	.113	.089
7 and 20	.098	.086	.105	.086	.094
Mean	.094	.084	.100	.090	.092

If all the conditions were satisfied which were postulated in the beginning of the discussion, all the values of $\sqrt{\frac{\pi c}{Tk}}$ should be equal. In the example just worked out the values of $\frac{k}{c}$ may vary at different depths according to the nature of the soil. Also, the temperatures, which were taken over a single year, contain irregularities that would be eliminated during a long series of observations. For the annual wave alone, the value of $\sqrt{\frac{\pi c}{Tk}}$ is greater for the upper 8 feet than it is for the lower 5 feet, but the semiannual wave shows the reverse. The means give nearly the same value at both depths.

Everett,[1] in discussing a series of observations taken over a long period of years, states that the values found from the annual terms are the more reliable. The values of the semiannual term vary considerably from year to year. In the section cut by the Schergin shaft (see p. 185) for the first 14 feet the soil is of "beach mold, becoming more and more sandy," and this is underlain by fine sand. The conductivity, k, of the upper portion should be less than that of the sandy portion below. Thus the material from 7 to 15 feet is chiefly

[1] Everett, J. D., op. cit., p. 437.

of this upper stratum, but from 15 to 20 feet it is all of fine sand. As the annual values of $\sqrt{\frac{\pi c}{Tk}}$ are greater for the upper portion, they bear out the fact that the conductivity is less.

As the semiannual term gives values of small weight in comparison with those of the annual term, and as they point to conductivities the reverse of what is believed to be correct, it seems best to confine our attention to the annual term alone.

Values deduced from the annual wave.

Depths.	$\sqrt{\frac{\pi c}{Tk}}$	$\frac{k}{c}$ year and foot.	$\frac{k}{c}$ c. g. s.	Material.
7 and 15......	0.105	285.0	0.0084	Muck, frozen.
15 and 20.....	.070	641.0	.0189	Fine sand, frozen.
7 and 20......	.092	371.0	.0109	Muck and sand, frozen.

Values of $\frac{k}{c}$ for various materials are given in the table below for comparison with those of frozen ground in the preceding table.

Values of $\frac{k}{c}$ for various materials.

Material.	$\frac{k}{c}$	Authority.
Dry sand.............	0.0036	B. A. C. Committee.
Wet sand............	.0144	B. A. C. Committee.
Sandy soil (average moisture).	.0043	Callendar and McLeod.
Water..............	.0013	R. Weber.
Ice.................	.0104	Straneo.
Craigleith sandstone..	.0231	Kelvin.
Sandy clay (moisture ?).	.0057	Ångström.
Argillaceous sand (moisture ?).	.0045	Ångström.

As the value of $\frac{k}{c}$ for wet sand is four times that for dry sand and the value for ice is eight times that for water, the value for frozen wet sand should be greater than that of unfrozen wet sand. There does not seem to be any value for muck or vegetable mold, but it would probably be very low when dry, though when wet and frozen it might approach the value found between the depths of 7 and 15 feet in the Schergin shaft.

The lower portion of the Schergin shaft is composed mostly of sand and clay, with a little sandstone and a trace of limestone. The greater part of the ground must have been saturated with water when the freezing took place. The diffusivity of clay is not available, nor the proportions of sand and clay in the section. The best that can be done with the data at hand is to assume that the value $\frac{k}{c}=0.019$ represents the diffusivity of the whole section. This amount in meter-year units will be 59.6.

SOURCES OF ICE.

SNOW ICE.

Snow ice or névé has been generally considered to be the source of ground ice ever since the question began to be discussed, and great changes of climate have been postulated in order to account for the large masses of this ice found in the field. Under present conditions the annual snowfall melts each year upon level places, and even were it all preserved by a protective mantle the resulting amount of ice would be only a few inches. Under different climatic conditions it might accumulate into a bed of great thickness, but the balance between snowfall and melting would have to be very exact in order not to bring about such a heavy deposit that glaciers would be formed.

The most favorable location for snow deposits is, of course, in areas of irregular topography where drifts may form. Even after the shrinkage, as the snow changes into névé, a considerable deposit of ice may result. If these drifts are preserved, they will show finely granular ice with a large content of air in irregularly scattered bubbles. If the ice is the result of more than one season's accumulation, it will be bedded in planes which do not approach verticality, although they may lie at fairly steep angles. The deposits themselves will be in sheets or lenticular. They may contain scattered inclusions of material which fell upon the snow while it was being deposited or layers of foreign material along the bedding planes.

When gullies or fissures are filled with snow, the resulting ice will naturally take a corresponding shape.

Ground ice derived from snow is not believed to occur in large masses under present climatic conditions.

GLACIER ICE.

Glacier ice is in general excluded from ground ice, as it does not often seem to form part of the ground. The term might well be applied, however, to the ice found under very old moraines or outwash deposits. In areas where the ground is permanently frozen most moraines probably contain ice. If they do not, it may be an indication of a warmer climate at the time when the moraines were deposited.

As shown in the discussion of the Flaxman formation on pages 142–149, some of the ground ice on the north shore of Alaska may be of glacial origin. This ice should certainly be called ground ice. If the lower end of the Malaspina Glacier were cut off from the active part, the ice under the forest could properly be called ground ice.

The only criteria known to the writer by which it is possible to separate glacier ice from snow ice is that the glacier ice shows undulatory extinction under crossed nicols and also has much larger granules. The character of its bedding would probably also separate it, for the beds of glaciers are commonly distorted until they are entirely unlike those of simple snow deposits. The inclusion of foreign material, such as boulders, would be decisive.

FRESH-WATER ICE.

Ice formed in standing water.—The many ponds and lakes in the tundra afford a widespread source of ice, but there is difficulty in postulating a method of preservation. No process now in operation seems to be capable of protecting such ice from annual melting. Ground ice of this origin should occur in lenses or horizontal beds, whose upper surface, unless disturbed by melting, should be horizontal. The lower contact may undulate with the bottom of the pond and may contain sticks and leaves. The material underlying the ice should be the same as that found at the bottom of ponds. In the area studied by the writer this material is usually a slimy gray mud containing vegetable remains. The ice itself should be free from inclusions or bedding and should show a vertical prismatic structure with large air bubbles flattened horizontally or elongated vertically. The thickness of this ice is limited only by the depth of ground frost in the region.

Ice may also form in bodies of water in cracks and crevasses, where its structure may be complicated by freezing from the sides as well as from the surface.

Frozen ponds are the supposed source of much of the ground ice described in the literature. Russell and Maddren are the American geologists who lay most stress upon this method of formation.

Ice formed in flowing water.—The ice formed each winter upon the surface of streams is almost certain to be melted or cut out every summer, so that it is to be considered as only a possible and not the principal source of ground ice. The heavy deposits of aufeis, or flood ice, however, afford an excellent source, and the chance of preservation is great. These deposits are described in detail elsewhere (p. 158). Ice of this origin is confined to river flood plains and consists of horizontal beds of considerable extent and possibly of great thickness. Actual deposits 15 feet in thickness have been observed by the writer. Middendorff reports them 18 feet thick in Siberia. The upper surface of an extensive deposit dips downstream with a slope approaching that of the river bed. The lower surface is nearly parallel with the upper surface, although irregularities may be expected according to the topography of the ancient flood plain.

The material immediately overlying the ice is, as a rule, material that a rapidly flowing stream might carry in spring, such as gravel or sand. This gravel or sand may be capped by turf, muck, or peat. The material under the ice may vary from river gravels to any formation which existed upon the ancient flood plain. Driftwood, shrubs, or even standing trees may be found.

The ice itself is horizontally bedded with bands of white and blue ice. There may be scattered inclusions of air or water-borne material, or even beds of sand and gravel. As a whole the ice is vertically prismatic, although the whiter portions, which probably represent water-soaked snow, may be finely granular. Some irregularities of the bedding may occur where the hydraulic pressure of the water has bulged and fractured the growing deposit.

This source of ground ice was first postulated by Middendorff, and has been accepted by Toll for some of the Siberian deposits and by Moffit for ice in the Nome region. Maddren also recognizes it as a possible source of some of the Alaskan ice.

In addition to the horizontal sheets of ice just described, mounds of ice are formed around springs which flow in winter. Tyrrell mentions them in the Klondike region, and the writer has observed several in the Arctic coastal region. Water may also seep down over the frozen face of a cliff and form a solid sheet of ice or mass of icicles. Stockton describes a narrow portico formed by icicles extending from the overhanging sod to the river ice below. Beechey has ascribed the ice in Eschscholtz Bay to this origin. It is probable that this ice is only a temporary deposit and is rarely incorporated into the ground under present conditions.

Ice formed in ground water.—Ascending water has been postulated by Tyrrell as the source of both vertical and horizontal sheets or veins of ice in the Klondike region. The writer does not consider this origin probable for the horizontal sheets, but ascribes them to aufeis. Water under considerable hydraulic pressure, however, might bulge up the muck over the water-bearing strata much as it does the ice in the river. In this way a dome-shaped mass of ice might form under the surface of the ground. What structure this ice would take is not clear, for the freezing would be complicated by the low temperature of the walls of the cavity. If the bulging took place suddenly, a vertical prismatic structure might result in the inclosed body of water, since the freezing would proceed most rapidly downward from the colder upper beds of earth. The two low mounds underlain by prismatic ice, described on page 214, may possibly have so originated.

Descending water is believed by the writer to be the source of the ice that occurs in wedge-shaped masses. The water may have frozen either as standing water in fissures or have been formed into ice by freezing against the walls of the fissures. Each individual vein of added ice probably has a complicated structure, and the repeated fracturing of the wedges increases the complications. Ice of this origin lies in a network of vertical wedges that cut the tundra into polygonal blocks. Cross sections show wedges of ice separated by masses of earth. The ice itself is typically whitish and contains numerous air bubbles oriented in vertical rows. The structure is complicated and may be either finely granular or short prismatic. Thin vertical sheets of earth may be included, and perhaps horizontal sheets may penetrate the sides of the wedges.

A theory has been advanced by Lieut. Belcher and elaborated by Holmsen that water which has descended through a spongy mass of peat, or even of clay, has there frozen into a mass of clear ground ice. This view has been considered at some length in the discussion of Holmsen's paper (p. 228). The writer regards it as a possible but very improbable source of ground ice.

The freezing of the stagnant moisture in the ground is a source of ground ice which from its nature must play a minor part. In ordinary wet ground the ice probably forms microscopic crystals scattered through the frozen mass. In such exceptionally wet places as peat bogs or the muddy bottoms of ponds the size of the crystals may be larger, so that they may be visible to the unaided eye. The mixed peat and ice described by Hesselmann[1] (see pp. 226–227) and the granulated ice and clay described by Holmsen and also by the writer are thought to come under this heading.

SALT-WATER ICE.

Undisturbed sea ice.—Only where shoals, islands, or bays afford protection from the ever-moving floes of the Arctic Ocean can thick horizontal sheets of sea ice be formed. In undisturbed areas the ice may reach a thickness of 6 to 8 feet in a single winter. Most of it melts out before the summer is over, and the rest is soon swept away by currents. Consequently, such ice must be covered with a protective mantle to preserve it as ground ice.

[1] Holmsen, Gunnar, Spitzbergens jordbundsis: Norske Geog. Selskaps Aarbok, vol. 24, pp. 1–132, 1912–13.

When the first year's ice is buried the freezing may proceed downward year after year, and if free circulation of the ocean water under the ice is hindered by shoals or in other ways the ice may attain a thickness only limited by the depth of ground frost in the region.

Exposures of ground ice derived from salt water may contain no salty ice near the surface, but salt can probably be detected well within the body of the ice. The structure is neither prismatic nor granular, but the ice consists of bundles of plates whose planes are nearly vertical. A general vertical aspect of the air bubbles should also be found.

Schrader has postulated this source for the ground ice of the Arctic coast, but the writer has seen no ice which seemed to have originated in this manner. There are no descriptions in the literature which lead him to suspect such an origin for ground ice. Under present climatic conditions such ice is preserved only in small amounts under slumping banks, and it can not be an important source of ground ice.

Brecciated sea ice.—The piling up of ice blocks against the land is described elsewhere (p. 173). This ice may carry the material embedded with it by which it will be preserved. It is evident that this method of formation can go on only at the shore line, so that only in those places where the shore line is stationary or being built out can deposits of ground ice from this source be expected. Stefánsson's description of the ice cellars at Barrow and Wainwright accords very well with what might be expected, for these cellars show beach formations incorporated with angular masses of ice. That the settlement at Barrow is built upon a recent beach deposit is shown by the finding of Eskimo snow goggles 27 feet below the surface of the ground.[1] The situation at Wainwright is not known to the writer. Lopatin was the first to suggest this origin for ground ice, but no one else except Stefánsson seems to have mentioned it.

Most of the shore of Arctic Alaska is being cut back by the ocean, so that ice of this origin can not be abundant. Stefánsson has ascribed to this source some of the ice exposed in tundra banks, so that according to this view the ice must have been formed when the present coastal plain was being elevated and the shore line advancing seaward.

[1] Ray, Lieut. P. H., International polar expedition to Point Barrow, Alaska, p. 339, U. S. War Dept., 1885.

MINOR FORMS OF ICE.

Frazil ice.—When a body of water is agitated by winds or currents the ordinary process of ice formation is impossible. Instead of a surface temperature at freezing and higher temperatures below the surface, the water may be cooled to the freezing point as far down as the disturbance reaches. In standing water this depth is usually only a few feet; in flowing water it may reach to the bottom. Owing to the agitation, sheet ice can not form. Centers of crystallization are caught by the moving water and embodied in it, and, if the water is at the freezing temperature, they may exist there for an indefinite period. In addition to the spicules of ice formed at the surface, others may possibly form under the surface of water which is cooled by radiation.

This process may go on until the water is filled with a mass of ice spicules, so that it resembles a mixture of snow and water. The whole process is described by Barnes,[2] who gives a summary of the literature upon the subject. It is a minor phenomenon on lakes and ponds, where it is confined to the surface, but in the rivers of northern countries it becomes of great importance in the formation of ice deposits. The frazil which forms in the stretches kept open by swift currents is carried under the sheet ice, where it lodges in great quantities. Barnes[3] records that near Montreal the sheet ice was underlain by nearly 80 feet of frazil, so that the channel was almost blocked.

Although a great thickness of ice may be formed in this manner, it is not in a favorable place for preservation, and so is not an important source for ground ice.

Anchor ice.—This kind of ice, sometimes called ground ice and also confused with frazil ice, is shown by Barnes to be formed upon the bottom of rivers during clear, cold nights. He ascribes it to the cooling of the bottom by radiation, the main reason being that it forms only when and where radiation

[2] Barnes, H. T., Ice formation, New York and London, 1906.

[3] Idem, p. 217.

is strong. His own observations upon river temperatures show that the water at the bottom of a swift river may be only slightly above freezing during cold weather,[1] so that a very small amount of radiation will cool the bottom sufficiently to bring about the freezing observed.

Ice of this kind may form in depths of 30 to 40 feet in sufficient amount to cause a considerable obstruction to the channel. When the sun shines strongly, the bottom is warmed and the anchor ice breaks off and comes to the surface, bringing up stones and even ship anchors. Barnes[2] quotes Scott as finding a mass of ice crystals upon a rope suspended in sea water. The ice was formed to depths of 30 to 36 feet. Dawson is quoted[3] as observing anchor ice in the ocean at depths of 60 to 70 feet.

There are few observations upon the thickness of anchor ice, only 2 or 3 feet being recorded. Undoubtedly frazil ice lodges against the growing anchor ice and adds to its volume. In structure anchor ice is complicated, being a spongy mass of intergrown crystals. Barnes says:[4]

> The growth of anchor ice is exceedingly beautiful, taking place in arborescent forms and resembling bushy weeds. So hard and thick does it become that it is often very difficult to thrust a sounding rod through it. It is very granular in structure.

Anchor ice can not be an important source for ground ice. It does not attain a great thickness and seldom lasts many days without being set free by warm rays from the sun. It also occurs only when the conditions are least favorable for burial and preservation, for as a rule rivers are not heavily loaded with material in winter, and if they were it is not probable that any anchor ice would form, as the muddy water would cut off radiation of heat from the bottom.

Mixtures of ice.—Though the greater part of the larger deposits of ground ice is probably composed of ice of one kind it is possible to have ice composed of several kinds intimately mixed. The following are some of the more important mixtures to be expected: (1) Snow ice upon fresh or salt water ice, or in a breccia composed of fresh or salt water ice; (2) fresh-water ice from pools upon salt-water ice, névé, or glacier ice; (3) veins of névé or fresh-water ice crossing other kinds of ice, formed by the filling of fractures; (4) snow and water ice, from the flooding of snow by fresh or salt water.

STRUCTURE OF ICE.

GENERAL FEATURES.

The crystallization of ice has been discussed by several investigators, who were chiefly interested in the motion of glaciers. McConnell, Mügge, Tarr and Rich, Drygalski, and Emden have made important contributions to the subject, and most of the writers upon ground ice refer to them as authorities. American investigators seem to a great extent to have neglected the examination of the ground ice with regard to its structure, or at least they have not properly emphasized the bearing of its structure upon the origin of the ice. On the other hand, nearly all the foreign writers devote some space to the matter, especially Toll and Tolmatschow.

In fresh exposures of ice the character of the crystallization does not usually show clearly, nor does it seem to show when the melting takes place too rapidly. The most favorable condition for study is when direct sunlight falls upon the ice while the temperature of the air is somewhat below freezing. A network of lines gradually forms over the surface, indicating the boundaries of the crystals. Later on air bubbles form between the crystals, so that the outlines can be seen. Later still the ice disintegrates into a mass of crystals peculiar to the kind of ice under examination. The structure may also often be brought out by allowing a piece of ice to melt slowly in the shade. It is said that a hot iron passed over the surface of a piece of ice will bring out the network of lines between the crystals. Fractures perpendicular to the surface of pond ice often show zigzag planes, which are suggestive of the sides of long vertical prisms.

Any detailed examination of the structure should include optical methods, such as inspection under the polariscope, yet field inspection is capable of throwing much light upon the question of its origin.

[1] Barnes, H. T., Ice formation, p. 167, New York and London, 1906.
[2] Idem, pp. 223–224.
[3] Idem, p. 225.
[4] Idem, p. 113.

SNOW ICE.

Ice which has resulted from the solidification of snow into névé, firn, or glacier ice is made up of a mass of granules, each one of which is an optically distinct crystal. The axes of the crystals may lie at all angles. In recent snowdrift ice, which may be called névé, the granules may run from the limit of visibility to the size of shot. In glaciers the size may range from that of hazelnuts to that of walnuts.[1] In the Canadian Rocky Mountains they have been measured as large as 7.6 centimeters in diameter.[2]

Ice derived from snow differs from that of glaciers in that the glacier ice shows undulatory extinction under crossed nicols.[3]

It is also generally recognized that snow ice has a high air content, the amount diminishing as the ice changes from white névé to blue glacier ice. Agassiz[4] shows that 1 kilogram of névé contains about 60 cubic centimeters of air; white glacier ice, 15 cubic centimeters; and blue glacier ice, 1 cubic centimeter.

It is shown elsewhere (p. 207) that the wedge-form ice also is granular and has a high air content, though it is not of snow origin. Consequently careful investigation is necessary to distinguish between these two forms.

FRESH-WATER ICE.

Ice formed in bodies of fresh water generally has a structure which is vertically prismatic, each prism being an optically distinct crystal. The axes of the crystals are all parallel to each other and perpendicular to the freezing surface. McConnel says:[5]

> Some of the ice in the St. Moritz Lake is built of vertical columns from a centimeter downward in diameter and in length equal to the thickness of the clear ice; that is, a foot or more.

Tolmatschow says:[6]

> Ice which forms upon the surface of water exhibits a parallel growth of long-stalked crystals. In thawing, this ice decomposes into a series of irregular prisms, which may be several inches long. * * * At first the freezing may be complicated, but later it becomes simpler and regular and gives an ice which as a whole is characterized by its prismatic structure, whereby it is easily separated from snow ice.

Drygalski[7] and Tarr and Rich[8] also described actual examples of prismatic ice, in which they are entirely in accord with the observations just quoted.

Fresh-water ice shortly before its disintegration in the spring is composed of vertical prisms which give way when stepped upon. There are many references to this phenomenon in the literature of northern countries.

Not only is the ice from standing fresh water prismatic but the ice of flowing water is also. Ordinary river ice does not differ notably from standing water ice. The heavy deposits of aufeis, described elsewhere (p. 158), show the same general structure as pond ice.

The writer has seen little reference in the literature to the freezing of water against inclined or vertical surfaces. Hess[9] states that in a vessel whose sides are good conductors of heat, ice forms chiefly with the axes of the crystals perpendicular to the cold surface. In icicles, though the central core may be an optically single crystal, the outer portions, if they are added to after a pause in the freezing, show a radial arrangement of crystals whose axes are perpendicular to the surface.

The well-known lines of air bubbles leading from all sides toward the middle of a block of artificial ice are indicative of the prismatic structure mentioned by Hess. The writer has examined specimens of ice from a mass that had formed from water flowing over a steep slope. They were composed of short irregular prisms with the greatest dimensions perpendicular to the surface. They were about 1 inch long and from one-fourth to one-half inch in diameter.

The generally accepted opinion is that the air content of fresh-water ice is small. The circumstances under which ice is formed, however, may play a great part in the quantity of air included in it. If the material on the bottom of the pond gives off much gas during the freezing, then the air content may be high.

[1] Drygalski, Erich, Grönland Expedition, vol. 1, p. 483, Gesell. Erdkunde Berlin, 1892.

[2] Tarr, R. S., and Rich, J. L., The properties of ice, experimental studies: Zeitschr. Gletscherkunde, Band 6, Heft 4, p. 247, 1912.

[3] Idem, p. 247.

[4] Agassiz, Louis, Nouvelles études et expériences sur les glaciers actuels, p. 158, Paris, 1847.

[5] McConnel, J. C., and Kidd, D. A., On the plasticity of glacier and other ice: Roy. Soc. Proc., vol. 44, p. 334, 1888.

[6] Tolmatschow, I. P. von, Bodeneis vom Fluss Beresovka: Russ. k. mineral. Gesell. Verh., 2d ser., vol. 40, p. 418, 1902.

[7] Drygalski, Erich, op. cit., pp. 405–419, 485–487.

[8] Tarr, R. S., and Rich, J. L., op. cit., p. 226.

[9] Hess, H., Die Gletscher, pp. 11, 12, Braunschweig, 1904.

The air from such a source usually appears in the form of rather large bubbles. Some bubbles are flattened out horizontally, showing that they were included in the ice while pressing against its lower surface. Other bubbles are elongated vertically, as though they had been caught between the points of downward-growing prisms. A concentration into horizontal rows indicates pauses in the freezing.

SALT-WATER ICE.

The only description of the structure of salt-water ice with which the writer is acquainted is that given by Drygalski,[1] from which the following extracts are taken:

> The fundamental difference between the ice of lakes (fresh water) and of the fjords (salt water) consists in that in the latter the plates throughout the whole thickness of the ice are formed with the flat direction perpendicular to the water surface while in the former case only at the commencement of the formation, and consequently only in the upper layers of the ice, are they inclined at right or oblique angles to the water surface, and from there on they lie parallel to it. * * * Bundles of plates are formed. * * * Within each bundle the edges of the plates are parallel, and also the depressions between the edges. * * * The direction of striation is constant in each bundle, but changes from one bundle to another. One can bring out the lamellar structure of the ice in any section which is not parallel to the plates and consequently perpendicular to the water surface. The bundles may have the size of walnuts, but are usually smaller. * * * The outlines of the bundles are irregular. * * * In melting out not only is there a separation of the bundles but also of the individual plates. This is characteristic of fjord ice and separates it from all other ice.

It is generally stated in the textbooks upon physics that when sea ice freezes the individual crystals are of pure ice. According to the writer's observations, the salts are squeezed out of the ice as strong brine or else remain included in pockets throughout the body of the ice. As soon as the temperature rises to the point where the included salts may form brine again the salts drain out of elevated portions of the ice, leaving the ice more and more pure as the temperature rises. It is entirely fresh to the taste when the air is at or above the freezing point. At the same time the ice becomes honeycombed or even disintegrated, so that a light blow may cause a large cake to fall to pieces.

[1] Drygalski, Erich, op. cit., pp. 419–429, 487–489.

As the writer was ignorant of Drygalski's observations, he did not examine the sea ice with sufficient detail to enable him to discuss his remarks. A recently drained block of sea ice upon the beach one summer showed above the former water line a honeycombed white and apparently granular structure, though the general arrangement was vertical. It broke up into short pieces whose vertical dimensions were the greater. Below the water line the ice was made up of thin, short, transparent prisms, which, although nearly vertical, diverged and converged, leaving air spaces or whiter ice between them. Once or twice striations upon the prisms were seen.

The short prisms noted above are probably the bundles of plates mentioned by Drygalski, and thus the writer's observations, though not detailed, are in accord with his. The important fact is that sea ice differs from fresh-water ice in being made up of irregular pieces instead of long prisms, and that it can be separated from snow by having a general vertical arrangement of striated bundles of ice plates.

MINOR FORMS OF ICE.

Frost crystals.—The walls of cavities in frozen ground are usually covered with frost crystals. Such ice can not play an important part in itself, but it may disturb the crystallization of water that later freezes within the cavity. The resulting structure would obviously be neither granular nor vertically prismatic.

Frazil and anchor ice.—In both fresh and salt water frazil and anchor ice are characterized by a complicated structure, varying from symmetrically arranged plates, similar to the frost crystals which grow in moist air, to a spongy mass of spicules of ice. New ice formed in the interstices of these spicules until there is a mass of solid ice would have a granular structure based upon the original crystals. Careful study would probably develop criteria by which such granular ice might be separated from other kinds.

PERMANENCE OF THE STRUCTURE OF ICE.

It is well known that the crystallization of ice will take place against great pressures, and although the writer is unaware of any experiments that throw light upon the structure of ice so formed, there seems no reason for doubting that the structure is the same as under ordinary conditions. The structure of the ice at the bottom of a heavy bed of winter ice is the same as at the top, although the pressure may be a few pounds greater. It seems safe, then, to say that a crystal, once formed, will preserve its character against any pressure which does not deform the ice. The experiments of Tarr and Rich [1] show that the elastic yielding point lies near the breaking point of ice, and also that prismatic ice can be changed to granular ice when the pressure is sufficiently great to fracture it.[2]

Bunge, among others, has suggested that the stresses set up by the annual contraction and expansion of the ice, especially if new ice is added in the frost-formed crevasses, may introduce pressures sufficient to alter the character of the crystallization. This may be the case, but it is not necessarily so. The same pressures are set up every winter in the ice of landlocked bodies of water, yet the prismatic structure is not destroyed. Also, ground ice is described below which is actually prismatic.

PRESERVATION OF ICE.

GENERAL FEATURES.

