Geology of the Utukok-Corwin Region Northwestern Alaska

By ROBERT M. CHAPMAN *and* EDWARD G. SABLE

EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA, 1944–53

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CONTENTS

ILLUSTRATIONS

[Plate 7-20 are in plate volume]

TABLES

EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4 AND ADJACENT AREAS, NORTHERN ALASKA, 1944–53

GEOLOGY OF THE UTUKOK-CORWIN REGION, NORTHWESTERN ALASKA

By Robert M. Chapman and Edward G. Sable

ABSTRACT

The mapped region includes about 7,500 square miles in the western part of northern Alaska, north of the De Long Mountains and east of the Chukchi Sea. Systematic geologic work in the area was first undertaken in 1901 and 1904 by the U.S. Geological Survey. More intensive exploration was done in 1923–24 and 1926, and in 1947–53 as part of the Geological Survey program of investigations for the U.S. Navy Department in and near Naval Petroleum Reserve No. 4. The program also included geophysical work, consisting of seismic and gravimetric surveys by the United Geophysical Co., Inc., and airborne magnetic surveys by the Geological Survey and the Navy. Kaolak test well 1 was drilled in this region in 1951.

The region includes parts of the Arctic coastal plain and Arctic foothills physiographic provinces. The major rivers that cross the area are the Utukok, Kokolik, and Kukpowruk Rivers, which empty into Kasegaluk Lagoon, on the Arctic coast; smaller rivers include the Pitmegea, Epizetka, and part of the upper Colville. The only permanent settlement in the area is an Eskimo village at Point Lay. Abandoned dwelling sites are common along the coast, and many are also seen along the major rivers. Archaeological reconnaissance studies have been made in parts of the area. Low vegetation covers most of the region and includes grasses, sedges, willows, lichens, mosses, and heath communities. The region has an arctic climate and is in the zone of continuous permafrost. Permafrost is known to reach a depth of 850 to 980 feet in one locality. Microrelief features in the area include grass tussocks and tussock rings, nonsorted circles and polygons, and features of slope instability.

Five Cretaceous formations crop out in the region: the Fortress Mountain and Torok formations, the Kukpowruk and Corwin formations of the Nanushuk group, and the Prince Creek formation of the Colville group.

The Fortress Mountain formation of Early Cretaceous age is more than 4,400 feet thick in this region and consists mostly of marine shale, siltstone, graywacke-type sandstone, and some conglomerate.

The Torok formation of middle or late Early Cretaceous age is more than 6,000 feet thick and is made up predominantly of marine shale and siltstone.

The Kukpowruk formation of late Early Cretaceous age consists mostly of marine rocks (inshore facies) and contains some nonmarine rocks (coastal facies) in the upper part and in the southernmost exposures. Dominant rock types are shale, siltstone, sandstone and claystone. Northeastward facies changes from sandstone to shale occur in the basal part of the formation, which overlies and intertongues with the Torok formation. The Kukpowruk formation thins northeastward from more than 5,000 feet to about 2,000 feet in thickness. The Kukpowruk formation is similar to the Grandstand formation of the Nanushuk group mapped in areas further east.

The Corwin formation is believed to be partly of middle or late Early Cretaceous age and may be partly of Late Cretaceous age. The formation consists of predominantly nonmarine rocks (coastal facies with possibly some inland facies), and it intertongues with and overlies the Kukpowruk formation. Shale, siltstone, claystone, sandstone, coal, conglomerate, ironstone, clay, and bentonitic clay constitute most of the rock types of the Corwin. The Corwin thins eastward in the northern part of the region and also thins northward from more than 15,400 feet near Corwin Bluff to about 4,500 feet along the lower Utukok River. Lithologically the Corwin formation is similar to the Chandler formation of the Nanushuk group that is exposed east of this region.

The Prince Creek formation of the Colville group of Late Cretaceous age is a nonmarine unit which overlies the Corwin formation. The dominant rock types, poorly indurated sandstone and conglomerate, are associated with ironstone, coal, bentonitic clay, shale, and claystone. The total thickness of the Prince Creek formation is unknown, and the thickest exposed section is 93 feet.

Rocks in the extreme southwestern part of the region include a unit of siltstone and shale which is possibly Jurassic in age.

Quaternary unconsolidated deposits, which are separated from the underlying rocks by an angular unconformity, include the Gubik formation of Pleistocene age, which mantles the coastal plain, elevated Pleistocene and Recent fluviatile deposits in the foothills, and Recent beach and stream deposits.

The major structural element of the region is a basin which deepens westward and northward and includes two negative elements: the Colville geosyncline of Mesozoic age and the Chukchi basin of Mesozoic and Cenozoic ages. The basin is partly flanked by positive elements: the Meade arch, the Barrow arch, the Brooks Range geanticline, and the Tigara uplift. Tangential forces originating in the Brooks Range geanticline and the Tigara uplift produced the present structural pattern that is superimposed upon the basin.

The region is divided into the eastern and western structural provinces. In the eastern structural province, complex anticlines in the southern foothills expose the Fortress Mountain formation and the highly deformed Torok formation. These anticlines are intermediate in complexity and direction of strike between the structural features south of the region and the structural features in the northern foothills. The major folds in the northern foothills and coastal plain in the eastern structural province mainly trend west and northwest, the result of northward-directed forces from the Brooks Range. These include prominent simple synclines and basins separated by complex anticlines which may in part be the expression of major thrust faults. Surface rocks are folded to progressively greater depths westward, but in a northerly direction the depth of folding is more irregular and has resulted in at least 2 posi-

tive and 2 negative elements which strike east-northeast. Structural salients in 2 parts of the region may represent northeast-striking structural highs. The western structural province is characterized by northwest-striking thrust faults which alternate with southwestward-dipping sections or partial limbs of synclines. This structural pattern is the result of eastward-directed forces from the Tigara uplift, west of the area.

Reflection seismic work has been done north of the Utukok River at the headwaters of the Kaolak River, and southward along the Utukok River into the southern foothills. Two areas that are structurally distinct are delineated within this region. They are separated by the major south-dipping and west-trending Carbon Creek thrust fault, which is believed to come to the surface within the Carbon Creek anticline. The northern or upper Kaolak River area includes the Torok, Kukpowruk, and Corwin formations. This shallow Cretaceous rock sequence is gently folded along nearly eastward-trending axes and has a regional dip to the south. About 12,000 feet of this sequence is present near the north boundary of the area and about 15,000 feet at the south boundary near the Utukok River. An underlying rock sequence of undetermined thickness dips homoclinally southward from the Barrow arch, which lies about 80 miles north of the map region. Within this area no faults are indicated in the seismic records. Two subsurface closed anticlines in the shallow Cretaceous sequence were mapped by seismic methods, and Kaolak test well 1 was drilled on one of these. The southern or Utukok River area is structurally more complex than the northern or upper Kaolak River area. Rocks of both the shallow Cretaceous sequence and the underlying sequence are folded. At least seven south-dipping reverse faults, which cut the Cretaceous sequence and at least part of the older sequence, are indicated. The bottom of the shallow Cretaceous sequence is conjectured to lie at depths ranging from 2,000 to 8,500 feet below sea level. A similarity between the structural features in this area and those in the foothills of Alberta, Canada, is suggested.

Gravimetric and airborne-magnetic surveys cover parts of this region. A gravity low lies northwest of Carbon Creek and north of the Utukok River; and a gravity high, coinciding with the Carbon Creek fault zone, lies on the south flank of the low area. A general southwestward decrease in magnetic intensity has been determined.

During Mesozoic time sediments were deposited northward into the Colville geosyncline and later into the Chuckchi basin. Deposition was interrupted by one or more orogenic intervals in early Mesozoic time and by several intervals of at least local uplift and nondeposition in middle and late Mesozoic time. Uplift in the Brooks Range geanticline resulted in the deposition of graywacke-type clastic rocks of the Fortress Mountain formation as a marginal facies that grades northward to finer grained clastic rocks. The history of at least the upper part of the Torok formation and the Kukpowruk and Corwin formations is one of essentially continuous deposition, although some erosional breaks and angular relations are recognized within these rocks, which filled the western part of the Colville geosyncline. The shoreline fluctuated considerably, resulting in intertonguing facies. The Torok formation may in part represent a major southward transgression of the sea in middle or late Early Cretaceous time, followed by a northward regression which continued during deposition of Kukpowruk and Corwin formations. The main source of sediment was in the Brooks Range geanticline, but some sediment was probably also shed from the Tigara uplift. The western basin of the Colville geosyncline was probably in part separated from an eastern basin in the Colville River area by the Meade arch. Sediments of the Prince Creek formation and probably also the upper part of the Corwin formation were deposited in the Chukchi basin, which had resulted from the northward shifting of the western basin of the Colville geosyncline. An erosional and orogenic hiatus may have preceded deposition of the Prince Creek. Continued uplift of the Brooks Range geanticline culminated in great deformation during Tertiary time, and the Tigara uplift also probably reached its maximum at about this time. Differential uplift probably continued throughout Quaternary time. During Pleistocene time, valley glaciers in the De Long Mountains increased the volume of streams, and extensive gravel deposits were laid down in the foothills, but the coastal plain was still mostly submerged. Permafrost began to develop. The present basin of deposition is the Chukchi Sea.

In general the Utukok-Corwin region does not appear to have good possibilities for petroleum in the rock units and structural features that have been observed or can be reasonably inferred. However, the presence of some good reservoir beds, some favorable structural features, and a few rocks containing petroliferous material should not be ignored. Rocks older than the Fortress Mountain formation of Early Cretaceous age do not crop out in this region and nothing is known of their character and occurrence in the subsurface. The Fortress Mountain formation is exposed only along the south boundary of the region, and its poor reservoir characteristics, complex structure, and unknown northward extent are factors unfavorable to petroleum exploration. The Torok formation is composed almost entirely of shale, and no favorable reservoir beds are known within it.

The Kukpowruk formation offers relatively few possibilities for petroleum exploration. Based on samples tested, the Kukpowruk formation has greater porosity in the eastern part of the mapped region, near the Utukok River, than in the western part; and its permeability is uniformly very low. In the southern part of this region, the anticlines are eroded nearly to or through the base of the Kukpowruk formation. Farther north most of or all the formation is present in anticlines, but the percentage of sandstone beds is much lower owing to facies change. Several low-permeability sandstone beds that contain petroliferous and asphaltic residue occur in the Carbon Creek anticline near the Utukok River.

The chiefly nonmarine Corwin formation in the outcrop area is generally less favorable for petroleum than the Kukpowruk formation. The porosity of the tested sandstones is low and essentially uniform throughout the area, and, with but one exception, the permeability is very low. Structurally, only the part of the region mapped north of lat. 69°25′ N. offers promise of favorable conditions for oil accumulation in the Corwin formation. South of this line the formation is breached in the anticlines. One sandstone bed that is exposed along the Kokolik River has a high asphaltic content, and several other sandstone beds in this vicinity have a slight petroliferous odor.

The Prince Creek formation seems to have little petroleum potential in this region. It is not thick or areally extensive, and its sandstone and conglomerate beds have poor to fair porosity and permeability.

Kaolak test well 1, in the extreme northern part of this region, was drilled through the Corwin formation and bottomed at 6,952 feet in equivalents of either the lower part of the Kukpowruk or the upper part of the Torok formation. No

commercial quantities of oil or gas were found, although there were 9 shows of oil and gas between 3,184 and 6,757 feet. Sandstone beds more than a few feet thick are uncommon. They have low porosity and are nearly impermeable.

Coal beds are common in the inland and Cape Beaufort-Corwin coastal parts of the region and are confined almost entirely to the Corwin formation. The coal ranges from subbituminous to medium-volatile bituminous in rank. In the inland part the coal beds range from a few inches to more than 13 feet in thickness, and 28 potentially minable beds were sampled. Coal beds are abundant throughout 4,000 feet of Kaolak test well 1. Along the Cape Beaufort-Corwin coast, more than 80 coal beds that exceed 1 foot in thickness are known, and at least 17 of these beds are between 2.5 and 9 feet thick. Substantial additional reserves could undoubtedly be delimited by further exploratory work. The locations of all the known major coal beds are shown on a generalized geologic map. All the known analyses of coal samples collected from this region are given in tables 10 and 11. An analysis of results of Fischer low-temperature carbonization assays of 27 samples from the inland part of the region is included.

INTRODUCTION

Location, size, and accessibility of the region.—The region mapped, hereafter called the Utukok-Corwin region, lies north of the De Long Mountains, the westernmost extension of the Brooks Range, in the extreme western part of nothern Alaska (pl. 7). The region includes about 7,500 square miles. It is south of lat 70° N., and is bounded on the west by the Chukchi Sea and by long 165°40' W. East of this meridian the southern limits of the region are along lat 68°45' to the Utukok River vicinity, along lat 68°50' to the Colville River vicinity, and along lat 68°55' to the eastern boundary of the map, which extends northward along long 169°40' to lat 69°40' and thence along the 170th meridian to the northern boundary. Parts of the drainage basins of the Colville, Utukok, Kokolik, Kukpowruk, and Pitmegea Rivers are included in the region. About 2,000 square miles of the region lies in the Arctic coastal plain province, about 5,200 square miles in the northern foothills section of the Arctic foothills province, and only 300 square miles in the northern part of the southern foothills section. The eastern part of the region lies in Naval Petroleum Reserve No. 4. Exploration of the region was undertaken as part of the Geological Survey's program of investigations for the U.S. Department of the Navy in Naval Petroleum Reserve No. 4 and adjacent public lands during the years 1944–53.

The Utukok-Corwin region can be reached by air and water from the nearest towns, Kotzebue and Barrow, which are about 150 airline miles to the southwest and north, respectively, and from Fairbanks which is about 480 airline miles to the southeast. Airstrips at Point Lay and Wainwright are used by small aircraft. The Alaska Native Service ship *North Star* visits the coastal villages annually.

Discussions of the Arctic coast and navigational features along it are given by Collier (1906, p. 9–10) for the part west of Cape Beaufort, and for the part north of Cape Beaufort by Paige, Foran, and Gilluly (1925, p. 7–10). Use of small boats on the ocean west of Cape Beaufort is hazardous because of the sudden storms and scarcity of suitable beaching sites. Vehicle travel along the base of cliffs in this part of the region should not be attempted because of soft sand and rock-falls, but travel by track vehicles throughout the rest of the region can be easily accomplished. Otherwise, the inland part is relatively inaccessible during the summer months.

Lakes suitable for pontoon airplane landings are numerous in the coastal plain, but only a few are present in the foothills. In the lower courses of the rivers, pontoon landings by small planes are possible at selected places, and at low-water stages sufficient space for wheel landings by small aircraft can be found on many gravel bars adjacent to the main rivers. During the winter season, ski-equipped airplane landings are possible at most places. In the ice-free season, space for pontoon landings is available on the bar sides of Kasegaluk, Agiak, and Ahyougatuk Lagoons.

The prominent eastward-trending sandstone ridges in the foothills afford exceptionally good routes for tracked-vehicle or foot travel. Travel on foot in the foothills is not difficult, but in the coastal plain province the swampy ground makes it very arduous.

The Utukok, Kokolik, and Kukpowruk Rivers are navigable with boats having a draft of less than a foot to within 10–20 miles of their headwaters. These main rivers, except for short stretches of the upper Utukok, are confined to one channel, and only in a few places is a riffle encountered that is shallow enough to hamper downstream travel. However, shallow channels and riffles make upstream travel difficult in the lower 30 miles and almost impossible farther upstream. A few bedrock rapids are present in the Utukok River in the northern foothills section.

Previous investigations.—The coastline of the Utukok-Corwin region was first visited by Europeans in 1778 (Cook, 1785, p. 460), but little geological information on most of the area was recorded previous to 1904, although whaling ships and revenue cutters had visited the coast (Jarvis, 1889; Stockton, 1890). In 1904 A. J. Collier, of the Geological Survey, examined the coastal region between Cape Thompson and Cape Beaufort (1906) and made a reconnaissance study of this coal-bearing area which had been noted briefly by F. C. Schrader in 1901 (Schrader, 1904). Some coal mining on a small scale was attempted during the late 1800's and early 1900's at various localities on the coast between Cape Beaufort and Cape Lisburne; some of this coal was used locally and by a few ships. The history of the early explorations and geological work in northern Alaska is outlined by Smith and Mertie (1930).

Following the establishment of Naval Petroleum Reserve No. 4 by Executive Order in February 1923, Geological Survey field parties, financed by the Department of the Navy, began a reconnaissance study of the Reserve. A party under W. T. Foran began surveys near Cape Beaufort in July 1923 and ascended the Kukpowruk, Kokolik, and Utukok Rivers in canoes for distances of 20 to 40 airline miles from the coast. The results of this work were published (Paige, Foran, and Gilluly, 1925) and also later incorporated in a regional bulletin by Smith and Mertie (1930). In late August 1924, a party in charge of W. T. Foran portaged from the Kaolak River to the lower Utukok River, ascended the Utukok to Disappointment Creek, and thence went up Disappointment Creek in search of a route through the De Long Mountains to the Noatak River. Very little geological work was accomplished on this trip owing to lack of time and to logistic difficulties. In early May 1926, P. S. Smith and his party reached the upper Kokolik River after an overland journey by dog team from Kivalina. The party then canoed down the Kokolik River in June and mapped the geology and topography along the river (Smith and Mertie, 1930, p. 22–27); this reconnaissance was completed on June 18.

The only other geological work in this region before 1947 was done in July 1946 by A. L. Toenges and T. R. Jolley, of the U.S. Bureau of Mines. They ascended the Kukpowruk River to a point about 24 airline miles from the coast and investigated the coal beds that are exposed at many localities along this part of the river (Toenges and Jolley, 1947).

Nature and scope of the investigation.—Field studies of the region were undertaken in 1947 and 1949–53 as parts of the Geological Survey's program of exploration for the U.S. Navy Department in and near Naval Petroleum Reserve No. 4. The purpose of the work was to map and study the stratigraphy and structure and to evaluate the petroleum possibilities of this region, which had been only partly investigated by rapid geologic reconnaissance during the earlier explorations in 1923–26.

The project was supervised by George O. Gates in 1947, by Ralph L. Miller in 1949–50, and by George Gryc since 1951.

The laboratory work, preparation of illustrations, and writing of the report was so interspersed with other projects that it is not possible to set exact limits on the time consumed in these activities. Most of the preparation was done in the spring of 1951, the summer of 1952, the late part of 1953, and throughout 1954–55. Chapman worked intermittently, and Sable worked almost continuously during this time. All plates and illustrations were prepared by Sable with the exception of the illustrations in the chapters on economic geology and geophysical work, which were prepared by Chapman. The parts of the text on economic geology and geophysical exploration and the sections on vegetation, wild life, and geographic names were written by Chapman. The chapters on stratigraphy, structural geology, and geologic history and the sections on topography and drainage, settlements and archaeology, climate, and phenomena related to climate were written by Sable.

Geologic data obtained from ground traverses which covered a relatively small part of the total region (pl. 7) were plotted on aerial photographs, which include high-altitude trimetrogon photographs taken in 1943 and 1947, and vertical photographs of approximately 1 : 20,000 scale that were made in 1948 and 1950. These photographs, taken by the Navy and Army, cover the entire region of the report. Geologic data were transferred from the photographs to planimetric maps at scales of 1 : 48,000 and 1 : 96,000 which were compiled by the Geological Survey, mostly from the trimetrogon photographs and from older maps. The resulting maps are not everywhere accurate in geodetic position of features, but they were the most detailed and accurate maps available at the time of this writing. The vertical aerial photographs were utilized in making stratigraphic and structural measurements and for photogeologic mapping of areas beyond the limits of field control. Where checked in the field, the differences between the photograph scale and 1 : 20,000 scale proved to be generally within 5 percent, and within 10 percent in areas of high relief. Low-angle photographs were taken along the Kokolik and Kukpowruk Rivers and parts of the upper Utukok River by the U.S. Navy in 1949 and were used in plotting field data and in the measurement of rock sections exposed in the cutbanks of these rivers.

Field operations, 1947–53.—On May 12 and 17, 1947, a party consisting of Raymond M. Thompson, geologist and party chief, William L. Barksdale, geologist, Edward G. Sable, field assistant, Charles T. Marrow, camphand, and Ernest H. Wadsworth, cook, was landed by a single-engine ski-equipped airplane on the Utukok River about 8 miles north of the headwaters. When the spring thaw was far enough advanced to make the river navigable, the downriver traverse was begun on May 26 in three 18-foot folding canvas boats. A detailed geologic reconnaissance was made of the area within a day's foot travel of camps on the river, and a triangulation net was established over most of the route to obtain vertical control. The mouth of the Utukok River was reached on August 4, and on the 7th the party moved to the village of Point Lay. From August 17 to 23 Thompson, Barksdale, Sable, and three Eskimo boatmen traveled south from Point Lay and made a rapid reconnaissance of the coastal bluffs between Cape Beaufort and Eesook on the north shore of the Cape Lisburne peninsula.