In discussing the possible sources of ice it has been shown that some ice, such as that in ice wedges and crystophenes,[3] is covered with a protective mantle at its very origin, and that other ice, such as brecciated ice, contains the material which may preserve a portion of it. As a rule, however, under present climatic conditions the ice must be covered with a protective mantle before it can be preserved from year to year. Whether the climate of former times was such that ice could have existed without protection is a matter of speculation. Even now the excess of melting over freezing is so slight that only a very little protection is necessary to preserve a portion of a winter's formation of ice so that it may last over the ensuing summer. The thickness of both the ice and the covering may then increase from year to year until stable conditions are reached. Below are given the most important methods of preservation observed by the writer and others.

[1] Tarr, R. S., and Rich, J. L., op. cit., p. 243.
[2] Idem, p. 247.
[3] Tyrrell, J. B., Crystophenes or buried sheets of ice in the tundra of North America: Jour. Geology, vol. 12, pp. 232–236, 1904.

MATERIAL TRANSPORTED BY GRAVITY.

Slumping.—The slumping of frozen cut banks is one of the most obvious methods by which ice may be buried and preserved (Pl. XXVI, *B*). The ice so covered may be of almost any origin. As banks are usually cut back by the forces which formed them, such deposits of ground ice are not only small but also temporary.

Creeping or seepage of material from steep slopes might bury larger ice deposits than could be buried by simple slumping, and the chance is greater that they will not be cut away by water action. Brooks suggests that some of the ice of Seward Peninsula has been preserved in this way.

Talus.—Ice in the interstices of talus or even under it falls near the dividing line set by the definition the writer has adopted for ground ice. Such ice among talus blocks is a common feature, even in mild climates. Capps has stated that in the Wrangell Mountains of Alaska, in latitude 62°, the ice may exist in such quantities that the talus flows after the manner of glaciers.

MATERIAL TRANSPORTED BY WATER.

Spring floods of rivers.—This method is obvious and has been suggested by many observers, beginning with Middendorff about 1846. Moffit gives a good description of the process. Though the material borne by spring floods may bury any ice which lies upon the flood plain, it is especially important in connection with deposits of aufeis. This kind of ice may reach a considerable thickness over the whole valley bottom, even overriding benches on both sides of the present flood plain. If this ice is buried by gravels during the first rush of water it has an excellent chance to remain for years as ground ice (Pl. XXVI, *A*).

As this origin and method of preservation is so evident, all horizontal sheets of ice upon the flood plains of rivers should be assigned to this source, unless careful examination excludes it. Tyrrell's crystophenes seem to fit this description, and the writer prefers to assign them to a source which is known to be sufficient rather than to one about which there seems to be grave reasons for doubt.

It has been suggested by Stefánsson that the same process might bury the sea ice near the mouths of rivers. As stated in discussing his observations (p. 238), this is a possible but improbable method.

Coastal outwash in spring.—Ponds and lagoons behind barrier beaches which were erected by the waves of the previous summer are filled by melting snow in the spring, so that they either overflow and cut channels through the barriers or, as seems more probable, they burst through them, spreading the material to a thickness of several inches over an area of the sea ice. The chances of preservation of the ice, however, are very small, for the barriers are formed only where wave action is strong.

Much peaty detritus collects in the bottom of shallow bays and may be carried out upon the ice in spring. The ice may also shove into such material during the expansion in the warm weather of spring. This material is a very good nonconductor of heat, so that a thin layer will protect the ice from melting. The location also is such that waves are able to exert little force in cutting the material away. The writer has seen much ice preserved in this way in the early summer, but it is probable that little of it can last through the year.

Sea wash.—In open seasons the Arctic Ocean does not freeze over until some time after ice has formed in protected areas. Late autumnal storms often overwash the barrier beaches and spread sand and gravel over the ice within them. As this ice is protected from wave cutting it is in a favorable position for preservation. Beach formations afford such poor protection against melting, however, that under present conditions this method of preservation is insufficient to bring about deposits of ground ice. If the climate were colder, the ice in the ocean would probably be heavier, and so the waves would be insufficient to afford as much material as at present.

MATERIAL TRANSPORTED BY WIND.

The transportation of sand, silt, or vegetable material has been frequently mentioned as a means of preservation of ground ice, and there seems to be no doubt of its efficiency in the neighborhood of easily transportable deposits where sand or silt dunes are being formed.

Sand.—On the north shore of Alaska sand dunes were nowhere observed, but much sand is carried by the wind, as is shown by its distribution over the ice and snow near the beach. Only occasionally does the sand become thick enough to hide the ice, except within a few yards of the beach, but scattered grains may be seen some miles from any local source. It is not probable that any ice is preserved by

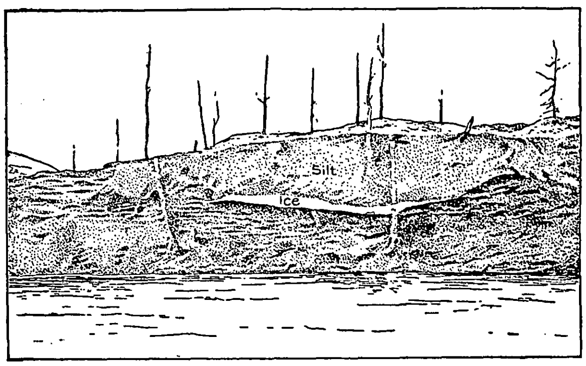
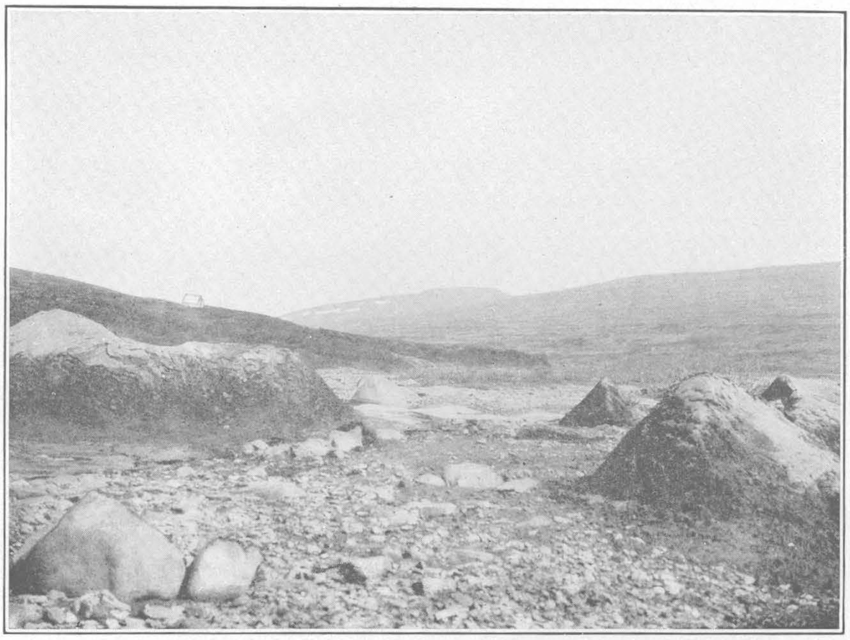


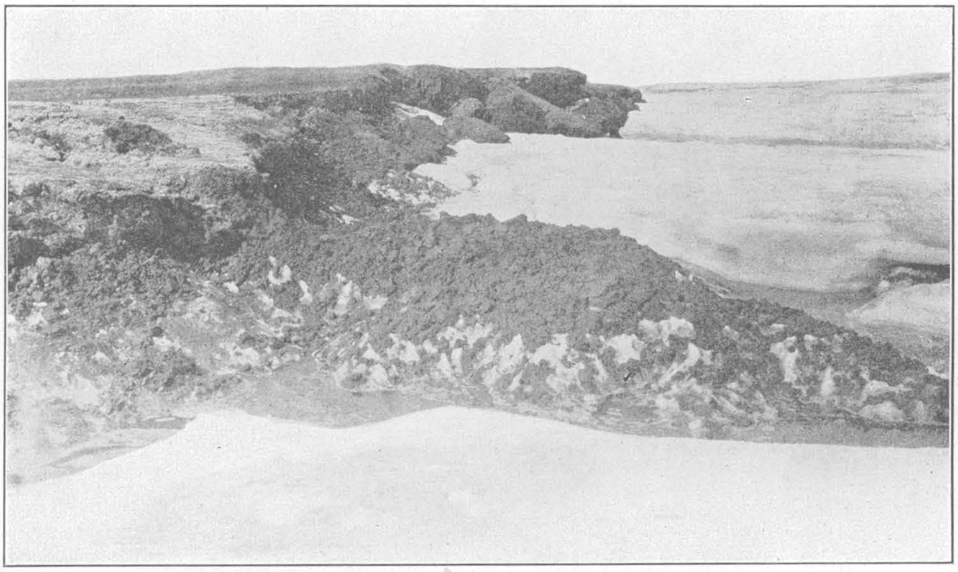
FIGURE 15.—Ground ice in wind-blown silts, Tanana River. After a photograph by H. M. Eakin.

wind-blown sand at the present day in this region, because sand affords such poor protection and ice so covered is likely to be exposed to cutting by waves or river currents.

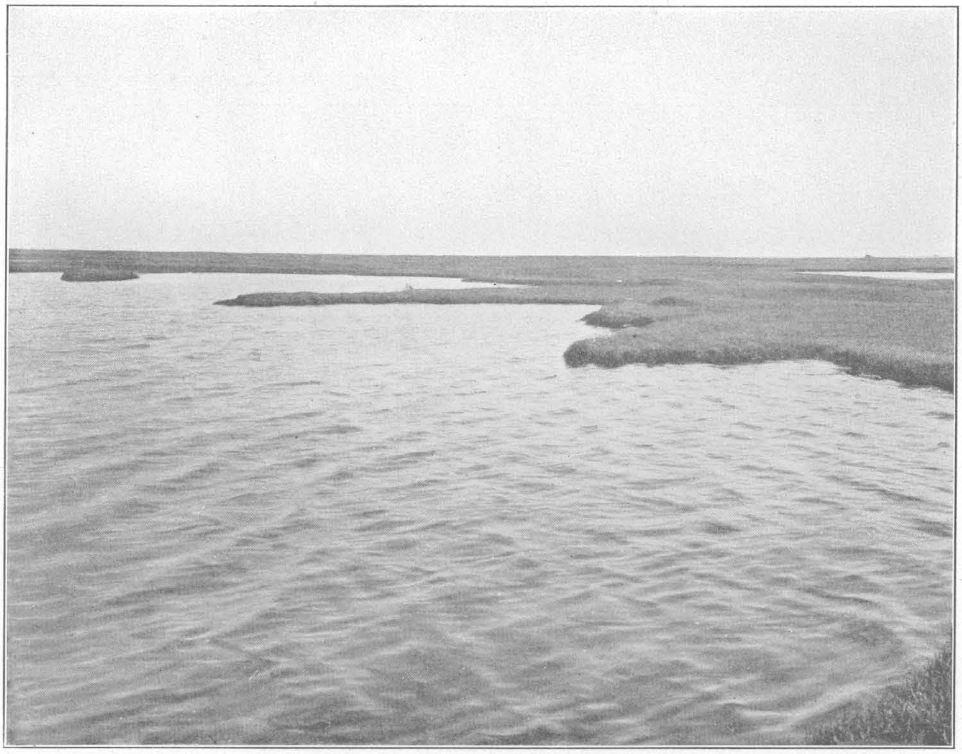
Silt.—The chance of preservation of ice by silt is much greater, for not only is the amount of material greater but the ice may be protected from water action. Even with silt the ice so preserved must be strictly local, for most of the material is dropped within a few hundred yards of its source. Boulders lie upon the tundra within that distance on the leeward side of the silt dunes of Canning River. The hollows among the dunes are a favorable place for ponds and snowdrifts and have a maximum amount of material available for the preservation of ice, but the writer has never seen ground ice in exposures in these areas of dunes.



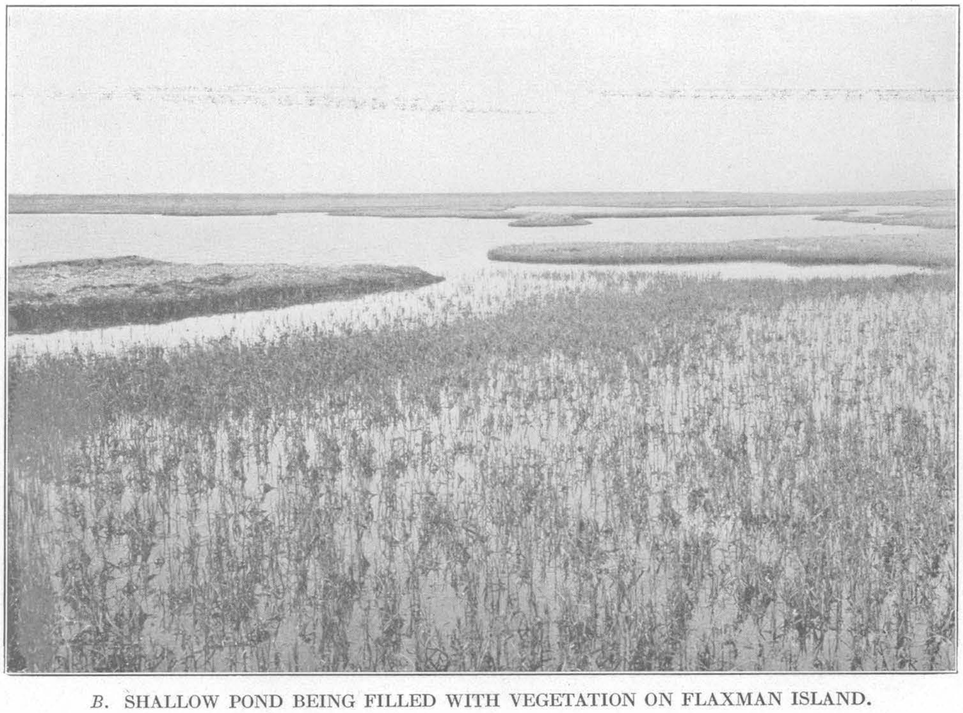
A. GRAVEL-COVERED REMNANTS OF AUFEIS NEAR NOME, ALASKA.



B. PRESERVATION OF SEA ICE UNDER A SLUMPING BANK ON FLAXMAN ISLAND.



A. POND ON FLAXMAN ISLAND.



B. SHALLOW POND BEING FILLED WITH VEGETATION ON FLAXMAN ISLAND.

H. M. Eakin, of the United States Geological Survey, has photographed an exposure containing ground ice near the mouth of Tanana River. (See fig. 15.) He says that this exposure is about 20 feet high and consists mainly of wind-blown silt. The bed of ice is about 30 feet long and 3 to 4 feet thick. The two buried trees shown in the exposure are in place, and one of them runs through the ice bed. He considers that this mass of ice is clearly a snowdrift covered and preserved by wind-blown silt, and the writer entirely agrees with him.

Vegetation.—The amount of wind-borne vegetation is very small, so that only exceptionally is it sufficient for a protective covering. The writer has never seen any ice on the coast which may have been covered in this manner. Snowdrifts at the foot of steep banks in the interior were often observed to have an inch or so of débris, sufficient to preserve a large snowdrift through the summer.

Wind-borne material is thus seen to play a minor part in the preservation of ice at the present day. Under different conditions it may have been more efficient, especially if the coastal plain at one time had no protective mantle of vegetation.

MATERIAL INCLUDED IN THE ICE.

Melting at the surface of a deposit of ice which contains included material will cause a concentration of this material over the ice. Glacial ice is buried in this way, but the process does not seem to be generally effective, for most of the ground ice is fairly free from inclusions of earth, except where ice has been shoved up on the shore. As the landward-pressing floes mount upon the beach they scoop up much material from the ground, so that a mass of blocks of ice mixed with sand or turf is formed. The upper parts of the resulting pressure ridge may be quite free from beach material, but the lower part is sure to contain it in large amount.

In summer the ice within reach of the waves will be rapidly cut away. The ice which is above sea level will melt away until a sufficient amount of material has been concentrated over it to preserve it. The outlines of the deposit will gradually be smoothed out, and it may be covered by vegetation, so that in time it becomes part of the ground. As the included material is apt to be mostly sand, which forms a poor protective mantle, the ridges usually waste away before the summer is over. Only two such deposits have been observed by the writer to last from year to year, and these had much muck in addition to sand as a covering.

VEGETATION.

PEAT.

One of the simplest and most widespread theories as to the origin of ground ice is that of the encroachment of a floating mass of sphagnum moss from the sides of ponds, until at last it covers the entire body of water. The pond once covered, the summer's melting can not take place, and the lake may freeze downward to the limit of ground frost. This explanation was first proposed by Turner, of the American observers, and has been adopted by Russell, Maddren, and Mendenhall. Toll[1] gives the credit of this theory to Baer and Schrenk, who anticipated the Americans.

Whatever effect this process may have in other localities it is not operative on the north shore of Alaska at the present day, nor does it seem to have been so in the past. The ice in general is covered by material which could not float. Where sphagnum (?) peat was found over the ice, the ice was of such a character that it could not have resulted from the freezing of ponds.

As the writer did not find any evidence as to the burial of ponds in this manner in the past, he kept careful watch for the process at the present day, and nowhere did he find any suggestion of it. The moss, which if not sphagnum is closely allied to it, does not grow in the water, but in damp places slightly above the water level, around the margins of ponds, or in flat areas where the drainage is sluggish.

The shores of smaller ponds, where not eroded by wave action, are as a rule nearly vertical, and the turf grows to the edge of the water, but nowhere does it overhang to any extent. The writer has frequently thrust down an iron-shod staff, and he always found

[1] Toll, Eduard von, Die fossilen Eislager: Acad. Sci. St.-Pétersbourg Mém., 7th ser., vol. 42, No. 13, pp. 28–29, 1895.

a solid wall. Many recently drained ponds have been seen, and on none of them was there any suggestion of a floating fringe of vegetation. In some places the turf had bent down, but it was composed of material which could not have floated. Plate XXVII, *A*, shows the abrupt turf-covered edge of a pond 2 feet deep and perhaps a couple of hundred feet across.

The shallow ponds were usually fringed or covered with vegetation, which was evidently growing up from the bottom (Pl. XXVII, *B*). This vegetation decays and accumulates until other forms may find a foothold, so that finally the pond is completely filled. The only ground ice possible in such places is that which forms in the interstices of the decaying vegetation.

That sphagnum moss is of minor importance in the formation of peat in temperate climates and also does not grow there in or upon water is brought out by Davis,[1] who, in describing the peat bogs of Michigan, says:

> Every locality visited was carefully examined to see if sphagnum showed any tendency to grow in water beyond advancing higher seed plants, as it has been reported to do, and in no single instance was it found beyond the sedges or shrubs which formed the marginal zone upon open ponds.

He also describes the burial of deep ponds by encroachment of floating vegetation thus:[2]

> The basin presents * * * a marsh of greater or less width, the lakeward extension of which is afloat, and which is of the nature of a mat or raft built up by the interwoven rhizomes or horizontal stems of sedges or rushes. * * * Extensive bogs and marshes are formed by these plants by building out from the shores of lakes, the felted and interwoven mats of their submerged stems and roots making a buoyant structure capable of supporting considerable weight.

He says elsewhere[3] that the order of appearance of sphagnum is apparently invariable—only after the floating mat has been grounded near the margins of the pond and usually after the appearance of such other vegetation as ferns.

The burial of ponds by a floating mass of sedges (not sphagnum) is typical of cool temperate climates, but no such thing occurs along the Arctic shore of Alaska. It is possible that near the southern limit of ground frost the process may take place, so that ground ice formed in that way may occur there.

ALGAE.

In July, after most of the shallow coastal ponds had entirely melted, ice was found at the bottoms of some of them, under a blanket a few inches thick, composed of an alga which resembled the *Spirogira* of stagnant pools in warmer climates. This ice was frozen to the bottom. When the seaweed had been removed the ice was clear and white. The alga may have been floating on the surface in the fall, so that clear ice formed under it. In the spring this blanket not only protected the ice and the ground under it from the direct rays of the sun but it greatly interfered with convection currents, which are the chief means by which surface heat is transmitted downward in water whose temperature is below 4° C.

Under present climatic conditions the ice so protected does not seem to last through the summer, but a very slight decrease in temperature would bring this about, and then small but constant additions to the material might build up the mantle until it was thick enough to protect the ice from the milder temperatures that now prevail.

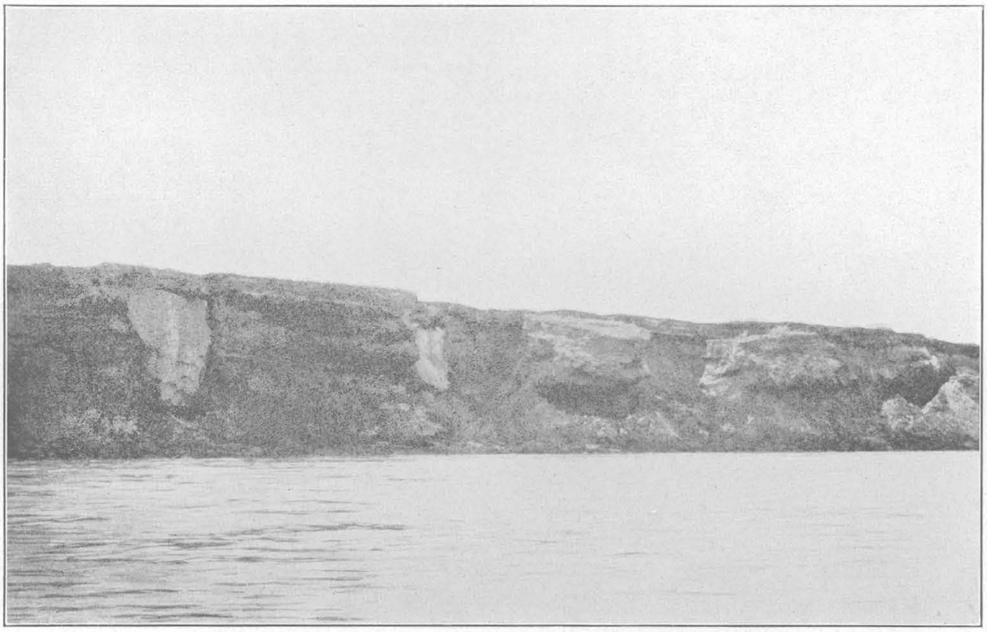
LIMIT OF THAWING.

In most places the upper surface of the ground ice lies immediately below the limit of annual thawing. The position of this limit has an important bearing upon the origin of the ice. Where the material has concentrated out of the ice by melting, it must obviously attain only to this thickness. Under Lieut. Belcher's theory, also, the ice forms at the limit of melting. Under the frost-crack theory the surface of the growing portion of a wedge should be at this limit, though the older portions of a wedge should lie below it, unless, as the writer has attempted to show, the process of growth tends to keep the mantle at a constant thickness. Consequently the preservation of ground ice whose upper surface lies just below the limit of thawing is more probably controlled by the position of this limit rather than by the transportation of material to cover the ice or the growth of vegetation upon its surface.

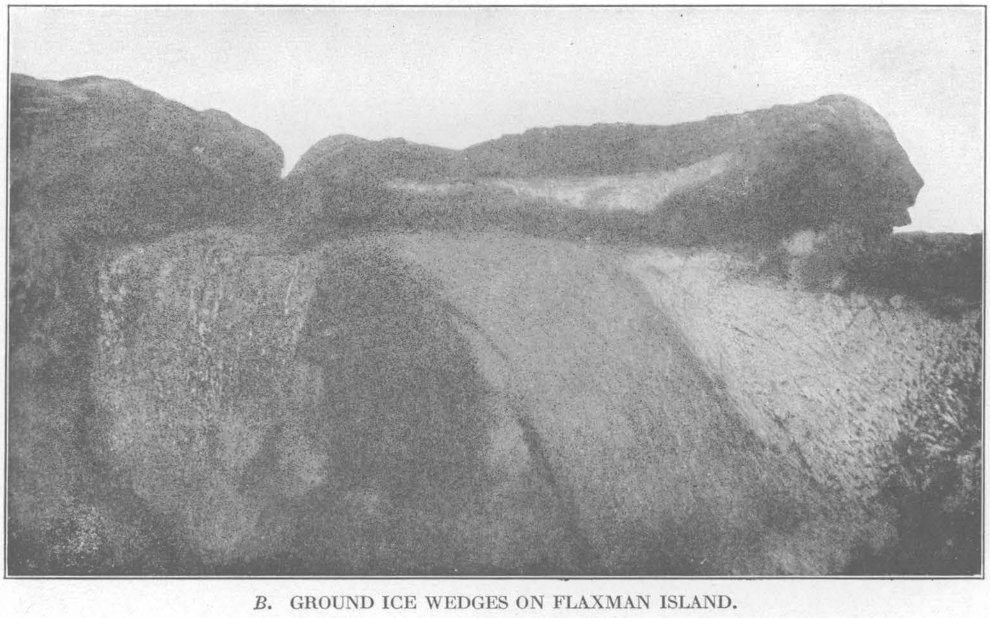
[1] Davis, C. A., Peat, essays on its origin, uses, and distribution in Michigan: Michigan Geol. Survey Rept. for 1906, p. 275, 1907.

[2] Idem, p. 135.

[3] Idem, pp. 158–159.

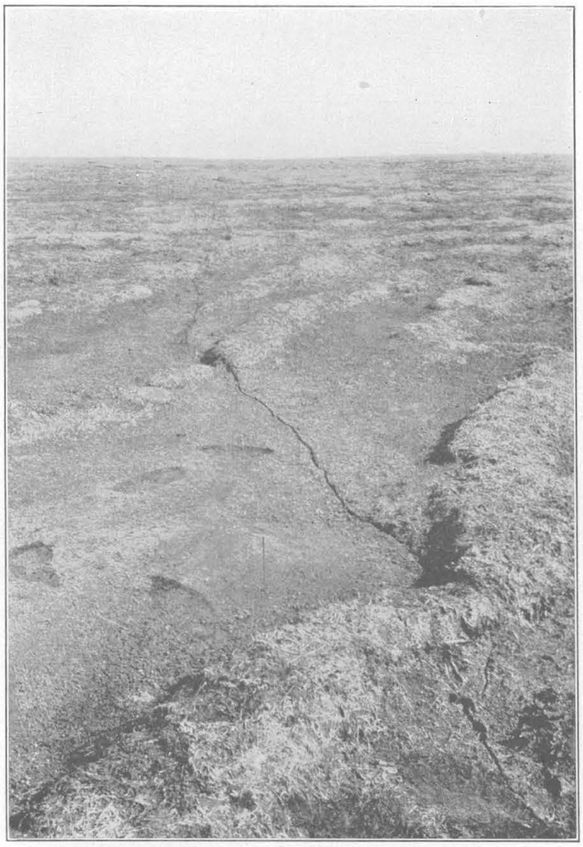


A. GROUND ICE WEDGES ON NOATAK RIVER.

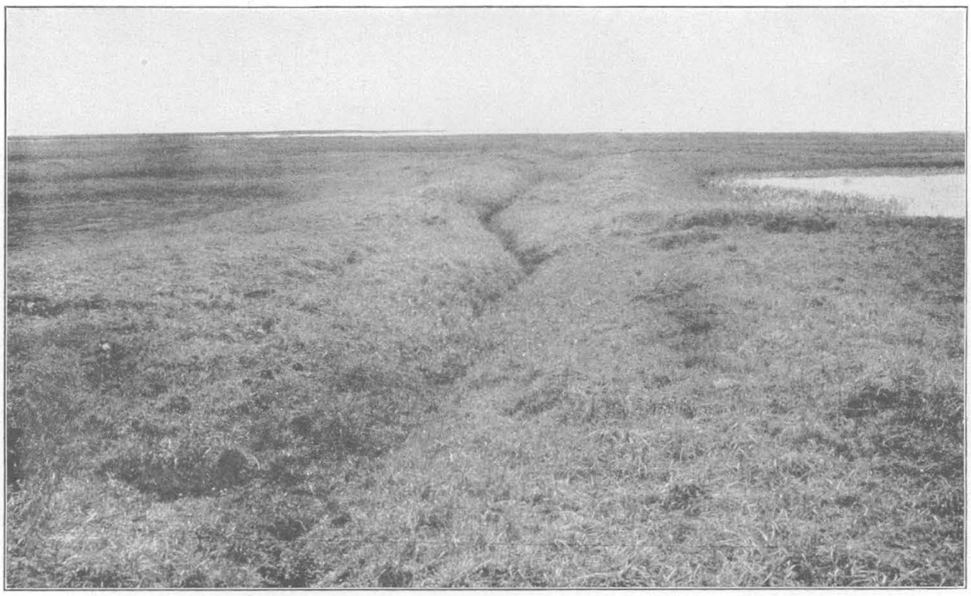


B. GROUND ICE WEDGES ON FLAXMAN ISLAND.

(See fig. 17, p. 207.)