The Kukpowruk and Kokolik Rivers were traversed by a boat party in 1949. On May 17 and 27 the party, consisting of Robert M. Chapman, geologist and party chief, Edward G. Sable, geologist, Dale A. Hauck and Gordon W. Herreid, field assistants, Paul H. Shannon, cook, and Ralph Solecki, archeologist, Smithsonian Institution, was landed by ski-equipped single-motor airplane on the Kukpowruk River about 16 miles from the headwaters. The downriver traverse was begun on June 13 in three 18-foot folding canvas boats, and the geologic work was carried to the reasonable limits of foot travel from camps located along the river. The mouth of the river was reached on July 30. On July 31 and August 1 the party was flown to Kokolik Lake, about 16 miles north of the headwaters of the Kokolik River, and the boat traverse to the mouth of the Kokolik River was completed on September 3. Triangulation nets for vertical control were established on both of these rivers.

Food supplies for these parties were cached at prearranged places along the rivers. The food caching, a hazardous operation, performed in 1947 by Robert F. Thurrell and in 1949 by Marvin D. Mangus, was carried out with complete success in both years. The food, which was put in 55-gallon steel drums to protect it from bears, was landed and cached during April and early May by means of a ski-equipped airplane. Mail and a few additional supplies were dropped from airplanes to the parties during the field season, except when suitable places for wheel or pontoon landings were available.

In the late part of the season of 1950, Charles L. Whittington, geologist and party chief, John M. Stevens, geologist, and the remainder of the party extended the mapping of the Carbon Creek anticline into the Utukok-Corwin region. This party mapped an area of about 115 square miles along the southwest side of the Utukok River between Carbon Creek and the headwaters of Elusive Creek, and part of their work is included in this report.

Geologic work was undertaken in the area of the upper Utukok River by Edward G. Sable and Marvin D. Mangus in 1950 and on the upper Colville River by Sable and Robert H. Morris in 1951. (See pl. 7.) In August 1951, exposures on the upper Colville River, downstream from those examined by Sable and Morris, were studied by George Gryc, geologist, and Lloyd A. Spetzman, field assistant.

Two previously mapped localities were reexamined and intensively sampled for microfossils: in 1952 the bluffs in the Archimedes Ridge anticline along the Kokolik River were sampled by C. L. Whittington assisted by Matthew V. Carson; and in 1953 the cutbanks along the Utukok River on the north limb of the Carbon Creek anticline were sampled by Robert S. Bickel, assisted by Carson.

During the summer of 1952 a detailed structural study of the Kokolik anticline was made by a party in the charge of Andrew Milek, geologist with Arctic Contractors.

In July and August of 1953 the Arctic coastline from Thetis Creek west to the Lisburne Hills was examined by Sable and H. Glenn Richards, field assistant. Geologic work was much delayed by an accident to the bush plane used for transportation from Umiat, and only about one-third of the time in the area could be spent in geologic field studies. A temporary camp was established on Aknasuk Creek, and from July 26 to August 19 the excellent rock sections between Thetis and Risky Creeks were described and measured. An 18-foot canvas boat with a small motor was used to a limited extent, but most of the traverses were by foot. The use of a larger, more seaworthy boat is advisable for transportation along this coast. From August 19 to 26, a less-detailed examination of the rocks west of Risky Creek to the Lisburne Hills was made from a camp established at Ahyougatuk Lagoon.

Seismic work in the region by United Geophysical Co., Inc., in 1950 and 1952 consisted mainly of reflection studies north and east of the Utukok River. (See p. 145–150.)

Gravimetric surveys were made in 1950 by the United Geophysical Co., and an airborne magnetic survey was made by the Geological Survey and the Navy in 1945. (See p. 151.)

A party financed by the Arctic Institute of North America under contract with the Office of Naval Research traversed parts of the Utukok River in July and August 1953. This party, under the direction of

J. Stewart Lowther, was engaged in paleobotanical studies of rocks herein mapped as Corwin formation and Prince Creek formation.

Acknowledgments:—As work in the Utukok-Corwin region was an integrated part of the larger explorations in Naval Petroleum Reserve No. 4, it is impossible to name all the many people whose cooperation and assistance contributed materially to the successful completion of the geological fieldwork. The U.S. Navy Arctic Contractors, and the Geological Survey personnel in Fairbanks and in the Reserve provided helpful support without which the field parties could not have worked effectively.

The authors particularly wish to acknowledge the geological work of Raymond M. Thompson and William L. Barksdale, which is incorporated in this report. They also wish to acknowledge the varied work of the Geological Survey geologists and field assistants mentioned in the section on field operations, including H. Glenn Richards, who aided substantially in the accumulation of data in the Corwin Bluff vicinity. Robert J. Hackman contributed part of the photogeologic interpretations. Information on Kaolak test well 1 was compiled in the Fairbanks laboratory by Mrs. Florence Rucker Collins. The identification of megafossils was done by Ralph W. Imlay and F. Stearns MacNeil, of fossil flora by Roland W. Brown, and of microfossils by Harlan R. Bergquist, all from the Geological Survey. Heavy-mineral identifications were made by Robert H. Morris. Harald A. Rehder, U.S. National Museum, identified Recent invertebrates collected along the seacoast. Finally, the reports and notes of the earlier Survey geologists, P. S. Smith, W. T. Foran, A. J. Collier, and the others already mentioned, were very helpful in the planning and compilation of the fieldwork.

The bush pilots of Wien Alaska Airlines and Alaska Airlines rendered invaluable support in the caching and other transportation activities throughout the field seasons.

The generous hospitality and friendliness of the people of Point Lay with whom the 1947 party spent several days was much appreciated. Many of the Eskimo names that have not been previously published were obtained in 1947 from Robert Tuckfield and Mickey Toorau of Point Lay.

GEOGRAPHY

GEOGRAPHIC NAMES AND SOURCES

Most of the geographic names given in the following paragraphs, together with their meanings and sources, have not been previously published. Many of the Eskimo names, especially those along the coast, are in local usage at the village of Point Lay; others were named by the Geological Survey personnel for purposes of convenience in referring to geographic features.

Adventure Creek.—A headwater tributary that joins the Utukok River about 10 miles southwest of Meat Mountain. It was so named by the 1924–26 field parties.

Agiak Lagoon.—A lagoon just east of Cape Sabine. The Eskimo name "agiak" means file, and this feature is so named because the shoreward side of the offshore bar is serrated and resembles the teeth of a file.

Ahyougatuk Lagoon.—A small lagoon about 15 miles west of Corwin Bluff. This Eskimo name means foundation or base of a house.

Aknasuk Creek.—A small creek that flows into the ocean about 3.1 miles west of Corwin Bluff. This Eskimo name for the creek was obtained by the U.S. Coast and Geodetic Survey.

Akporvik Hill.—A ridge extending southeastward from Cape Sabine. This Eskimo word means racetrack or runway or a flat, open, easily traveled ridge top.

Akulik Creek.—A small creek that flows into the ocean 6 miles southwest of the mouth of Tulugak Creek. The Eskimo word means fancy trimming.

Amatusuk Hills.—A prominent eastward-trending ridge that lies about 30 airline miles inland between the Kukpowruk and Kokolik Rivers and just north of Deadfall Creek. The name first appeared in bulletin by Smith and Mertie (1930). It is undoubtedly of Eskimo origin, but its meaning is not known.

Amo Creek.—The westernmost tributary of the upper Colville River which enters at the major eastward swing of the river. The creek was named by the 1950 party from an Eskimo name for wolf, because several wolves were seen in this vicinity. The Amo anticline lies almost along the lower course of the creek.

Angle Creek.—A small north-flowing stream east of the Kokolik River. Named by the 1949 party because of the angular drainage pattern that is structurally controlled.

Archimedes Ridge anticline.—This westward-trending anticline lies between the Utukok and Kukpowruk Rivers. The name is derived from a ridge near the Utukok River, between the 1947 camps 5 and 6, that gives the impression on vertical photographs of an Archimedes screw owing to the effect of snow and shadows.

Avingak Creek.—A westward-flowing tributary that enters the Kokolik River about 50 miles southeast of Point Lay. Avingak is the Eskimo name for lemming, and the creek was so named by the authors because these animals were abundant in this vicinity in 1949. The Avingak Creek anticline is cut by the headwaters of this creek.

Barabara syncline.—A northeastward-trending syncline that is intersected by the Kukpowruk River about 10 airline miles inland. It was named because of the proximity of the axial zone to an Eskimo barabara or sod hut on the river bank.

Beaufort syncline.—A southwestward-trending syncline west of the Kukpowruk River and east of Cape Beaufort.

Blizzard anticline.—A major eastward-trending anticline lying between upper Disappointment Creek and the Pitmegea River.

Cape Beaufort.—A low promontory near the coast about 47 airline miles south of the mouth of the Kukpowruk River. It was named in 1826 by Frederick W. Beechey, R. N. ". . . in compliment to Captain Beaufort, the present hydrographer to the Admiralty." (Baker, 1906, p. 123.) The Eskimo name for this cape is Kakiagtak.

Cape Sabine.—A promontory on the coast about 26 miles southwest of Cape Beaufort. "So named by Beechey, 1827, presumably after Gen. Sir Edward Sabine." (Baker, 1906, p. 540.)

Carbon Creek.—A major westward-flowing tributary that enters the Utukok River about 83 airlines miles from the coast. Origin of the name is unknown.

Coke basin.—A structural basin on the Kukpowruk River about 63 airline miles upriver from the coast. It was named because of an outcrop of moderately good coking coal on the river near the axis.

Corwin Bluff.—A prominent bluff and coal mining locality on the coast about 14 miles west of Cape Sabine. Named for the U.S. Revenue vessel *Corwin.* Captain Hooper of the cutter *Corwin* used coal from the Corwin Bluff mine for fuel as early as July 1880. (Baker, 1906, p. 197.). Schrader reports in his 1901 field notes that coal had been mined here for the previous 40 years.

Deadfall Creek.—A tributary of the Kukpowruk River entering just south of the Amatusuk Hills. It was named by the 1949 field party because of an Eskimo-built rock deadfall trap found near the mouth of this creek.

Deadfall syncline.—A westward- and southwestward-trending syncline between the Kokolik River and the west coast. It is named from Deadfall Creek which flows through its eastern part.

Disappointment Creek.—A tributary that enters the Utukok River about 6 miles upstream from the mouth of Carbon Creek. It was named by W. T. Foran in 1924 when it was discovered that the creek did not head in a pass through the De Long Mountains.

Driftwood Creek.—The major eastern headwater fork of the Utukok River, which joins the main Utukok River about 10 miles southwest of Meat Mountain and just above Adventure Creek. It was named by the 1924–26 field parties. The Eskimo name for the creek is Karvak. Two anticlines, East Driftwood and West Driftwood, lie north and west of the creek.

Dugout syncline.—A small syncline between the Pitmega and Kukpowruk Rivers, named because its concave shape resembles a dugout canoe.

Eesook.—A place on the coast about 11.4 miles west of Corwin Creek. The coastal bluffs end at this point, and this Eskimo word means "end of the bluff."

Eesook syncline.—A westward- to northwestward-trending syncline 3 to 9 miles southeast of Eesook. This is the westernmost simple syncline in rocks of the Nanushuk group.

Elusive Creek.—A tributary that enters the Utukok River about 9 miles downstream from Carbon Creek. The Elusive Creek syncline is a northwestward-trending structural feature that intersects the Utukok River near the mouth of the creek.

Epizetka River.—A small river that flows into the ocean just north of the Kukpowruk River. The name is probably derived from the name Kepizetka that Collier learned from the natives near Cape Lisburne in 1904. Collier believed that the name was applied to what is now the Kokolik River (Baker, 1906, p. 244).

Eskimo Hill.—A prominent low hill about three-fourths of a mile northeast of the mouth of Carbon Creek. It was named by Foran in 1924.

Flintchip syncline.—This syncline lies mainly between the Utukok and Kokolik Rivers and north of the Driftwood anticlinal area, and it was named for the flint-chipping sites found on hills in this vicinity.

Foggy syncline.—A westward-trending syncline east of the Utukok River and northeast of Meat Mountain.

Folsom Point syncline.—A westward-trending syncline that is intersected by the Utukok River west of Disappointment Creek. It was named because a flint Folsom point was found near the Utukok River within this syncline in 1947.

Harris anticline.—An eastward-trending anticline that intersects the Utukok River 5 miles north of the mouth of Elusive Creek. It was named for Lieutenant Harris, of the U.S. Navy photo squadron that was based at Umiat in 1948–50.

Howard syncline.—A westward-trending syncline that lies between the Utukok and Kukpowruk Rivers about 4 to 6 miles north of the Amatusuk Hills. It was named for Ensign Howard who made one of the earliest inland exploration journeys from the Kobuk River to Point Barrow.

Igloo Mountain.—A prominent mesalike hill about 6 miles east of the Kukpowruk River and about 64 airline miles upstream from the mouth of this river. It was named by P. S. Smith in 1926. According to his notes this hill is called Oomiak mountain by the Eskimos. The reason for changing this name is not clear.

Ikikileruk Creek.—A small creek that enters the ocean about 13 miles east of Cape Sabine. This Eskimo name means narrow.

Iligluruk Creek.—The creek is a major westward-flowing stream which joins the Kokolik River in the southern foothills section. The meaning of this Eskimo name is unknown; it was first used by Smith and Mertie (1930). The Iligluruk structural high lies northeast of the confluence of the two streams.

Ivisaruk River.—A northward-flowing tributary of the Kuk River, which heads against the Utukok River about 45 miles inland from the coast.

Kahgeatak Creek.—A small creek that enters the ocean about 7 miles north of Cape Beaufort. The meaning of the Eskimo name, which was obtained by the U.S. Coast and Geodetic Survey, is not known.

Kahkatak Creek.—A stream that enters the ocean at Cape Beaufort. This Eskimo name was obtained by the U.S. Coast and Geodetic Survey.

Kakiagtuk.—The Eskimo name for Cape Beaufort. Meaning not known.

Kaolak River.—A tributary of the Kuk River that heads against the Utukok River about 50–60 airline miles inland.

Kasegaluk Lagoon.—A large lagoon extending from Icy Cape southwestward nearly to Cape Beaufort. The geographic name was first used by P. S. Smith; it is of Eskimo origin, but the meaning is not known. The Kasegaluk syncline is a northwestward-trending structural feature which strikes into the lagoon about 4.5 miles south of the Kukpowruk River mouth.

Kokolik anticline.—A small southeastward-trending anticline which crosses the Kokolik River about 12 miles north of Tingmerkpuk River.

Kokolik River.—A major river heading in the De Long Mountains and entering the ocean at Point Lay. The name was first reported by Jarvis in 1898 and is of Eskimo origin (Baker, 1906, p. 377). Kokolik is the Eskimo name for the bistort, an edible flowering plant that is abundant in the Arctic.

Kokolik Warp syncline.—An eastward-trending syncline that intersects the Kokolik River about 80 airline miles above the mouth.

Kookrook Creek.—A small creek that flows into the ocean 0.9 mile west of Corwin Bluff. This Eskimo name for the creek was obtained by the U.S. Coast and Geodetic Survey.

Kukpowruk River.—A major river that heads in the De Long Mountains and enters the ocean about 10 miles south of Point Lay. The Eskimo name, meaning big river, has long been in local usage. It was first reported in 1890 (Baker, 1906, p. 386).

Kukpowruk syncline.—A syncline east of Cape Beaufort, the axis of which almost coincides with the local northeast direction of the Kukpowruk River.

Lookout Ridge syncline.—An eastward-trending syncline that intersects the Kokolik and Utukok Rivers in the latitude of Carbon Creek. It is named for Lookout Ridge, which is formed by part of this syncline in the area east of the Utukok River and north of the Colville River.

Meat Mountain.—A prominent, high mesa just east of the Utukok River and about 145 airline miles upstream from the coast. It was named by the 1923–26 parties and is derived from the Eskimo name, Nikipak, for this mesa, which means meat.

Meridian Creek.—A northward-flowing creek which enters the Colville River south of Disappointment Creek and heads in Lake Noluck, south of this region. This creek was probably named by the 1924 party.

Mutaktuk Creek.—A small creek that enters the ocean about 1 mile east of Agiak Lagoon. The Eskimo name means "no parka."

Niklavik Creek.—A small northward-flowing tributary that enters the Kokolik River about 12 airline miles inland. The name, which is probably of Eskimo origin, was first used by Smith and Mertie (1930), and the meaning is not known.

Norseman anticline.—A poorly exposed anticline about 37 miles upstream from the mouth of the Kokolik River. It was named because a Norseman airplane landed near it on the river to pick up 2 members of the 1949 party.

Oilsand syncline.—A syncline exposed on the Kokolik River about 10 miles southeast of the Norseman anticline. It was named because of an outcrop of oil-bearing sandstone that occurs on the north limb.

Omicron Hill.—A prominent low hill on the axis of the Carbon Creek anticline about 2 miles east of its intersection with Elusive Creek. It was named by the 1950 field party because this designation was used for their triangulation marker situated atop this hill.

Oxbow syncline.—A westward-trending syncline west of Elusive Creek and intersecting the Kokolik River. It was named because of the oxbow lakes along the Kokolik in this vicinity.

Pitmegea River.—A northwestward-flowing river that enters the ocean at Cape Sabine. The name, which was first published in 1890 (Baker, 1906, p. 500) is of Eskimo origin, and its meaning is not known.

Pitmegea syncline.—A small syncline northeast of the upper Pitmegea River.

Plunge Creek.—A small eastward- and northward-flowing creek that cuts across the West Driftwood anticline about 6 miles west of the junction of the Utukok River and Driftwood Creek. It was named in 1950 because of its location near the west end of the plunging anticline.

Point Lay.—The permanent village on the offshore bar near the mouth of the Kokolik River.

Poko Mountain.—A prominent, large mesa 6 miles west of the Kokolik River and near the confluence of the Kokolik and Tingmerkpuk Rivers. This is the Eskimo name for the mesa, and, according to P. S. Smith's notes, it means seal poke or seal parka (?).

Punak.—A low hill about one-half a mile inland and halfway between Agiak Lagoon and Mutaktuk Creek. It is an Eskimo name that means skinny.

Punak Creek.—A small creek that enters the ocean about 5.8 miles east of Mutaktuk Creek. This name, according to the Eskimos, means someone starved here, although it is believed to be the same word that applies to the above mentioned hill.

Risky Creek.—A small creek that flows into the ocean 5.4 miles west of Corwin Bluff. It was named by the 1953 field party because it is the last available beaching point in several miles for small boats traveling from Corwin to Ahyougatuk Lagoon.

Seaview syncline and anticline.—These structural features lie between Cape Sabine and the Kukpowruk River.

Seismo Creek.—The westward- and northward-flowing tributary of the Utukok River that heads south of Meat Mountain. It was named by the 1950 field party for the seismic operations of that year in this vicinity.

Snowbank anticline.—An eastward-trending anticline that is exposed on the Kukpowruk River about 17 airline miles above the mouth and extends eastward across the Kokolik and Utukok Rivers. It was named in 1949 because of the heavy snowbanks that remained on the bluffs in the axial zone in late July.

Tepsako River.—A small river that is mentioned by the 1946 U.S. Bureau of Mines party. The river is not definitely located, but it is reported that the Point Lay Eskimos mine coal on this river 10 miles east of Point Lay.

Thetis Creek.—A small creek that enters the ocean about 8 miles west of Cape Sabine.

Thetis mine.—An abandoned coal mine on the coast about 5.5 miles west of Cape Sabine. It was named for the U.S. Revenue Service vessel *Thetis* that refueled with this coal. It was first used by the *Thetis* in 1889 (Baker, 1906, p. 622).

Thetis syncline.—A northwestward-trending syncline between the Pitmegea River and Thetis Creek.

Tingmerkpuk high.—A structural salient between the Kukpowruk and Tingmerkpuk Rivers southwest of Poko Mountain.

Tingmerkpuk River.—A major headwater tributary of the Kokolik River that rises in the vicinity of Tingmerkpuk Mountain. It was named by one of the 1923–26 field parties from the Eskimo name for this mountain, which means "big eagle."

Tolageak.—An old abandoned village site on Kasegaluk Lagoon at the south side of the mouth of the Utukok River. The meaning of this word is not known.

Toonak Creek.—A creek that flows into Kasegaluk Lagoon about 11 miles northeast of the mouth of the Kokolik River. Toonak is the Eskimo name for the creek and means "devil."

Tulugak Creek.—A small creek that enters the ocean close to Cape Beaufort. This is an Eskimo name, which means "raven."

Tupikchak basin.—An almost circular structural basin between the Utukok and Kokolik Rivers and northeast of Poko Mountain, whose axis is continuous with that of Tupikchak syncline.