A. FROST CRACK ON THE SURFACE OF A RECENTLY DRAINED AREA ON FLAXMAN ISLAND.



B. FROST CRACK LYING BETWEEN PARALLEL RIDGES WHICH INCLOSE DEPRESSED POLYGONAL BLOCKS ON FLAXMAN ISLAND.

OBSERVATIONS ON THE NORTH SHORE OF ALASKA.

GROUND ICE WEDGES.

THEORY OF FORMATION.

The theory of the origin of ground ice here presented was formed in July, 1914, after nine summers spent upon the north shore of Alaska. An article was written in December of the same year and afterward published.[1] This article has been expanded and embodied in the present discussion.

On reexamining the literature, with which the writer already had a fair acquaintance, it was found that in 1883 Bunge had propounded a similar theory. Bunge, however, did not give detailed descriptions of exposures, nor describe the stages of growth of the ice wedges with sufficient clearness to make his exposition plain to those who followed him. In fact, by citing others as supporting him he greatly weakened his own case, for the men whom he cited held theories that differed greatly from his own.

Hooper, in 1881, also suggested a probability of the growth of ice in cracks in the ground, under successive changes from freezing to thawing.

The writer here endeavors to present his theory with such detail that it may be grasped and to support it with diagrams and photographs showing the stages of the formation of ground ice according to this view.

He went into the field in the summer of 1906 with the idea that the coastal ground ice occurred in horizontal sheets and did not learn its real distribution until 1914. During the first eight summers, although the ground ice was examined at every opportunity, little insight was gained into the method of its formation.

The usual theory advanced in the literature is that bodies of snow or ice were buried by peat or wash material and thus preserved. The writer sought to interpret the Alaskan coastal ground ice in this way, but could neither postulate a satisfactory source for the ice nor find any workable hypothesis to account for its preservation. Not until the summer of 1914 did he discover that most of the ice was formed in place in the ground. A vertical wedge of ice within a peat bed first drew his attention to the fact; for such a dike of ice could not have stood up in the air for the hundreds of years that were necessary for the formation of the peat.

Several dozen photographs of the ice were made, but most of them were later damaged by water, so that the writer has to depend chiefly upon sketches which were often hastily made. Fortunately, P. S. Smith, of the United States Geological Survey, some years ago had secured photographs of ground ice on Noatak River. One of these photographs illustrates wedge-form ice of the kind that is the subject of this chapter. (See Pl. XXVIII, *A*.)

[1] Jour. Geology, vol. 23, pp. 635–654, 1915.

FROST CRACKS.

During the Arctic winter frequently loud reports are heard, coming apparently from the ground. Often the sound is accompanied by a distinct shock, which is in fact an earthquake of sufficient intensity to rattle dishes. The writer has spent six winters in the region under discussion, living most of the time upon the tundra, which is chiefly underlain by muck. Many camps have been made upon other formations, such as sands and silts, and his impression is that the sound of the cracking ground was heard everywhere. This impression has been confirmed by a prospector who has lived nearly 30 years in the country.

It was at first thought that the reports were caused by the cracking of hard snowdrifts, but the cracks in these drifts were seen to run into the ground below. When the snow melts in the summer fresh open cracks can be seen cutting across all the tundra formations, even across mud and growing moss beds, and dividing the surface into polygonal blocks, which resemble mud-crack blocks but are of a much larger size. These blocks have an estimated average diameter of about 16 yards and have a tendency toward the hexagonal form, although rectangles and pentagons are commonly developed.

Occasionally a crack is seen to run across a flat surface, with no associated features (see Pl. XXIX, *A*), but usually it is accompanied by other modifications of the surface. Either the cracks lie in a gentle depression which surrounds elevated polygonal blocks or they run between two parallel ridges which surround depressed blocks. These features do not vary from block to block, but each is locally developed over a considerable area. Few of the elevated blocks have a relief of more than 1 foot, but that of the depressed blocks may be twice as much.

The parallel ridges form shallow reservoirs, very similar to those of the block system of irrigation, especially when they take a rectangular form, as many of them do. They may contain ponds and are invariably swampy, so that when crossing such an area dry footing can only be had on the ridges. (See Pls. XXIX, *B;* XXX, *A*.) On Flaxman Island the tendency of the depressed blocks is toward a rectangular arrangement, and the frost cracks extend in a straight line for a distance sufficient to include several polygons. One double ridge was paced for a hundred yards in nearly a straight line. On either side similar ridges ran parallel to it about 75 feet away. These ridges were perpendicularly intersected by four others equally spaced, thus forming blocks about 25 yards square.

In an area of elevated blocks near by there were many places where these cracks radiated symmetrically from a point, so that fairly regular hexagons were formed.

FORMATION OF ICE WEDGES.

The open frost cracks are in a favorable position for being filled with water from the melting snow, as most of them lie in depressions upon a flat surface. Those that by chance should get no water may become filled with ice crystals deposited by the damp air by internal "breathing." The crack is thus filled with solid ice from the freezing of the water, or contains much ice in the form of frost crystals, so that a narrow vein of true ground ice is formed in the portion which lies below the depth reached by the annual thawing. When the frozen ground expands under the summer's heat, the readjustment to the strain may take place in four ways: (1) The pressure may melt the ice, so that the crack is closed again; (2) the ground may be sufficiently elastic to absorb the strain, so that no deformation occurs; (3) the ground may be deformed and bulged up, either as a whole or locally along the edge of the ice wedge; (4) the ice itself may be deformed.

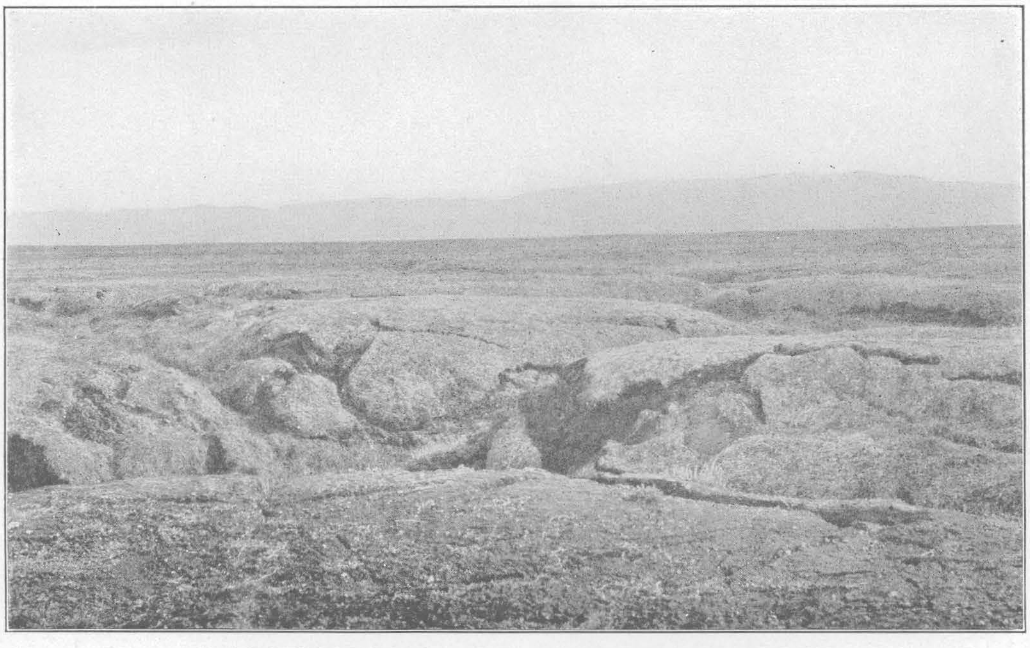
If the summer's strain has been relieved by readjustment of the material within the polygonal block, the next winter will again bring about the conditions which caused the first cracking of the ground. The first crack contains ice and probably is a plane of weakness for tensile strains, especially if the crack has been only partly filled. If it is a plane of weakness, new cracks will annually open at the same place and a constantly growing body of ice will be formed there. That this condition is common in tundra formations is shown by the constant association of ice wedges with definite centers of frost cracks.

Thus the growth of the wedge goes on from year to year, possibly failing during mild winters, when all the cracks may not be forced open in order to relieve the strain. The writer's observations show that the ice may increase until it underlies about one-fifth of the area of the block, but there is no theoretical reason for stopping at this stage. The wedges might grow until the amount of ice would exceed the amount of earth, so that instead of intrusions of ice into the earth an exposure would apparently show intrusions of earth into a heavy body of ground ice. Although nothing approaching this possible stage of development has been seen by the writer, the descriptions of localities in Siberia by Maydell and Toll, which show intrusions of earth scattered through a heavy body of ice, lead the writer to believe that there we possibly have ice wedges in an advanced stage of growth.

APPEARANCE OF THE WEDGES.

Cracks have been seen accompanied by no other surface manifestations (Pl. XXIX, *A*) and with no visible ice below them. The smallest wedge that has come under observation was about a foot wide. No doubt there are smaller wedges, especially in areas such as recently drained lake bottoms, where the process is just beginning. The thin veins have nearly parallel sides and flat tops, as shown in figure 16. As the ice increases in size it approaches more and more to the wedge shape, as the growth is greatest near the top, where the crack opens widest. There is a tendency in the large

A. FROST CRACKS, PARALLEL RIDGES, AND BLOCK PONDS ON FLAXMAN ISLAND.



B. EROSION OF A POLYGON FIELD NEAR THE 141ST MERIDIAN.

wedges to spread out under the surface of the ground. This tendency is exaggerated in oblique sections. (See fig. 17 and Pl. XXVIII, *B*.)

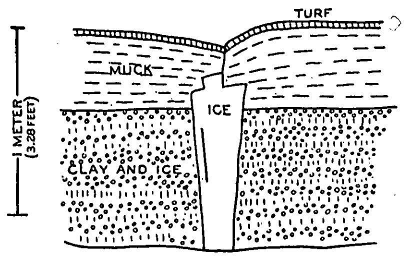


FIGURE 16.—Narrow ice wedge in a deposit of mixed clay and ice granules. There is an open crack within the wedge.

The bottom of an ice wedge has never been observed by the writer. Most of the bluffs on the north shore of Alaska are less than 10 feet high, and their bottoms are concealed by slumping. The maximum vertical dimension observed is about 10 feet, but the wedge had a thickness sufficient to have carried it two or three times that distance before pinching out. The ultimate depth must depend upon the

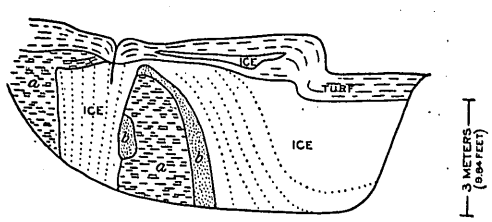


FIGURE 17.—Two joining ice wedges; the one on the right is cut obliquely. The dotted lines represent lines of air bubbles within the ice. *a*, Muck and clay, much disturbed; *b*, sand. (See Pl. XXVIII, *B*.)

depth of annual change in the ground temperature in the region. In the Schergin shaft (p. 184) the annual change is not noticeable at 50 feet. It is not probable that the cracks extend to the extreme limit, but once having been started by the great tension at the surface they may be expected to approach that depth. In discussing the question it seems safe to assume 30 feet as a working basis.

In muck formations the upper surface of the ice is usually less than 2 feet under the ground, about the limit to which the summer's thawing penetrates. This surface is usually horizontal or undulates with the surface of the ground. One or two exposures showed a dome-shaped surface and another a central projection above the general surface (fig. 16). Some more complicated exposures are shown in figures 19 and 20. The overlying material, as a rule, is muck capped by a few inches of turf. Occasionally it is peat capped by growing sphagnum (?) moss.

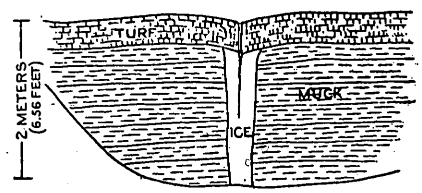


FIGURE 18.—Narrow ice wedge in muck beds. An open frost crack runs through the turf and into the ice.

STRUCTURE OF THE ICE.

A fresh transverse section of an ice wedge shows a face of whitish ice with numerous parallel vertical markings. These markings are usually formed by whiter ice, which con-

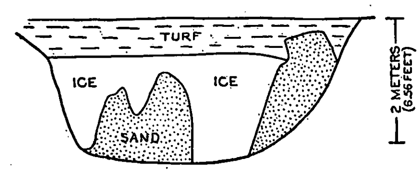


FIGURE 19.—Complicated exposure of ice in sand.

tains a large amount of air bubbles. In many specimens it is visibly granular, yet it shows a general vertical structure. As a rule the granules are less than half an inch in diameter, the average being about a quarter of an inch. Some specimens of ice when allowed to lie in the shade on a cool day broke up into short, irregular pieces, the greatest dimensions of

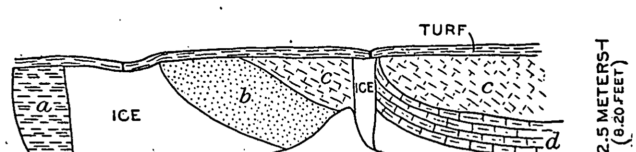


FIGURE 20.—Complicated exposure of ground ice. *a*, Clay; *b*, sand; *c*, peaty detritus, no structure visible; *d*, peaty detritus with upturned beds.

which were vertical. These pieces were an inch long and half an inch in diameter.

From the method of formation the crystallization should be irregular. Where water freezes in an open crack, short prisms might develop with the axes perpendicular to the freezing surface, which in these places is vertical. The axes of the ice crystals in the walls would have a disturbing effect, as would also any frost crystals within the crack. Every new crack runs across the crystals indiscriminately, and the new intrusion of ice adds to the complication. A careful study of the structure of wedge ice would probably develop criteria by which it may be separated from névé ice.

The writer's notes upon the air bubbles bring out nothing as to their shape and size. The chief characteristics are their abundance and orientation into vertical rows. In content of air wedge ice may closely resemble névé ice, the

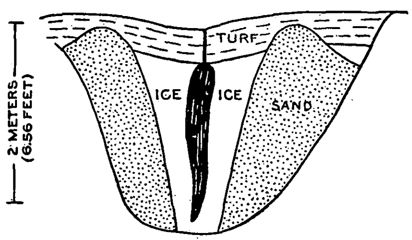


FIGURE 21.—Ice wedge in sand. A tunnel has been cut in the ice by drainage of surface water through the frost crack. The sand on either side is apparently bulged up.

difference lying in the distribution of the air bubbles. In recent névé ice examined by the writer the bubbles were scattered haphazard throughout the ice. Any concentration is more apt to occur along horizontal lines than along vertical ones.

At the sides of the wedge the markings of the ice are inclined from the vertical and approach parallelism with the sides. As the growth seems to occur near the center of the wedge the older lines, though originally vertical, are spread apart at the top. Oblique sections of wedges give exaggerated angles of inclination or even curves (fig. 17).

In several places cracks were seen running down a few feet into the ice as prolongations of an open frost crack in the tundra above. Once or twice isolated open cracks were seen within the body of the ice, so that a thin sheath knife could be shoved in for several inches (fig. 16). Near the edge of a bank these open cracks may become drainage lines for surface water, so that a tunnel is developed within the ice (fig. 21). As the tunnel widens the roof caves in, and a deep gully is formed in the bank. These gullies work back and around the polygonal blocks and make walking rather difficult in the neighborhood of an old bank (Pl. XXX, *B*).

Some earth is likely to get down into the open frost crack while it is being filled with water, especially when the overlying material is mud or clay. Under growing peat the chance is not so great. The exposures of ice are usually so dirty from the mud which has dropped off from above that vertical earth veins might not be noticeable.

The possibility also exists that the pressure exerted by the growing wedge should fracture it so that earth inclusions might make their way into the sides of a wedge. Such an occurrence has never been seen by the writer, although it is reported from Siberia (fig. 30, p. 217).

STRUCTURE OF INCLOSED BLOCK OF EARTH.

The typical formation associated with ice wedges in the region under discussion is muck, a black mud containing much vegetable matter more or less decomposed. It varies from a peaty detritus that shows signs of having been water-laid to sand or mud mixed with varying amounts of decaying vegetation. Undisturbed sections of this muck usually show horizontal bedding. Occasionally sand or a

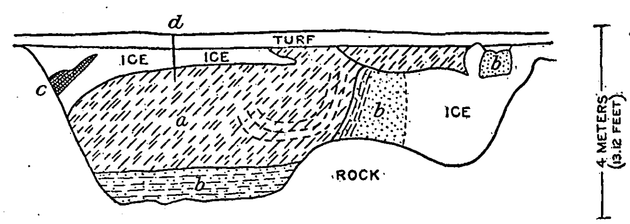


FIGURE 22.—Complicated exposure of ground ice. *a*, Disturbed muck and clay; *b*, clay; *c*, peat; *d*, a frost crack through the turf and ice.

slimy clay was seen under the muck at points where a good exposure revealed the lower strata (fig. 22). As the ice wedge grows in thickness and presses against the edges of the cleaved muck and sand beds they may become upturned and in time bent to the vertical or even beyond, causing the ridges which run along either side of the frost crack in the area of "depressed blocks." In areas of "elevated blocks" the process is not so easily understood. It may be that the block as a whole has been bulged up sufficiently to bring its surface above the general level, or else a central depression has been filled in and capped by turf.

The upturned beds of muck on either side of a wedge are a striking feature, and almost invariably occur in good exposures (figs. 23 and 24). Wherever the muck is underlain by sand, the sand is apparently forced up along the edge of the wedge, so that it lies between the ice and the upturned beds of muck. Some

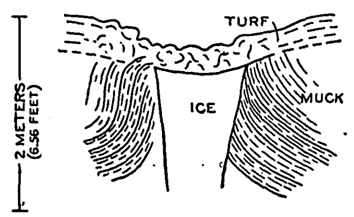


FIGURE 23.—Ice wedge in a muck bed, showing upturned strata.

of the illustrations show the sand apparently forced higher than the ice, or nearly through the layer of turf (fig. 21). The bedding of peat, on the other hand, does not seem to be disturbed by the growth of wedges.

In figure 25 is shown a hypothetical section of ice wedges and a depressed polygon block.

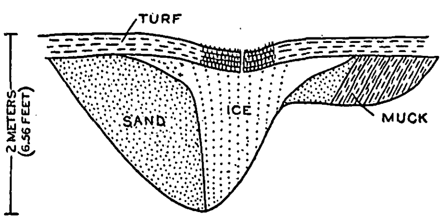


FIGURE 24.—Large ice wedge which spreads out under the surface of the ground. The vertical lines indicate rows of whiter ice full of air bubbles. The material on both sides is sand. To the right are upturned muck beds.

The writer was unable to ascertain the factors which control the character of block development. The "elevated blocks" are characteristic of drained areas and seem to be nearly constant features near banks. The "depressed blocks" are associated in the writer's mind with flat, marshy country. This, however, may be the effect rather than the cause of the difference in character of the blocks. The network of depressions will drain the elevated blocks, but the ridges form dams which interfere with surface drainage.

As the growing vein of ice becomes more wedge-shaped the pressure from its walls exerts a vertical component against the sides of the wedge. This tends to force the wedge upward. If an upward movement should occur, the ice would carry its protective covering with it and be able to exist level with or even somewhat above the general surface of the block. Since a bulging of the block by the growing wedge seems necessary, some upward

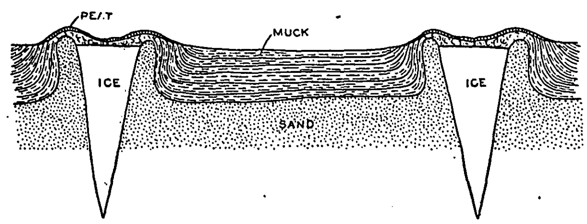


FIGURE 25.—Hypothetical section of ice wedges and depressed polygonal block.

motion of the wedge may take place without bringing the top of the wedge up to the general level. In the depressed blocks (Pls. XXIX, *B*, p. 205, and XXX, *A*, p. 206) the surface of the ground between the parallel ridges (probably underlain by ice) is higher than that of the blocks on either side.

THICKNESS OF PROTECTIVE MANTLE.

The usual covering of the ice is muck capped by turf, or peat capped by growing sphagnum (?) moss. As the thickness of this mantle increases by surface growth, the limit of the summer's thawing should rise, thus allowing a constant upward extension of the surface of the ice wedge at the locus of growth. Apparent upward growth of the surface was seen at only two or three places. In one place (see fig. 16, p. 207) there is an upward projection of ice above the general surface of the wedge, indicating a sudden change of the limit of thawing. In the other places the surface was dome-shaped, indicating a gradual change. As most exposures show the surface of the wedges to be nearly parallel with the surface of the ground, it seems that a balance must be maintained between the thickness of the covering and the increase in area to be covered, as the wedge becomes wider.

The rate of growth of turf must be very slow in this region, for there are many half-buried boulders on the surface of the tundra, which have been there since glacial time, or at least since the coastal plain emerged from the sea. Many bare spots exist where the turf has not been able to obtain a footing.

Wherever the protective covering is of muck, creeping of the soil will tend to close up the open frost crack. This will thin the covering, and if the rate of surface growth of turf is not sufficient to counteract the resulting decrease in thickness the upper surface of the ice will be lowered by melting. The increased slopes will cause more material to creep down over the ice, thus keeping the protective mantle up to the required thickness. A shallow depression will thus be formed, the slopes being sufficiently steep to cause the proper amount of creeping.

If the covering is sphagnum (?) moss the conditions may be somewhat similar. The moss and subjacent peat may also close the crack by creeping. At the same time the bed will become thinner, but growth of the moss will soon cause it to become thicker. If the moss grows too rapidly, the depression will be filled, and the conditions of moisture favorable to growth will cease. Thus it is possible for the growing ice wedge to maintain a peat covering of constant thickness.

CHARACTER OF EXPOSURES OF ICE WEDGES.

When a bank is undercut by wave or river action large masses of tundra commonly break off. As the frost cracks are planes of weakness, the break is likely to be along the ice wedges (Pl. XXXI, *A* and *B*), especially in high banks, where whole blocks break out, leaving many reentrant angles in the resulting bank, along which a nearly continuous exposure of ice may be seen. There appears to be a heavy horizontal sheet of ice of great thickness, whereas, in fact, little of it extends back more than a few feet from the face of the exposure.

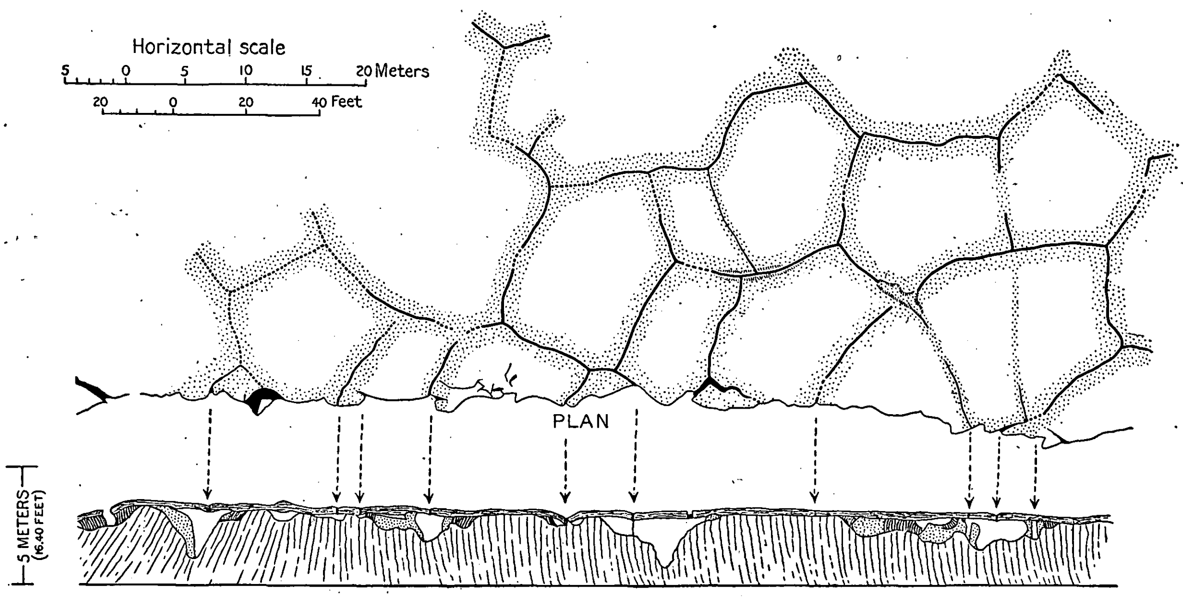
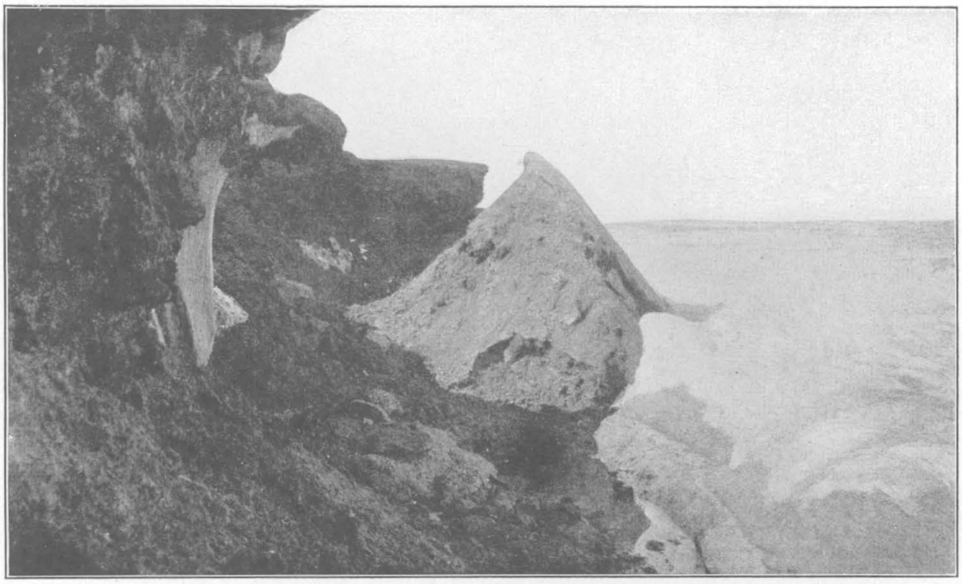


FIGURE 26.—Map of frost cracks on the tundra, with a sketch of the exposures of ground ice in the bank at one edge of the mapped area. Heavy lines represent frost cracks open in July. The dotted lines show evident loci of frost cracks. Stipple marks show areas probably underlain by ground ice. In the section below the map white areas represent ground ice; dotted areas, sand; lined areas, upturned muck beds. The rest of the exposure has slumped.