Tupikchak Creek.—A westward-flowing tributary of the Kukpowruk River that lies in the axial zone of Tupikchak syncline, and about 13 miles north of Igloo Mountain.

Tupikchak syncline.—An eastward-trending syncline that intersects the Kukpowruk and Kokolik Rivers and lies about 10 miles north of Poko Mountain. It is named because of the Eskimo name for the group of hills on the Kokolik that make up part of this syncline. According to P. S. Smith's 1926 notes the word means "new house."

Turbid Creek.—A small tributary that enters the Kukpowruk River about 10 miles northwest of Igloo Mountain. It was named by the 1949 party because of its exceptionally yellow muddy water.

Utukok River.—A major river that heads in the De Long Mountains and enters Kasegaluk Lagoon about 27 miles northeast of Point Lay. This long established Eskimo name means "old river," and it was first reported by Jarvis in 1898 (Baker, 1906, p. 656.).

Westbend syncline.—An eastward-trending syncline that intersects the Utukok River at its major westward bend near the south edge of the coastal plain.

TOPOGRAPHY AND DRAINAGE

Two physiographic provinces, the Arctic coastal plain and the Arctic foothills (Payne and others, 1951), are in the Utukok-Corwin region; and although they are radically different, they merge imperceptibly along an irregular boundary extending northwestward from Cape Beaufort. The Arctic foothills province is divided into the northern and southern foothills sections. The boundary between these sections extends from the vicinity of Eesook, at the west boundary of the map, eastward and northeastward to the Colville River, at the east boundary. The boundaries of the physiographic divisions are shown on the index map (pl. 7).

The Arctic coastal plain province, in the northern and western parts of the mapped region, is characterized by relief of less than 300 feet, many lakes and marshes, poorly defined meandering streams, and few outcrops that are confined to the cutbanks of the major streams. At its southern boundary the coastal plain gradually gives way to low hills of the northern foothills section (fig. 7) which includes about the southern three-fourths of the mapped region. The northern foothills section is a roughly eastward-trending belt, 40–50 miles wide, of rolling terrain within which relief and altitude increase southward; the belt is marked by prominent cuesta ridges and mesas that reflect the underlying structural features, and which are commonly separated by wide lowland areas. More than 90 percent of these lowlands is covered by tundra, and they are characterized by numerous swampy areas, small ponds, lakes, and other evidence of poor drainage. Outcrops in river bluffs in the northern foothills are numerous, and rocks are exposed along tributary streams and on the ridges where vegetal cover is thin or absent. Relief is as much as 2,200 feet, and it averages about 600 feet. The south boundary of the northern foothills section lies in a belt of lowlands (fig. 8).

Only the northern part of the southern foothills section is included in the Utukok-Corwin region, and it is made up mostly of lowlands interrupted by rounded hills and whaleback ridges with relief of about 1,000 feet. The hills are well drained, but the lowlands are swampy and contain many ponds and a few small lakes.

The Utukok, Kokolik, and Kukpowruk Rivers, the three major streams that drain the Utukok-Corwin region, are in general single-channel streams in the stage of early maturity. They head in the De Long Mountains, flow north and northeast through the foothills, and upon entering the coastal plain flow northwest. In the southern foothills they appear to be antecedent streams and commonly flow transverse to the east-northeastward-trending topographic features which are parallel to the structural grain. In the northern foothills, although still generally crossing east-striking structural features, the streams are more strongly controlled by structure; trellis and rectangular drainage patterns have also developed, especially in the tributary streams. The trellis pattern of the northern foothills gives way to a dendritic pattern of consequent streams near the coastal plain, and the major rivers themselves appear to be consequent and superimposed streams entrenching themselves in unconsolidated deposits and bedrock. The abrupt northwestward trend of the rivers in the coastal plain is thought to be due to their development as consequent streams flowing on an initial northwest slope of the emergent coastal-plain surface.

The Utukok River drains about 3,200 square miles and is 250 river miles in length;[1] 2,200 square miles of the drainage area lie in the northern foothills section and 400 square miles are in the coastal plain province.

The Kokolik River drains 2,200 square miles, 1,100 of which lie in the northern foothills and 500 in the coastal plain. The total channel distance is 200 miles.

The Kukpowruk River drains 2,800 square miles, 1,050 of which lie in the northern foothills and 75 in the coastal plain. The channel distance is 160 miles.

From the drainage divides in the De Long Mountains to the northern limit of the southern foothills, the gradient of the Utukok River averages 30 feet per mile, and the Kukpowruk River about 36 feet per mile. Here, the Utukok and Kokolik are shallow streams with numerous braided channels; main channel depths at low water range from 6 inches to 5 feet. Stream widths average 50 to 100 feet and on flood plains are as much as 4,000 feet wide. The Kukpowruk River is more noticeably incised, and its channel depths range from 6 inches to 10 feet. The river val-

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[1] No specific measurements of depth or discharge of the major rivers were made in this area. Stream gradients were computed from fourth-order triangulation points, stadia traverse, and altimeter readings; horizontal measurements of mean channel distances and widths were taken from maps and aerial photographs.

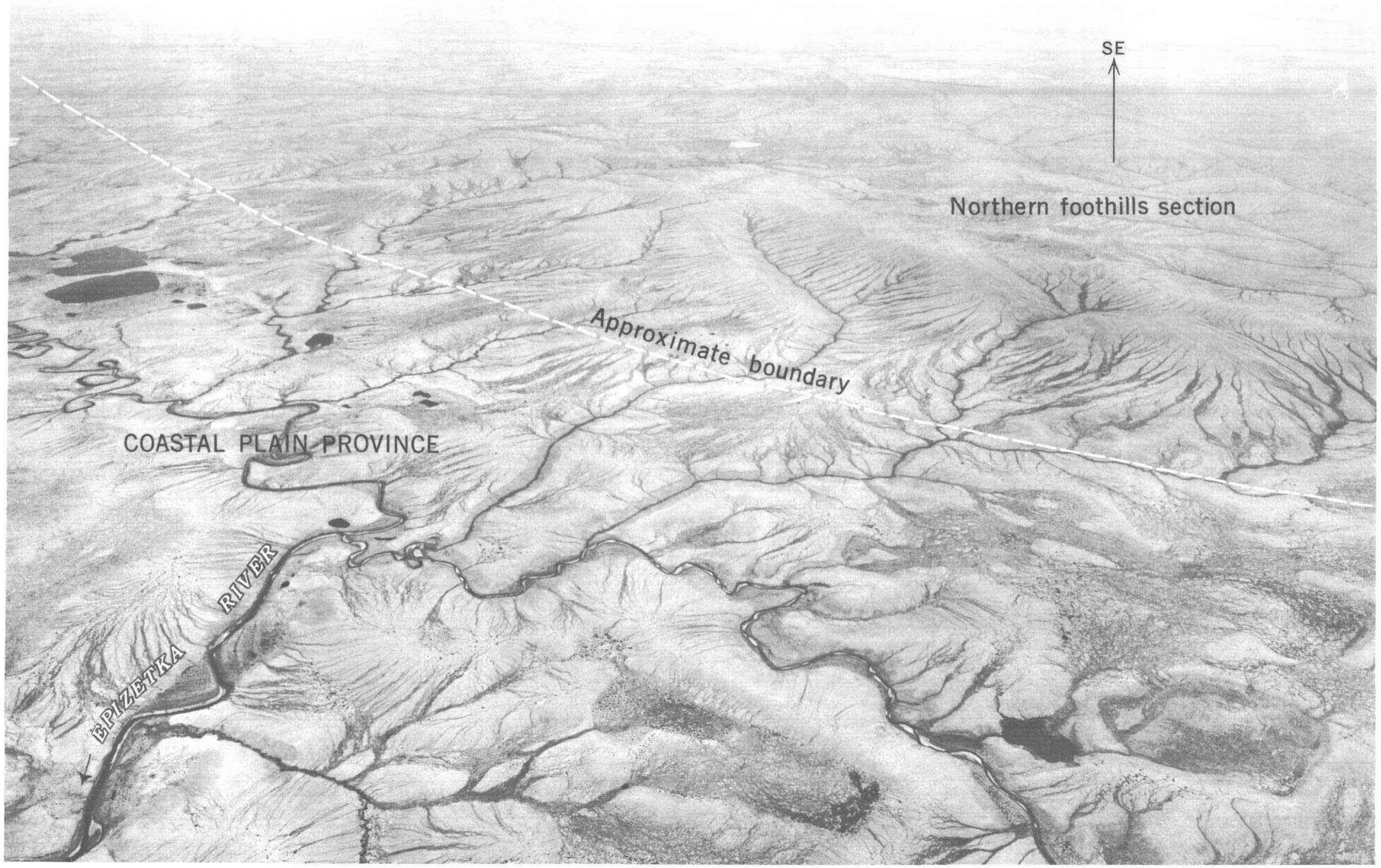


FIGURE 7.—Aerial view of northern foothills section and Arctic coastal plain province east of the Kukpowruk river, Utukok-Corwin region, Alaska. Linear bedrock ridges, trellis drainage pattern, and relatively well drained character of the northern foothills section merge northward into poorly drained nearly flat coastal plain where dendritic drainage has developed. Farther north, numerous large lakes are conspicuous features. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force, approximate altitude 12,000 feet.

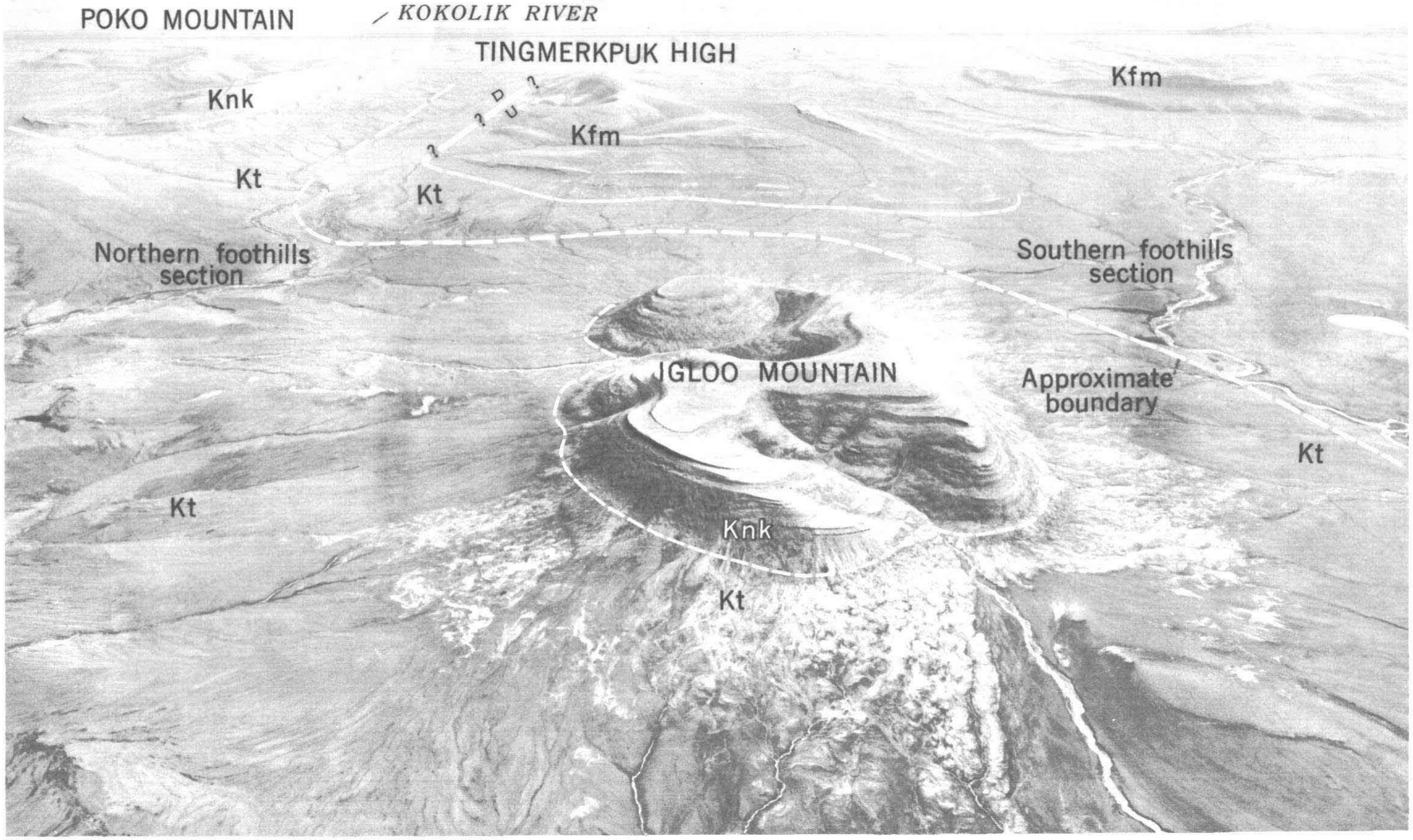


FIGURE 8.—Aerial view of southern and northern foothills sections looking east toward Kokolik River, Utukok-Corwin region, Alaska. The high synclinal mesas, Igloo and Poko Mountains, composed of Kukpowruk formation (Knk), are typical of the northern foothills. Rounded hills of Fortress Mountain formation (Kfm), as in Tingmerkpuk high, are characteristic of the southern foothills. Intervening lowlands underlain by Torok formation (Kt) form boundary between the two foothills sections. Photograph by Air Photographic and Charting Service, U.S. Air Force, approximate altitude 12,000 feet.

northwestward flowing consequent stream, at right angles to the trend of the tributaries.

The part of the Colville River which is included in the southeastern part of the Utukok-Corwin region flows north and east and in part forms the boundary between the northern and southern foothills sections. The river is a single-channel stream, deeply entrenched in bedrock, and is in part controlled by eastward-trending structural features.

In winter the streams are frozen solid to the riverbed in many places. Spring breakup occurs in mid-May and begins with melt water flowing over the ice and eroding interconnecting channels. This was observed in the headwaters of the Utukok River on May 12, 1947, and in the Kukpowruk River headwaters on May 25, 1949. The "anchor ice," which is frozen to the streambed, breaks last, usually several days after the initial flow. This occurs near the crest of spring rise, and large angular pieces of ice break and rise abruptly to the surface, imperiling boat travel. The streams are bank full, yellowish brown with silt and mud, and overflow all but the highest vegetation-covered gravel bars. During the spring breakup of the Utukok River in 1947, even many of these were covered. The lower courses of the streams were not observed during this time.

Stream discharge fluctuates rapidly during the summer season. Following the spring thaw, levels of the major streams fall several feet, and the smallest tributaries become completely dry. During prolonged dry periods in the summer, many of the larger tributaries are dry or reduced to small trickles; the major streams are clear and very low, and large expanses of gravel bars are exposed. The tundra is capable of absorbing great quantities of water before runoff begins; and although a rapid 2- to 3-foot rise of the river level may closely follow several days of rainy weather, flash floods are unknown.

Kasegaluk Lagoon begins 23 miles north of Cape Beaufort, extends 125 miles northwest along the Arctic coast, and has a maximum width of about 4½ miles. It is relatively shallow and is separated from the Arctic Ocean by a low offshore bar which in most places is not more than 1,500 feet wide. Several breaks in the bar give access to the ocean. In most places, particularly on the landward side, the lagoon is extremely shallow, even at high water. Natives of Point Lay are familiar with the channels, the deepest of which generally appears to lie along the landward side of the offshore bar.

The coastline from Cape Lisburne northeastward past Icy Cape seems to be one of emergence. This is evinced by ancient beach levels above present sea level, at least from Thetis Creek northward, by the active downcutting of young streams in the area from Corwin Bluff to Kasegaluk Lagoon, by the formation of offshore bars west of Kasegaluk Lagoon and the large deltas being built by the major rivers, and by the presence of Pleistocene marine deposits in parts of the coastal plain. Relative dates of emergence of various parts of the coast are not known with certainty; however, it is believed that the coast north of the Kukpowruk River has emerged most recently and that the Cape Beaufort to Cape Lisburne part of the coast is older. North of the Kukpowruk River, coastal features are those of a young emergent coastline; south of the Kukpowruk, numerous low islands and landward extensions of the offshore bar represent a filling in of the lagoon by landward bar migration; and farther south and west, wave-cut cliffs of the Cape Beaufort to Cape Lisburne coast may resemble mature to old features of an emergent coastline.

However, the history of the coastline has probably been complicated by other factors than those stated above. The coast as far south as Cape Beaufort has recently been affected mainly by epeirogenic forces. Although epeirogenic uplift has also affected the coastal area southwest of Cape Beaufort, this part lies nearer to the orogenic belts of the Brooks Range geanticline and the Tigara uplift (Payne, 1955). The orogenic forces from these tectonic elements may have been locally counteracted or reinforced by the epeirogenic forces. Much additional information could be obtained by detailed studies of the Quaternary beds, including the present coastal deposits, and geomorphologic studies.

SETTLEMENTS AND ARCHAEOLOGY

The only permanent settlement in this sparsely populated region is the coastal village of Point Lay on the narrow offshore bar west of the mouth of the Kokolik River. The schoolhouse is a conspicuous landmark, and low wooden houses and tents constitute the major part of the settlement, which is about 25 feet above the ocean. Another landmark, about one-quarter of a mile south of the village is a pingo or ice pressure mound (called Kullie by the Eskimos), which rises about 20 feet above the bar. About 60 Eskimos were permanent residents of Point Lay in 1947; a weather and shortwave radio station has been established, as well as a Government-owned store and a small airstrip. The increase in population from 12 people in 1923 (Paige, Foran, and Gilluly, 1925) is principally due to migration to the facilities available here.

Shallow wells have been dug for fresh water but were not in use in 1947, the water having become brackish; instead, water was being obtained from the Kokolik River or from fresh-water lakes on the mainland and transported by boat to the village. However, the easy access to the open ocean, the central location in relation to the major rivers and along the established winter sled route, and the relatively mosquito-free position of the off-shore bar apparently compensate for the lack of a local water supply.

Although the Point Lay Eskimos live largely by hunting and fishing, and caribou, seal, walrus, and beluga are taken regularly, many food staples and supplies are also brought in early autumn by the Alaska Native Service ship *North Star*. No domesticated reindeer were being kept by the Point Lay people in 1949, although a Government-built corral still standing at the mouth of the Kokolik River was used in the 1930's and early 1940's.

Coal is brought in by the *North Star* or is dug by the Eskimos from coal beds on the Kukpowruk River. A minor amount of coal is obtained along the ocean beach, where it is thrown by severe storms. Occasionally the Corwin mine near Cape Lisburne is used. Although driftwood is scarce in the vicinity of Point Lay, owing to constant foraging by the villagers, it is fairly abundant on less frequented parts of the coast, and the Point Lay Eskimos augment their fuel supply with boatloads of this wood.

During 1949 the U.S. Coast and Geodetic Survey established a temporary camp on the barrier beach about 6 miles south of Point Lay and opposite the mouth of the Kukpowruk River. Eskimos were employed as laborers, and a number of them, mostly from Point Lay, established their own temporary camp adjacent to the main camp.

Many abandoned huts and villages can still be seen along the coast in this region, and a few places north of Point Lay are intermittently used as family dwelling sites. A more complete description of the old settlements is given by Smith and Mertie (1930, p. 99–107). In 1953 several sod huts and hut sites were seen at the mouth of Thetis Creek and at the west end of Ahyougatuk Lagoon, and a few scattered shelter cabins were present along the coast. Two roofless cabins and a coal barge near the mouth of Kookrook Creek are all that remain near Corwin Bluff. Older village sites are found on the Utukok and Kukpowruk Rivers. Remains of an old settlement, Tolageak, were seen in 1947 at the mouth of the Utukok River. The site was marked by a small graveyard and a few driftwood poles rising above the flat tundra. No excavations were made, but a few wood and bone articles were exposed in low banks being undercut by the stream. Signs of recent campsites were also present. Another village site of about 20 dwellings at the junction of Disappointment Creek and the Utukok River included a sod hut and many small rectangular depressions and mounds. Historic-contact material (tin cans, cartridge shells) was in evidence on the surface, and some depressions contained flint artifacts and articles of stone, ivory, and bone. These sites are believed to be of fairly recent origin (Thompson, 1948); two villages of historic time were found on the Kukpowruk River by Solecki (1950).

Inland travel by the Eskimos is done during the winter. Only rarely do they go even a short distance inland during the summer season. Abundant evidence of recent and old hunting and trapping parties was seen along all the main rivers and included steel traps, rock deadfall traps, remnants of temporary campsites, axe- and saw-cut logs, cans, stoves and other abandoned equipment. Campsites are commonly found near an outcrop of coal which was used for fuel.

Many stations where flint was chipped were observed in the foothills province along all major rivers. A Folsom point found by Sable in 1947 (Thompson, 1948), the first to be found in these northern regions, has stimulated new interest in the disputed theories of early migrations to the American continent. Subsequently other Folsom-type points have been found farther east (Solecki and Hackman, 1951).