On a 250-mile boat trip from Flaxman Island to Point Barrow in the summer of 1914 exposures of muck banks invariably revealed ice. Many miles were examined closely on foot or from the boat, and very little ice was observed which was not definitely in the form of vertical wedges, associated with frost cracks on the surface of the tundra.

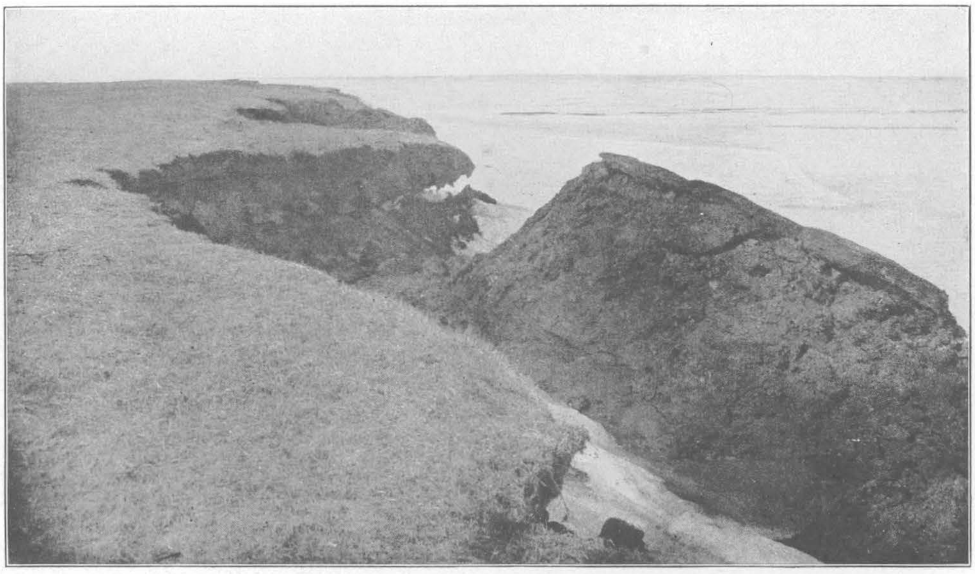
DETAILS OF A FROST-CRACK AREA.

In figure 26 is shown a plane-table map of an area of frost cracks and below it a sketch of the exposures of ground ice in the bank. The polygonal blocks were of the elevated type. The relief was very faint, being somewhat ob-



A. TUNDRA BLOCK BROKEN OFF FROM FLAXMAN ISLAND.

Ice wedge at left.



B. TUNDRA BLOCK BROKEN FROM THE NORTH SIDE OF FLAXMAN ISLAND.

scured by sand which had drifted up from a sand spit on the left. The exposure was somewhat slumped but gave sufficient details to be illustrated. The heavy lines on the map show open frost cracks; the dotted lines, the evident locations of cracks. Where there was no surface indication, no lines were drawn. The shaded areas are supposedly underlain by ice wedges.

The average diameter of 11 blocks shown on the map is about 36 feet. The largest block is about 36 by 49 feet and the smallest 16 by 26 feet. The largest wedges of ice are about 8 feet wide at the top, and this width has been used in estimating the areas probably underlain by ice, except where surface indications pointed to new centers of development. About 20 per cent of the tundra is probably underlain by ice.

ASSOCIATED FORMATIONS.

Wedges of ground ice, with their accompanying surface features, are typically associated with muck formations. None were seen elsewhere. River silts, elevated deposits of sand and gravel, and soft shales have been carefully examined. The only ice found in such places was evidently of another form and of a different origin. Straight lines leading across the gentle surface undulations of sand spits have frequently been observed, and they can be explained only as frost cracks. No polygonal forms have been seen in such places. The writer is unable to say whether ice wedges develop in such sands, for the exposures made by fresh wave cutting are seldom more than 2 or 3 feet deep, which is less than the depth reached by the summer's thawing of sand.

RATE OF GROWTH OF ICE WEDGES.

Fresh ice-filled cracks 8 to 10 millimeters wide have been observed in the ground immediately above the ice wedges. This may be put as the maximum width of the crack. Open cracks about 5 millimeters wide have been found in the ice itself near the upper surface. The width, of course, diminishes downward. If 5 millimeters is assumed as the width at the top it would require only 600 years to build up a wedge 3 meters wide, which is about the maximum width seen in the region. If the cracks do not all open every winter this period must be multiplied by some factor. The writer frequently observed open cracks during the early years of his residence in Arctic Alaska, but as he did not realize their bearing he did not keep any record of their abundance.

About 1,000 years seems to be the age of the largest wedges. Unless some unknown cause prevents a greater growth, the temperature could not have been sufficiently low to bring them into existence at an earlier date or else the coastal plain has not been elevated above sea level for a longer period.

It would be well worth while to endeavor to measure the actual rate of growth of ice wedges over a series of years. In this way considerable insight as to the age of existing wedges might be gained. By measuring wedges of different sizes some law might be found by which the rate of growth could be extrapolated beyond the limit of size found in the locality. If the frost-crack theory is found to apply in areas where the wedges are more greatly developed than in Alaska a fairly definite time limit could be set for the existence of the Alaskan coastal plain above sea level. In areas of greater development a minimum might be set to the duration of the cold climate which was the cause of their development.

A series of posts in pairs might be set well into the ground on both sides of the ice wedge. Careful measurements made over a period of years would show any growth of the wedge. Any irregularities from possible disturbances of the posts would be eliminated by having a sufficient number of pairs of posts.

UPWARD BULGE OF SURFACE OF GROUND.

If we assume that the elevated blocks are bulged up by the growing ice, the amount of general elevation of the surface of the tundra can readily be calculated. If 20 per cent is taken for the surface compression of the block, as has been done for the north shore of Alaska, the average compression will be 10 per cent. An average block 11 meters in diameter will be compressed horizontally 1.1 meters to an assumed depth of 8 to 10 meters. This will cause an increase in a vertical direction of about 1 meter.

In the depressed blocks the adjustment is concentrated into the surrounding ridges, and the conditions are different. The depressions are being continually filled with growing vegetation, as well as by wind-blown material. In this way a much greater general elevation of the surface of the tundra is possible.

ULTIMATE STAGES OF GROWTH OF ICE WEDGE.

It seems to the writer that the wedges should bulge up the inclosed polygonal block more and more as they encroach upon it, so that a stage would be reached where a central mound of earth would rise above the surface of the block, which is generally underlain by ice. The earth block should now be pyramidal, with the apex pointing upward, and the wedges of ice should be in contact along the greater part of their upper edges. A perpendicular section through the middle of the inclusion of earth would show a section of a pyramid, but one which was taken eccentrically through the inclusion would invariably show earth overlain by ice. In this way the inclusions of earth overlain by ice which appear in the photographs in Von Toll's work (Pls. XXXII, XXXIII, XXXIV) might find an explanation, but the fact that some of the inclusions are apparently cylindrical is hard to reconcile with the writer's understanding of the theory.

As the wedges grow into contact along their upper edges, the deformatory pressure of the summer's expansion of the ground is supported more and more by the ice itself, until at last the included earth is in such subordinate amount that new conditions are set up. That the annual fissuring of the ground must go on even after it is chiefly underlain by ice is shown by the numerous contraction fissures in all ice covering bodies of water, though it is not certain that the original polygonal network of fissures would be maintained. If these fissures are filled with new ice the old ice must either be bulged up or caused to flow horizontally, unless the compression can be absorbed by the elasticity of the ice. It is possible that the pressure might melt enough of the ice to relieve the strain, but because of the low temperature of the ground and the plasticity of ice under strains, it is more likely that it will be deformed.

Consequently, if bodily flowage is not possible, the surface of the ice must gradually bulge upward, of course carrying its protecting mantle with it. The great thickness of the New Siberian ice may be thus explained, if it is to come under the frost-crack theory.

The conditions seen by the writer in Alaska are widely different from those described in Siberia. He does not maintain that the ground ice of both localities can be explained by the same theory, but as no other theory explains all the facts in the Siberian field the frost-crack theory may be entertained as a working hypothesis. Detailed study is necessary to show the intermediate stages. If they are found, the theory can be expanded so as to fit them.

If the ice of New Siberia is to be accounted for under this theory, the surface must have grown upward many feet. If 30 feet is assumed as the depth to which the fissures are opened by the annual changes in temperature, then the ice under discussion, which is at least 60 feet thick, must have increased 30 feet in thickness by upward growth.

MISCELLANEOUS FORMS OF GROUND ICE.

In many places along the coast there are exposures of a mixture of nearly equal amounts of clay and ice granules. The ice granules are clear and from one-half to three-quarters of an inch in diameter. There are also horizontal patches of clear ice an inch thick and 4 or 5 inches long. The clay granules are about the same size as the ice granules. They are roughly concentrated into horizontal rows, and this arrangement, with the intervening ribbons of clear ice, gives a stratified appearance to the formation. The clear ice in many places has fine vertical lines of air bubbles, which suggests a prismatic structure. Figure 16 (p. 207) illustrates an exposure of this ice. The clay granules shown in the illustration have rootlets in them, but elsewhere they are of a slimy clay similar to that found on the bottoms of shallow ponds.

The origin of this ice is not clear. Concentration out of saturated earth, as described by Hesselmann,[1] seems the best hypothesis. It is

[1] Holmsen, Gunnar, Spitzbergens jordbundsis: Norske Geog. Selskaps Aarbok, vol. 24, p. 42, 1912–13.

possible that the granules might increase in size in the manner suggested by Chamberlin[1] for glacial ice.

Another minor form of ground ice is found in ribbons or thin sheets of clear ice alternating with layers of earth. Only one actual exposure was observed by the writer, but as the details of such an exposure would be quickly masked by melting it is possible that this form is fairly common. In figure 22 (p. 208) parallel curved lines are drawn to indicate such ribbons of ice, which in the place sketched were 3 to 6 millimeters thick. In July, 1914, when the sketch was made, no ice was seen, but only the marks left on the surface where the ice had melted out. When examined during the previous October, a short time after a block had broken off and revealed the exposure, the ice was seen to be clear and near the outside to contain fine lines of air bubbles running perpendicularly to the plane of the ribbon. This orientation still occurred where the ribbons were bent upward. These alternating bands of ice and earth occurred both in the slimy clay and in the muck which lay above. The phenomenon at first suggested conchoidal cleavage of the tundra under the winter's contraction and subsequent filling of the cracks with surface water, but later insight into the working of frost wedges forced the abandonment of this hypothesis. In the clearness of the ribbons as well as in the apparent prismatic structure, it is very different from the finely granular and air-filled ice of the wedges. There was no way to determine whether the ice and earth bands had been horizontal at first and had been disturbed afterward or had been formed in their present attitude.

This same kind of ice has been noted by Quackenbush at Eschscholtz Bay, by Holmsen in Spitzbergen, and by several of the Siberian observers. The presence of thin bands of ice, which increased in amount toward the bottom of the Schergin shaft, is mentioned by Middendorff.

The writer is at a loss to explain this banded form of ice, where it has evidently been formed after the ground formations had been deposited. There are objections to the hypothesis that the ice has concentrated out of the moisture in the freezing ground; the same objections are raised against Lieut. Belcher's hypothesis as elaborated by Holmsen. (See p. 229.) Nor does it seem possible that small fractures in the frozen ground, caused by gradual contractions as the increasing cold penetrated downward, could have become filled with water. The ground circulation would have been previously shut off by the freezing.

It may be that in the readjustment of the polygonal blocks, owing to the pressure of the growing ice wedges, conchoidal fractures are formed in the frozen ground. These spaces may be filled with surface water, but it is difficult to explain the solidity and clearness of the ice in comparison with the ice in the wedges, which is whitish.

The only notable exposure of ground ice upon the coast that did not show ice in the form of wedges was examined in July, 1912, before the writer had worked out this theory. The exposure is 3 or 4 miles east of Collinson Point, at a place where the ocean is cutting a 40-foot bank into the gentle seaward slope of the Anaktuvuk Plateau. In many respects this exposure resembles some of the exposures described by Quackenbush at Eschscholtz Bay.

This exposure was in a crescentic slump scarp which showed about 100 feet of ice that had a maximum vertical thickness of 7 feet. The upper surface of the ice was parallel with the surface of the ground and lay about 18 inches below it. The hillside here sloped about 15°. Immediately over the ice was an apparently undisturbed layer of yellow and black clays in thin alternating beds. Over this was about a foot of turf mingled with clay, which was slumping down over the lower clay and ice. The ice immediately below the soil had a perpendicular face, but 3 or 4 feet lower the slope decreased until one could stand upon the surface of the exposure. On this floor mud and blocks of turf had lodged, so that the lower part of the ice was concealed.

Where the ice was clean on the outside it was unusually clear and blue. The greater part was nearly free from air bubbles. In many places a network of lines over its surface showed that its structure was granular. The average size of the granules was 10 to 20 millimeters, a larger size than that of those in other ex-

[1] Chamberlin, T. C., and Salisbury, R. D., Geology, 2d ed., vol. 1, pp. 309-310, 1905.

posures, where later investigations have shown the ice to be in the form of wedges. A block of this clear ice that was left in the shade for a few hours disintegrated into small fragments. Where the nearly horizontal foot of the exposure could be seen it was crisscrossed with many closely spaced straight lines, which were perhaps the locations of as many fractures. In one place there was a roughly V-shaped mass of discolored ice, which contained many vertically elongated air bubbles. Close inspection showed this discolored ice to be in part composed of thin alternating bands of clear and yellowish ice, which curved parallel to the line of demarcation between it and the body of the exposure, much as if it had been frozen while flowing down the side of a depression in the clear ice. Several irregular masses of clay were inclosed in the main body of the ice, as is shown in figure 27.

FIGURE 27.—Exposure and section of ground ice near Collinson Point. A, Front view; B, profile.

As no glaciers came down to the coast in this neighborhood, and as no boulders of the Flaxman formation are found within several miles, this ice is probably not glacial. A recent slump could hardly have buried a snowdrift under a former steep bank, for the size of the granules points to a great age for the ice. Still the inclosed masses of clay, the granulation, and the locality make a buried snowdrift the probable source of this ice.

Very little ground ice was seen inland, probably because no search was made in favorable localities. In winter the snow obscured most of the river banks, and in summer the packing routes usually lay along the tops of the banks. On Canning River, near the end of the Shublik Mountains, a fresh cut against a 12-foot flat showed 4 to 5 feet of clear ice overlain by 6 inches of gravel and as much muck and moss. Small willows were growing at the top. The ice was definitely prismatic and in no way could it be told from the needle-shaped crystals of river ice over which the observer had been recently walking. This ice seems clearly to be aufeis that has been buried by gravels.

Much ice was observed in the 4 to 6 foot banks of the flat between the two distributaries of the same river. The ice lay far back under the overhanging turf, so that its structure could not be made out from the canoe in which the observer was traveling.

On the east bank of the east mouth of Katakturuk River, about a mile from the coast, were two exposures of ground ice, each about 50 feet long. They lay under gentle domelike elevations which rose 3 or 4 feet above the general delta level. One of these exposures, when carefully examined, showed about 3 feet of ice under 1 to $1\frac{1}{2}$ feet of turf. Where the exposure was quite fresh the ice was solid, blue, and very clear. Where weathered, it was white and showed a vertical prismatic structure. Individual crystals could be traced for 12 to 18 inches, and by running the point of a knife along the surface of the exposure a mass of needles 8 inches long and three-quarters of an inch in diameter could be stripped off. These domes can hardly be remnants of a former generally higher level of the delta flat. No gravels or sand were seen above the ice but only turf. The burial of flood ice by wash material is excluded, for the river here is transporting material as large as small cobblestones. The most probable hypothesis is that these domed exposures of ice were formed where hydraulic pressure had bulged up the frozen turf. Water then solidified in the cavity. According to Tyrrell, horizontal sheets of ice of great extent are thus formed.

REVIEW OF THE LITERATURE ON GROUND ICE.

The wide distribution of ground ice in polar and subpolar regions makes it desirable that the extensive but widely scattered literature on its occurrence be made conveniently accessible to geologists. It is for this reason that the following annotated résumé is presented. In its preparation extensive use has been made of the publication of Mr. Gunnar Holmsen, to which reference has been made.

SIBERIA.

ADAMS.

M. F. Adams[1] is credited with having given the first intelligent description of ground ice, which he saw in the Lena delta in 1806 while investigating a mammoth skeleton that had been reported by the natives. At this place there was an escarpment 3 versts long and 30 to 40 fathoms high. The substance was a pure, clear ice of a piquant taste. It was covered to a thickness of a third of a meter with moss and friable earth. Great masses of earth became detached from the hill. This earth formed wedges (coins) which sank down between the masses of ice (glaçons). The mammoth remains were found in the earth wedges between the ice masses.

FIGURIN.

Figurin[2] in 1823 describes ice layers and veins which cut across the exposures in different directions. The ice had a turbid aspect and was mixed with loam. Figurin is credited by Middendorff with having first mentioned the audible cracking of the ground in winter.

MIDDENDORFF.

Middendorff, whose observations in Siberia during the years 1844–1846 have been published at some length, gives only a few descriptions of ground ice. The writer has not attempted to go through the whole work but has confined himself to verifying the references given in later literature.

In the Schergin shaft at Yakutsk, at a depth of 104 feet, lay 280 feet of clay and sand, which were crossed with thin layers of ice whose thickness ranged from 1.5 millimeters to that of a sheet of paper. These thin layers were almost invariably intrusive between the fine wavy layers of the rock itself, and only a few of them filled fine fissures which cut each layer of earth perpendicularly. The ice layers increased in amount toward the bottom of the shaft and formed planes of weakness, so that the ground was easy to excavate.

Above this deposit there were a couple of thin beds of limestone, as well as a heavy bed of sandstone, which contained iron pyrite and lignite (Braunkohle). In the ice-bearing deposit itself were layers of limestone and sandstone of different thicknesses, as well as pyrite and bituminous wood.[3]

The cracking open of the ground under the action of the frost is reported by Figurin, and Middendorff quotes him as relating that in northern Siberia the earth often breaks open with a terrific report on account of the frost, to such a degree that in the middle of the winter lakes found outlets through the fissures. Wrangell is also cited as describing a similar occurrence. Middendorff visited the locality described by Wrangell and came to the conclusion that the appearance and disappearance of lakes were frequent and that they were brought about by other causes. Furrows were frequently seen upon the tundra in the summer, and many of them could be followed for the distance of a verst. The furrows were 4 to 6 inches wide, and shallow. These furrows, which occur on lower as well as on higher parts of the tundra, cut each other in different directions, forming irregular figures, which are mostly small. The largest block measured 114 paces in circumference.

> Finally I add yet another to the just-described phenomena, whose origin remains entirely a mystery to me. One of the moss islands in the lower course of the upper Taimyr River * * * was covered with ponds. These formed here regular elongated quadrilaterals, 25 paces wide and 40 paces long, with a depth of only 2 feet. They were separated from one another by low, broad ridges 3 paces wide, through whose middle ran a furrow from a span to a foot wide, of the kind we have described above.[4]

Middendorff's chief contribution to the theory of ground ice is his description of the aufeis of the Siberian rivers. This ice, which is more fully described under the heading

[1] Tilesius, W. G., Acad. Sci. St.-Pétersbourg Mém., vol. 5, pp. 406–455, 1815.

[2] Toll, Eduard von, Acad. Sci. St.-Pétersbourg Mém., 7th ser., vol. 42, No. 13, p. 20, 1895.

[3] Middendorff, A. T. von, Sibirische Reise, Band 1, Theil 1, pp. 97–98, 1848.

[4] Idem, Band 4, Theil 1, pp. 504–506, 1859.

"Cenozoic deposits" (p. 158), is formed in the following way: In the winter the rivers tend to freeze solid at their shoals, so that the flow is impeded. The water bursts out of the ice from the hydraulic pressure and floods over the surface, where it freezes. The process may go on all winter, so that a heavy deposit of ice may be built up over the whole flood plain of the river. Such a deposit is mentioned as extending several miles along a river. The width was in places half a mile, and the ice extended over the banks and into the forest on either side. Some thin beds of sand or gravel were incorporated in the ice, adding to the stratified appearance seen in the alternating bands of white and blue ice, which marked successive deposits of snow in the growing bed of aufeis. That this kind of ice is common in Siberia is attested by many observers.

If such a deposit of aufeis were covered by a protective mantle of sediment during the spring floods it would remain as ground ice until cut away by the meandering of the river.[1]

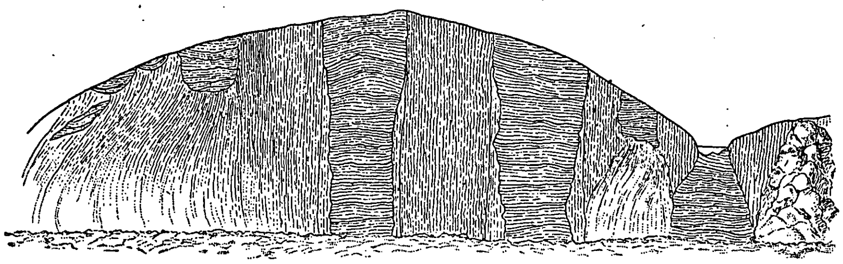


FIGURE 28.—Exposure of ground ice at Schandran, after Maydell. Inclusions of earth are marked by wavy horizontal lines.

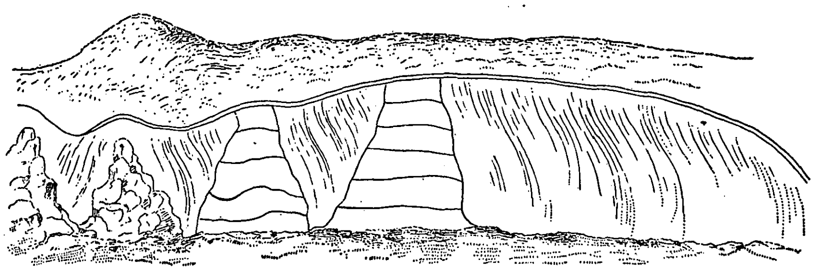


FIGURE 29.—Exposure of ground ice at Schandran, after Maydell. Pyramids of earth which have weathered out of the ice appear at the left.

MAYDELL.

Maydell in 1871 made valuable observations upon the ground ice in Siberia. His notebooks were turned over to Toll, who published extracts from them.[2]

No. 4.—A cellar was dug in a bank at Chomos-Urach. The earth was unfrozen for a depth of 14 inches, then came 5 inches of frozen ground, and then about 15 feet of solid, white ice, like a vein. The ice was pure white but not transparent because it was full of countless air bubbles which were arranged in vertical rows. The rows were so close together and the bubbles so small that they had the appearance of cracks running through the ice.

No. 5.—At Schandran a considerable amount of ice came into view. The greatest visible thickness of the ice was 26 feet. It was overlain by sod and clay to a thickness of 32 inches. The upper surface of the ice was parallel to the surface of the ground. In the ice wall there were inclusions of earth, mostly in the form of vertical cylinders, the largest 10 feet in diameter. Some of the cylinders shown in the illustrations (figs. 28 and 29) are wider at the top and others at the bottom. Some of them were seen to be surrounded by ice, and others were found to be so by digging a pit behind them. It seemed as if there were shafts in the ice masses into which the earth had entered as into a pot. Some of these inclusions ran the whole vertical length of the profile, but others ended a few feet below the surface of the ice. The earth of the

[1] Middendorff, A. T. von, op. cit., Band 4, Theil 1, pp. 430–453, 1859.

[2] Toll, Eduard von, Acad. Sci. St.-Pétersbourg Mém., 7th ser., vol. 42, No. 13, pp. 18 et seq., 1895.

inclusion is stratified in regular horizontal layers as in a connected series of beds.

The ice is somewhat yellow and is filled with air bubbles as well as very fine cracks, many of which carry clay layers as thick as a sheet of paper. The ice wall melts back into pots

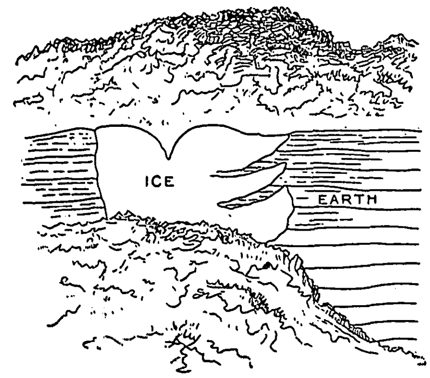


FIGURE 30.—Exposure of ground ice at Schandran, after Maydell. Inclusions of earth extend into the side of an ice wedge.

of semicircular form, out of whose bottom rise pyramids formed from the vertical inclusions of earth (fig. 29).

In figure 30 is shown a wedge of ice which has horizontal inclusions of earth.

LOPATIN.

Lopatin[1] saw in 1867–68, in latitude 68°, on the shore of the ocean north of Siberia, an ice formation 7 feet thick, consisting of a mixture of ice fragments, water-soaked snow, and sand, which melted only after five months. In a locality where the temperature was lower such ice beds should last an entire year or even centuries, and ground ice might be thus formed.

Lopatin also describes ice veins which have been formed by the freezing of water in fissures. The size of these ice masses may range from the diameter of the finest capillary to 7 feet. The length may be 23 feet.

NORDENSKJÖLD.

Nordenskjöld,[2] about 1878, while on the *Vega*, noticed that the fresh water which floated on the surface of the ocean near river mouths would freeze if carried down into the cold salt water below. He advanced the theory that the river-borne mud and sand, by sinking, might thus carry down fresh water, which would freeze and form ground ice under the ocean. This ice would be later covered by mud during the spring floods and protected.