An Eskimo skeleton, associated with several chert cores and a caribou skull from which the antlers had been hacked, was found partly embedded in the tundra along the Utukok River between 1947 camps 10 and 11 (pl. 7). The human skull and the above-mentioned artifacts were contributed to the Smithsonian Institution.

Archeological work in the region included a reconnaissance inland from the mouth of the Utukok River by Helge Larsen (Larsen and Rainey, 1948) in 1942. Ralph S. Solecki, archaeologist with the Smithsonian Institution, accompanied the 1949 Geological Survey party and collected considerable material along the Kokolik and Kukpowruk Rivers. Three phases of culture in northern Alaska are postulated by Solecki (1950).

All artifact material is apparently of local origin and includes gray and black chert, common in coarse river gravels of the area, caribou antlers, and walrus ivory and driftwood, which can be obtained from the coast.

The discovery of several inscribed sandstone slabs on the high ridge east of the Utukok River 4½ miles southeast of Carbon Creek in 1947 aroused much short-lived speculation. Letters, names, and dates had been inscribed on the slabs and included the name "WEIR

WARD" and the date "1844" (Thompson, 1948). The authenticity of the date has since been disproved (C. L. Whittington, written communication, 1951). Other inscribed sandstone slabs found in 1950 near the top of Eskimo Hill, less than 1 mile east of the mouth of Carbon Creek, included 1 slab which contains deeply inscribed designs and scratches, rectangular in outline, inside of which are scratches at right angles in a reticulate pattern. These markings are considerably weathered and lead to the belief they may be prehistoric petroglyphs.

VEGETATION

Lengthy descriptions of the vegetation in northern Alaska are given by Smith and Mertie (1930, p. 72–82) and by Spetzman (1959). In general the vegetation is dwarfed, and except for willow bushes immediately adjacent to the streams, most plants are less than 2 feet in height. Most of the Utukok-Corwin region is covered by tufted cottongrass, sedges, lichens, mosses, and heath communities of glandular and dwarf birch, small willows, mosses, lichens, mountain heather, dwarfed blueberry bushes, lingenberry-mountain cranberry, crowberry, cloudberry, and many colorful wildflowers. These range from 1 to 24 inches in height but average less than 12 inches.

The tundra, which covers nearly all of this treeless Arctic region, may be described as the vegetation and soil(?) cover composed of low plants, shrubs, and the underlying humus and soil to the upper surface of perennially frozen ground. The thickness of the active layer of soil ranges from about 6 inches to 3 feet in this area. Tundra can be roughly divided into poorly drained and well-drained types, largely on the basis of topographic factors. Each type has distinct features, but transitional areas also occur.

Poorly drained tundra covers about 65 percent of the region and occurs throughout the coastal plain, on drainage divides, and in lowlands in the foothills. It includes cottongrass tussock or niggerhead meadow tundra and marsh or wet sedge meadows. The cottongrass tussock tundra, which reaches maximum distribution in lowlands and interstream areas, is almost entirely formed by tussocks, the most widespread microrelief surface features in this part of Alaskan tundra. The tussocks are similar in form and origin to those on the Seward Peninsula (Hopkins and Sigafoos, 1951). Tufted cottongrass, *Eriophorum vaginatum spissum*, grasses, mosses, reindeer lichen, sedges, and low willows in protected areas, are the most common plants of the vegetation. Marsh includes shallow lakes, ponds, and bogs, which contain sedges, grasses, aquatic flowering plants, and algae. Sedge and cottongrass tussocks are locally present, but most marshes are essentially level, with open emergent vegetation extending slightly above the water surface and a layer of peat underlying the marsh. In the foothills province, some marshes occur in abandoned stream meanders and lowlands, and isolated marshes and small lakes also occur in highlands where frozen ground and surrounding areas of higher altitude restrict drainage. They are very common throughout the coastal plain.

Well-drained dry upland meadow or alpinelike tundra is present on partly barren highland bluffs and hills in the foothills and on gravel deposits above the flood-plain level of streams. Mosses, lichens, heath shrubs, flowering plants, and some grasses and sedges occur in patches or strips between barren active soil areas on the hills. Bedrock and talus on hills are partly covered by lichens, mosses, and flowering plants. Low-lying gravel bars and terraces adjacent to present streams have a partial to nearly complete cover of willows, mosses, grasses, and flowering plants, but the more exposed gravel terraces at higher altitudes are relatively barren except where they are being encroached by cottongrass tussock tundra.

Some plants were collected by members of the parties as time and conditions permitted. The collections were made hastily and are very incomplete. Specimens were determined by Dr. E. H. Walker, of the Smithsonian Institution, and other botanists as follows:

Flowering plants from the Kukpowruk River between lat 68°30′ and 69°30′ N., in June–July 1949

[Field specimen numbers Robert M. Chapman 131 through 156]

Anemone multiceps (Greene) Standl. (131)
Anemone parviflora Michx. (135)
Artemisia globularia Cham.; det. by J. P. Anderson (138)
Artemisia trifurcata Steph. var. *A. trifurcata heterophylla* (Besser) Kudo; det. by L. H. Jordal (142)
Aster sibiricus L. (141)
Astragalus alpinus L. (139)
Astragulus umbellatus Bunge (147)
Caltha palustris L. var. *arctica* (R. Br) Huth.; det. by J. P. Anderson (134)
Draba chamissonis G. Don (154)
Dryas octopetala L. (151)
Erysimum pallasii (Pursh) Fern. (136, 153)
Geum glaciale Adams (133)
Hedysarum mackenzii Rich. (137)
Myosotis alpestris Schmidt. *asiatica* Vesterg. (144)
Oxytropis nigrescens (Pall.) Fisch. ssp. *pygmaea* (Pall.) Hult. (152)
Pedicularis lanata Cham. and Schl. (145)
Pedicularis langsdorfii Fisch. (149)
Polemonium coeruleum L. (=P. *boreale* Adams) (140)
Potentilla uniflora Ledeb. (148, 150)
Ranunculus sulphureus Soland (146)
Senecio atropurpureus (Ledeb.) Fedtsch. ssp. *frigidus* (Rich.) Hult. (143, 156)
Smelowskia calycina (Steph.) C. A. Mey. ssp. *integrifolia*? (Seem.) Hult. (155)
Youngia (=*Crepis*) *americana* Babcock; type of n. sp (132)

Most of the willows are less than 3 feet high, but in some localities they are as much as 15 feet in height and 3 inches in diameter. Small trees, believed to be balsam poplar, as much as 9 feet high and 2 inches in diameter, were seen growing on a southeast-facing slope along the Utukok River near the mouth of Disappointment Creek.

WILDLIFE

Excellent descriptions of the northern Alaska animal life are given by Smith and Mertie (1930, p. 82–99).

Arctic grayling, the only fish that was noted in the streams and lakes in this region, are common but not abundant. Ptarmigan, hawks, falcons, jaegers, plovers, and smaller birds are abundant in the foothills province, and some ducks, geese, loons, owls, and eagles were seen. Ducks, geese, and many kinds of shore birds are common in the coastal plain province, in addition to the other kinds mentioned with the exception of hawks, falcons, and eagles. A few swans were noted on Kasegaluk Lagoon.

Caribou are abundant in the region, particularly in the foothills province. Usually one can see at least 10 during a day's travel, and occasionally, late in the summer, herds of several thousands may be seen. Large wolves are fairly common and are seen most often when their prey, the caribou, are in the vicinity. Grizzly bears can be seen occasionally throughout the area. While not numerous, they range widely and relentlessly seek and destroy food caches that are not adequately protected. The bears were not a real danger to men or camps, because they almost invariably flee once they sight or scent man. No moose or signs of moose were seen in the area.

Red, black, and cross foxes, ground squirrels (called sik-sik or sigerik by the Eskimos), hoary marmots (called sik-sik-puk or sigerikpuk by the Eskimos) lemmings, shrews, and voles are the most common small mammals. White foxes are common in the coastal area. Wolverines are quite rare in this region, and only four have been reported near the Utukok and Kokolik Rivers by Geological Survey parties. A porcupine, previously unreported in this region, was seen in late August 1950 near Meat Mountain (C. L. Whittington, oral communication, 1950), and two more were seen near Corwin Bluff in 1953. Rabbits have been reported by the Eskimos, and signs of rabbits on the Kokolik and Kukpowruk Rivers in 1926 were reported by Smith and Mertie (1930). None have been seen in more recent years.

Insects of many kinds are common, but no effort was made to identify any but the ubiquitous ones. Mosquitoes are so abundant and annoying during late June, July, and early August that the use of mosquito-proof clothing and tents is necessary. Although the mosquitoes are numerous and annoying in this region, even during calm periods they do not equal the myriads encountered farther inland. The almost constant breezes and strong winds in the region serve to keep the mosquitoes from flying most of the time; mosquito-free days were common in 1947 and 1949. Flies and gnats are common during about the same period as the mosquitoes. Flies have been noted as early as mid-May, and gnats in early June.

CLIMATE

A discussion of climate in northwestern Alaska by Smith and Mertie (1930, p. 51–72) includes observations on temperature, precipitation, wind, and navigational factors, and parts of the Utukok-Corwin region visited by early parties are included in this discussion. Collier (1906, p. 11) gives a short résumé of weather observations along the coast of the Cape Lisburne peninsula.

The only weather station in the Utukok-Corwin region is at Point Lay where records have been kept since the early 1940's. However, the records are not continuous and contain a limited amount of data. They show that the prevailing wind directions are northeast and southwest; that almost without exception August is the month of heaviest precipitation, with a recorded maximum of 6.24 inches in 1946; and that freezing or near-freezing temperatures occur in every month of the year.

The Geological Survey field parties made general observations of meteorologic conditions in May, June, and July of 1947 along the Utukok River, and in May through August on the Kukpowruk and Kokolik Rivers in 1949. Observations of temperature by maximum-minimum thermometer, wind direction by compass, roughly estimated wind velocity, and amount of precipitation were made at camp locations along major river valleys. The observations are the first of this kind to have been made in the inland part of the region, but they are limited in scope. Table 1 gives the monthly totals and averages of these observations in 1947 and 1949.

In general, two types of climate, coastal and inland, were noted in the Utukok-Corwin region. The coastal type appears to be restricted to the Arctic coastal plain and to the foothills bordering the Chukchi Sea in the western part of the region. The types of climate are probably influenced by the differing topography of the two provinces, as well as by distance from the ocean. During the summers of 1947 and

TABLE 1.—*Climatic data of the Utukok-Corwin region, collected during the summers of 1947 and 1949*

Date	Clear days (per-cent)	Cloudy days (per-cent)	Days with precipitation (percent)			Wind																		Temperature (° F)					Estimated precipitation (inches)
			Snow	Rain and drizzle	Fog and haze	Directional averages (percent)									Maximum mph averages and directions								maximum mph	Min	Max	Avg Min	Avg Max	Avg	
						Calm	N.	NE.	E.	SE.	S.	SW.	W.	NW.	N.	NE.	E.	SE.	S.	SW.	W.	NW.							
1947																													
May 17–31	68	32	7	15	------	14	5	10	36	18	18	0	0	0	15	12	28	22	18	------	------	------	45	23	55	29	44	37	0.1
June	67	33	0	33	------	8	19	17	32	4	11	3	1	5	14	14	20	------	8	15	------	8	45+	30	75	44	61	53	.5
July	41	59	0	55	3 (?)	22	17	16	2	0	41	2	0	0	11	13	10	------	11	15	------	------	25	45	85	52	65	59	1.0
Total																													1.6
Average	59	41	3	34	1 (?)	15	14	14	23	7	23	2	------	2	13	13	19	7	12	10	------	3	38	23	72	42	57	50	
1949																													
May 17–31	36	64	46	20	0	4	23	8	4	15	30	8	8	0	11	15	------	15	30	8	8	0	35+	20+	60	28	44	36	1.7
June	36	64	33	40	23	4	16	9	0	2	30	17	10	12	14	13	------	30	23	19	18	15	35+	28	60	33	46	39	1.2
July	74	26	3	33	20	6	12	21	5	6	27	15	5	3	16	27	13	26	17	21	20	15	50+	31	68+	42	59	51	1.0
August	26	74	6	80	33	27	4	3	8	8	41	4	5	0	5	5	10	15	15	15	12	------	35	32	62	41	54	48	1.6
Total																													5.5
Average	43	57	22	43	19	10	14	10	4	8	32	11	7	4	12	13	6	22	21	16	16	8	39	28	62	38	51	44	

1949, the coastal plain appeared to have lower temperatures, more precipitation, and a higher percentage of cloudy days than the foothills. As a result, snowbanks along river cuts in the coastal plain and at the north edge of the foothills linger until late summer or may be perennial, but most of those in the foothills melt by mid-July.

Strong windstorms from southerly and easterly directions were common in the inland part of the region in 1947 and 1949, and many were of gale velocity. In December 1951 the derrick at Kaolak test well 1 was blown down by wind estimated at 100 miles per hour (Gryc, 1952, p. 1249). Wind is a source of constant irritation to field workers, and few topographic features offer any shelter from the blasts. Many gales and strong winds are concurrent with clear weather and high barometer readings, and they contribute greatly to rapid evaporation of surface waters. Winds of gale velocity are also common along the coast. In July 1953 strong southeast winds estimated to be more than 80 miles an hour forced down a bush plane near Aknasuk Creek and continued almost unabated for several days. The strongest winds during the time that the field party was in this vicinity were from southerly and northerly directions. Prevailing winds along the northwest coast greatly affect the depth of water in Kasegaluk Lagoon and are of importance in the navigation of small boats in the lagoon. Northerly and westerly onshore winds drive ocean waters into the lagoon through several breaks in the offshore bar, thereby raising the water level as much as 2 or 3 feet, and conversely, southerly and easterly offshore winds lower the water level in the lagoon.

FEATURES RELATED TO CLIMATE

The Arctic climate is a major factor in producing geomorphic features in the Utukok-Corwin region. Mechanical disintegration of rock, soil flowage, soil creep, and permafrost, all results of temperature and moisture conditions modified by other factors, contribute to the production of surface forms. Observations of geomorphic features in the area were limited to brief descriptive examinations in scattered localities.

Soil creep and soil flow are important agents of denudation in the foothills province and are indicated by the widespread occurrence of smoothly rounded ridges, mudflows, streaked surfaces on sloping ground, and many linear microrelief features. Although precipitation is light, the tundra usually contains a large amount of water caused by the melting of frozen ground during the summer. The water content increases downward as frozen ground is approached, and a nearly saturated layer as much as several inches thick overlies the frozen ground and acts as a gliding plane in the development of flowage and creep features. It is believed that these agents are important contributors to the high silt and mud content of streams during high water.

The work of wind as an erosive or depositional agent appears to be minor in this region. On hillsides and summits exposed to the high winds, abrasion produces fluting and rock pedestals in sandstone; and in fresh cutbank exposures fine material is wind eroded, but these features are rare, as the widespread vegetation cover inhibits wind erosion. No extensive windblown sand or loess deposits are known in this region.

Chemical weathering and leaching are also minor. During spring melting, yellow and brown tundra streams contain great amounts of organic material in solution and suspension. A slimy yellowish-brown to orange precipitate, presumably ferruginous, is formed on the bottoms and sides of stagnant tundra pools and bogs. Chemical solution is greatly retarded by the presence of frozen ground, and no sure indications of soil leaching were recognized. Solution cavities are absent from the rocks.

PERMAFROST

Permafrost, or perennially frozen ground, is defined as "a thickness of soil or other superficial deposit, or even of bedrock, at a variable depth beneath the surface of the earth, in which a temperature below freezing has existed continually for a long time (two to tens of thousands of years)" (Muller, 1945, p. 3). Northern Alaska, including the Utukok-Corwin region, lies entirely in the continuous permafrost zone, as contrasted to most other parts of Alaska where permafrost is absent, sporadic, or discontinuous (Péwé, 1954, p. 317, fig. 69). Conditions which affect the depth of seasonally frozen ground (active layer), and the thickness, upper limits (permafrost table), and lower limits of permafrost are discussed by Muller (1947), Black (1951), Hopkins, Karlstrom, and others (1955), and others. Although in general permafrost is slowly thawing, recently formed permafrost has been recognized in all permafrost zones (Hopkins, Karlstrom, and others, 1955, p. 115–117).

Permafrost is believed to underlie nearly all the land area covered by this report, but may be at considerable depth or absent beneath large rivers and deep lakes. The upper limit of permafrost ranges from 6 inches in depth in poorly drained tundra, to a depth of more than 3 feet in well-drained tundra where vegetation is sparse. Evidence of recent rise of the permafrost table was found in 2 localities. In July 1947 on the Utukok River at its junction with Disappointment Creek, manmade implements believed to be 50 to 100 years old were found in frozen silt 1½ feet below the ground surface. The site, a river terrace underlain by gravel and mantled by at least 2 feet of the silt, is relatively well drained and supports a dense growth of willows, mosses, and flowering plants. Since the time the inhabitants left this site, it has been subjected to periodic flooding by the river, and the resulting deposits of silt and growth of vegetation have formed an insulating mantle into which the permafrost table has risen. In mid-June of 1949, wooden articles and a pick, presumably left by the Geological Survey party of 1926, were found embedded in frozen ground less than 6 inches below the surface. At this locality, near a tributary of the Kukpowruk River, the ground is gently sloping poorly drained tundra. This, however, may not represent a true rise in the permafrost table but a surface thaw that had not reached the normal depth of other years or the maximum depth of that year. The thickness of permafrost in the area near Kaolak test well 1 has been inferred from electric log records. Here, the probable lower limit of frozen ground is at least 850 feet and possibly as much as 980 feet deep (C. L. Mohr, written communication, 1951).

GROUND ICE

Ground ice, a common feature of poorly drained Arctic tundra regions, refers to "bodies of more or less clear ice in permanently frozen ground" (Leffingwell, 1919, p. 180). Two distinct types may be easily recognized: ice parallel to bedding planes and ice sharply truncating bedding planes. Genetically, ground ice can be separated into that which is formed prior to deposition and then buried and that formed within a sediment during or after deposition. The literature regarding ground ice, including observations in Alaska, has been extensively summarized and discussed by Leffingwell (1919, p. 179–243), Taber (1943, p. 1510–1529), and others.

Ground ice observed in the Utukok-Corwin region occurred in frozen sediments under level or gently sloping tundra surfaces. The fine-grained sediments appear to be lacustrine or quiet-water stream deposits as indicated by the general absence of steeply inclined crossbedding, dominant clay and silt sizes, and layers with varved appearance.