[1] Toll, Eduard von, op. cit., p. 31.
[2] Idem, p. 69.

TOLL.

To Baron von Toll we are indebted not only for some of the most important observations upon the Siberian ground ice but also for a summary of the earlier literature. His field of investigation covered much of the Siberian mainland and extended to the islands of the Arctic Ocean, where ground ice attains its greatest recorded development.

At Bor-Urach River, in Siberia, Toll dug seven holes in the tundra, and in all of them found ice about a meter below the surface. In the last hole he measured the following section:

Section in hole dug in tundra at Bor-Urach River, Siberia.

	Meters.
1. Thawed ground	0.3–0.4
2. Alternating layers of ice (3 centimeters thick) and clay (5 centimeters thick)	1.
3. Clean-bedded ice (0.2 meter thick), partly with sloping layers, and an inclusion (0.5 meter thick) of alternating clay and ice beds	.7
4. Clean, horizontally bedded ice	8.3
5. An inclusion of stones.	
6. Horizontally bedded ice	3.5

A meter under No. 6 there was a cone of cobblestones inclosed in ice. After digging 2.5 meters into this cone the work was stopped, at a total depth of about 15 meters. The shaft reached 8.5 meters below the level of the surface of the stream and 5 meters below that of the river bottom.

As ice was found about 1 meter below the surface in all seven holes, the whole area is considered to be underlain by ice, as a "stone-ice" hill. The ice-cemented cobblestones at the bottom are in the bed of the river. The area was flooded by the aufeis described by Middendorff. The inclusions of gravel and clay are explained as successive outwash upon the growing bed of aufeis.

As a support to the theory that the ice in this locality is composed of aufeis, Toll refers to the profile of the opposite bank of the river, where he saw about half a meter of ice under a meter of ground. This ice was homogeneous and whitish and was crossed with perpendicularly arranged air bubbles, which gave it a striped appearance. The air bubbles were held to point to a snow origin, which is to be expected in beds of aufeis.[1]

The ice of the New Siberian Islands was examined in 1886 by Toll in May and by Bunge in June. Toll thus describes the Great Liakof Islands.[2] (See Pls. XXXII, XXXIII, and XXXIV.)

In the steep coast, consisting of Quaternary beds, I could distinguish here and there a connected lower horizon of stone ice, and also an uninterrupted upper horizon of layers of clay, sand, and peat. * * * Near Cape Tolstoi, a lower gray-green ice horizon can be followed for a distance of several versts along the coast. The ice bed reaches into the overlying clay beds in broad, low pillars, similar to blocks; or, on the contrary, part of the upper horizon penetrates into the lower ice horizon, as loam masses 10 feet wide and 15 to 70 feet high, according to the height of the ice wall. In the loam beds are alternating thin bands of ice and loam. The mammoth remains were found by the guide, embedded in a loam-filled depression, surrounded on both sides by ice. The similarity to the description of Adams is striking.

The color of the ice wall is a gray green, but in hand specimens the ice is entirely transparent and colorless. It contains closely scattered air bubbles 1 to 2 millimeters in diameter. No bedding was here apparent. * * * The bank showed yet another instructive phenomenon. The covering of the ice was here crossed by some fissures a few centimeters wide which reached down into the "stone ice." The fissures were filled with a mixture of clay and ice * * * which was easy to distinguish from the primary ice by its color and structure. The impossibility of these small fissures filled with impure ice as the origin of the entire mass of "stone ice" is apparent.

Toll says that there is no doubt that the ice is the older formation and that the dark stripes of earth are younger intrusions. Four stages of formation are postulated. (1) A broad ice layer (formed from snow) covered the whole island with the exception of the mountains. This ice layer was torn apart and fissured, or crossed by small cracks. (2) These fissures and canals were filled with thin ice, clay, and sand layers, or they were closed again after being partly filled. (3) Sediment was laid down over the ice. (4) This sediment was covered by the present vegetation.[3]

Toll found in the frozen sandy clay beds, under the peaty surface layers, specimens of *Alnus fruticosa*, consisting of the whole trunk and roots to a length of 15 to 20 feet. The bark was intact. He says:

This find makes it evident that here on the Great Liakof Island, at 74° latitude, a vegetation flourished temporarily, which to-day reaches its northern limit 4° to the south on the mainland, and that the remains could in no manner have been floated from a distance but grew here in the very place.[4]

Toll thus describes the structure of the ice of Kotelni Island:

The ice was almost structureless in new exposures, * * * but when the sun shone upon the wall the hairlike lines became noticeable. A few hours later the single grains could be differentiated. The ice showed that it was constituted of fragments that were prismatic and irregularly joined together but firmly attached. * * * Some granules were prismatic; others were flattened on the sides and pointed at the end, or more or less compressed cubic granules. * * * The largest granules measured 10 by 5 millimeters.

After giving the observations of Emden upon the prismatic structure of water ice, Toll says:[5]

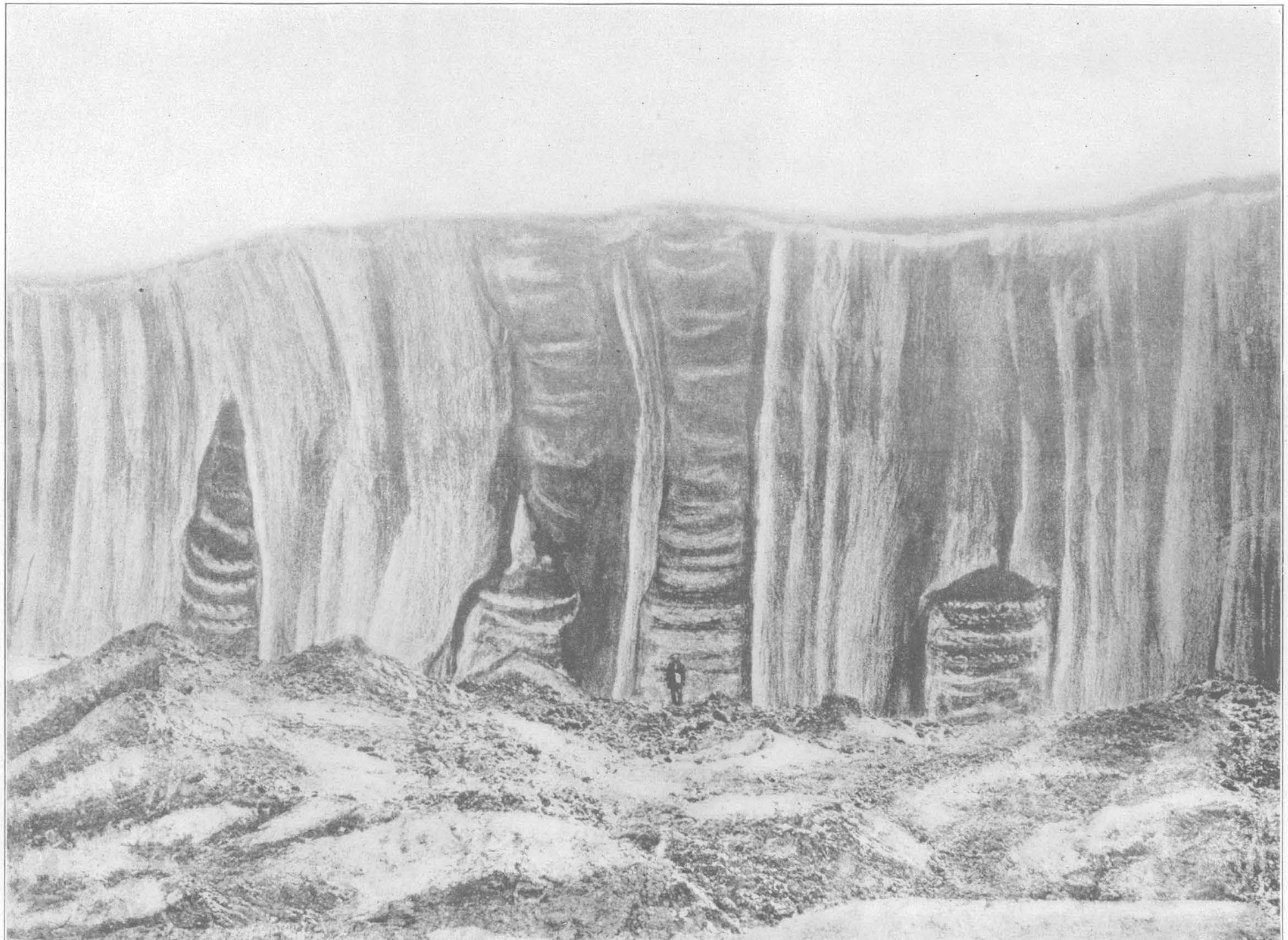
If we should postulate frozen lakes for the fossil ice of the islands, then we must, as just mentioned, find ice prisms of considerable length and not the granules described by me. Ice prisms, however, were certainly seen in the fossil aufeis formation * * * at Bor-Urach. * * *

Perhaps the question might be raised whether pond ice might not in the course of time, by the pressure of frost, become uncrystallized in such a manner as to take on the observed structure of fossil ice.

Toll then quotes Emden, Heim, and Drygalski as to the size of granules, which are shown to vary according to the temperature and position. The granules of firn ice are smaller than those of true glacier ice, and the granules of glaciers in cold climates are smaller than those in warmer regions. He says:

At all events the intense cold of Arctic Siberia must have restrained the growth of the granules. We see then that the structure of the New Siberian Quaternary ice beds speaks for their origin from snow beds and strongly against the acceptance of a water formation. The whole region was covered with an ice layer. This ice cover, cut up by brooks of melted ice, * * *

[1] Toll, Eduard von, op. cit., pp. 40–48.
[2] Idem, pp. 51 et seq.
[3] Idem, p. 59.
[4] Idem, p. 60.
[5] Idem, pp. 62 et seq.



GROUND ICE OF THE NEW SIBERIAN ISLANDS.

After Von Toll.

GROUND ICE OF THE NEW SIBERIAN ISLANDS.

After Von Toll.

remained so long, in consequence of a temperature constantly below 0° C., that it was covered with terrestrial and lacustrine formations through the action of wind and water, and then, during a climate which constantly grew colder, it was able to last until to-day as a witness of a time which is older than the period of the great Siberian mammals.

In conclusion, Toll makes the following statements:

1. There are different types of ice in the frozen ground of Siberia. (*a*) Modern formations—ice in fissures, veins, and thin layers, as water and snow ice. (*b*) Quaternary and perhaps recent ice, as remains of aufeis formations in river valleys. (*c*) Quaternary ice of the type of the New Siberian Islands, a remnant of earlier glaciation.

2. The mammoth remains are not in the ice, but in the frozen clay and sand layers, though often overlying fossil ice masses.[1]

During the years 1900–1902 Toll again visited the New Siberian Islands, where he lost his life. In the narrative published by Baroness von Toll the writer has not been able to find much of importance bearing on this matter. Toll seems to be more strongly than ever of the opinion that the ground ice is a remnant of the glacial epoch. He mentions finding a ground moraine under the ground ice.[2] He finds that the ice cliffs have in places retreated several hundred fathoms during the nine years since his former visit.[3] Baidscharachs, conelike earth hills which fringe the base of a melting ice cliff (Pl. XXXIV), are the remains of frozen loam and sand masses in the ground ice.[4] Their sharp-pointed appearance is due to two factors—their loesslike composition and their frozen state.

During post-Tertiary time North Siberia was covered with ice as Greenland is to-day. The modern ground ice is a remnant of the old glacier. As the post-Tertiary remains are never found in the ice itself, but in the earth by which the ice is covered, this fauna must have first entered the country after the climate had become so mild that the limit of growth of various forms of vegetation was several degrees farther north than now.[5]

[1] Toll, Eduard von, op. cit., p. 86.

[2] Toll, Baroness von, Die russische Polarfahrt der *Sarja*, p. 411, 1909.

[3] Idem, p. 481.

[4] Idem, pp. 534–535.

[5] Idem, p. 602.

BUNGE.

In his journey to Cape Bykof, in the Lena Delta, in 1883, Bunge made a few observations upon ground ice. He later presented a theory of its formation in frost cracks. He says:[6]

When one steps upon the tundra almost anywhere in the delta, it appears divided into countless irregular polygons of differing size, whose edges are higher than the middle. Between the edges of two such polygons, a small furrow is found, which is used as a pathway by lemming. * * * These furrows correspond to a fissure which reaches deep into the earth and is filled with ice. The fissure will become wider through flowing and freezing water. During high water and generally during the whole summer the banks break down in great blocks, corresponding to the above-described polygons. * * * Besides these broad, easily noticed fissures on the surface the whole ground is crossed by small fissures which are filled with clear ice. In our excavations * * * we continually met such ice veins, and the loud reports in the ground, especially in the increasing cold of the fall, testifies that the forming of fissures goes on continually.

In examining another exposure he says that at the first glance it seemed as if the blocks consisted entirely of ice, indeed as if the upper earth layers of the island rested upon a foundation of ice. It was not hard to convince himself that the ice here also originated through fissure formation.[7] In another locality the greater part of the bank was covered (bedeckt) with ice; only here and there the earth showed, and it was stratified. The first impression was that the ice was a part of the ground and that the ice masses were embedded in the earth. The conclusion was soon reached, however, that the ice was only a secondary deposit from the gathering of water in the fissures where it freezes. When a big mass of earth breaks off, which is assisted by the formation of the ice in the fissure, the ice comes to light. The grounds for this conclusion are stated as follows:[8]

Nowhere where the earth and ice are in contact can one see an overlapping of the earth upon the ice; always the opposite. On the borders of an ice surface one succeeds with less labor in reaching to the earth; in the middle we did not succeed, although we

[6] Bunge, Alexander von, Acad. Sci. St.-Pétersbourg Bull., vol. 29, pp. 444–445, 1884.

[7] Idem, p. 454.

[8] Idem, p. 460.

worked hard and dug a hole more than 2 feet deep. * * * Further, if the ice masses were bedded, we should think them to have come about from accumulated snow masses. These must show a horizontal bedding, * * * but nowhere is a horizontal bedding visible.

With respect to the ground ice of Great Liakof Island, which he visited in June, 1886, Bunge says that the ice walls reach a height of 72 feet, much larger than he had observed on the mainland. The ice is turbid and contains many air bubbles and earthy intrusions. He sees no reason to depart from his theory of frost-crack fillings previously advanced in his description of the Cape Bykof region in 1883. Besides the great ice beds, thin horizontal layers of ice are found between the horizontal earth strata.[1]

Bunge's first statement of his theory in a letter from the field to the Academy of Sciences at Petrograd has been given above. As there stated it is lacking in detail as well as in clearness, yet anyone who was actually engaged in the study of the question in the field should have comprehended him. He brings out the fact that the ice grows in fissures which cut the ground into polygonal blocks.

Twenty years later he gives a much better statement of the theory, which is quoted below:[2]

When in the autumn the cold increases one hears in the northern tundra of Siberia frequent loud cracks and reports within the earth, like shots under the surface of the earth; the deeper the cold now penetrates the earth the more distant and deeper appear these reports and call to mind a distant cannonade. There is no doubt that these detonations are brought about by the formations of crevices and fissures, which in their turn arise through the contraction of the ground as a result of the cold.

These fissures, always advancing farther, reach to considerable depths. Such fissures and crevices we meet everywhere in earthworks, where they are always filled with clear ice. After this the melting of the snow about the middle of June takes place very rapidly, so that ponds of snow water are formed in the tundra. The temperature of the water in these pools reaches a scarcely believable height. For example, I found * * * on the 16th of June (old style) under an air temperature of +10° C., in a superficial pool, +16° C., even 17.5° C., although the pool was constantly being fed with inflowing snow water. This high temperature is naturally to be ascribed exclusively to the action of the sun, although the thickness of the thawed earth on the bottom of the pool did not amount to more than a centimeter. The water warmed in this way now flows in very considerable amount into the fissures in the ground, of which we may immediately convince ourselves. * * * The water, owing to its comparatively high temperature, reaches the greatest depth of the fissures and freezes rather quickly there in the strongly cooled ground. In the moment of freezing it naturally expands very strongly and an enormous pressure comes about, which presses apart the walls of the fissure. Through this pressure the originally horizontally deposited loam and humus layer becomes influenced to such a degree that folds are formed. * * * With the gradual cooling the ice naturally contracts again, and in consequence of this a new crack is formed between the ice and the walls of the fissure, into which water again flows, and this process can continue for a long time. It follows from what has just been said that the walls of the fissure are most strongly pressed apart at the bottom and consequently the fissure will take a broadened form in the lower part. * * *

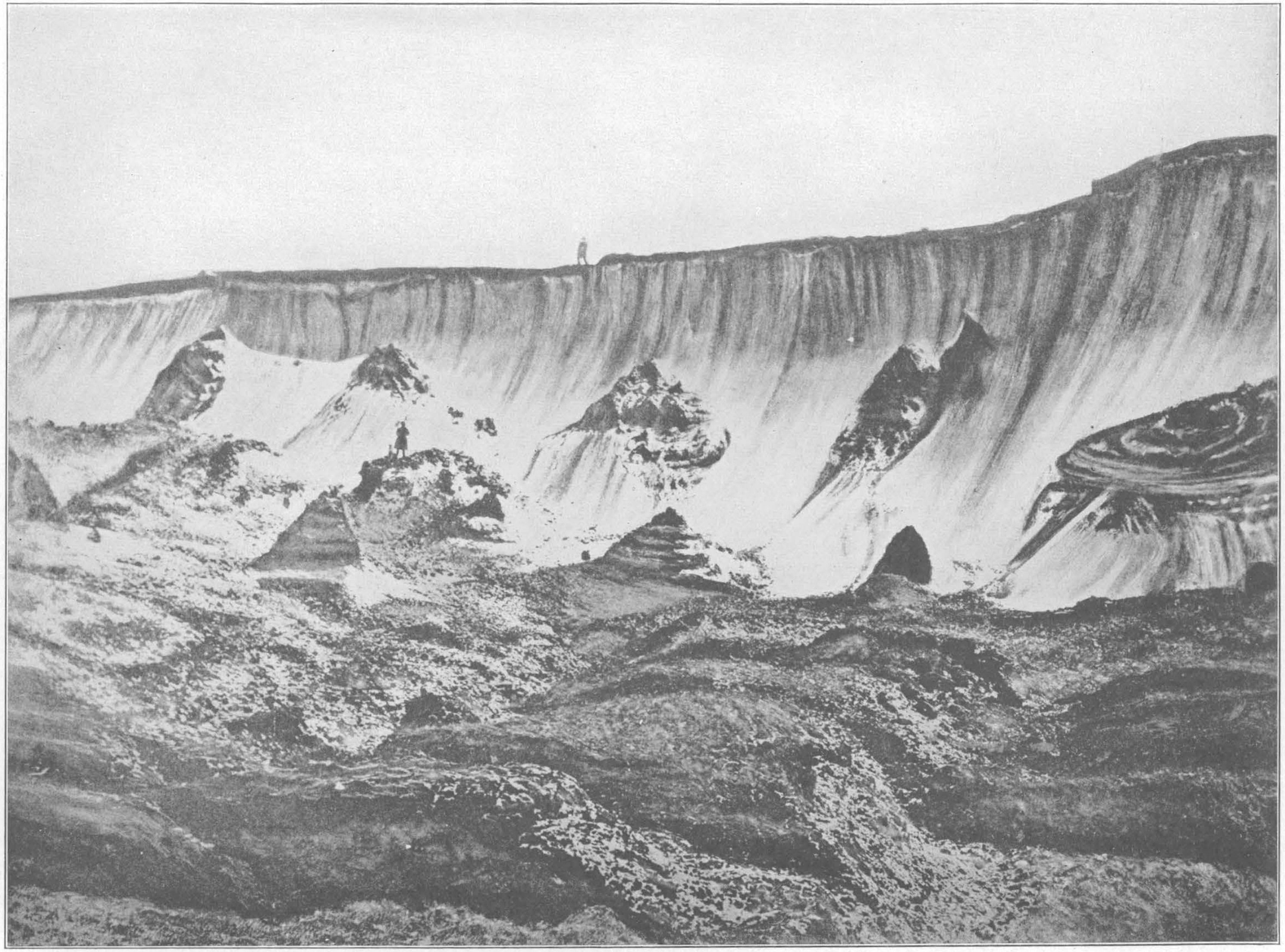
In this manner heavy bodies of ice can accumulate, especially when the pressure of the ice meets no especial resistance from the side of the mass, as is the case when the fissure runs parallel to the free wall of a profile. When the profile reaches the ice layer (through thawing) a picture of a continual horizontal layer is shown, although its thickness (in a horizontal direction) should be only very slight. In consequence of the slight heat conductivity of the ice, it thaws much slower than the loam beds on either side, and therefore the ice prevails in the profile by a great amount.

After what has just been said, the unusual aspect of the tundra is at once clear to the observer; it appears divided throughout into polygons whose middles lie deeper than the edges. The distinct elevation of the edges is explained through the thickness of the ice which is contained in the fissures, by which the polygons are inclosed. Naturally, such ice is not always of the same composition with regard to its structure, and contains inclusions in different degree. Besides, the ice formed under the influence of enormous pressure, which exists in the bottoms of the fissures, is impaired (?) in its structure completely, and under no circumstances permits its origin to be postulated.

The circumstance now appears clear that the ice, crossed throughout by small cracks and bubbles, which latter are arranged in vertical rows, shows that it was formed out of water which in freezing contained a large quantity of air. * * * I might add that two entirely impartial and independent observers—the Englishman Beechey, in Bering Strait, and Lopatin, in the Yenisei tundra, have come to an entirely identical agreement with my view.

[1] Bunge, Alexander von, Acad. Sci. St.-Pétersbourg Bull., vol. 29, p. 252, 1884.

[2] Bunge, Alexander von, Russ. k. mineral. Gesell. Verh., 2d ser., Band 40, pp. 205–209. 1902.



GROUND ICE OF THE NEW SIBERIAN ISLANDS.

After Von Toll. The pyramidal inclusions of earth are called Baidscharachs.

HERZ AND TOLMATSCHOW.

While excavating a mammoth skeleton on the River Beresovka much ground ice was seen in the neighborhood by Herz, the zoologist in charge of the work. His observations, originally in Russian but partly translated and published in English, have been discussed at some length by Tolmatschow. According to Herz,[1] the mammoth was found on the slump that lay against a cliff rising 55 meters above the river bed. The upper strata of earth in the cliff, covered with a layer of moss, is 30 to 52 centimeters thick. Beneath this layer is a loamy mass averaging 2 meters thick, with lamellar plates of ice 15 to 18 centimeters thick stretching through the mass. Under this alluvial layer there is a vertical wall of ice, which stands free for a distance of 5 meters above the mammoth. The photographs of this bank show an apparently solid cliff of ice, but the angle from which it was taken is not calculated to bring out the details, except in the immediate foreground.

Herz does not give a detailed description of the exposure. There must have been earth inclusions, as the following quotation shows:[2]

> According to my opinion, the entire cliff region rests on a glacier, which was disintegrating and in which there were deep crevices. The water that flowed down * * * from the neighboring hills, mixed with earth, stones, and pieces of wood, gradually filled these crevices. The whole was later covered with a layer of soil.

That the ice could have resulted from burial of aufeis is considered by Herz as improbable when the altitude of 50 meters is considered in connection with the size of the river. He adds:

> Do we not see here before us primitive or, as Baron Toll puts it, "stone ice," which resulted from the previous glacial period?

Samples of the ice around the mammoth were taken to Petrograd, where they were examined by Tolmatschow.[3] The ice was found to be granular and full of air bubbles. The average size of the grains was 5 to 8 millimeters and the air content from 50 to 180 cubic centimeters.

> The first conclusion we may arrive at from these observations is that the ice just described can not have been formed directly from water. Ice coming from the surface of water—for instance, from a pond—shows a parallel increase of long-stalked crystals whose optical axes are perpendicular to the freezing surface. * * * When melting, such ice divides into a series of irregular prisms, some decimeters long. * * * The large quantity of air of the ice [from the Beresovka] * * * differentiates it from ordinary freezing of water and confirms its snowy nature.

Tolmatschow evidently did not understand the significance of Bunge's theory any more than Toll did, for he states that in the case of the Beresovka the supposition of Bunge is untenable.[4] The preservation of aufeis is also excluded, from the lack of proper crystallization and horizontal bedding. Tolmatschow's opinion is that the ice from the Beresovka is from snowdrifts of perhaps recent formation and not necessarily of glacial time. The snowdrifts are locally protected by loam and not entirely melted during the summer. He says:[5]

> These beds increase, come into contact, melt together, and in a long series of years form a thick cover of snow. * * * For this explanation we need not make any supposition about oscillation of climate, * * * and we may very well suppose that the process is also going on in Siberia now.

DISCUSSION OF THE SIBERIAN LITERATURE.

In this paper the important contributions to the literature that are dated as late as 1903 have been abstracted. The only work that was consulted of later date was Baroness von Toll's narrative, but the indexes of the bulletins of the Imperial Academy of Sciences of St. Petersburg of later dates were searched without finding any promising material.

The evidence as to the widespread occurrence of wedges of ground ice is very strong.

1. The audible formation of frost cracks is mentioned by Figurin, Wrangell, Middendorff, and Bunge.

2. Open frost cracks that cut the surface of the ground into polygons are mentioned by Middendorff, Toll, and Bunge.

3. Parallel ridges that are separated by frost cracks and surround depressed polygonal

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[1] Herz, O. F., Smithsonian Inst. Ann. Rept. for 1903, p. 613, 1904.

[2] Idem, p. 616.

[3] Tolmatschow, I. P. von, Russ. k. mineral. Gesell. Verh., 2d ser., vol. 40, pp. 417–420, 1902.

[4] Idem, p. 435.

[5] Idem, p. 440.

blocks are described by Middendorff and Bunge.

4. Wedges of ice have been described by Adams, Figurin, and Lopatin.

5. Numerous air bubbles that are oriented into vertical rows are mentioned by Maydell, Toll, and Bunge.

6. Inclusions of earth, which are possibly the distorted remnants of ice-inclosed polygonal blocks of earth, are mentioned by Maydell, Toll, and Bunge and suggested by Herz.

Adams.—Adams's description of the inclusions of earth is so vague that the relations of the ice and earth are uncertain. Toll gives a figure which shows the inclusions as wedges, apex downward, in a solid body of ice. As there is no such illustration in Adams's notes, it was probably drawn by Toll and not by Adams himself. Consequently it is not certain which way the wedges really did point, although the wording favors Toll's understanding. If these wedges are remnants of original polygonal blocks of earth which were gradually compressed by growing wedges of ice, the writer's conception of the process is that they would be smallest at the top, for the growth of the wedge of ice is greatest there.

Middendorff.—The thin layers of ice found in increasing quantity clear to the bottom of the Schergin shaft have an important bearing upon the theory of the formation of such deposits. As limestone and sandstone occur above the beds of sand and clay in which the ice is found, the ice must be a secondary formation. It could not have frozen during the deposition of the material. The ground frost also must have pentrated from the surface and can not be the result of the gradual burial of successively frozen surface deposits, as has been suggested for some of the Alaskan ground ice.

The writer entirely agrees with Middendorff that frost-formed fissures in the ground are incapable of absorbing sufficient water to drain lakes and ponds, although it is possible that they might open drainage lines to neighboring depressions. The writer has seen approximately straight cracks a couple of hundred yards in length, but nothing approaching a verst in length, although theoretically such lengths are possible.

The regular rectangular ponds, separated by wide ridges through whose middle ran frost cracks, described by Middendorff, have also been observed by the writer. (See Pls. XXIX, *B*, p. 205, and XXX, *A*, p. 206.)

Maydell.—In exposure No. 4 one corner of the pit was free from ice, and in the rest of the pit the ice was pure white and full of vertical rows of air bubbles. This is strong evidence for wedge-shaped masses of ice and excludes a solid bed. The origin of the vein of earth running into the ice is not easily explained, but a wedge might conceivably be fractured by the great pressure exerted in its growth.

Exposure No. 5 presents difficulties of interpretation, for it contained vertical cylinders of earth included in a solid body of ice, and smaller pot-shaped inclusions were sunk into the surface. These inclusions are horizontally stratified, as if they were parts of a connected series of beds. The illustrations show a wavy stratification that is not easily accounted for, either by original deposition or by the filling of a pothole in the ice. The pyramids of earth which lie at the foot of the thawing bank show that the inclusions of earth are numerous and disconnected. Instead of cylinders cone-shaped masses of earth should more likely occur. However, according to the theory, there should be disconnected inclusions of earth where the original polygonal block existed, and such inclusions are shown in this exposure. The wavy stratification may be the result of compression.

Figure 29 (p. 216) shows such cone-shaped intrusions of earth as the writer is led to expect.

In all these descriptions it must be kept in mind that an absolutely clean exposure is rare and that generalizations must be made. From Maydell's notes it seems as if parts of the exposure were concealed, yet the figures given by Toll show details everywhere.

New Siberian Islands.—The amount of ice exposed in the New Siberian Islands is much greater than anywhere else, and any theory as to the formation of ground ice will be severely tested to account for the great vertical and horizontal exposures. There can be no doubt as to the vertical dimensions, for the illustrations of the ice cliff of Great Liakof

Island show that it is many times higher than the human figures at its base (Pls. XXXII, XXXIII, XXXIV, pp. 218-220).

Here also cylindrical inclusions of earth reach across the whole exposure, but instead of potlike inclusions at the surface we have basal inclusions cut off above by ice. The pyramidal masses of earth at the base of the cliff in the illustration (Pl. XXXIV, p. 220) show that the inclusions of earth are isolated and somewhat symmetrically distributed. The color of the ice, which is transparent gray-green in fresh exposures, with closely spaced air bubbles, does not correspond to the whitish ice seen by the writer. The ice was not horizontally stratified. Toll casually mentions furrows on the surface of the tundra, but he does not clearly say that they cut the tundra into polygonal blocks.[1] Bunge does not mention the surface features.

Conditions in the New Siberian Islands, where a small amount of earth is included in banks of ice, are radically different from those observed by the writer in Alaska, where a small amount of ice is included in banks of earth. Great modifications in the frost-crack theory, as developed for the Alaskan localities, must therefore be made in order to fit the conditions at the New Siberian Islands. If the long cylinders of earth are extremely compressed polygonal blocks, the surface of the ice must have grown upward to keep pace with the vertically expanding blocks of earth. Another difficulty lies in the great height of the ice cliffs in the New Siberian Islands, in some places 70 feet.

Still, the symmetrically distributed inclusions of earth are a strong suggestion that the ground ice there is the result of the growth of ice in symmetrically arranged frost cracks. The question should be studied in detail on the ground. The north shore of Alaska shows only the incipient stages, but there must be places in Siberia where the ice wedges are larger than those in Alaska and yet smaller than those which presumably exist in the New Siberian Islands. The locality described by Maydell at New Schandran seems favorable, for here are larger inclusions of earth, some of them pyramidal.

[1] Toll, Eduard von, Beiträge zur Kenntniss des russischen Reiches, Band 3, Fol. 3, p. 313, 1887.

Tolls' theory, outlined on page 218, of a snow field buried to form the ground ice of this locality is entirely possible but not probable. The inclusions of earth are supposed to be the result of earth-filled cracks and fissures, yet the pyramidal earth mounds at the base of retreating banks show that the inclusions of earth are round or polygonal. There is great difficulty in seeing how deep fissures could become filled before the naked ice walls were widened at the top by melting. The amount of material in the inclusions is significant in comparison with the thin veneer upon the surface of the ice. The lack of horizontal bedding, or even of horizontal beds of earth in the ice, is strongly unfavorable to the derivation of the ice from snow in a region where there was sufficient transportable material to eventually cover the ice.

The granular structure of the ice, as already shown (p. 218), may as well indicate the wedge-shaped masses of ground ice as ice derived from snow, if indeed the short prismatic granules do not favor the former and exclude the latter.

The writer leaves the origin of this ice an open question, but holds the opinion that the most favorable line of inquiry will be along the lines suggested under the theory of ice wedges.

Herz and Tolmatschow.—The samples of ice from the Beresovka that were collected by Herz and described by Tolmatschow, although granulated, are not decisive of anything. As Maddren[2] has pointed out, the samples were collected on a slump and can in no way have any bearing upon the question of the true ground ice in the bank above. Even if collected in place in the ground ice, granulation does not indicate that the ice has been formed from snow, as has been already shown.

Bunge's theory.—In outline this theory is almost exactly the same as that which the writer has independently propounded for the ground ice of Alaska. Bunge emphasizes the rapid inflow and sudden freezing of the surface water with resultant pressure. The writer believes that the water slowly drains into the cracks and that it gradually freezes against the cold sides until the cracks are filled up. As no pressure can be exerted unless the water is confined in freezing, the writer does not think that

[2] Maddren, A. G., Smithsonian Misc. Coll., vol. 49, p. 54, 1905.

this pressure comes greatly into play. Even if the crack should be suddenly filled with water the freezing would probably proceed from the bottom upward, for the inrushing water would be cooled off in descending and the narrowing crack would contain less water to freeze in the lower portion. Thus Bunge's idea that the greatest growth would be at the lower part of the fissure is opposite to the writer's, that the growth is the greatest at the top.

Bunge's statement that a fissure near a bank was a favorable locality for the growth of an ice wedge was unfortunate, and his citation of Beechey as supporting him was still more unfortunate, for Beechey says that the ice in Eschscholtz Bay was simply a veneer against the face of the cliff, perhaps formed in a crevice in the falling bank or else was the result of the freezing of water that flowed over the face of the cliff.

Bunge shows that the parallel ridges of depressed polygonal blocks are formed by the pressure of the growing ice wedge, but this is almost the only support he gives to his theory, except to remark that in his excavations he frequently met with small (vertical?) veins of ice in the ground. In the areas studied by Bunge the ice wedges were probably in an advanced stage of development, so that he did not see the actual wedges that are so striking a phenomenon in Alaska.

Even though there is a vagueness in his statement and though he does not illustrate the theory with diagrams and photographs of actual exposures, it is incomprehensible that none of the later investigators understood Bunge's meaning. Before the writer developed the same theory he had gone over most of the Alaskan literature, in which were extracts from Bunge and others of the Siberian workers. He accepted their understanding—that Bunge's theory applied only to longitudinal fissures, especially near falling banks. It was only after his own theory had been published in the Journal of Geology that the writer found that Bunge had previously propounded practically the same theory.

Holmsen so frequently mentions the polygonal markings of the tundra that if he were aware of Bunge's theory he would at once have anticipated the ground ice he found under the markings.

Toll does not seem to have given Bunge's theory any thought, except to dismiss it. Tolmatschow excludes it, because a longitudinal crack could not account for a curved exposure of ground ice.

NOVA ZEMBLA.

BAER.

Baer makes the following statement:[1]

> In the clayey alluvial land of Nova Zembla * * * I saw fissures 1 to 2 inches wide stretching in all directions of the compass and forming polygons with each other. * * * One always finds ice in the depths of the fissures, at least until August.

SPITZBERGEN.

HOLMSEN.

In the summer of 1912 Gunnar Holmsen studied the ground ice of Spitzbergen and published his observations at some length. He gives valuable tables of air and ground temperatures in his discussion of the distribution of ground ice. The report is published in Norwegian, but an English translation was available to the writer. Below are given some of Holmsen's more important descriptions of exposures, as well as his theory of the formation of ground ice:

> The terrace surface shows divers frost phenomena and often "polygon marks." * * * The uppermost part of the terrace is cut by cracks 2 to 3 meters deep, which are narrow enough so that the ice lies in the shade. * * * Seen from the mountain above, at a great distance, the system of cracks resembles the genuine "polygon field," with polygons from 12 to 20 meters in diameter, and is without doubt the same kind of formation as I imagine the cracks to have come about through strong frost. * * * Under a thick cover of slightly stratified clayey gravel ice is encountered. * * *
>
> In the frozen terraces it has been my fortune * * * to see ice in all the places where I have looked for it in reasonably new cuts. * * *
>
> *Exposure No. 2.*—The ice was exposed in a profile of 10.42 meters. * * * Lowest down a small ice wall was chopped out, whereby one could see that the ice was bedded and contained a clay bed about 5 centimeters thick. The beds slanted out from the valley side, apparently parallel to the terrace surface. Outside of the clay bed the ice was so clean that it could be melted for drinking water. Over the ice lay a clay bed without stones 62 centimeters thick.

[1] Baer, K. E. von, Expédition à Novaïa Zemlia et en Laponie: Acad. Sci. St.-Pétersbourg Bull., vol. 10, p. 274, 1866.

* * * The next day the hewn-out ice wall showed that the ice was granular from the size of a pea to that of a hazelnut.

Exposure No. 3.—The cave was 70 centimeters high and 3 to 4 meters deep. The roof and walls of the cave consist of clear ice. * * * The upper layers of the ice are richest in clay layers.

Exposure No. 4.—In the upper ditch we met thin layers of ice alternating with layers of earth 80 centimeters under the terrace. * * *

Exposure No. 5.—The stream disappeared entirely within the terrace to come out again 10 to 12 meters farther down. The ice hangs as a roof over the stream, both where it disappeared and where it came out again. * * * It was here less clean than I have seen it in other places, as it contained intrusions of a fine black slate gravel.

Exposure No. 6.—In a terrace whose height above the valley bottom is 4 meters, the little streams run in narrow troughs of a depth of a couple of meters. * * * I believe these fissures to have come about by frost (compare the formation of "polygon fields") or by a sliding down of the whole terrace. * * * When one steps down into the fissures one can see the ice everywhere, it being always quite clean and does not show any bedding. It has a beautiful greenish tint and is covered by 60 centimeters of earth. * * *

Exposure No. 7.—The surface of the terrace is a pronounced hillock field, which is formed on the basis of a true "polygon field." It is also believable that the underlying ice * * * plays a part in the formation of the "polygon field." * * * In the upper ditch we found no ice, while the lower one, at 68 centimeters vertical depth, showed many bands of ice alternating with slate gravel. A little farther in we met with a hollow, in under the terrace, at the same elevation as the stream bed. The cave went in about 1.5 meters. * * * In this locality by the use of dynamite a ditch was blasted, which showed ice beds 4 meters under the terrace surface. The frozen ground above the ice * * * was 3.4 meters thick. * * * The upper layers of ice alternated with clay and sand layers. In one cut the various ice layers had a total thickness of 1.2 meters. The lower ice layers measured 22 centimeters. The ice layers here, too, extend parallel to the surface, which here slopes 2° to 3° downward toward the river. * * * From the flat bottom of the ditch a bore hole was sunk to a depth of 1.4 meters. The layers of frozen earth and clay alternated with the ice, but as usual increased with thickness with the depth. The thickest layer of ice under the ditch was 35 centimeters thick.

Exposure No. 9.—At 30 centimeters under the terrace surface we encountered the uppermost ice layers. Bands of ice to a thickness of 30 centimeters alternated with earth layers up to 15 centimeters in thickness to the bottom of the excavation (1.7 meters).

Exposure No. 10.—In the bank, out against the stream, we dug a ditch. * * * The material was finely assorted gravel. * * * It showed stream bedding out from the valley side at an angle up through the valley, with a fall of nearly 30°. The frozen ground was reached 50 centimeters right in from the surface of the slope and the fallen layers of the earth were about the same depth. The strata are cut by more flat-lying ice bands 3 to 5 centimeters in thickness. After the ditch had been dug 2 meters horizontally into the terrace we met a considerable cavity, the roof of which was 4.6 meters below the surface of the terrace. The rear wall of the cave was reached with a long pole at a distance of 2 meters from the ditch, and its bottom was a couple of decimeters above the creek bed. * * * The later blastings in the same ditch showed no thicker ice, while smaller lumps of ice and bands of ice a centimeter thick alternated with the sloping layers of gravel. Still it appeared as if the amount of ice increased with the depth.

Between 6 and 10 is an air-line distance of 3,500 meters. Besides the localities named, the ice in the ground has been found by borings in intermediate places. * * * The investigations at first were carried on to prove the presence of the ice, and the bore holes, therefore, were placed in places where, from the topography, one might expect to encounter the ice at a slight depth. * * * One may conclude nevertheless that there is ice in the ground everywhere between 1 and 10, even though the overlying frozen ground in places is so thick that the results of the borings in such places became less certain.

Exposure No. 11.—The cut where the ice is exposed is 70 meters long, curved, and with the usual semicircular slides. * * * Over the ice is a thin cover of earth with moss peat on top. In no place is the thickness of the earth cover more than 30 centimeters. Inside of the cut, therefore, one can explore with a crowbar and scrape away the earth, which here is not frozen. The surface of the ice is smooth and flat as a skating rink and the ice contains no earth inclusions. The profile is 1.5 to 2.5 meters in size.

Exposure No. 12.—A stream has cut out a gully about 3 meters deep in the sloping plain at right angles to the river and valley. In the bottom of the gully was ice. * * * Its color here also was greenish, and it was clear, without earth inclusions. * * * The surface of the terrace constituted an extended hillocky field, * * * which strengthens my opinion that the ground ice has an influence on the forming of ground structure.

Exposure V.—The material in the terrace was assorted and it is without doubt a marine terrace. At the top * * * is seen 60 meters of horizontally bedded gravel. Below there was "taele" without stream bedding, which alternated with the horizontal strata of ground ice.

The "polygon field" on the drier terraces is covered by a plant life, principally small bushes, and there appears in the damp places, on the foundation of the "polygon field," a "hillock field," with mosses, half grass, grass, and bog cotton. * * * On the extensive stretches in the middle of the valley appear swamp fields with innumerable pools of water between the hillocks. * * * Between these pools stretch hillocks or "islands" of peat moss, which under travel over the valley prove to be harder and one does not sink in so deep.

Exposure [*X*].—The ice showed itself everywhere in these ditches to be of small thickness compared to the earth strata, which consisted of fine river gravel. Nowhere was anything but ice bands a centimeter thick.

Exposure [*Y*].—The material in the frozen ground consisted of river gravel. * * * The ice appeared in horizontal flakes, 1 centimeter thick, which thinned out to sheets of the thickness of paper and disappeared. The combined thickness of the ice beds in this cut did not exceed 12 centimeters.

Exposure [*Z*].—At a depth of 10 centimeters we here met with clay-mixed ice of a different kind than the usual. The ice is porous and the clay lies spread around in it in spots of a square centimeter size without order. * * * The ice springs up in irregular * * * shell-formed layers, but shows also a structure which possibly is crystallographically vertical to this direction. This white "taele," with its few inclusions of clay, reached a depth of 1 meter. * * * At a depth of 1.6 meters the gray "taele" was relieved by an ice band of clean ice a couple of centimeters thick. Still farther down thicker ice bands were found. The ground ice is in the forming in this place.

A condition which must be given weight is that ground ice has nowhere been seen in the great cuts which the rivers of the transverse valleys have formed in the loose strata. * * *

I have at no place been able to determine the thickness of the ground ice. * * * The greatest profile I have examined (No. 2) showed a thickness of 15 meters, of which 10.42 meters was accessible and 4.5 meters were shown by boring at the foot of the terrace. * * * The greatest thickness of clear ice which I have observed is something over 2 meters.[1]

On pages 35–36 Holmsen presents Högbom's theory that the Spitzbergen ice is formed from stagnant water between overlying peat beds and the frozen earth strata, as follows:

Högbom's supposition that the ice at present seems to be under formation is fully supported by the profile I had dug. * * * That the ice should have been formed from the peat strata, however, seems challenged by my investigations. In the majority of the occurrences described there are no peat layers. Even in those places where peat layers appear over the ice these can hardly be put in connection with its formation, except when they rest immediately on it.

With regard to dead glaciers as a possible origin for the ice, he says:[2]

The overlying material also shows quite constant thickness in the flat valley bottom, which with difficulty can be coupled with the idea of the cover of a naked glacier mass. Also, it should be likely that stones which have been frozen in the glacier should have come to sight in the ice at one or the other of the many cuts I have seen. But this is never the case. Finally, the lack of restratified moraine material over the ice is conclusive that it can not have come about this way.

If, then, the closer investigation of the ground ice shows that it does not owe its origin to the glaciers, there are still certain characteristics in its structure which necessitate that one can not offhand regard it formed as water ice. When it is cut loose from the great ice beds it appears quite solid, but during its melting grains appear of the same size and form that can be observed in the spring in ice which is formed from snow—that is, as hail the size of a pea. On the other hand, I have never seen the ice falling apart in oriented pillars as the tablet ice usually does. Thinner ice beds lying between frozen earth layers are, however, now and then porous, with a structure of tablet ice and often with air bubbles in vertical strips. * * *

The outer shell of the ice in the natural profiles is saturated with dirty clay water, so that the surface of the ice is gray in color. The gray tone is a few inches thick, and inside of this the clean ice is light bluish or greenish. In one place it was also a strong green. It should also be remembered that if there is only a small addition to the thickness of the ice the main axes of the ice crystals become short, and they can then with difficulty be distinguished from granules of snow ice except by optical investigation. When the ice contains air bubbles these are always oriented vertically to the cooling surface, and this I have taken as an indication that the ice has been formed by the freezing of water.

The presence of marine shells above the ice in some localities appears to me as conclusive evidence that the ice is formed inside of the earth strata, as it can not be imagined that the ice, at least in its thinner layers, has been able to exist during the *Mytilus* time of Spitzbergen, even though this warmer period, according to the opinions of Högbom, has been accompanied with greater precipitation and deeper snow cover in winter.

Holmsen quotes a description, by K. Hållen, of some peat bogs in Norway, in which some knolls remained frozen throughout the summer.[3] A vertical cut through it showed upward-arching concentrated layers of bog earth, in which were found intruded pieces of clean ice. He gives Hesselmann's description of how the upper bog strata one cold night in September was frozen together to a compact mass of ice needles and peat.

This frozen body of peat rested, however, on a bed of porous, fluted, peat-mixed ice 6 to 7 centimeters

[1] Holmsen, Gunnar, Spitzbergens jordbundsis: Norske Geog. Selskaps Aarbok, vol. 24, pp. 12–28, 1912–13.

[2] Idem, pp. 37–38.

[3] Idem, p. 41.

thick. * * * In its consistence the ice resembled prismatic ice, which in the spring during the thawing is found on the seas [ponds], but was still more loose and porous. * * * When the peat freezes at a temperature not too low, the upper drier and porous layer freezes first, which later hinders evaporation.

Holmsen presents his theory as to the formation of ground ice as follows:[1]

In a similar manner the deposits of ground ice in Spitzbergen must be considered to have come into existence, and like these again the extensive occurrences of the same formation in Arctic Asia and America. It has been demonstrated in Spitzbergen, and it also appears from the large literature about the other better known occurrences of ground ice, that the overlying earth strata consist of clay and different kinds of peat, just such kinds of earth as absorb much water. As my own investigations have shown, there is no doubt that the overlying earth strata have an influence on the formation of the ice. Under moss peat the ice is clean and free from earth inclusions, and also the ice here lies nearest the surface. The last may be owing to heat insulation. Under clay the ice often alternates with frozen layers of earth, and under the coarser river deposits the alternations between the clear ice and earth layers are most frequent. The drier the overlying layers of earth, the deeper the ice lies under the surface. It should also be noted that in coarser gravels, outwashed moraine material, etc., ground ice, except in the form of covered glaciers, has never been observed. It seems, therefore, as if the conditions for the new forming of the ice in such ground is not present. Further, the ground ice occurs only in flat stretches where the drainage of the ground water is slow.

In the flat-bottomed valleys of Spitzbergen the thawed earth keeps very wet during the short summer, from the time the snow melting begins until the first night frost makes its appearance. Even on sloping plains the frequent movement of detritus indicates that the earth is saturated. The first phase of the development of ground ice is shown in its appearance in the moss knolls of the valley bottom. * * * The next step must be considered by occurrence No. 11. Here also the ice lies immediately under the thawed earth strata, and therefore is in all probability in its upper part subject to melting a part of the year. Under this thawing there is a possibility that the porous ice goes over to its compact form, in which it later appears.

Some of the occurrences investigated are, as will be seen, so deep lying that even in warm summers they are below the limits of ground frost [below the limits reached by the summer's thawing]. In such places the lower beds will hardly grow any more. But just in these occurrences (Nos. 3, 4, 7, 9, etc.) are found the uppermost alternating layers of ice and clay, before one gets down to the main body of the ice. Each layer shows that the conditions for ice forming have been present. In warm summers the upper ice layers will probably disappear, but the deeper lying ice grows; in colder periods there will again be formed a higher lying ice layer, separated from the layer below by more or less frozen earth. If the surface is even and the earth very homogeneous the ice layers show great regularity. On the contrary, if the nature of the material varies this at once has an effect on the ice. The moss peat seems to have an especial effect, for the ice under the thick layers of it is not seen to contain earth inclusions. The thickness of the ice layers always increases with the depth until one gets to the compact clean ice, whose thickness is so great that it has been impossible for me to determine it.

[1] Op. cit., pp. 43–44.

With regard to the earth inclusions in the ground ice of Siberia and Eschscholtz Bay, Holmsen presents the following hypothesis:[2]

Salt (alkali?) deposits are found in many places upon the frozen earth, both in Spitzbergen and Greenland, as well as a salt-water well in Siberia. It seems probable from this that the vertical channels in the ground ice may have been melted through the assistance of salt solutions. The salt solutions may be made stronger by the extraction of salt from the ground, and we can also believe that considerable amounts of salt are given off in the decomposition of the large bodies of the mammoth * * * whose remains are sometimes found in these holes. The salt solution thins out by the melting of the ice, but its concentration is again augmented by the freezing, and it may happen that the melting stops when the solution gets a freezing point corresponding to that of the surrounding ice. The ground ice then shoots up around the inclusion and is also formed anew over it, closing it at the top. If one imagines the inclusions to have formed in this way, they consequently do not always need to be younger than the surrounding ice. That the originally horizontal layers of the inclusions may appear folded is due to smaller movements in the ice bed, movements which in size resemble those which produce the frost cracks.

After reviewing the literature, Holmsen gives the common characteristics of the occurrence of ground ice, closing his report with the following statements:[3]

1. Ground ice occurs in places whose mean temperature for the year is 4° to 6° below 0° C.

2. It is distributed on the plains, whereas it is lacking on slopes.

3. The earth layers which lie over the ice are such as have a capacity to absorb much water.

These common traits for ground ice from widely separated localities argue for a common cause for its origin. The similarity between the occurrences makes it improbable that the "stone ice" of the New Siberian Islands should be due to a covered inland ice; that the ice masses along Kobuk River should

[2] Idem, pp. 71–74.
[3] Idem, p. 131.

have been formed in a different way, as lakes frozen to the bottom; and that the ground ice of Spitzbergen at the present time is new formed from ground water in its own way. The geographic distribution of the ground ice indicates a uniformity of origin, and the detailed analysis of the conditions in the different occurrences leads to the same uniformity. Whatever opinion one may have about its formation, the ground ice of the Arctic region, with the conditions mentioned, is a common phenomenon which deserves the attention of the geologists as a considerable factor in the morphology of these regions.

DISCUSSION OF HOLMSEN'S REPORT.

The first thing the writer wishes to bring out is the general resemblance between the surface features of Spitzbergen and Arctic Alaska. The second is that Holmsen does not give a single detailed description of an exposure in which the boundaries of the ice beds are visible. Ice was found here and there, in crevices, gullies, cut banks, and by digging, boring, and blasting. From this he concludes that the surface of the ground is everywhere underlain by horizontal sheets of ice of greater or less thickness. As the writer has brought out in the introduction to the discussion of ground ice, very erroneous conclusions may be drawn as to both the vertical and horizontal distribution of ground ice, unless the actual boundaries of each exposed ice bed can be seen.

As an illustration of Holmsen's deductions as to the thickness of the assumed universal ice sheet, exposure No. 2 (p. 224) is cited. The illustration shows the upper portion of an ice deposit immediately under the surface of the terrace (underneath the man). Below this level slumping has concealed the exposure. At the base of the bank an excavation revealed some more ice. Holmsen says:

> The greatest profile I have examined (No. 2) showed a thickness of 15 meters, of which 10.42 meters (the height of the bank) was accessible, and 4.5 meters were shown by boring at the foot of the terrace.

He mentions "polygon fields" cut by gullies into blocks 12 to 20 meters in diameter. (See p. 224.) The photographs would serve equally as well for the Alaskan tundra. He also mentions "hillock fields." (See p. 225.) His description of these hillock fields corresponds to the writer's description of depressed polygonal blocks. (See Pls. XXIX, *B*, p. 205, and XXX, *A*, p. 206.)

Clear ice with no inclusions of earth was found in the gullies and crevices in the polygon areas. As the writer has already shown (p. 208), gullies are apt to be formed only in the ice wedges, so that they may be expected to reveal ground ice everywhere. He believes that we have here wedges of ground ice inclosing polygonal blocks of the original tundra formation. No fresh exposures showing any details are described, so it is impossible to affirm that wedges do occur, but there is nothing which in the least excludes their occurrence. Most of the bodies of clear ice free from inclusions of earth might as well be composed of ice wedges.

With reference to the bedded strata of ice and earth, some of the exposures at least do not bear out the inference drawn from them. In exposure No. 2 the photograph shows a slumped bank. Any ice found under such a slump may be from recent local snowdrifts or flood ice, and such ice must be disregarded in discussing the question as to the origin of the true ground ice, a small exposure of which may be seen at the top of the same bank. As the ice in question was granulated, it may very well have been an old snowdrift, or series of snowdrifts, separated by clay which had oozed out from the bank in the summer. The photograph shows no details. In exposure No. 7 two ditches were dug, whose position is not made clear. The lowest one revealed bands of ice and gravel. This excavation is apparently at the base of another slumped bank. The cave which they found under the bank, at the same elevation as the stream bed, probably marks the former undercutting of the bank by the river. Snowdrifts (or flood ice) may have filled the mouth of this cave and later may have been concealed by slumping.