Ground ice, which is contemporaneous with or younger than the sediments in which it is found, was observed along all major rivers of the Utukok-Corwin region. It is most commonly exposed in the coastal plain, but also in the foothills wherever clay and silt-size sediments of Quaternary age are exposed. Two distinct ice forms that are conformable with the sediments were recognized: ice lenses, lenticular masses several feet in length and as much as 2 feet in thickness; and thin layers of clear ice ranging from one-eighth of an inch to several inches in thickness, which occur at intervals throughout the sediment, presenting a varved appearance. The latter type is termed "ice-gneiss" by Taber (1943, p. 1512). Ground ice in some localities consists exclusively of these forms, but commonly also contains ice wedges (Leffingwell, 1919, p. 205–212) which are roughly carrot shaped in cross section and which truncate the bedding of the sediment and the layered ice. Good exposures of ground ice associated with humus, silt, clay, and gravels were examined a mile south of 1949 camp 22 on the Kokolik River, in a cut 500 feet long and 50 feet high, the lower 20 feet of which was obscured by slumped material (figs. 9 and 10). The thawed "active" layer extends 2 feet below the surface and is composed mainly of an interwoven mat of decaying vegetation. The ice occurs in predominantly clay and silt-size material that contains from 30 to 50 percent of clear ice layers and lenses of the ice-gneiss type, ranging from 1/32 to 4 inches in thickness. Six large ice wedges, 12 to 40 feet wide at the top, and several smaller wedges, 1 to 3 feet wide, are separated by the stratified deposits. The wedges cross the horizontal bedding planes at angles from 30° to 90°, and at several wedges the silt and ice strata are bent upwards within a few feet of the wedge to vertical attitudes against the sides of the wedges. The surface layer of tundra is apparently undisturbed. The ice composing the wedges has a milky-gray and foliated appearance owing to numerous air bubbles and tubes and minute particles of silt and sand alined subparallel to the sides of the wedges. Wedge-shaped or lenticular pockets of silt, sand, and gravel are included in some of the wedges and also are subparallel to the sides. The bottoms of the wedges are not exposed, but 3 wedges are connected by an undetermined thickness of milky ice 25 to 30 feet below the surface. The tops of the larger wedges are truncated abruptly by the unfrozen surface layer. In one 18-foot-wide wedge, a crack 1/16 to ¼ inch wide extends 3 feet downward into the ice and upward to the ground surface. This part of the wedge, expressed on the tundra surface as a gullylike fissure about 1 foot deep, extends at least 50 feet away from the exposure. In other wedges vertical "contraction cracks," believed to be indicative of actively growing ice wedges, were not seen, and the tundra surface correspondingly shows no distinct fissures. One wedge, 3 feet wide at the top, is overlain by 13 feet of frozen ground and 2 feet of thawed ground. It is believed that most of these

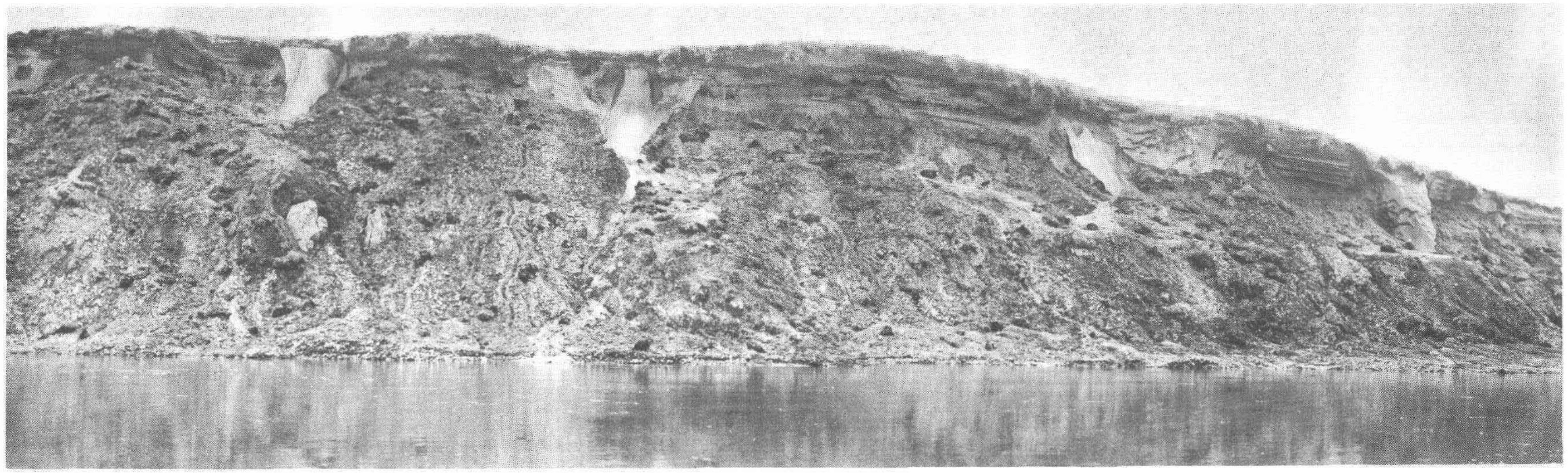


FIGURE 9.—Ground-ice exposures consisting of "ice-gneiss" layers separated by ice wedges, along west bank of Kokolik River south of Deadfall syncline. Note that layers are bent upward against sides of wedges. Height of bluff, 50 feet.

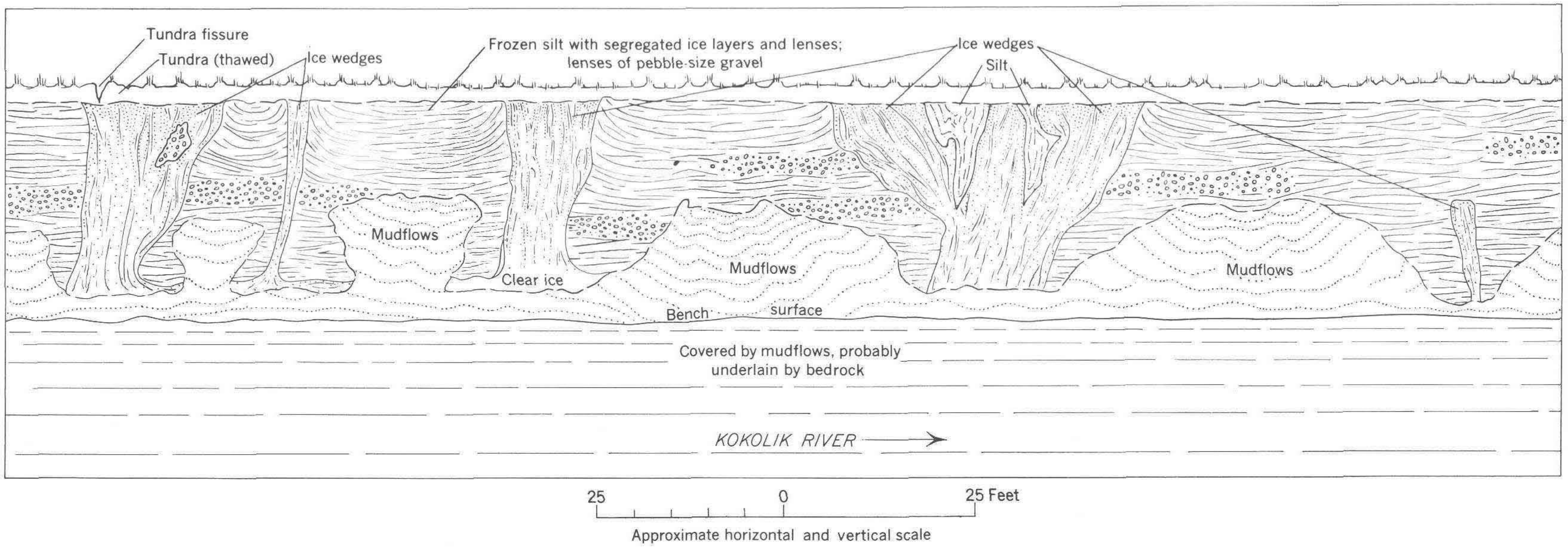


Figure 10.—Sketch of ground ice exposed along west bank of Kokolik River south of Deadfall syncline. Left part of same bluff shown in figure 9.

wedges are no longer active. The tundra surface above the cutbank slopes gently towards the cutbank, and soil creep and flow have probably been instrumental in covering the "relict" wedges.

On the Utukok River near 1947 camp 4, a fresh cut exposes 2 feet of gravel overlain by 3 feet of silt and a mantle of 2 feet of peat, soil, and living vegetation on a flat poorly drained tundra surface. The main part of the ground ice occurs in the silt layer and consists of clear layered ice of the ice-gneiss type, ranging from 1/8 to 1/4 inch thick, and 3 ice wedges, which in cross section are from 12 to 20 inches wide at the top of the silt layer and abruptly narrow to a few inches width in the tundra mantle. Vertical contraction cracks extend downward into the ice wedges for about 1.5 feet, and the positions of the wedges are expressed on the tundra surface as fissures a few inches deep which intersect to form tundra polygons. The bottoms of the wedges are obscured by slump; no ice was seen elsewhere in the underlying gravel. Upward bends of the ice-gneiss layers against the sides of the wedges occur in all 3 wedge localities. These wedges are relatively small and appear to be active.

A similar occurrence of ground ice was observed near 1947 camp 3 along the Utukok River. Ice-gneiss layers in silt at this locality range from 1/4 to several inches in thickness and are associated with small ice wedges. Between 1947 camps 13 and 14 on the Utukok River a cutbank 300 feet long and 20 feet high contains ice-gneiss layers interrupted by ice wedges as much as 15 feet wide. Nearly all the wedges contain vertical cracks as much as a few feet long which extend into the overlying tundra and intersect to form tundra polygons. Ground ice was present in all surface fissures, and polygons truncated in 2 places by the cutbank were found to have ice wedges at each end.

From the widespread occurrence of surface fissures which form polygonal outlines (tundra polygons) on poorly drained tundra surfaces, an interlacing network of active ice wedges beneath the surface has been inferred by Leffingwell and other investigators. Older inactive ice wedges may not have surface expression, and the proportion of ground ice of this type is probably greater than is apparent. Leffingwell (1919, p. 211) states that in 1 locality about 20 percent of the tundra was probably underlain by ground ice, the wedge type being the most obvious. Studies of aerial photographs of the coastal plain in the Utukok-Corwin region show that more than 50 percent of the tundra surface contains tundra polygons which are as much as 150 feet in diameter. Tundra polygons were observed from the air on floors of shallow lakes; the fissures in many places almost parallel the lake outlines, with other intersecting fissures trending perpendicular to the shorelines. This type of fissure pattern also follows the outlines of cutoff river meanders. Most of the tundra polygons observed appear to be of the raised-center type with the fissures lower than the edges of the polygons. In flat very poorly drained areas, particularly in interstream areas in the coastal plain, depressed-center polygons were seen. The fissures lie between raised parallel ridges that are 6 inches or more above the swampy center of the polygon.

During the destruction of ice-wedge areas by the undercutting of a bank by wave or river action, large masses of tundra and frozen ground often break off along the ice wedges (Leffingwell, 1919, p. 210). The resulting reentrant angles produce a serrate appearance to the bluff faces, and these can sometimes be recognized on aerial photographs as localities where ice wedges are present even when polygonal ground cannot be clearly seen. Examples of serrate bluff edges can be seen on aerial photographs of the ground-ice localities described above, and they are also associated with polygonal ground in the coastal plain and along most of the coastline south of the Utukok River. In many localities, however, the surface mat of interwoven tundra vegetation maintains its level attitude as the sediments and ice beneath it are removed, so that the tundra mat overhangs the water surface by as much as 20 feet. The tundra subsequently subsides owing to its own weight, curving over the bank and resembling a gigantic blanket. This type of tundra slump inhibits further thawing of frozen ground until the tundra mat breaks away and the bank face is again exposed.

Thaw lakes (Hopkins, 1949) and oriented lakes (Black and Barksdale, 1949, p. 113–115) are common features of the coastal plain in this region. They are the results of ground subsidence caused by the melting of ground ice, and they increase in size by thawing and wave erosion.

Pingos or icing mounds, discussed by Porsild (1938), are present in poorly drained tundra on the Arctic coastal plain. Several pingos were seen in this province east of the Utukok River, but none were examined. They appeared to be less than 30 feet high.

Beaded drainage (Hopkins, Karlstrom and others, 1955, p. 141) is common in poorly drained tundra of the foothills provinces. This occurs in small streams in the tundra in which water flow is interrupted at intervals to produce small irregularly spaced ponds with the appearance of roughly strung beads. No extensive examination of these was made. They may form along ice wedge junctions, and the ponds may result from deeper melting of ice, or they may be the result of local damming by soil flowage.

MICRORELIEF FEATURES

Microrelief features in poorly drained relatively flat tundra in this region include grass tussocks, tussock rings, peat rings, tussock-birch-heath polygons, frost scars, frost mounds, and nonsorted circles and polygons. Grass tussocks, elongate peat rings, elongate tussock-birch-heath polygons, nonsorted stripes, soil terraces, soil lobes, lobate terraces, and tundra mudflows are found in the poorly drained sloping tundra. Well-drained tundra on level ground surfaces contains nonsorted and sorted circles and polygons and on sloping ground contains sorted and nonsorted stripes, rock streams, and stone garlands. The above features have been described and discussed by many investigators in other areas, including Hopkins and Sigafoos (1951), Washburn (1950), Sigafoos and Hopkins (1952), and Sharp (1942).

Grass tussocks are as much as 2 feet in diameter and 1.5 feet in height. Many are uniform in size in local areas; they appear to be largest where drainage is poorest. Near 1947 camp 5 in early July, frozen ground was at 10 inches depth beneath the tussocks and under relatively bare soil between the tussocks. On slopes of about 5° to 20°, soil flowage may produce a downslope alinement of the tussocks. Tussock rings were seen on nearly all level tundra surfaces where grass tussocks are the dominant form of vegetation.

Frost scars are most common in tundra areas of moist soil and occur in a variety of shapes and sizes. During the summer the bare soil surfaces of active frost scars are flat to slightly convex upward, and except in lowlying areas, the surfaces are dry.

Although peat rings, tussock-birch-heath polygons, and transitional forms between these and tussock rings are common in the area, no quantitative observations were made of these features. They are similar to those discussed by Hopkins and Sigafoos (1951) and occur in similar environments.

Nonsorted circles and polygons were examined in well-drained tundra on the level tops of hills near 1947 camp 5, Utukok River. They are regularly spaced domes as much as 3 feet in diameter and 3 to 4 inches high, and their centers are composed of a residual soil of clay- to angular-pebble-size fragments. They are bounded by circular or vaguely polygonal vegetation-bounded fissures a few inches deep in material similar to that in the centers, but containing more pebbles. Centers of the circles and polygons are more moist than the edges, and moisture increases downward to frozen ground which was at 1 foot depth in July 1947. Vegetation around the edges consists mainly of mosses and a few flowering plants. On slopes as much as 15°, circles and polygons become elongate with downslope axes, and the elongate forms are transitional to nonsorted stripes which occur on slopes of from 15° to 25°. Bands of clay and silt-sized detritus and scattered pebble-sized rock fragments trend parallel downslope, range from 1.5 to 3 feet wide, and are separated by vegetation-covered stripes as much as 8 inches wide which include small drainage channels. Vegetation-free stripes are slightly convex upward. The soil underlying the vegetation-covered stripes appears to be the same as the exposed soil, with a few larger cobbles. These may be either inactive stone-polygon and stone-stripe features which upon continued comminution have disintegrated to finer sized particles or young features in the process of formation.

Stone polygons, stone garlands, and stone stripes, although uncommon features in the foothills, nevertheless occur at various localities on barren hilltops and hillsides. Stone rivers were seen in the foothills where bedrock is exposed above slopes of 15° to 25°. Angular fragments ranging from cobble to boulder in size form the streams which are about parallel to each other and in some places coalesce downslope. They are rarely more than 25 feet wide and 200 feet long and are free of vegetation except for lichens.

Other features of slope instability including soil terraces, soil lobes, lobate terraces, and tundra mudflows are common throughout the foothills province but were not closely examined during investigations in the area.

STRATIGRAPHY

Sedimentary rocks exposed in the Utukok-Corwin region include 1 unnamed Jurassic(?) unit, 5 named Cretaceous units, and Quaternary deposits. Their surface distribution is shown on the geologic maps (pls. 8 and 9), and the inferred distribution of some of the units is shown on the structure sections (pl. 18). The succession of stratigraphic units is given in table 2.

The generalized facies diagram (fig. 11) shows the relative positions and relations of the major rock units in the Utukok-Corwin region. Suggested correlations of rock units in this area with those of the Colville River region, 150 miles east, are shown on figure 12.

The terminology used in the rock descriptions of this report includes bed, sets of beds, unit, sequence, and section. Bed is used to denote a layer of rock that is visually separated from the overlying and underlying layers by a change in lithology, a physical break, or both, similar to Payne's (1942) definition of lamina and stratum; sets of beds is used to denote a succession of beds of similar lithologic character, as shale and claystone, which lie between rocks of visually different character, such as sandstone. The terms "unit" and

TABLE 2.—*Summary of sedimentary rocks and surficial deposits, Utukok-Corwin region, Alaska*

Geologic age		Unit name		Areas of surface exposure	Character	Thickness (feet)
Period	Epoch					
Quaternary	Recent		Flood-plain and beach deposits.	Foothills, coastal plain, and coast.	Gravel, sand, silt, and mud. Marine and nonmarine.	0-50(?)
	Pleistocene.		High-level terrace deposits.	Foothills.	Gravel, sand, silt, and ice. Nonmarine.	0-25+
			Gubik formation.	Coastal plain.	Sand, silt, clay, gravel, and ice. Marine and nonmarine.	0-113+
			Unconformity			
Cretaceous	Upper	Colville group	Prince Creek formation.	Northern part of northern foothills and coastal plain.	Sandstone, conglomerate, shale, bentonite, and coal. Nonmarine.	93+
			Unconformity (?)			
	?	Nanushuk group	Corwin formation.	Northern foothills and coastal plain.	Shale and claystone, siltstone, sandstone, conglomerate, coaly shale and coal, ironstone, bentonite. Dominantly nonmarine.	4,500± to 15,500±
	Lower		Kukpowruk formation.	Northern foothills. Locally in coastal plain.	Shale, siltsone, and sandstone. Dominantly marine.	2,000± to 6,000±
			Torok formation.	Northern and southern foothills.	Shale and siltstone. Marine.	6,500±
			Fortress Mountain formation.	Southern foothills.	Siltstone, shale, sandstone, and conglomerate. Marine.	4,400±
			Unconformity (?)			
Jurassic(?)			Unnamed siltstone and shale unit.	Foothills of Cape Lisburne peninsula.	Shale, siltstone, and sandstone. Marine (?).	Unknown

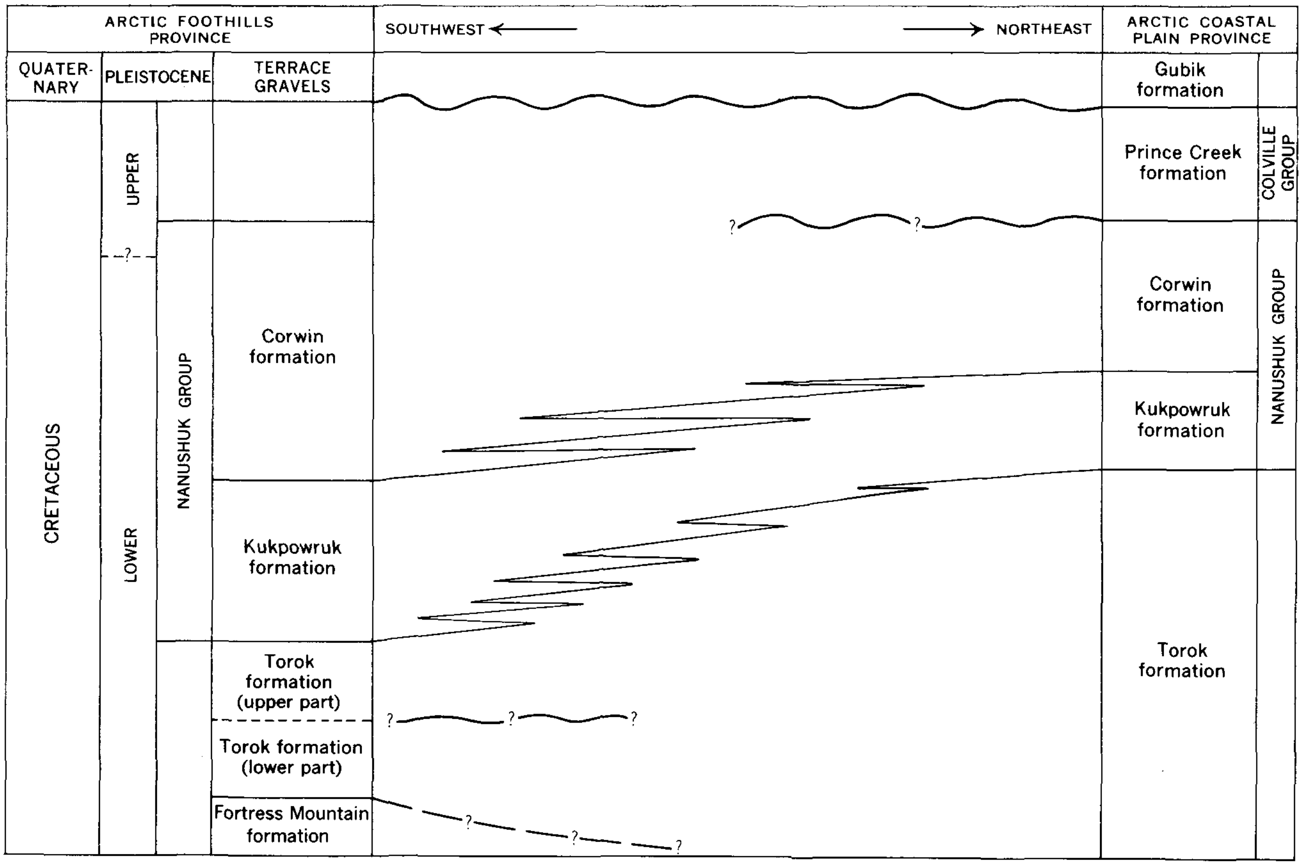


FIGURE 11.—Generalized facies diagram of Cretaceous rocks and surficial deposits in the Utukok-Corwin region (wavy lines represent unconformities).

"sequence" are applied informally to any stratigraphic interval, and the term "sequence" is also used in a genetic sense, as in a graded bedding sequence. Section denotes a specific measured or estimated stratigraphic interval.