Exposure No. 9 also revealed bands of ice and earth "under the terrace surface," but as the details are lacking this exposure can not be discussed.

With the possible exception of exposure No. 9, these exposures seem to reveal nothing which bears upon the formation of the true ground ice.

The thin bands of ice described on page 226, at exposure Y, are apparently similar to those described by the writer and others. The mixed clay and ice described on page 226, at exposure Z, is also similar to that seen in Alaska (fig. 12, p. 180) and is probably of a similar origin.

Holmsen says that the ice is finely granulated and that he has never seen prismatic ice except in the thin beds, yet he believes that the ice originated from the freezing of water. (See p. 226.) The apparent granulation he explains thus:

> If there is only a small addition to the thickness of the ice the main axes of the ice crystals become short, and they can then with difficulty be distinguished from granular snow ice except by optical investigation.

The writer sees no reason why slow additions to the ice by upward freezing should proceed in a different way from more rapid additions by downward freezing, which produces the prismatic structure. As to the vertically oriented air bubbles, Holmsen does not say whether they occur in vertical rows or whether each bubble is elongated vertically. If the former, the evidence is in favor of ice wedges. The writer neglected to note the shape of the individual bubbles in the wedges, so he is unable to discuss this point.

He quite agrees with Holmsen that the presence in places of marine shells above the ice is conclusive that the ice has formed inside of the earth since the area came above sea level. It is very improbable that any deposit of ice could exist under the sea while the shells were being deposited.

On page 227 he states that the protective mantle is of clay and different kinds of peat, "just such kinds of earth as absorb much water," yet a few lines lower he says that "under the coarser river deposits the alternations between the clean ice and earth layers are most frequent." A few lines below he says again:

> It should also be noted that in coarser gravels, outwashed moraine material, * * * there has never been observed ground ice except in the form of covered glaciers.

The first step in the formation of ground ice, according to his theory, is in the mixed peat and ice. This mixture has a "fluted" structure resembling prismatic ice. The next step is illustrated by exposure No. 11, which is a solid body of ice with no inclusions of earth. By this one great stride he gets over the chief difficulty in the whole theory—that is, how somewhat prismatic earth-mixed ice can change to nonprismatic earth-free ice. His explanation is that "in its upper part the ice is subject to melting a part of the year. Under this [melting] there is a possibility that the porous ice goes over to its compact form in which it later appears."

If water ice was invariably clear, without any inclusions, we might expect that water would percolate through porous earth until it came into contact with the frozen portion of the ground and then freeze into a sheet of clear ice, lifting the overlying earth as the ice grew in thickness. But water ice does have inclusions of all sizes.

If downward freezing does not displace the peat lumps in the ice of the Norway bog against a slight possible buoyancy the supposed upward-growing ice sheet will certainly not be able to lift the several feet of soil which overlie it.

This upward growth of the surface of an ice bed is only possible in places where the upper surface of the ice bed is reached by the summer's thawing. A certain portion of the ice must melt each summer and the water must be dispersed, unless we postulate the floating of clay and sand. No additions can be made to the ice until the thawing stops in the autumn. Then the deep-seated low ground temperatures will lower the temperature of the surface of the ground ice bed so that the moisture in the overlying saturated earth may freeze against it. Any growth of clear ice upon the top of the ice bed must occur in the short interval between the times when the thawing stops and the overlying earth is frozen solid. The temperature adjustments must be very delicate to allow the growth continually to exceed the melting, so that a heavy bed of clear ice is built up. A warmer summer will thin the bed and a colder one will raise the level at which the new ice is formed, leaving a layer of earth between it and the heavier bed below, thus forming the bedded ice which is discussed below. When the protective mantle is growing in thickness, as in peat, the conditions for such a bed of clear ice are unfavorable, yet it is under just such a covering that clear ice is chiefly found.

With respect to the ice beds which alternate with clay the process is still more difficult to understand. Also the described exposures do not fit the theory proposed. Holmsen states that "the thickness of the ice layers always increases with the depth until one gets to the compact clear ice, which thickness is so great that it has been impossible for me to determine it." Under exposure No. 10 (see p. 225) he found bands 3 to 5 centimeters thick in a ditch apparently at the bottom of a bank. "Later blastings in the same ditch showed no thicker ice, while smaller lumps of ice and bands of ice a centimeter thick alternated with the sloping layer of gravel."

As regards the theory alone, the great thickness of the alternating beds presents many difficulties. As the same cycle of summer temperatures has affected the whole area, the deposits should show parallel features everywhere; but they do not, for under peat Holmsen finds solid ice. At exposure No. 9, at 30 centimeters under the surface of the terrace, are bands of ice 30 centimeters thick, alternating with layers of earth 15 centimeters thick as far down as 1.7 meters. At exposure No. 4 thin alternating layers of ice and earth were met 80 centimeters under the surface. At exposure X nothing but ice bands a centimeter thick were seen—a small thickness in comparison with the earth strata. At exposure Y was a series of horizontal flakes a centimeter thick whose combined thickness did not exceed 12 centimeters.

In an area to which no surface material is being added a series of beds increasing in thickness downward would demand a climate whose summers, after maintaining a constant temperature long enough to build up a heavy bed of ice, suddenly cooled enough to raise the limit of thawing (15 centimeters in one place) and then remained constant again for a long time. Each bed of earth represents a sudden change and each bed of ice a period of no change. These periods must shorten in an accelerating manner to bring about beds whose thickness constantly decreases. Even if the beds do not increase in thickness downward, the alternations of sudden change and long pause in a cooling climate are not borne out by modern meteorologic investigations. The material between the beds of ice comprises a considerable thickness in some of the exposures. The summers certainly must have been much warmer in order to thaw all the earth from the surface of the ground down to the postulated heavy lower bed of ice.

If additions are made to the surface of the area, either of outwash material or by growth of turf and peat, then beds of ice and earth of varying thickness might occur in a constant climate. Even though peat may not be increasing in thickness at present, it certainly did so while forming in the past. Unless its growth always stopped exactly when the summer's thawing could just penetrate it, bands of ice should be also seen under a mantle of peat.

The condition where the thickness of the covering is increasing and the climate not constant is too complicated for discussion. It is easily seen, however, that the balance between the two must be delicate in order to allow beds of considerable thickness to be formed. While the surface layer is constant the climate can not change; while the surface layer increases in thickness the summers must grow just warm enough to penetrate to the increased depth, or else a new bed of ice will be started.

Holmsen's theory of the formations of potholes in the ground ice by salt solution seems hardly tenable. The first difficulty is to find a source for the salt and to get it concentrated locally. The salt contained in the few feet of tundra material which overlies the ground ice must be very small. Even in marine formations much of the salt must have been carried away by surface drainage. Any salt in the ground would hinder the formation of ground ice, but after the ice had formed the same salt could hardly redissolve the ice.

As the salt originally in the ground is insufficient, it must have come in from the outside. The bodies of large animals are suggested, but the amount of salt furnished by them must play an unimportant part, else in each pothole we should find the remains of the animals which furnished the salt that formed the hole. Salt springs might have burst out after the ground ice was formed and the brine might have concentrated into pools over a wide area. The springs must then have stopped flowing. Such a development of salt springs in the past over all the areas where earth inclusions in the ground ice have been recorded is not within the limits of probability.

A local mass of brine on the surface of the ground, if it does not flow off, will sink downward and will undoubtedly thaw the frozen earth and eat into the ice until its dilution gives it a freezing point equal to the temperature of the ground. We then have a pothole full of weak brine, the bottom of which is covered with the few feet of protective mantle which originally capped the area. As the brine would attack the sides of the hole as well as the bottom, the pothole should be cone-shaped. The stronger brine, concentrated out of the solution when it freezes at the top during the extreme surface cold of the next winter, should be able to eat farther into the ground ice, whose temperature will be higher than that at which the concentrated solution will now freeze. A limit must be reached somewhat below the depth to which the brine freezes each winter, for the concentration of the lower portion of course ceases as soon as the upper portion stops freezing.

It seems to the writer that no possible amount of salt on the surface of the tundra could melt down more than a few feet into the ground ice. The narrow cylindrical potholes in the New Siberian ice, which reach to a depth of 70 feet, could never have been formed in this manner.

If such a pothole should be formed the difficulty remains to account for its filling with earth. The material transported by both wind and water is negligible over most of the areas underlain by ground ice. Slumping from the sides is excluded if the hole is to retain its vertical walls. Any sudden inflow of water-borne material can not be postulated for an area which is covered chiefly with muck; and where the inclusions of earth do not contain such water-borne material the exposed walls could hardly remain vertical during the time necessary for filling by any slow process.

Holmsen's explanation of the earth inclusions which are overlain by ice is impossible. The pothole having conveniently emptied itself of the brine which originally thawed it out, and having become partly filled with earth, "the ground ice shoots up around the inclusion and is also formed anew over it, closing it in at the top." The walls would flatten out, so that a saucer-shaped depression would be formed before the slow growth of ice could bring the surface of the inclusion up to the general level of the ground.

To sum up Holmsen's paper—the writer disagrees with him as to the interpretation that his exposures show a universal horizontal bed of ice or series of beds of ice of great thickness. His theory of the formation of ground ice, although within the limits of possibility, is not brought out in a way to settle the difficult points embodied in it. The exposures as described do not bear out his theory, but the descriptions may be faulty.

ESCHSCHOLTZ BAY, ALASKA.

Maddren[1] quotes the important parts of the literature upon this region up to 1890.

KOTZEBUE.

The explorer, Kotzebue, in 1816, reports that he saw masses of the purest ice, of a height of a hundred feet, under a cover of moss and grass.[2]

BEECHEY.

At the same locality, in 1826, Beechey found only a few insignificant patches of ice. The largest of these was particularly examined by Mr. Collie, one of Beechey's officers. On cutting through the ice in a horizontal direction he found that it formed only a casing to the cliff, which was composed of mud and gravel in a frozen state. The facing is believed to be from snow banks or from the freezing of water which seeps down from the surface of the tundra. With reference to a neighboring exposure, he says: "The ice here, instead of merely forming a shield to the cliff, was embedded in the indentations along its edge, filling them nearly even with the point."[3]

COLLIE.

Mr. Collie's theory as to the formation of the ice cliffs, announced in 1831, is as follows:

> They may have been formed from waters collected in deep fissures and cavities that intersected the falling cliff near its margin. * * * The fall of a mass of

[1] Maddren, A. G., Smithsonian Explorations in Alaska in 1904: Smithsonian Misc. Coll., vol. 49, pp. 1–117, 1905.
[2] Idem, p. 68.
[3] Idem, pp. 70–72.

mud from the outer side of one of these walls would expose this ice, forming a case over the inner side of the fissure in which it was accumulated.[1]

BELCHER.

Lieut. Belcher, in 1831. proposed another theory:

He conceives that between the superficial layers of spongy peat and the mass of frozen mud which forms the substance of the cliff the water oozing downward through the peat during the thaw of each successive summer is stopped at the point where it comes into contact with the perpetually frozen earth below, and then accumulates into a thick horizontal sheet of pure transparent ice.[2]

KELLETT.

In 1849 Capt. Kellett visited the locality and came to the conclusion that the ice was more than a veneer upon the face of the cliff and that Kotzebue was right in thinking "that it formed part of a solid iceberg." Dr. Richardson, after discussing the observations made by Kellett and his officers, comes to the conclusion that "further observations are still needed to form the foundation of a plausible theory."[3]

DALL.

W. H. Dall examined Elephant Point in 1880. He says:

On the highest part of the ridge, perhaps 250 feet above high-water mark, at a depth of a foot, we came to a solidly frozen stratum consisting chiefly of bog moss and vegetable mold but containing good-sized lumps of clear ice. There seemed no reason to doubt that an extension of the digging would have brought us to solid, clear ice, such as was visible at the face of the bluff below.

He concludes that the whole ridge "was chiefly composed of solid ice overlain with clay and vegetable mold." In giving the details of the ice face, he says:

In other places the ice was penetrated with deep holes into which the clay and vegetable matter had been deposited in layers, and which (the ice melting away from around them) appeared as clay and muck cylinders on the ice face. Large rounded holes or excavations of irregular form had evidently existed on the top of the ice before the clay, etc., had been deposited. * * * The layers were waved, as if the deposit had been affected by current action while going on.[4]

[1] Maddren, A. G., op. cit., p. 77.
[2] Idem, p. 78.
[3] Idem, pp. 92–99.
[4] Idem, p. 105.

HOOPER.

Capt. Hooper visited the place in 1880 and found stream-melted holes 30 feet deep showing solid walls of clear ice. He dug several holes in the top of the cliff and always found ice a few feet down.[5]

Capt. Hooper again examined the locality in 1881 and reiterates the fact that the quantity of ice is too great to be accounted for by Beechey's and Collie's theories. Among the details he mentions that "a number of wedge-shaped pieces of ice found in the banks around Eschscholtz Bay were probably formed by a small crack in the ground filling with snow and ice, and continuing to enlarge under successive changes from freezing to thawing."[6]

NELSON.

Nelson, a naturalist with Hooper, describes a beaver's nest which was revealed in the bank: "Only a few yards away on either side of the beaver nest, and apparently back of it, on about the same level, was ice apparently surrounding the mass of frozen earth upon which the nest rested."[7]

CANTWELL.

Maddren also mentions the ice cliffs seen by Lieut. Cantwell on the Kobuk:[8]

A series of ice cliffs * * * was observed, composed of a solid mass of ice extending three-quarters of a mile along the left bank, covered by a thin layer of dark-colored earth, and rising to a height of 150 feet.

QUACKENBUSH.

Quackenbush has recently examined the Eschscholtz Bay region. He gives detailed descriptions and diagrams of the actual exposures as he saw them in 1907–8:

There are 14 masses of pure ice * * * exposed in these two hills. * * * The largest is about 100 feet in length and the smallest 15 feet; in vertical thickness they vary from 1 to 8 feet; that is, this amount is exposed. * * * One is a wedge-shaped mass, which may be called a "dike," 7 feet high, 2 feet wide at the bottom, and 5 feet across the top. * * * [One of the largest ice layers had a length of] about 75 feet. Beneath the mud slide solid ice was traced forward to the horizontal distance of 30 feet, and taking the angle of the mud slope into consideration it

[5] Idem, p. 103.
[6] Idem, pp. 108–109.
[7] Idem, p. 112.
[8] Idem, p. 113.

appears that the entire thickness of pure ice is at least 18 feet, of which the upper 8 feet is exposed. * * * [Another exposure] is 10 feet in thickness, and its horizontal base rests on silt at an altitude of 50 feet. * * * The ice is distributed in apparently isolated masses at various elevations from the beach to the top of the bluff, but some of these glaciers are very nearly on the same level and may have been connected in the portion of the bluff now washed away, and they may also be still connected within the remaining deposit. The ice is not confined to the face of the bluff, where it might have formed in cracks, but in the cases of the ice wall, * * * it evidently extends back into the frozen silt.[1]

A year later, in 1908, at the same place, he found changes in the exposures.

Other changes noted were the complete disappearance, by melting, of the vertical exposures of the two glaciers at the sides of the beaver dam, which left clean walls of frozen silt in their places; these ice masses could therefore not have been more than 2 or 3 feet thick (horizontally) in 1907. * * *

One small clear glacier embedded in silt showed a distinct line of stratification running horizontally across the middle. Pieces of ice cut out from the cliff glaciers at a space of a foot or more from the exposed surfaces were full of round, oval, or much-elongated air bubbles or cavities. * * * Fragments of ice taken from the glaciers, ice dikes, and ice cracks, melted, when exposed to the sun, so as to show a polyhedral, granular structure at the surface, and these granules could usually be easily rubbed off with the finger; they * * * averaged about three-sixteenths or one-quarter of an inch in diameter, though in different parts of a single mass of ice they might plainly show or be apparently not formed.

Owing to the poor exposures in 1907–8, it was impossible to arrive at any final conclusions concerning the origin of the ice masses, but a few remarks may be of interest. Some of the small glaciers may have been recently produced from snow or water in crescentic cracks at the heads of cirque-shaped slides, but other glaciers are too thick horizontally to have been formed in this manner. * * * Two ice-filled cracks exposed in excavating the mammoth skeleton were evidently formed by the infiltration of water after the ground had become frozen, for otherwise they would not have contained laminae of dirt parallel with the walls; moreover, the vertical crack passed through the middle of the skeleton and intersected a rib. This ice is therefore comparatively new, and since its granular structure was well shown, this structure is not necessarily proof of snow origin for other granular masses of ice. The ice dike in the stratified glacier on Goose Bay was plainly formed since the deposition of the beds through which it cuts. * * * It is not impossible that other masses may have been interstratified on a flood plain. On the other hand, in the single case in which the contact of ice with underlying silt could be clearly seen, the glacier was as clean at the bottom as everywhere else, and not even a leaf or twig was to be found embedded in it nor in the silt; if the ice had been formed by the freezing of ponds or streams one might expect to find gravel or sticks, etc., on the bed. * * *

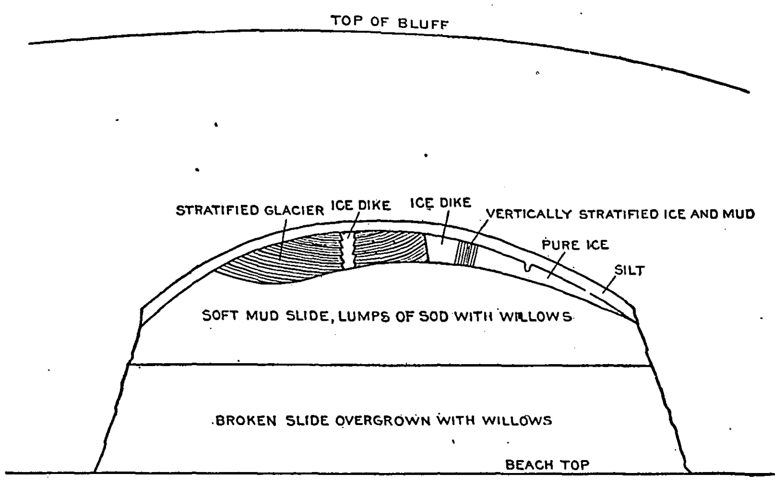


FIGURE 31.—Exposure of ground ice in Goose Bay. After Quackenbush.

[In Goose Bay] three glaciers are visible, one of which * * * has a remarkable structure [figs. 31 and 32]. Its entire length is 65 feet, and the vertical face has a height of 6 feet at one end while it tapers out at the other. The high end consists of half-inch layers of pure ice alternating with muck containing considerable plant remains. The layers are grouped into five thick strata, and a vertical dike of pure ice running through the middle of the stratified portion of the glacier, separates the upwardly bent ends of these strata, which match on opposite sides of the dike. The latter is about 2½ feet wide in the middle, being slightly narrower below and broader above. Next the end of the stratified portion there is another wedge-shaped mass of pure ice 4 feet wide at the bottom and 5 feet across the top. Adjacent to this dike there is a section, averaging 4 feet in width, formed of nearly vertical layers one-half inch thick of pure ice and muck alternately. The remainder of the glacier consists of pure ice. * * * Solid ice extends downward below the first described dike and forward under the mud slide, adding at least 6 feet to its total vertical thickness. The silt seems here to

[1] Quackenbush, L. S., Am. Mus. Nat. Hist. Bull., vol. 26, pp. 98–100, 1909.

have been deposited unconformably upon the top of this curious glacier, though slides may have modified the upper contact.[1]

On Buckland River "several broad, wedge-shaped glaciers are exposed in the upper bluff."[2]

DISCUSSION OF THE LITERATURE ON ESCHSCHOLTZ BAY.

Some of the ice of this locality is without any doubt in wedge-shaped masses, and most of the exposures may be explained by the theory here presented. Under this theory of formation, most of the contradictory reports of the early explorers may be reconciled. Kotzebue's record of a hill of solid ice may be dismissed as an exaggeration, yet great masses of ice are often exposed when the polygonal blocks break off along their edges. Beechey's investigations, which showed that the ice was simply a veneer against the cliff, are a strong support of the presence of wedges exposed longitudinally. Again, Kellett found so much ice in some localities that he went back to the original idea of a solid iceberg. Hooper saw ice walls extending back along a stream-cut gully. As already shown, these gullies are apt to form along the wedges, and they therefore nearly always reveal ice.

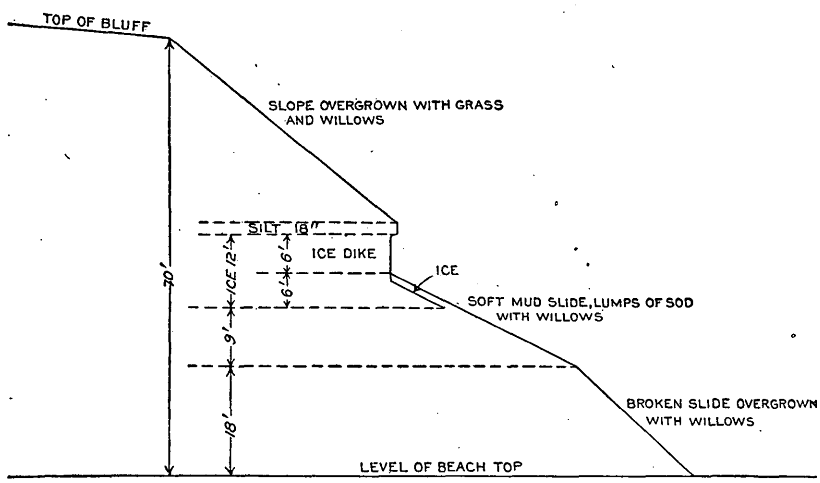


FIGURE 32.—Section through the ice dike shown in figure 31.

Dall from insufficient evidence came to the opinion that the whole area was underlain by solid clear ice. The muck and clay cylinders which he saw in the ice face point strongly to polygonal blocks surrounded by ice wedges. Hooper on his second visit mentions that he saw a number of wedge-shaped pieces of ice in the banks.

Quackenbush[3] mentions several wedge-shaped exposures of ice, one of them showing upturned muck beds. The ice which disappeared from either side of the beaver dam may have been a longitudinal section of a wedge. Air bubbles and granulated ice occur in all of the exposures, including the dikes, and he concludes that some of the ice must have formed after the ground had become frozen solid.

No descriptions of the surface of the tundra are given by any of the observers. As ice in the form of wedges is shown to exist there in several places, and possibly in many, the writer predicts that a "polygonal field" will be found upon the surface.

As to the enormous exposures of ice described by Lieut. Cantwell upon the Kobuk, there is either some fault in the wording of the description or else exaggeration, for no one since his time has seen ice cliffs approaching in size those that he described as 150 feet high.

NORTH AMERICA IN GENERAL.

PARRY.

In 1821 the Arctic explorer Parry described the sea ice as attached to the bottom near shore in places in the Parry Archipelago. This ice is often covered by several feet of water. Parry suggests that if it were buried by outwash from the land it would be preserved as ground ice.[4]

[1] Quackenbush, L. S., op. cit., pp. 100–103.
[2] Idem, p. 120.
[3] Idem, p. 103.
[4] Parry, W. E., Journal of a voyage for the discovery of a northwest passage in 1819–20, p. 201, Philadelphia, 1821.

DALL.

Dall, who examined the Eschscholtz Bay region in 1880, ascribes ground ice in general to the freezing of shallow lakes of muddy water upon the wide coastal plain, formed by an elevation of the land which occurred probably at the end of the Miocene. This ice was covered by clays brought down by spring freshets, and a carpet of Arctic vegetation gradually spread over these clays, so that the ice has been preserved to the present day.[1]

TURNER.

In 1886 Turner[2] gave a theory which is seemingly so simple and competent that it has been accepted by many observers. In thrusting a stick under the edge of the sod resting on the water of the pond he could

> feel with but little interference from grass roots, far under, yet the water was too deep * * * to touch the bottom of the pond. I now saw that the margins of the pond were being gradually encroached upon by the matting of the grasses, which in the course of time would entirely cover the surface, and in their turn be succeeded by a growth of sphagnum, which by its retention of cold would prevent the ice formed in the water below from being thawed out. * * * These lakes of ice have been the source of the ice bluffs presented on various parts of the coast.

This theory is discussed on page 203. Toll states that Baer and Schrenk, in discussing the Siberian ground ice, had advanced the same theory some years previously.

RUSSELL.

In 1890 Russell[3] restated the same theory that Turner had previously advanced.

> As the moss covers the lakelets more and more completely during a series of years, the ice formed by the freezing of the water in winter is more and more thoroughly protected, and is finally completely shielded from the heat of summer. A body of clear ice is thus formed in the tundra, similar to the strata of ice exposed at certain localities along the coast of Bering Sea and in the banks of the Yukon.[4]

From the repeated formation and burial of such ponds by moss, Russell postulates a series of lenticular masses of ice embedded in peat, as a characteristic feature of exposures of ground ice.

Russell ascribes the encroaching mat of vegetation to the growth of moss, and in this he has been followed by later observers, but the writer has shown that moss probably does not play an important part in any climate. (See p. 203.) Also, on the Arctic coast at least, no floating mats of vegetation have ever been observed.

SCHRADER.

Schrader, who traversed the Arctic coast from the Colville to Cape Lisburne in 1901, a part of which area the writer has also examined, did not see much ice. He says: "Even along the coast it is not extensively exposed. Here long stretches of the low tundra country are apparently underlain by rock or earthy deposit."[5] The most extensive exposures are at Cape Halkett and Cape Simpson, where the ice "seems to be practically continuous for a distance of several miles. Cape Halkett, one of the most prominent promontories along this part of the coast, * * * terminates in an ice cliff rising 30 feet above tide level and is overlain by a foot or two of muck. * * * The ice cliffs appear merely to represent completely solidified bays, lagoons, lakelets, or perhaps other coastal bodies of ponded water, now raised into low anticlines and cut back by wave action."[6]

The writer in August, 1914, when the exposures were good, examined this locality while following the bank in a small boat. Much wedge-shaped ice was seen, but nothing approaching such a long exposure as Schrader's illustration shows. (See Pl. XXXV, *A*, p. 238.) Still, as it was in an area that contained wedge-shaped ice, and as long exposures are possible

[1] Dall, W. H., Correlation papers, Neocene: U. S. Geol. Survey Bull. 84, p. 267, 1892.
[2] Turner, L. M., Contributions to the natural history of Alaska, p. 15, Signal Service, U. S. Army, 1886.
[3] Russell, I. C., Notes on the surface geology of Alaska: Geol. Soc. America Bull., vol. 1, pp. 99–162, 1890.
[4] Idem, p. 128.
[5] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, p. 92, 1904.
[6] Idem, p. 96.

in such places, the ice which Schrader saw may really have been that kind. Both the writer and Stefánsson (see p. 238) have several times traversed this locality without seeing any heavy deposit of ice.

MENDENHALL.

In speaking of the ground ice of the delta of Kobuk River Mendenhall[1] agrees with Russell and others that the tundra lakes have been buried by advancing moss over their surface and thus preserved as ground ice.

TYRRELL.

Tyrrell[2] has described the ground ice of the Klondike and has advanced a new theory as to its origin. The ice which he saw occurred as a rule

> in more or less horizontal sheets of clear ice, from 6 inches to 3 or more feet in thickness, lying between layers of muck or fine alluvium, usually where the muck is divided horizontally by a thin bed of silt. Most of them * * * are from 2 to 4 feet below the surface, though some are deeper. * * * Many vary from 100 to 1,000 feet in length and from 50 to 200 feet in width. * * * They are of very even and regular thickness throughout [though they are not strictly horizontal, but approximate closely the surface upon which they lie, so that the] apparently level sheet of clear ice was 5 or 6 feet higher at its upper end than at its lower, * * * showing that these ice sheets do not partake of the character and attitude of frozen ponds or lakes.
>
> In the majority of cases the ground ice sheets are in the vicinity of springs that can be plainly seen issuing from the bases of the neighboring hills, but in other cases no such springs are apparent. In these latter cases, however, wherever the gravel has been removed and the underlying rock has been exposed springs have been found.
>
> The mode of formation of these underground sheets of ice is therefore as follows: Water issuing from the rock beneath a layer of alluvial material rises through the alluvium, and in summer spreads out on the surface, tending to keep it constantly wet over a considerable area. In winter, if the flow of water is large and the surface consists of incoherent gravel, the water will still rise to the surface and there form a mound of ice. If, on the contrary, the flow from the spring is not large and the ground is covered with a coherent mass of vegetable material, such as is formed by a sphagnum bog, the spring water, already at a temperature of 32° F., rises until it comes within the influence of the low temperature of the atmosphere and freezes. This process goes on, the ice continuing downward as the cold of winter increases, until, a few feet below the surface but still within the influence of the low external temperatures, a plane of weakness is reached in the strata of frozen vegetation or alluvial deposit, such planes of weakness being generally determined by the presence of thin bands of silt or fine sand.
>
> As any outlet is now permanently blocked, the water is forced along this plane of weakness and there freezes, and thus the horizontal extension of the sheet is begun. While thus increasing in extent, the ice also increases in thickness by additions from beneath until it has attained a sufficient thickness so that its bottom plane is beyond the reach of the low atmospheric temperature above, after which it continues to increase in extent but not in thickness.
>
> With the advent of the warm weather of summer the growth * * * ceases, but the cold spring water which continues to rise up beneath it has little power to melt it, and its covering of moss or muck, being an excellent nonconductor of heat, protects it from the sun and wind and prevents it from thawing and disappearing. Thus at the advent of another winter it is ready for a still greater growth. * * *
>
> Veins or dikes of ice rising from the bedrock into the overlying ground * * * evidently represent the former course of a spring which had changed its point of discharge. More or less vertical masses of ice are also sometimes met with in the gravels themselves, indicating the positions of former water channels from the bedrock toward the surface.

Tyrrell's hypothesis of the formation of both horizontal and vertical sheets of ice does not seem to bear analysis. Water under sufficient pressure to lift locally the upper few feet of frozen muck which restricts its flow would distort the frozen layer and probably weaken it, if not fracture it, so that the water could escape and relieve the pressure. It is necessary for the frozen layer (only a few feet thick) to be so strong that it is not bulged up, even with a hydraulic pressure sufficient to force water at least 500 feet horizontally through frozen ground. The pressure must fracture the ground to that distance horizontally and yet not distort or break the few feet of frozen ground over it. The writer has no idea of the amount of pressure that would be required for this, but it must be many times that to which the ground above yielded at the initiation of the supposed horizontal sheet of ice.

The writer's opinion is that a blocked spring under high pressure would bulge up the frozen ground and fracture it. Ice might form under

[1] Mendenhall, W. C., Reconnaissance from Fort Hamilton to Kotzebue Sound, Alaska: U. S. Geol. Survey Prof. Paper 10, p. 45, 1902.

[2] Tyrrell, J. B., Crystophenes or buried sheets of ice in the tundra of northern America: Jour. Geology, vol. 12, pp. 232–236, 1904.

the dome in the cavity thus produced. If the escaping water carried much material it would be deposited upon and around the mound, building it up to a greater size. Some such origin is postulated for the gravel-covered mounds that are described on pages 150–155.

It is difficult to see why the vertical dikes of ice in gravel should represent the position of former ascending watercourses or springs. Any fractures in the ground may as well have been filled by surface waters as by ascending waters; in fact, in most flat areas of frozen ground they could hardly escape this filling when the snow melts in spring.

The presence of these vertical dikes of ice in the Klondike is important in considering the distribution of wedge-shaped masses of ice, for there is every probability that they come under this category.

PURINGTON.

Purington[1] mentions large ice sheets similar to those described by Tyrrell. They are from 25 to 150 feet in diameter and are found not only in creek beds but on the slopes and show no regularity of distribution. In the Seward Peninsula ditches "the difficulties with ground ice were very great. At one place 800 feet of such an ice sheet was found. * * * At another point 1,100 feet of flume * * * were built over an ice sheet."[2]

MADDREN.

Maddren[3] in his account of a trip in search of mammoth remains describes the ground ice of the Old Crow basin and neighborhood. In his discussion of the Siberian mammoth finds he has much to say about the ground ice there also. In an appendix he lists all the literature on Eschscholtz Bay to the date of his publication.

> Beds of ice were observed as far as we were able to ascend the Old Crow River. They appeared on top of the banks, always at elevations of 100 or more feet above the stream, for a distance of more than 100 miles along the stream. * * * The ice varies greatly in color, structure, and thickness. Some is of a brownish hue, having much the same color as peat water and containing quantities of comminuted vegetable matter, in some parts distributed evenly through the mass and at other places concentrated in thin layers like sheets of paper between thick masses of clear ice. Some is whitish and granular, especially at its surface, and often contains cavities of gas bubbles. At other places masses of green and blue ice were observed.[4]

The ice beds have a covering of peat that ranges from 2 to 15 feet in thickness. In most places this protective covering to the ice is composed entirely of vegetable remains.

Maddren's observations upon these deposits lead him to the opinion that the ground ice has been formed from water in lakes upon the top of lacustrian silts which had been deposited in large Pleistocene lake basins, in a climate probably warmer than that at present. At the close of the Pleistocene, these silts were elevated and thrown into gentle folds. Shallow lakes formed in these folds as well as in other local depressions. Moss and peat gradually encroached upon the surface of the lakes and finally buried them. The colder climate brought on by elevation gradually froze these lakes and the freezing extended into the silts to the depth at which they are found frozen at the present day.[5]

Maddren's presentation of Lieut. Belcher's theory of formation is an improvement upon the original. He says:

> The water sinks through the moss blanket from the surface and also seeps underneath it from higher levels. This tends to lift the living moss with its thawed underlying layers of vegetable humus or peat, floating it in a state of semibuoyancy above the frozen substratum of alluvium or peat so the ice may accumulate season after season, as long as there is a growing and buoyant equilibrium maintained between the annually thawed peaty superstrata and the constantly frozen substrata.[6]

Lieut. Belcher did not bring out the possibility of a buoyant action of the water; his theory was that as soon as the water came into contact with the frozen substratum it stopped, and the rest is left to the imagination of the reader.

STEFÁNSSON.

At times between 1906 and 1912 Stefánsson[7] traveled up and down the northern coast of Alaska where the writer has been working.

[1] Purington, C. W., Gravel and placer-mining in Alaska: U. S. Geol. Survey Bull. 263, p. 119, 1905.
[2] Idem, p. 125.
[3] Maddren, A. G., Smithsonian explorations in Alaska in 1904: Smithsonian Misc. Coll., vol. 49, pp. 1–117, 1905.
[4] Idem, p. 15.
[5] Idem, pp. 36–38.
[6] Idem, pp. 44–45.
[7] Stefánsson, Vilhjálmur, Ground ice in northern Alaska: Am. Geog. Soc. Bull., vol. 42, pp. 337–345, 1910.

He has given detailed descriptions of several exposures of ground ice and has advanced some theories as to their origin. He arrives at three conclusions as to its character: (1) That there are no large continuous sheets; (2) the ice probably nowhere attains a great thickness, the maximum being less than 8 feet; (3) the earth on top of the ice is seldom, if ever, thick, the average being not over 2½ feet. His own observations are confined to the coast between Smith and Harrison bays (which includes Cape Halkett), but he also presents the observations made by the Government school-teacher at Wainwright upon the ice exposed in sinking an ice house into the tundra. Other ice houses are mentioned at Barrow, as well as the one made at the writer's headquarters at Flaxman Island.

He presents four methods by which he has seen ground ice in formation, and as testimony in regard to the actual process is of great value they are quoted below.

Formation of underground ice along the seashore through wind pressure.—Along a gravel beach running from Cape Smyth toward Point Barrow there were in the summer of 1908 a number of mounds, the largest rising 12 or 15 feet above their base level, and with a circumference of say 50 feet. Some were a considerable distance apart, others touched each other and formed a sort of double or treble mound. Scratching into these heaps with a stick showed that the main body of them was ice, with a covering of gravel. Tongues of ice had been thrust into the land. When the tide fell and the water retreated the main body of the ice broke away, leaving pieces, weighing tens of tons, in some cases, embedded in the ground. It is probable, because of the thinness and porosity of the gravel, and the consequent penetration through it of every summer shower, that even the largest of these ice blocks will disappear in a few years and the beach resume approximately its former appearance. Some apparently persisted in former times, however, for the icehouse dug in the spring of 1908 * * * was excavated through gravel mixed with boulders of ice evidently formed in muddy water, such as is formed in autumn along the beach, where a southwest gale heaps muddy slush ice in the shore water. * * *

Preservation of sea ice under mud deposited by rivers.—* * * I have seen the mud layer deposited by the water, as it loses its current at the river's mouth, thick enough to preserve ice several inches thick into autumn of the following year; with favorable conditions it seems that a thin ice layer of one year might be added to by a thin layer of the next, and thus ice deltas be formed much as mud deltas are in rivers. * * *

Ice and snow preserved by drifting sand.—On the Jones Islands (miscalled Thetis Islands on some charts) * * * I found in the summer of 1907 ice and snow under a few inches of damp sand. This was late in July, but it seemed to me evident that the snow and ice had been there more than one season. * * * It seems that sand drifts there to some extent at all seasons, so that a snow bank might get a considerable coating before spring and a much thicker one before the summer sun had thawed even the unprotected drifts near it. * * *

Ice preserved by the shifting of channel of a meandering river.—In the banks of the Colville there may be found ice outcroppings at least 25 to 40 miles from the river mouth. * * * As ice benches along cut banks are frequently maintained late into the summer, even in locations not particularly favorable, and as sand bars are often piled up with astonishing rapidity in the Arctic rivers, it seems not unlikely that one of these benches should now and then be covered with sand or mud sufficiently deep to preserve it indefinitely.

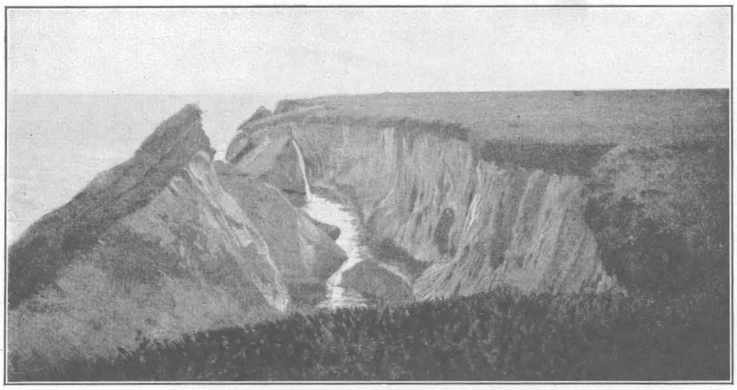
Mention is made also of the temporary preservation of ice and snow by landslides under steep banks.

With regard to method No. 1, undoubtedly the friction of the wind upon the surface of the ice is one of the chief causes of its motion, but currents often move the ice against the wind, so that the term "wind pressure" seems objectionable. The first idea gained by the writer from the heading was that ice or snow had been blown into the ground. This process is discussed more fully by the writer on page 173. The idea is not original with Stefánsson. Lopatin suggested it in 1867.

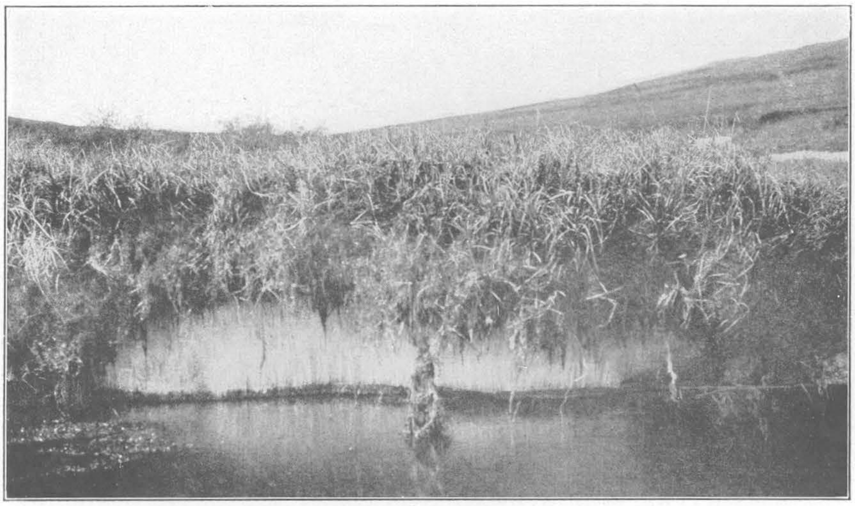
With regard to method No. 2, the writer's observations are negative. Sufficient material may be deposited upon the ice at the mouth of rivers to preserve it from surface melting, but the ice so covered is in a very unfavorable location for preservation. The rivers, as a rule, break out in May and quickly melt away the ice near their mouths, so that there may here be open water for several miles two months before the ice in general leaves the coast. Not only is such ice at the mouths of rivers exposed to wave action for almost double the time but the warm river water has a much greater melting effect than that of the ocean. The chance of preservation is greatest for ice which has formed at high tide upon the mud bars, but here it can not attain a thickness of more than a foot or so.

The other two methods are discussed on pages 201–202.

Stefánsson gives illustrations of the banks near Cape Halkett which show ice in appar-



A. GROUND ICE NEAR CAPE HALKETT.



B. ICE UNDERLYING VEGETATION, SPRUCE CREEK, SEWARD PENINSULA.

C. ICE UNDER CREEK GRAVELS, LOST CREEK, SEWARD PENINSULA.

ently irregular detached masses. The drawings show no slumping at all, so that they presumably show the actual boundaries of the ice beds. The writer has examined this same stretch of coast during a season of good exposures, and has not seen a single exposure where the ice presented such an aspect. As has been stated above, the ice here was all in wedge-shaped masses. Many slumped exposures showed ice sticking through the earth in an irregular manner, and the writer is inclined to believe that Stefánsson's sketches were of such exposures.

In another publication Stefánsson[1] describes the same portion of the coast as follows:

In many places the face of the cliff showed a series of what appear to be boulders of ice embedded in the wall of the cut bank, somewhat as stones are in earth in other places. * * * When the cut bank is as much as 16 feet high the base is always exposed, for the ice does not seem to go deep down.

The origin is ascribed to brecciated sea ice or buried river ice.

The writer has never observed the base of the ground-ice wedges, even when there were good exposures. Plate XXXV, *A*, shows about 30 feet of ice at Cape Halkett.

GILMORE.

Gilmore[2] gives an interesting account of the actual formation of ice against banks in a manner such that it might be mistaken for true ground ice. A slight expansion of this process may account for some of the exposures described in the literature.

In ascending to the top of the escarpment * * * it was found that a mass of frozen muck, estimated to be 20 feet long and 15 to 20 feet in thickness, with a vertical face of 20 to 30 feet, had moved outward at its center for fully 50 feet but had not yet become detached at its ends. The crevasse formed by the displacement was filled with water to such a depth that the bottom could not be found with a long pole. Back of the crevasse, in the surface of the bluff, were numerous parallel cracks varying from 6 to 18 inches in width and many feet in length. These had water standing in them nearly to the top of the ground. The conditions observed here appeared to the writer to explain the presence of the ice on the faces below. With the advent of winter, assisted by the already frozen ground, the water in the crevasses becomes frozen solid. A subsequent outward movement of the blocks would leave the ice clinging to the face of either the cliff or the block, or both, and under the influence of the rays of the summer sun would rapidly smooth the broken and ragged edges. On the faces of blocks 1 and 2 [see fig. 33] such layers of ice were observed, and where protected by the wet mantle of overhanging turf and moss were thawing away very slowly. In places the ice was so thin the writer, with a few strokes of his pick, was able to penetrate it and into the frozen muck wall behind.[3]

Collie advanced the same theory in 1831 for the ice of Eschscholtz Bay.

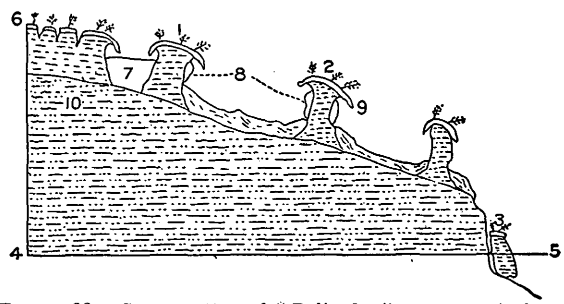


FIGURE 33.—Cross section of "Palisades" escarpment, showing formation of superficial ice. 1, 2, 3, Blocks of frozen silt; 4–5, water level of the Yukon; 4–6, 150–170 feet; 7, crevasse filled with water; 8, ice on faces; 9, overhanging turf; 10, lacustrian silts.

BROOKS.

Brooks[4] describes the ground ice of the Kougarok region as follows:

Along the northward-facing slopes of the valley it forms in many places almost continuous layers for several miles. It ranges in consistency from a frozen mud to almost pure ice. * * * The ice beds, as a rule, slope with the valley wall and in some places extend up the hillside to a height of a hundred feet above the streams. This ice can probably best be explained by the accumulation and subsequent solidification of winter snow which has become buried by the talus and alluvium.

SMITH.

Smith[5] gives two illustrations of ground ice which are reproduced in this report (Pl. XXXV, *B*, *C*). Both these views show the vertical prismatic crystals so characteristic of fresh-water ice.

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[1] Stefánsson, Vilhjálmur, My life among the Eskimo, pp. 383–384, 1913.

[2] Gilmore, C. W., Smithsonian exploration in Alaska in 1907: Smithsonian Misc. Coll., vol. 51, pp. 1–38, 1908.

[3] Idem, pp. 20–22.

[4] Brooks, A. H., The gold placers of parts of Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 328, pp. 299–300, 1908.

[5] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles, Alaska: U. S. Geol. Survey Bull. 433, pl. 12, 1913.

The same geologist describes the ground ice of Noatak River as follows:

In the upper part of the outwash deposits at many places are beds of ice, more or less mixed with mud or silt, but in many places almost pure. A typical ice bed 20 feet or more thick is shown. * * * [See Pl. XXXV, *B*.] Twigs and branches of willow and spruce are in places interbedded in peaty layers with the ice, indicating alternations of deposition and land surface.[1]

MOFFIT.

Moffit[2] describes ground ice from the Nome region as follows:

Beds of clear ice occur very commonly with the gravel deposits of the streams and the Nome tundra. Thin beds are associated more closely with the silt deposits than the lower gravels, although most of the gravels are frozen. Most of the ice beds are either in the silts or between the silt and underlying gravel. Veins of ice in some places cut across the silt beds, and in general ice forms a considerable proportion of the silt deposits.

Ice beds when associated with stream gravels are found along the lower slopes between the hills and stream channels. They are always overlain by a protective covering of some kind, either silt or moss. * * * In some localities they are absent altogether and in others they reach a thickness of several feet. * * *

The distribution of the ice beds in the coastal plain about Nome is irregular and dependent on conditions that we do not understand. They do not differ in appearance or position from those of the stream valleys, and probably were formed much in the same way.

Concerning the formation of ice beds of this region and of Alaska in general there is a great difference of opinion, and it is evident that the last word on the subject has not been said. * * * The burial of ice under a thin covering of gravel by spring floods is of common occurrence on streams of the Nome region. On such of these streams as have wide flood plains and low gradients broad sheets of ice and snow accumulate, some of which, even if unprotected, last into summer. Many such ice sheets, however, or portions of them are covered during the floods of early spring by a few inches of sand or fine gravel, and when thus protected, especially if so situated that the stream does not reach them, they may last throughout the summer. * * * There can be no question that veins of ice such as are seen cutting the silts in many places were formed after the silts were laid down.

PRINDLE.

Beds or lenticular masses of ice 40 feet in maximum thickness are mentioned by Prindle[3] as occurring in the Fairbanks district. In some places they are interbedded with muck. A section illustrating this interbedding is given below:

Record of shaft on Dome Creek.

	Feet.
Muck	6
Ice	9
Muck	12
Ice	11
Muck	44
Gravel	35

As no details of the structure or horizontal extent of the ice beds are given, no conclusion can be drawn as to the processes of formations. The interbedding is best explained as being successive deposits of aufeis in a region where deposition was building up the general level. If the muck includes no river-borne material immediately over the ice, this explanation can hardly be correct.

DISTRIBUTION OF GROUND ICE.

As already stated, wherever the ground is permanently frozen ground ice may exist. Its actual distribution seems limited somewhat both by the topography and the character of the deposits. Holmsen[4] states that it is lacking upon slopes. Although this statement is generally true, several exceptions have been mentioned. The writer has noted ground ice upon the seaward slopes of the upland south of Camden Bay. The country at Eschscholtz Bay and also at some of the Siberian localities is described as undulating. Fresh exposures are ordinarily required to reveal the presence of the ice, and as such exposures are rare except near water, the ground ice may be somewhat more generally developed on slopes than present observation seems to indicate.

Of course ground ice is not to be expected in hard rock but in what would be unconsolidated deposits if they were not cemented by frost. Of the unconsolidated deposits some are more favorable for the formation of ground ice than others. Coarse sand and gravel deposits seem to have much less ice than clay and silt. The most favorable material is muck.

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

[2] Moffit, F. H., Geology of the Nome and Grand Central quadrangles, Alaska: U. S. Geol. Survey Bull. 533, pp. 53–54, 1913.

[3] Prindle, L. M., A geologic reconnaissance of the Fairbanks quadrangle, Alaska: U. S. Geol. Survey Bull. 525, p. 93, 1913.

[4] Holmsen, Gunnar, op. cit., p. 131.

Typically the ice does not occur in great continuous sheets but in isolated masses. Even the great deposits of the New Siberian Islands have many inclusions of earth. Horizontal sheets over 1,000 feet in length have been met with in constructing ditches, but most of the ice masses are less than 100 feet in diameter. The writer shows that in the Arctic tundra of Alaska the ice is distributed in a network of vertical wedges, and from the evidence in the literature he is of the opinion that this distribution is typical of many widely separated areas.

Although a few occurrences of ice are reported at places where the upper surface of the ice lies at a considerable depth, as a rule it lies at or close to the limit of annual thawing. The lower limit is of course variable.

To sum up the distribution of ground ice, we find that it may occur in any region where the ground is deeply frozen, especially in muck deposits in level areas.

AGE OF GROUND ICE.

The age of the ice may be equal to or less than that of the cold climate under which it was formed. In the discussion of the age of the frozen ground we found a thousand years as a lower limit. The ice may be this old, at least.

The relative ages of the ice and frozen ground will of course be different, according to the methods of formation of the ice. A body of ice that is buried and preserved may be nearly contemporaneous with the ground formation. Where the ice is formed in place, it will of course be younger.

Such methods of formation by burial as are possible under modern conditions can not point to a very great age, nor can the doubtful method of formation in place advanced by Tyrrell. Belcher's theory, as elaborated by Holmsen, is also very doubtful, and nothing is known of the rate of supposed upward growth of the ice.

The theory of burial of great Pleistocene snow fields, as advanced by Toll and others, necessitates such changes in climate that the postulated great age should be questioned.

If the theory of the origin of the wedge shaped masses of ice is true, as outlined above, we have a method of estimating the age of the ice with a fair degree of accuracy. The width of the wedge and the rate of growth are all that is necessary for this calculation. The width is readily ascertained, and a rough estimation from field evidence may be made of the rate of growth. In the area studied by the writer an age of 500 to 1,000 years is indicated.

It is possible to ascertain the rate of growth much more accurately by actual measurements over a series of years, as is suggested under the discussion of this form of ice (p. 211). With a value thus found, a much more reliable estimate of the age of the wedges might be made.

The presence of frozen mammoth remains, including even the flesh, in regions of ground ice has attracted much more attention to the ice than it otherwise would have received. The earlier opinion was that the mammoth were found in the ice. This opinion gave rise to many fantastic theories. The later observers seem agreed that no mammoth remains are ever found in the ice itself, but in the earth above the ice or included in it. According to the theory of the preservation of snowdrifts by burial, the mammoth must have existed long after the cold climate had settled down over the Arctic regions, but if the ice has grown in place in the ground they may have died out as the cold became intense.

SUMMARY.

Erroneous conclusions have been drawn as to the distribution of ground ice, chiefly from observations of poor exposures. Scattered outcrops of ice are grouped into a single heavy bed of clear ice when, as a matter of fact, the ice in the ground may be only slightly in excess of that actually visible. Careful examination has revealed the existence of the following kinds of ground ice: (1) Grains of clear ice, the largest an inch in diameter, mixed with earth; (2) thin undulating sheets or ribbons of ice alternating with thin beds of earth; (3) heavy horizontal beds of clear ice; (4) heavy beds of ice alternating with beds of earth; (5) heavy deposits of ice with isolated earth inclusions; (6) a network of vertical wedges of ice surrounding polygonal bodies of earth.

The first two kinds are of minor importance, and no satisfactory explanation of their origin has been given. The third kind is met with chiefly upon flood plains of rivers, and is best explained as resulting from the burial of aufeis by spring floods. The fourth kind is not common. It may represent a building up of the surface of the ground by successive deposits of ice like the third kind. No satisfactory explanation has been given for the fifth kind of ice, the New Siberian type. The writer thinks that the wedge theory may furnish the best explanation. The sixth kind of ice is of widespread occurrence upon the coast of Arctic Alaska; it probably exists also in Spitzbergen and Siberia.

Only two theories as to the formation of ground ice are recognized as being of importance—(1) burial of aufeis by material moved by spring floods; (2) formation of vertical wedges of ice by growth in place.

Other theories which are recognized as possible but not probable are the following: (1) Burial of heavy widespread deposits of snow by transported material; (2) burial of ponds by floating vegetation; (3) growth of beds of ice in place from concentration of moisture in the ground.

If heavy beds of ground ice were formed by the burial of snow, the age indicated is very great. A sufficient amount of snow would be furnished only in glacial time. All the other methods are capable of originating ground ice under modern conditions and so do not indicate a great age for the ice. The only process capable of yielding quantitative results is that giving rise to the wedge-shaped masses of ice. From this an age of 500 to 1,000 years is estimated for the ice of the north coast of Alaska.

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