Terms designating sedimentary rock types are based on the Wentworth scale, and the adjectives clay and silty refer to grain size. The terms "shale" and "claystone" essentially follow the terminology used by Pettijohn (1949, p. 269-270). Claystone is applied to rocks

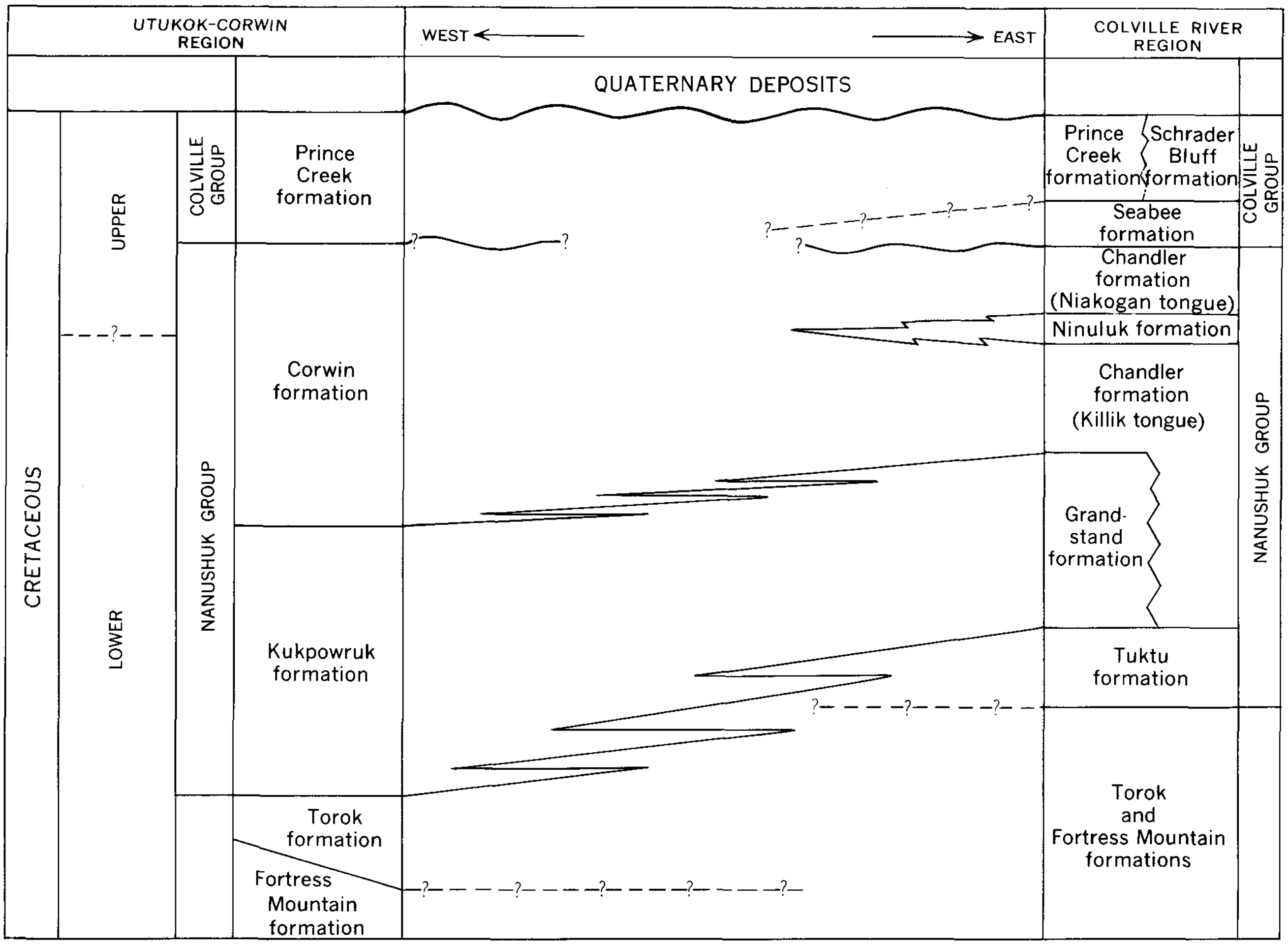


FIGURE 12.—Generalized facies diagram showing suggested correlations between Cretaceous rocks of the Utukok-Corwin region and of the Colville River region (wavy lines represent unconformities).

composed dominantly of clay-sized material that occur in beds one-half of an inch or more in thickness. It may be even-bedded, nodular, lenticular, or massive. In the described sections, most of the units designated as clay shale also contain claystone interbedded with and grading laterally and vertically into shale.

The color designations conform insofar as possible to the color names of the National Research Council Rock-Color Chart (Goddard and others, 1948).

JURASSIC(?) AND CRETACEOUS SYSTEMS

Exposures in the extreme southwestern part of the Utukok-Corwin region, along the coast west of Risky Creek to Ahyougatuk Lagoon and inland from the lagoon to the upper part of Thetis Creek, have not been studied in detail. As the result of boat traverses along the sea cliffs and foot traverses in the hills bordering the coast, two rock units have been mapped (pl. 8); an unnamed Jurassic(?) unit of siltstone and shale and Cretaceous rocks mapped as undifferentiated Nanushuk group and Torok formation.

SILTSTONE AND SHALE UNIT

The siltstone and shale unit, of unknown thickness, is exposed south of Ahyougatuk Lagoon and is believed to extend southeastward south of Eesook syncline to at least the headwaters of Thetis Creek. This sequence contains rocks identical with those which overlie Triassic rocks near Cape Lisburne west of this area. No recognizable organic remains were found in these rocks, which are provisionally assigned to the Jurassic period. Rock types consist of dark-gray to black thin-bedded hard siltstone and shale with a few medium-gray very fine grained sandstone beds and scattered siliceous ironstone nodules. Where exposed along hillsides, the unit gives a finely striped appearance to the slopes and further differs from the Torok formation and the Nanushuk group in its darker color and higher degree of induration.

TOROK FORMATION AND NANUSHUK GROUP UNDIFFERENTIATED

Rocks mapped as undifferentiated Nanushuk group and Torok formation are exposed along the coast from a point 1.6 miles west of Risky Creek to Ahyougatuk Lagoon, and strike inland in a belt which extends southeastward from the coastal exposures. Part of the seacliff exposures contain thick shale sections which may represent Torok formation, and in the vicinity of Eesook, sandstone and shale, in part fossiliferous, resemble the Kukpowruk formation. Nonmarine rocks probably equivalent to the Corwin formation have also been recognized along the coast, in the headwaters of Aknasuk and Risky Creeks and within Eesook syncline.

Regarding the coastline exposures from Aknasuk Creek to Eesook, R. M. Thompson (1947, written communication) states:

> The lower part (west of Risky Creek) is predominantly shale with thin siltstone and sandstone beds, and the upper part (near Eesook) has many thick very fine grained sandstone beds and carbonaceous sandstone and siltstone. The sequence is highly folded and faulted (and) resembles the lowermost unit of the Utukok River area (Kukpowruk formation). A fossil found at Eesook (since lost) is probably the same pecten type which occurs in the lower marine unit (Kukpowruk formation) of the Utukok (area).

Microfossils present in 2 shale samples of this undifferentiated sequence collected near Eesook include *Verneulinoides borealis* Tappan (abundant in 1 sample), *Saccammina lathrami* Tappan (rare) and *Haplophragmoides topagorukensis* Tappan (common) in both samples; and 1 occurrence each of *Hyperamminoides barksdalei* Tappan (rare), *Bathysiphon brosgei* Tappan (very abundant), *Miliammina manitobensis* Tappan (common), *Tritaxia manitobensis* Wickenden (common), and *Trochammina rutherfordi* Stelck and Wall (common).

STRATIGRAPHIC RELATIONS

The relations of these rocks south and west of the type section of the Corwin formation have been in question since the earlier investigations. Collier (1906, p. 30–31) refers all the clastic rocks "* * * southwest of the area occupied by the Corwin formation, and lying between it and the Carboniferous rocks exposed at Cape Lisburne * * *" to "upper Mesozoic beds," and provisionally to Early Cretaceous age. He interpreted these rocks to normally overlie the Corwin formation, then thought to be Jurassic, but recognized the possibility of a fault contact with the Corwin formation. From a regional viewpoint, Smith and Mertie (1930, p. 217) suggest that the contact is due to faulting which resulted in making the western rocks appear to overlie the Corwin formation and that these rocks in reality are older than the Corwin formation. Recent studies have established the presence of fault zones in this area and substantiate the opinion of Smith and Mertie, and the "upper Mesozoic beds" unit of Collier has been separated into the two general units discussed above.

CRETACEOUS SYSTEM

LOWER CRETACEOUS SERIES

FORTRESS MOUNTAIN FORMATION

NAME AND DEFINITION

The Fortress Mountain formation was named after Fortress Mountain, near the Ayiyak River, 190 miles east of the area of this report (Patton, 1956, p. 219–221). In the Utukok-Corwin region, the name Fortress Mountain formation is applied to the clastic rock sequence which directly underlies the Torok formation in the southern foothills section (Sable, 1956, p. 2640, fig. 3). No exact time or stratigraphic correlations between these rocks and the rocks in the type area of the Fortress Mountain formation are implied.

DISTRIBUTION AND OCCURRENCE

The Fortress Mountain formation is exposed in three separate areas along the southern boundary of the mapped area (pls. 8 and 9): the East and West Driftwood anticlines, which cross the Utukok River at approximately lat 68°52' N; the Iligluruk "high," east of and adjacent to the Kokolik River at lat 68°47' N; and the Tingmerkpuk "high," between the Kokolik and Kukpowruk Rivers at lat 68°46' N.

Outcrops of the formation are mainly limited to scattered stream cuts, although bedding traces of resistant rocks are locally common on ridge tops. The traces, however, are rarely reliable for determining bedding attitude, as they have been considerably disturbed by frost action. Rocks of the formation form distinctive rounded mud- and rubble-covered whaleback ridges and hills which are relatively featureless but are more than 700 feet high in the Driftwood anticlines, 900 feet in the Iligluruk "high," and are estimated to be more than 1,000 feet high in the Tingmerkpuk "high." These hills are surrounded by lowlands underlain by the Torok formation, and they differ from hills of Kukpowruk formation rocks in the absence of cuestalike and mesalike topography and the lack of sharply defined and persistent rock traces. As seen on aerial photographs of these areas (fig. 8), dark-appearing tundra covers the lower flanks of the hills, whereas the light-appearing ridge tops are commonly bare with subdued traces, mud heavings, and fine linear features caused by flowage of rock detritus. The ridgetops provide good, although discontinuous, routes for foot travel and track vehicles, and the many chipping sites found on the ridgetops indicated that they have been frequently used by the Eskimo for hunting observation points.

CHARACTER AND THICKNESS

Interbedded shale, claystone, siltstone, sandstone, and conglomerate in approximate decreasing order of abundance constitute the Fortress Mountain formation in the Utukok-Corwin region. This sequence differs from the Torok formation in its greater abundance of coarse clastic rocks, and from the Kukpowruk and Corwin formations in its weathered color, nature of outcrop, absence of coal, rarity of ironstone, and the usually more argillaceous and indurated character of the coarser clastic rocks.

Silty shale, clay shale, and claystone make up about 50 to 70 percent of the Fortress Mountain formation and are medium to dark gray and rarely yellowish gray, nodular, blocky, and fissile, and are poorly to moderately indurated and slightly calcareous to noncalcareous. They occur in beds less than 2 inches thick and in sets of beds many tens of feet in maximum thickness. Contacts with siltstone and sandstone are gradational to abrupt, and bedding planes within the shale commonly show polished and slickensided surfaces.

The siltstone is light to dark gray, rarely greenish gray, platy to blocky, in part sandy, well indurated, in part laminated or finely crossbedded, moderately calcareous to noncalcareous, in part iron stained, and has low porosity. The beds range from a fraction of an inch to 2 feet in thickness.

In color the sandstone is mostly lighter than the siltstone and ranges from light to medium gray and olive gray, and less commonly it is greenish gray. It weathers olive gray to yellowish gray and rarely yellowish brown and iron stained, and is commonly fine grained to silty but in part is medium and coarse grained, fairly well sorted, moderately indurated to very hard, argillaceous, micaceous, and moderately calcareous to noncalcareous. It contains small-scale crosslaminations restricted to layers less than a few inches thick, "swirly" bedding, ripple marks(?), clay pellets, a few chert pebbles and sandy iron-stained nodules, and casts of irregular to straight linear markings and mudflow markings on the bottoms of beds. The sandstone commonly shows graded bedding. Beds range from less than an inch to more than 10 feet in thickness. The porosity is uniformly low.

Conglomerate of graywacke type occurs as thin lenses within or at the base of sandstone beds. The matrix of clay to coarse sand-size particles is greenish gray to dark olive gray and encloses scattered granules and small pebbles of black, gray, red, and bluish chert, carbonaceous fragments, white quartz, greenish sandstone, mafic igneous rock, and gray limestone.

Siltstone, sandstone, and conglomerate constitute about 30 to 50 percent of the Fortress Mountain formation in the region of this report and increase in abundance southward. These resistant beds are scattered throughout the formation, but sets of beds form resistant units as much as several hundred feet thick, which are separated from each other mostly by shale and thinly bedded siltstone. There are two such units in the Driftwood anticlines: one in the uppermost part of the formation, the other about 3,500 feet below the top. These units appear to be lenticular and pinch out abruptly both transverse and parallel to their trend. Consequently, their value for correlative purposes over even a few miles is uncertain.

Graded bedding is common in rocks of the Fortress Mountain formation. The lower contact of a graded sequence is abrupt and irregular; sandstone, conglomeratic sandstone, or conglomerate overlies clay shale and the bottom surface of the coarse clastic contains reverse impressions of the initial mud surface. These include what appears to be fill of lobate or elongate scour depressions, some of which contain longitudinal striations, mudflows, worm trails and borings, elongate and circular fucoidal markings, and possibly ice-crystal markings. Within the coarse clastic rock, numerous carbonaceous fragments and clay pellets are randomly distributed. Typically, the sandstone grades upward into finer grained sandstone of a more uniform texture, which exhibits "swirly" bedding in cross section. It then grades into sandstone and siltstone containing small-scale cross laminations, and it is successively overlain by laminated siltstone, silty shale, and finally clay shale, whch is again abruptly overlain by coarse sandstone or conglomerate containing some or all of the features described above. Sequences such as this are repeated rhythmically but range considerably in thickness—from a few inches to many feet. Although the above sequence is an ideal example and cannot be seen everywhere, some graded bedding characteristics are present in most good exposures of the formation and are reliable in the determination of order of superposition of a succession of strata.

The total thickness of the Fortress Mountain formation is not known in this region. A partial section of 4,400 feet was computed from scattered outcrops along the Utukok River on the south flank of East Driftwood anticline. From measurements of partial sections south of the mapped region, the maximum thickness of the formation is estimated to be as much as 5,000 feet but may vary considerably owing to facies changes.

STRATIGRAPHIC RELATIONS

No distinct contacts between the Fortress Mountain formation and the Torok formation are exposed in the mapped region, but the two formations appear to be conformable and gradational. The contact is drawn at the top of the uppermost ridge-forming resistant clastic unit of the Fortress Mountain formation and is therefore along a topographic break in slope. Because of the extremely lenticular nature of these clastic rocks, the contact does not denote a time line except in local areas. The base of the Fortress Mountain formation is not exposed in this region.

FOSSILS AND AGE

No distinctive megafossils were found in rocks of the Fortress Mountain formation within the mapped region. Sandstone and siltstone beds at several localities contain a few hexagonal impressions which were identified by Roland W. Brown as *Retiphycus hexagonale* Ulrich, presumably a plant form about which little is known. Four miles east of this region one ammonite fragment of a previously undescribed genus (R. W. Imlay, oral communication, 1956) was collected on the Colville River in rocks of the formation, probably in the upper part. The ammonite is probably of late Early Cretaceous (Albian) age.

TOROK FORMATION

NAME AND DEFINITION

The Torok formation is defined to include the predominantly shale sequence that underlies the Nanushuk group in the Arctic foothills province of northern Alaska. The type locality is on Torok Creek and on the Chandler River between the mouth of Torok Creek and the mouth of the Kiruktagiak River (Patton, 1956, p. 222–223). The upper part of the formation can be traced westward from the type locality into the Utukok-Corwin region, a distance of 200 miles.

DISTRIBUTION AND OCCURRENCE

In the region of this report, the Torok formation is exposed in the 3- to 12-mile-wide lowland belt that lies along the boundary between the southern and northern foothills sections and also in lowlands of the northern foothills section in the axial zones of breached anticlines. These belts of Torok formation encompass about 1,700 square miles, or 25 percent of the area. The northernmost known outcrops of the Torok formation are in the axial zone of the Carbon Creek anticline, west of the Utukok River; and the westernmost exposures are beyond the western limit of this area probably as far as the Ipewik and Kukpuk Rivers.

Outcrops of this formation are limited almost entirely to stream cutbanks (fig. 13) and consequently are small and not connected. Owing to the scarcity of exposures, similarity in composition, lack of known key horizons, and the many structural complexities, accurate total thickness of the section is not known, and an approximate thickness can be calculated in only a few localities.

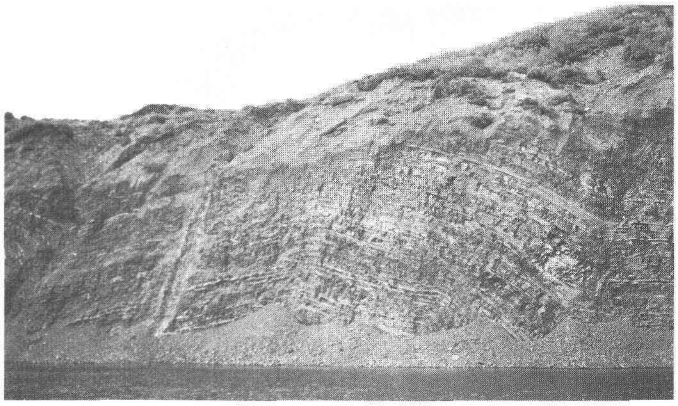


FIGURE 13.—Folded shale, claystone, and siltstone in the Torok formation unconformably overlain by fluviatile deposits, exposed along Utukok River south of Lookout Ridge syncline. Bluff height about 50 feet. (Photograph by R. M. Chapman, July 1947).

The lowlands underlain by the Torok formation appear to be monotonously featureless in contrast to hills formed by rocks of the Kukpowruk formation, although they contain many small hills and ridges more than 100 feet in height. A typical lowland area of this type, the axial area of Blizzard anticline (fig. 14) between the Kokolik and Utukok Rivers, is flanked by high cuesta hills on which are exposed resistant bedding traces of the Kukpowruk formation. On aerial photographs of the lowlands, white to light-gray areas represent rock traces or mud heavings, and numerous medium- to medium-light-gray areas of thin tundra cover alternate with darker patches of tundra which in some cases reflect trends of near-surface bedrock.

CHARACTER AND THICKNESS

Rocks of the Torok formation are predominantly clay shale, claystone, and silty shale but include about 10 to 15 percent of siltstone and a lesser amount of sandstone, which is confined mainly to the middle and upper parts of the formation.

The shale and claystone are interbedded and intergrade with each other and with the coarser clastic rocks. They occur in sets of beds ranging from less than an inch to hundreds of feet in thickness, although individual beds are commonly less than 4 inches thick. They are mostly medium to dark gray but some are olive gray and yellowish gray, and rarely greenish gray; they weather grayish yellow, bluish gray, and cream colored and are poorly to moderately indurated and predominantly noncalcareous but are in part slightly to moderately calcareous and in part finely laminated; they have a blocky, fissile, or nodular fracture with the blocky fracture dominant and commonly

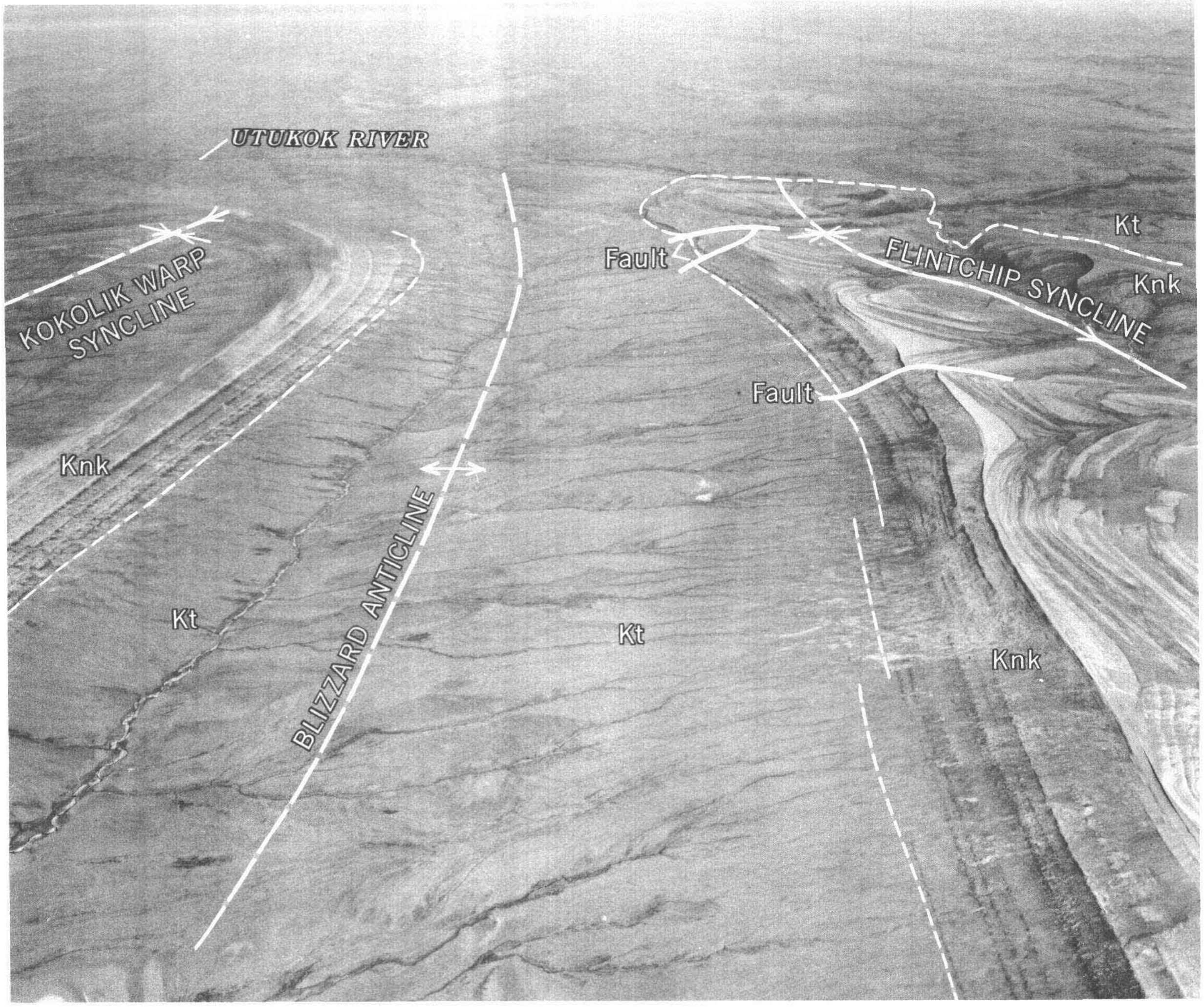


FIGURE 14.—Aerial view of typical structure and topography in the northern foothills section. Looking east toward Utukok River, Utukok-Corwin region, Alaska. Stream in left foreground flows through lowlands underlain by Torok formation (Kt), and roughly parallel to inferred axial trace of Blizzard anticline. High cuestas of Kukpowruk formation (Knk) flank the lowland. Intertonguing contact of the Torok and Kukpowruk formations shown at right, on north limb of Flintchip syncline. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force; approximate altitude 12,000 feet.

contain some small ripple marks and mud cracks, mudflow markings, and whitish or yellowish efflorescence along fractures. Locally they contain concretions of silty limestone, claystone, and pyrite as much as 6 inches in diameter. Brown or white calcite veins occur in contorted zones.

Siltstone interbedded with shale occurs as individual beds generally less than 6 inches but as much as 2 feet thick and in sets of beds that range 20 feet or more in thickness. It is light to dark gray and yellowish gray, weathers pale yellowish brown or olive gray, is moderately to well indurated, is slightly calcareous to noncalcareous, has platy to blocky fracture, and is rarely ferruginous. Ripple marks, mudflow markings, and graded bedding are fairly common; and ironstone nodules, pyrite concretions, scattered and layered carbonaceous plant fragments and mica flakes, argillaceous pellets, burrows, trails, fucoidal markings, and pelecypods are present in some beds.

The sandstone resembles the above-described siltstone in appearance and occurs interbedded with shale and siltstone in units ranging from a few inches to more than 15 feet in thickness. It is commonly very fine grained, dirty, and more calcareous than the siltstone. Sandstone is most common in the uppermost part of the Torok formation, although a sandy section which may be generally persistent exists well down in the formation. A few sandy beds are also present near the base. Resistant units appear to increase in abundance from east to west. These clastic rocks in the upper part of the Torok formation resemble rocks of the Kukpowruk formation except for their generally darker hue and absence of rusty weathering, whereas those in the lower part resemble clastics of the Fortress Mountain formation. Exceptions include sandstone and siltstone several thousand feet below the top of the Torok formation near the axis of the Amo Creek anticline along the upper Colville River, on Adventure Creek, on Seismo Creek, and between the West Driftwood anticline and Flintchip syncline. These sandstone beds appear to be relatively clean and possess the rusty weathering typical of coarse clastic rocks of the Nanushuk group as compared to the dominantly olive-gray-weathering and dirty character of the Fortress Mountain formation. All these sandy sections appear to lie in the middle part of the Torok formation, and although their thickness and lateral extent are not known, they may be correlative.

The resistant beds of sandstone and siltstone within the shale units of the Torok formation are commonly lenticular and cannot be traced along the strike for appreciable distances. For example, the traces which reflect resistant sandstone beds estimated to be 30 to 50 feet thick in the upper part of the formation west of Meat Mountain cannot be followed for more than a few miles along strike. This is well shown on aerial photographs of the west end of Dugout syncline, west of the Kukpowruk River. The disappearance of most of these traces is believed to be due to facies changes from coarser clastic rocks to shale. A few large cutbanks afforded opportunities for direct observation of abrupt pinch-outs. On the north flank of Archimedes Ridge anticline, 2.8 miles southwest of 1949 camp 23 (pl. 8) a 40-foot section including more than 60 percent of siltstone and sandstone thins northward within 300 feet to a thickness of 10 feet. As there are few good exposures of the Torok formation, it was not possible to determine the lateral and vertical extent of these facies changes.

Iron-stained shale beds containing abundant carbonaceous material, soft cream-colored limestone, and concretions and nodules of several types constitute very minor parts of the sequence and are described below.

A section of rocks somewhat different from the monotonous shale-siltstone exposures of the Torok formation is exposed along the east bank of the Utukok River, 1.5 miles above its junction with Driftwood Creek. Here, 490 feet of interbedded shale and siltstone contains a distinctive 2-foot bed of massive limestone that is very pale orange to cream colored, dark yellowish orange weathering, finely laminated, and soft and is underlain by a thin poorly exposed bed of yellowish-orange weathered sand. The limestone is about 40 feet below the top of the section. Fifty feet below the sand a 1-foot bed of deeply iron-stained carbonaceous clay shale, associated with considerable gray mud, was exposed. This section is believed to lie in the middle part of the Torok formation.

Rocks considered to be in the basal part of the Torok formation in this region were examined in an incompletely exposed section on the north side of East Driftwood anticline along a northward-flowing tributary of Seismo Creek. The section, from top to bottom, includes:

	Estimated thickness (feet)
1. Clay shale, dark-gray to olive-gray, fissile; with a few 1- to 4-inch interbeds of siltstone	100(?)
2. Covered	50
3. Clay shale, as above; with scattered pyrite nodules	50
4. Covered	100(?)
5. Clay shale, as above; contains scattered lenses of moderate yellowish-brown claystone as much as 6 inches in diameter, septarian concretions as much as 2 inches in diameter, and lenses as much as 1½ feet by 6 inches of medium-dark-gray silty limestone with poorly developed cone-in-cone structure	25(?)
6. Covered	75(?)
7. Clay shale, as above; with 1 to 2 inches of dark-greenish-gray nodular to blocky shale	50
8. Rocks covered to topmost sandstone of Fortress Mountain formation	100
Total thickness	550(?)

A similar sequence was observed on the upper Colville River 10 miles east of the above section in what is believed to be the same stratigraphic position.

Measured thicknesses of sections in the Torok formation are approximate. Nowhere is the total formation completely exposed, and although the upper limit of the formation has been found in many foothills anticlines, the lower part of the formation is known to be exposed only in the extreme southern part of the region. In all thick sections, some small folds and faults of unknown magnitude were recognized, particularly near anticlinal axes. Thicknesses were computed from well-exposed but discontinuous outcrops at three localities: along Adventure Creek, on the south limb of West Driftwood anticline; between East Driftwood anticline and Meat Mountain, on the south limb of Meat Mountain syncline; and north of the Colville River along long 160°10' W., on the south limb of Foggy syncline. The Meat Mountain section, 6,400 feet thick, represents the probable total thickness of Torok formation in that locality.

The Foggy syncline section, 6,000±feet thick, measured from the top of the formation, and the Adventure Creek section, about 5,200 feet thick, measured from the bottom of the formation, do not represent total thicknesses. Farther north, the largest exposures of Torok formation in this region crop out along the west bank of the Kokolik River on the north limb of Archimedes Ridge anticline. Although not entirely continuous, they extend 5 miles south of exposures of the Nanushuk group on the south limb of Howard syncline. A minimum thickness of 4,800 feet and a maximum of 7,200 feet were computed, and about 6,500 feet is believed to be a reasonable average thickness in this vicinity. The following section is shown on plate 10.

Section of the Torok formation, exposed on the north limb of the Archimedes Ridge anticline along the west bank of the Kokolik River between lat. 69°12.5′ N. and 69°14′ N., measured by E. G. Sable in August 1949, and reexamined by C. L. Whittington in July 1952.

Kukpowruk formation:

Torok formation (6,458 ± feet):

		Feet
1.	Talus and silty shale, dark-gray, platy	20
2.	Silty shale and clay shale	20
3.	Covered	90
4.	Silty shale and clay shale; 70 percent of unit; interbedded with platy to blocky medium-dark-gray siltstone containing ripple marks trending N. 45° W., (wave length of 4 in. and amplitude of one-half of an in.), and worm trails	50
5.	Talus and poor exposures. Clay shale and silty shale with a few interbeds of siltstone from 6 in. to 1 ft thick	110
6.	Mostly covered. Silty shale and siltstone talus	630
7.	Siltstone, silty shale, and very fine grained sandstone; interbedded	80
8.	Siltstone and silty shale, interbedded; siltstone (75 percent of unit) medium dark gray, carbonaceous, with massive to platy partings 1 in. to 2 ft thick, finely crossbedded and laminated; includes a few beds of fine-grained sandstone	80±
9.	Talus of clay shale and silty shale	40±
10.	Siltstone, very fine grained sandstone, silty shale, and clay shale; interbedded similar to unit 8. Siltstone and sandstone coarsely cross bedded and contains carbonaecous fragments	20
11.	Siltstone, medium- to dark-gray, carbonaceous; with thin interbeds of sandstone, silty shale, and clay shale	20
12.	Partly covered. Talus of predominantly clay shale with few beds of siltstone	2, 580
13.	Clay shale, interbedded with siltstone; shale more than 90 percent of section, siltstone beds from a few inches to 3 ft thick. Minor folds and possible faults	590
14.	Covered by talus of shale, siltstone, and mud slump	180
15.	Silty shale, clay shale, and siltstone or very fine grained sandstone; shale predominant; siltstone in beds from 6 in. to 2 ft thick, finely crossbedded and laminated, contains shallow irregular ripple markings and mud cracks	510
16.	Clay shale. Angular lower contact with unit 17	170±
17.	Siltstone or very fine-grained to silty sandstone with interbeds of silty shale. Siltstone thin-bedded, argillaceous, in wedge-shaped unit which thins northward to 10 ft in 300 horizontal ft	40±
18.	Poorly exposed. Clay shale with subordinate amounts of silty shale and few interbeds of siltstone and very fine grained sandstone mostly less than 1 ft but as much as 2 ft thick	620
19.	Clay shale, nodular to blocky; with interbedded lenses of siltstone and very fine grained sandstone as much as 3 ft thick and 10 ft long	430
20.	Siltstone, dark-gray to brownish-gray, weathers grayish-yellow, platy to blocky, micaceous; contains coaly wood fragments, ironstone nodules, and calcite veining	5
21.	Shale	10
22.	Siltstone, as in unit 20	3
23.	Mostly covered. Clay shale and silty shale, interbedded with a few thin beds of siltstone	160±
	Total thickness	6, 458±

STRATIGRAPHIC RELATIONS

The contact between the upper part of the Torok formation and the Kukpowruk formation is gradational and intertonguing. An increase in coarse clastic beds and lenses in the uppermost part of the Torok formation culminates in the high percentage of these clastic rocks that constitute the Kukpowruk formation. Likewise, it is believed that the contact between the lower part of the Torok formation and the Fortress Mountain formation is conformable and gradational in this area, although the evidence for this is less certain.

Angular relations between rock units within single exposures of the Torok formation are not uncommon; however, most of these resemble foreset bedding and are not believed to represent major depositional breaks. As an example, a cutbank along an unnamed tributary of the Colville River, 2 miles east of Amo Creek, exposes a shale-on-shale contact at which the lower beds dip 39° N., and the overlying beds dip 15° N. Above this, beds gradually revert to a dip of 40°–45° N. Other similar relations were seen in many cutbanks in the area and may have been formed by subaqueous slump down low initial slopes, or changes in current rate and direction.

Other angular relations that were recognized in two localities by photogeologic studies of the region may be more significant and may denote one or more tectonic breaks within the Torok formation. These relations consist of discordant structural trends within the formation. Strike of beds in the upper part of the Torok formation is generally parallel to the strike of overlying rocks of the Nanushuk group, whereas beds in the lower part of the Torok strike east-northeast, subparallel to the regional trend of older rocks in the southern foothills section and the De Long Mountains. On the south flank of Meat Mountain syncline, three-quarters of a mile north of Seismo Creek, sandy traces in the lower part of the formation striking N. 80° E., appear to be truncated by east-striking traces higher in the section. This relation can be traced for at least 3 miles. A similar discordance is also present in the Torok formation between the west plunge of West Driftwood anticline and the east flank of Tupikchak basin. Beds in the upper part of the formation strike north, in alinement with the flank of Tupikchak Basin, whereas the lower beds strike N. 40° E., or parallel to the trend of the West Driftwood anticline. The locations of the above discordances are shown on plate 8. They could not be mapped for more than a few miles because of insufficient exposures. The interpretation that these lines of discordance represent one or more tectonic unconformities in the Torok formation is supported to some extent by observations of regional structure (see p. 144), and by the microfossil assemblages (p. 77–83). It is nevertheless possible that the lines of discordance are surface expressions of faults. Further fieldwork in conjunction with photogeologic studies, particularly west of the Kukpowruk River where rocks are better exposed, may clarify the problem, which is of regional significance.

AGE AND CORRELATION

As a lithologic unit, the Torok formation in this area is similar to the Torok formation at the type locality. Likewise, the stratigraphic position of this unit, immediately underlying rocks of the Nanushuk group, is consistent in all northern Alaskan areas where these rocks are exposed. The upper part of the Torok formation, at least, can be traced from its type locality to the region of this report.

The lower part of the Torok formation is known to overlie the Fortress Mountain formation and is believed to be in part equivalent to it, on the basis of structural analyses east and south of this area. The upper part of the formation is known to be gradational into and equivalent in part to the lower part of the Kukpowruk formation in this region (p. 91–94). A depositional or tectonic break within the sequence is inferred from structural studies and microfaunal evidence, but it has not been proved. Since the overall lithologic characteristics of the Torok formation are everywhere similar, and because the inferred unconformity cannot be mapped throughout the region, the name Torok formation is assigned to the entire rock unit between the Kukpowruk formation and the Fortress Mountain formation, and no formal divisions are made.

Rocks now included in the Torok formation of this region were tentatively considered to be of Late Cretaceous and Early Cretaceous age by early investigators, although age determinations of fauna were uncertain (Smith and Mertie, 1930, p. 218–232). In more recent investigations only a few megafossils were found in this sequence. Collections from the upper part of the Torok formation include the following, which were identified by R. W. Imlay:

USNM 24463. Field sample 49ACh62. East bank Kukpowruk River, lat 68°54′30″ N., long 163°01′ W., Torok formation, probably within 1,000 ft of top. *Panope*? *kissoumi* McLearn.

USNM 24477. Field sample 49ASa65. North bank of Kukpowruk River, lat 68°55′ N., long 163°04′ W. Torok formation, upper 300 ft. *Panope*? *kissoumi* McLearn.

USNM 24475. Field sample 49ACh182. Kokolik River, lat 69°00′30″ N., long 161°56′ W., Torok formation, about 400 ft below top. *Flaventia*? n. sp.

These fossils are also present in the overlying rocks of the Kukpowruk formation in this region and may emphasize the gradational nature of the upper contact of the Torok formation.

Other collections from probable Torok formation or from unknown stratigraphic positions within the Torok formation include 1 sample collected by P. S. Smith in 1926, previously identified by J. B. Reeside, Jr., and reexamined by Imlay in 1953. They also include 2 samples from 1950:

USNM 13717. Field sample 26AS37. Igloo Mountain, near Kukpowruk River, approximate lat 68°46′ N., long 162°50′ W., Torok(?) formation.
Arctica? sp.
Panope? *kissoumi* (McLearn)
Inoceramus sp. juv.
Pleuromya sp.

USNM 22480. Field sample 50ASa32. Plunge Creek, north of West Driftwood anticline, lat 68°53′24″ N., long 161°21′ W., Torok formation, upper part(?).
Ditrupa n. sp.
Tancredia sp.

50ASa18. West side of Adventure Creek, lat 68°51′ N., Torok formation.
Retiphycus hexagonale Ulrich (hexagonal markings).

Although the above fossils are not in themselves diagnostic, the position of the Torok formation, between Fortress Mountain and Kukpowruk formations in this region and in part equivalent to the Kukpowruk formation, point to a late Early Cretaceous age for the Torok in this region. All the above samples, with the exception of 50ASa18, are shown in table 8.

Shale samples collected for microfossils in the Torok formation along the Utukok River (table 3), the Kokolik River (table 4), and the Kukpowruk River (table 5), contain a meager microfauna, and most of the fossils are also found in the overlying Kukpowruk formation. The lower part of the formation, however, sampled on the south flank of the Driftwood anticline along Adventure Creek (table 3), also contains *Doro-*

TABLE 3.—*Known occurrences of microfossils along the Utukok River*

[Fossils identified by H. R. Bergquist. Abundance of fossils as indicated by number of specimens per sample: F, 1–6; R, 7–12; C, 13–25; A, more than 25. Samples collected by R. M. Thompson and W. L. Barksdale in 1947 and E. G. Sable in 1950]

Field collection	Foraminifera																																						Other fossils				Location
	Saccammina lathrami Tappan	*Haplophragmoides topagorukensis* Tappan	*Verneuilinoides borealis* Tappan	*Tritaxia manitobensis* Wickenden	*Miliammina awunensis* Tappan	*Trochammina rutherfordi* Stelck and Wall	*Trochammina* sp.	*Bathysiphon brosgei* Tappan	*Ammodiscus rotalaria* Loeblich and Tappan	*Gaudryina canadensis* Cushman	*Marginulina gatesi* Tappan	*Marginulina planiuscula* (Reuss)	*Rectoglandulina kirschneri* Tappan	*Saracenaria* sp.	*Globorotalites alaskensis* Tappan	*Pallaimorphina ruckerae* Tappan	*Gaudryinella irregularis* Tappan	*Conorboides umiatensis* Tappan	*Lenticulina macrodisca* (Reuss)	*Gavelinella stictata* (Tappan)	*Dentalina* sp.	*Globulina lacrima* Reuss	*Eurycheilostoma robinsonae* Tappan	*Bathysiphon vitta* Nauss	*Astacolus* sp.	*Ammobaculites* sp.	*Ammobaculites fragmentarius* Cushman	*Ammobaculites wenonahae* Tappan	*Miliammina manitobensis* Wickenden	*Globulina prisca* Reuss	*Lenticulina erecta* (Perner)	*Miliammina* sp.	*Ammodiscus* sp.	*Dorothia chandlerensis* Tappan	*Gavelinella awunensis?* Tappan	*Reophax* sp.	*Glomospira corona* Cushman and Jarvis	*Glomospira* sp.	Charophytes	Echinoid spine	Radiolaria	*Inoceramus* sp.	
Corwin formation																																											
47ATm35	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Lat 69°36′ N., long 160°30′ W.
47ATm40	R	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Lat 69°41′ N., long 160°47′ W.
47ATm24(27c)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	C	F	---	---	Elusive Creek syncline, south limb.
47ATm10(32)	A	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Folsom Point syncline, south limb.
47ATm10(29G)	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	F	A	F	F?	---	Do.
47ATm10(29D)	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ABa54	F	---	R	A	C	F?	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
Kukpowruk formation (upper part)																																											
47ABa92	F	F	F	---	---	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Elusive Creek syncline, south limb.
47ATm19(36)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	C	---	---	---	Lookout Ridge syncline, south limb.
47ATm19(34)	C	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ABa83	F	A	A	---	---	---	---	F	A	F	F	F	F	F	F	A	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	F	---	---	---	Do.
47ABa50	C	---	A	A	A	A	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Folsom Point syncline, south limb.
47ATm10(27)	---	F	---	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ABa63	---	F	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	F	---	---	---	Flintchip syncline, south limb.
47ABa29A	---	---	C	C	A	R?	R	---	---	C	---	---	---	---	---	---	R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ATm9(9)	F	F	C	---	R	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Kokolik Warp syncline, north limb.
47ATm9(8)	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ATm9(6A)	---	C	C	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ATm9(6B)	---	R	C	---	---	---	---	---	---	---	---	---	---	---	---	---	---	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.
47ABa90	F	A	R	---	---	---	---	---	F	F	F	F	---	---	---	C	---	F	F	F	F	F	F	F	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Elusive Creek syncline, south limb.
47ABa88	F	---	---	---	---	---	---	---	---	---	---	---	---	---	F	---	F?	F	---	F	---	---	---	---	F?	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	Do.

Kukpowruk formation (lower part)																																											
47ATm15(11)		F	F						F																	F													F				Lookout Ridge syncline, south limb.
47ATm15(4)		R						C	F	F							F																						F				Do.
47ABa44A		F				F?																																					Folsom Point syncline, south limb.
47ATm10(19)	F																																										Do.
47ATm10(14)	F		F	F	C		F			C																	C																Do.
47ATm10(5)	F	A	A								F		F?					R	F	F								F	F	F													Do.
47ATm10(4)			F							F																																	Do.
47ATm13(12)		R	C	R	A					A																																	Howard syncline, south limb.
47ATm13(6)	F	C	F	F																																							Do.
47ABa73	F																																										Do.
47ABa71		C		A	F			R																																			Do.
47ABa67		C																C													R												Do.
47ATm23(3)		F																									F																Elusive Creek syncline, south limb.
Torok formation (upper part)																																											
50ASa334	F?																									F																	Flintchip syncline, south limb.
50ASa332									F?																							F											Do.
Torok formation (lower part)																																											
50ASa25	C							R	F																								F	F?									Adventure Creek, west Driftwood anticline, south limb.
50ASa24	C							C																																			Do.
50ASa21	F							C	F								F																										Do.
50ASa22	C							F	R																																		Do.
50ASa23	C							F	R												F													R?	F?								Do.
50ASa19	C							R																										F?									Do.
50ASa17	C							F									F				F					F								F?		F							Do.
50ASa16	F							C	F																									F?			F						Do.
50ASa15								C																																		F	Do.
50ASa14	A							F	A																									C	R								Do.
50ASa13	C							C	C							F																		F									Do.
50ASa12	F							F	F																									F									Do.
50ASa11	F							F	R																																		Do.
47ABa6A																		F																									Do.

TABLE 4.—*Known occurrences of microfossils along the Kokolik River.*

[Fossils identified by H. R. Bergquist. Abundance of fossils as indicated by number of specimens per sample: F, 1–6; R, 7–12; C, 13–25; A, more than 25. Samples collected by R. M. Chapman and E. G. Sable in 1949]

Field collection no.	Foraminifera																					Other fossils	Location
	Haplophragmoides topagorukensis Tappan	*Miliammina manitobensis* Wickenden	*Bathysiphon brosgei* Tappan	*Glomospira* sp.	*Trochammina rutherfordi* Stelck and Wall	*Ammodiscus* sp.	*Verneuilinoides borealis* Tappan	*Saccammina lathrami* Tappan	*Tritaxia manitobensis* Wickenden	*Miliammina awunensis* Tappan	*Ammodiscus rotalaria* Loeblich and Tappan	*Hyperamminoides barksdalei* Tappan	*Ammobaculites fragmentarius* Cushman	*Siphotextularia? rayi* Tappan	*Psamminopelta bowsheri* Tappan	*Trochammina* sp.	*Conorboides umiatensis* Tappan	*Valvulineria loetterlei* (Tappan)	*Bathysiphon vitta* Nauss	*Dorothia chandlerensis* Tappan	*Trochammina eilete* Tappan	Charophytes	
Corwin formation																							
49ASa209																						F	Oxbow syncline, south limb.
Kukpowruk formation (upper part)																							
49ACh168	F																						Flintchip syncline, south limb.
49ACh152	R	F																					Poko Mountain syncline at axis.
Kukpowruk formation (lower part)																							
49ASa204	R		F	F																			Howard syncline, south limb.
49ACh194					F																		Deadfall syncline, at axis.
49ASa194	R																						Kokolik Warp syncline, north limb.
49ACh186						F	F																Kokolik Warp syncline, south limb.
49ACh184							F	F															Do.
49ASa188									A	F												R	Flintchip syncline, north limb.
49ACh181											F												Do.
49ACh180	C					F	F?		F			F	R?	F									Do.
49ACh167	C		F					F	F														Tupikchak syncline, north limb.
49ASa164	C								F														Tupikchak syncline, south limb.
49ASa156	C								F														Poko Mountain syncline, south limb.
49ASa155	A			F?			F		F						F								Do.
49ASa154	R												F										Do.
Torok formation (upper part)																							
49ASa201	F?																						Howard syncline, south limb.
49ASa198	F?																						Do.
49ASa196	F?																						Do.
49ASa195	F							F	F													R	Do.
49ASa176	R		F						F?														Flintchip syncline, south limb.
49ASa175	F																						Do.
Torok formation (lower part)																							
49ACh147			F						F?							F?	F	F					Lat 68°46′ N., long 161°58′ W.
49ACh148	F		F													R?			F	C	F?		Lat 68°45′ N., long 161°56′ W.
49ACh149			F																F				Lat 68°45′ N., long 161°56′ W.
Torok formation (stratigraphic position uncertain)																							
49ASa144		F?						F?															Approximate lat 68°47′ N., long 162°05′ W.
49ASa145	F		F																				Approximate lat 68°47′ N., long 162°05′ W.
49ASa146			R																F				Approximate lat 68°47′ N., long 162°05′ W.
49ASa147	F		C														F						Approximate lat 68°47′ N., long 162°05′ W.
49ASa148			R																				Approximate lat 68°47′ N., long 162°05′ W.
49ASa149	F																						Approximate lat 68°47′ N., long 162°05′ W.
49ACh155																	F						Lat 68°50′ N., long 162°03′ W.
49ACh156																	F						Lat 68°50′ N., long 162°03′ W.
49ACh157			F		F																		Lat 68°50′ N., long 162°03′ W.
49ASa158									F														Lat 68°48′ N., long 162°04′ W.
49ASa160	F																						Lat 68°48′ N., long 162°04′ W.
49ASa161								F															Lat 68°47′ N., long 162°04′ W.
49ASa162	F		F																				Lat 68°50′ N., long 162°03′ W.

TABLE 5.—*Known occurrences of microfossils along the Kukpowruk River*

[Fossils identified by H. R. Bergquist. Abundance of fossils as indicated by number of specimens per sample: F, 1–6; R, 7–12; C, 13–25; A, more than 25. Samples collected by R. M. Chapman and E. G. Sable in 1949]

Field collection	Foraminifera																											Other fossils	Location
	Glomospirella gaultina (Berthelin)	*Ammobaculites wenonahae* Tappan	*Miliammina sproulei* Nauss	*Trochammina rainwateri* Cushman and Applin	*Saccammina lathrami* Tappan	*Verneuilinoides borealis* Tappan	*Tritaxia manitobensis* Wickenden	*Marginulina* sp.	*Gaudryina* sp.	*Miliammina* sp.	*Miliammina awunensis* Tappan	*Gaudryina canadensis* Cushman	*Psamminopelta bowsheri* Tappan	*Miliammina manitobensis* Wickenden	*Trochammina eilete* Tappan	*Haplophragmoides topagorukensis* Tappan	*Trochammina* sp.	*Bathysiphon brosgei* Tappan	*Ammobaculites fragmentarius* Cushman	*Haplophragmoides* sp.	*Ammodiscus rotalaria* Loeblich and Tappan	*Verneuilinoides* sp.	*Trochammina rutherfordi* Stelck and Wall	*Ammodiscus* sp.	*Hyperammminoides barksdalei* Tappan	*Gaudryinella irregularis* Tappan	*Bathysiphon vitta* Nauss	Charophytes	
Gubik formation																													
49ASa142	F	F	F	F?																									
Corwin formation																													
49ACh127					F																								Howard syncline, north limb.
49ACh91						F?	F	F?																					Deadfall syncline, north limb.
49ACh82																												F	Kukpowruk syncline, north limb.
49ACh77									R	F																			Kukpowruk syncline, south limb.
49ACh78					F	F	R				C	C	R																Do.
49ACh49																												F	Coke basin, south limb.
Kukpowruk formation (upper part)																													
49ASa137									F?					F															Barabara syncline, south limb.
49ASa111							F								F?														Kasegaluk syncline, south limb.
49ACh113		F?	F?			F	F									R	F?												Do.
49ASa97											F					F													Deadfall syncline, south limb.
49ACh88																												F	Do.
49ACh95							F									F													Deadfall syncline, north limb.
49ACh98						R	F									C		F	F?										Do.
49ASa101											R																		Do.
49ACh100																F													Do.
49ACh104																				F?									Do.
49ACh107																C					F?								Do.
49ASa90							F?				C											F?							Kukpowruk syncline, north limb.
49ASa93																F			F										Do.
49ACh86																												F	Do.
49ASa94							F									F													Do.
49ACh84																R		F											Do.
49ASa70			F																										Tupikchak syncline, north limb.
49ACh58					F	F	R				C	F?																	Tupikchak syncline, south limb.
49ASa58					F						F												F?						Coke basin, north limb.
Kukpowruk formation (lower part)																													
49ACh111							F																						Kasegaluk syncline, south limb.
49ACh119		R			F	F	R									A		F						F					Howard syncline, south limb.
49ASa102a																C									F				Deadfall syncline, north limb.
49ACh72						F																							Kukpowruk syncline, south limb.
49ACh70																										F?			Tupikchak syncline, north limb.
49ASa64					F															F?							F		Coke basin, north limb.
Torok formation (upper part)																													
49ASa103		F?					F									C													Deadfall syncline, north limb.
49ACh63																F?													Tupikchak syncline, south limb.
49ACh47															F			F											Coke basin, south limb.
49ACh48	F?																F		F		F						F		Do.
49ACh46															C			F	F?		F								Do.
49ACh45															F			F											Do.
49ACh44															F			F											Do.

thia chandlerensis Tappan, which is not certainly known from the upper part of the formation. In regard to this section, H. R. Bergquist states:

> In a suite of 14 samples of shale of the lower part of the Torok formation from the south flank of the Driftwood anticline, there occurred a meager microfauna consisting mostly of very small flattened specimens of *Haplophragmoides topagorukensis* Tappan and fragmentary tests of *Bathysiphon brosgei* Tappan. Specimens of *H. topagorukensis* were common to abundant in 9 samples. Flattened and distorted specimens of *Ammodiscus rotalaria* (Loeblich and Tappan) were found in several samples but were common to abundant in only 2 samples. There were scattered occurrences of a few specimens of *Saccammina lathrami* Tappan and of a few other species, and in 2 samples there were a few specimens of *Gavelinella awunensis*? Tappan. Broken and twisted specimens of *Dorothia chandlerensis* Tappan were found infrequently but were common in 1 sample. The presence of this species is important to the identity of the section as it is one of the few fossils that characterize the lower part of the Torok formation.
>
> The fauna in general is similar to that in lower beds of the Torok, found elsewhere in northern Alaska; it is small and typically lacks most of the species that identify the upper part of the formation. However, it lacks pyritic casts of the radiolarian *Lithocampe*? sp., which are prevalent in samples from type exposures of the lower part of the formation.

Microfossils from the upper part of the Torok formation include *Haplophragmoides topagorukensis* Tappan, *Bathysiphon brosgei* Tappan, *Ammodiscus rotalaria* (Loeblich and Tappan) and *Saccammina lathrami* Tappan, all of which are long ranging. A few specimens of *Trochammina eilete* Tappan and *Tritaxia manitobensis* Wickenden are also present, according to H. R. Bergquist.

The most intensively sampled sections of the Torok formation in the Utukok-Corwin region are in the north flank of the Archimedes Ridge anticline on the Kokolik River (table 6). Although the sections lie from about 4,200 to 6,300 feet below the top of the formation, the samples contain a fauna resembling that in the upper part of the formation found elsewhere in the region, and they lack *Dorothia chandlerensis* Tappan known from the lower part of the Torok. The following remarks about the above sections were made by H. R. Bergquist:

> Only a meager microfauna was found in samples collected by Whittington in the Archimedes Ridge anticline. Of the 155 samples examined, 94 were barren. The fossils are very poorly preserved, dark- or grayish-brown Foraminifera. Many of the specimens are small, flattened, or crushed, and distorted. About 20 species of Foraminifera were identified from the 61 fossiliferous samples; however, 8 species were represented by only 1 specimen each and 6 species by less than 4 specimens each. Specimens of *Haplophragmoides topagorukensis* Tappan

TABLE 6.—*Known occurrences of Foraminifera in the Torok formation on the north limb of Archimedes ridge anticline, Kokolik River*

[Fossils identified by H. R. Bergquist. Abundance of fossils as indicated by number of specimens per sample; F, 1–6; R, 7–12; C, 13–25; A, more than 25. Samples collected by C. L. Whittington, in 1952]

Field collection	Barren samples (X)	*Haplophragmoides topagorukensis* Tappan	*Bathysiphon brosgei* Tappan	*Gaudryinella irregularis* Tappan	*Trochammina rainwateri* Cushman and Applin	*Gavelinella stictata* (Tappan)	*Gaudryina canadensis* Cushman	*Glomospirella gaultina* (Berthelin)	*Textularia topagorukensis* Tappan	*Ammobaculites wenonahae* Tappan	*Siphotextularia*? *rayi* Tappan	*Globulina prisca* Reuss	*Conorboides umiatensis* Tappan	*Saccammina lathrami* Tappan	*Ammobaculites fragmentarius* Cushman	*Ammodiscus rotalaria* (Loeblich and Tappan)	*Marginulina planiuscula* (Reuss)	*Psamminopelta*? sp.	Approximate stratigraphic position (in feet below top of formation)
52AWh220–52AWh226	×																		4,200–4,610
52AWh219		F																	
52AWh218		F	F																
52AWh217			F	F	F	F	F												
52AWh216	×																		
52AWh215		F				F		F	F										
52AWh214										F									
52AWh213		F	F			F	F					F							
52AWh212		F																	
52AWh211	×																		
52AWh210		C	F																
52AWh209		C					F												
52AWh204–52AWh208	×																		
52AWh203		F																	
52AWh200–52AWh202	×																		
52AWh199		F?																	
52AWh196–52AWh198	×																		
52AWh195		F?			F								F?						
52AWh194			F		F								F?						
52AWh193				F															
52AWh192		F?	F																
52AWh190–52AWh191	×																		5,080–5,200
52AWh189		F								F?									
52AWh188		R												F					
52AWh187									F?										
52AWh186	×																		
52AWh185		F							F										
52AWh184																			
52AWh183		F																	
52AWh182		F																	
52AWh181		F																	

TABLE 6.—*Known occurrences of Foraminifera in the Torok formation on the north limb of Archimedes ridge anticline, Kokolik River*—Continued

Field collection	Barren samples (X)	*Haplophragmoides topagorukensis* Tappan	*Bathysiphon brosgei* Tappan	*Gaudryinella irregularis* Tappan	*Trochammina rainwateri* Cushman and Applin	*Gavelinella stictata* (Tappan)	*Gaudryina canadensis* Cushman	*Glomospirella gaultina* (Berthelin)	*Textularia topagorukensis* Tappan	*Ammobaculites wenonahae* Tappan	*Siphotextularia? rayi* Tappan	*Globulina prisca* Reuss	*Conorboides umiatensis* Tappan	*Saccammina lathrami* Tappan	*Ammobaculites fragmentarius* Cushman	*Ammodiscus rotalaria* (Loeblich and Tappan)	*Marginulina planiuscula* (Reuss)	*Psamminopelta?* sp.	Approximate stratigraphic position (in feet below top of formation)
52AWh180	×																		5,200–5,800
52AWh179		F																	
52AWh178	×																		
52AWh177		F	F																
52AWh176		F	F					F											
52AWh172–AWh175	×																		
52AWh171		F																	
52AWh163–52AWh170	×																		
52AWh162		F																	
52AWh161		F													F				
52AWh157–52AWh160	×																		
52AWh156		F						F?											
52AWh155	×																		
52AWh154		F																	
52AWh149–52AWh153	×																		
52AWh148		F?																	
52AWh145–52AWh147	×																		
52AWh144		F?	F?																
52AWh138–52AWh143	×																		
52AWh137																F			
52AWh129–52AWh136	×																		
52AWh128		F?																	
52AWh122–52AWh127	×																		
52AWh121		F	F												F				
52AWh118–52AWh120	×																		5,800–6,200
52AWh117		F													F				
52AWh116	×																		
52AWh115		F													F				
52AWh114															F?		F		
52AWh113			F																
52AWh112			F?																
52AWh111		C	C					F?	F						F				
52AWh110		C	C													F		F?	
52AWh109		F																	
52AWh108	×																		
52AWh107			F																
52AWh106			F																
52AWh105			F													F			
52AWh104		F	F						F										
52AWh103		F		F															
52AWh102	×																		
52AWh98–52AWh101	×																		6,200–6,300
52AWh97		F																	
52AWh92–52AWh96	×																		
52AWh91		F																	
52AWh87–52AWh90	×																		
52AWh86																F			6,100?–6,200?
52AWh85		R	F						F?	F?						R			
52AWh84		F	F						F?							F			
52AWh83		F			F						F?					F			
52AWh82	×																		
52AWh81		F	R								F					F			
52AWh80		R	F																
52AWh79		F			F?				F?										
52AWh78		F							F?										
52AWh77	×																		
52AWh76		F							F?										
52AWh72–52AWh75	×																		

and *Bathysiphon brosgei* Tappan make up by far most of the Foraminifera found. Specimens of *H. topagorukensis* occurred in 44 samples and were common in 2 of them. Specimens of *Ammodiscus rotalaria* (Loeblich and Tappan) were found in 16 samples, ranging from 1 to 7 specimens in a sample. Specimens of *Textularia topagorukensis* Tappan occur rarely (1 to 3 specimens) in 4 samples, and a few fragments of *Ammobaculites fragmentarius* Cushman were found in 3 samples.

The more common species in this collection, however, offer little clue to the identity of the fauna, as all three are found throughout the Early Cretaceous sedimentary rocks of northern Alaska. The few specimens of *Textularia topagorukensis*, the fragmentary specimens of *Ammobaculites fragmentarius*, and very rare specimens of *Eurycheilostoma robinsonae* Tappan and *Gavelinelli stictata* (Tappan) suggest a fauna from the lower part of the *Verneuilinoides borealis* faunal zone (Albian) of the Cretaceous of northern Alaska. Two other calcareous specimens, identified as *Marginulina planiuscula* (Reuss) and *Globulina prisca* Reuss, are also species known only from the *Verneuilinoides borealis* zone. Thus, I would consider the fauna to be part of that zone, even though it is limited and lacks *V. borealis* and some of the other characteristic species.

LOWER AND UPPER CRETACEOUS SERIES—NANUSHUK GROUP

The Nanushuk group, named after the Nanshuk River in south-central part of northern Alaska, is defined as a sequence of marine and nonmarine rocks that directly overlies the Torok formation and underlies the Colville group (Gryc, Patton, and Payne, 1951). The Nanushuk group includes rocks of inshore, offshore, coastal, and inland facies which exhibit intertonguing both in their outcrop belts, which have been recognized throughout most of the northern foothills and in the subsurface (Payne and others, 1951). The Nanushuk group can be traced as a gross unit from the Colville Valley region into the Utukok-Corwin region, where it is similarly defined to include the rock sequence overlying the Torok formation and underlying rocks mapped as the Prince Creek formation of the Colville group (Sable, 1956). In the central and eastern areas of northern Alaska, however, a more detailed division of the Nanushuk group has been made (Detterman, 1956) than can be applied to rocks in the Utukok-Corwin region. In this region, the Nanushuk group is much thicker than in the central and eastern areas; but, although some facies similar to the rocks in those areas have been recognized, it has been possible to distinguish and map only two major units, a lower marine and an upper nonmarine sequence, the Kukpowruk and Corwin formations (Sable, 1956).

KUKPOWRUK FORMATION

DISTRIBUTION AND OCCURRENCE

The resistant rocks of the Kukpowruk formation form the high mesas and cuestas that are characteristic of the northern foothills section and which rise abruptly from the lowlands underlain by the Torok formation to 2,000 feet in the southern part and to 700 feet in the northern part of the northern foothills. About 75 percent of the 5,300 square miles included in the northern foothills section contains exposures of or is underlain by the Kukpowruk formation. The formation or its equivalent is also believed to be present nearly everywhere in the subsurface of the Arctic coastal plain, but the only known exposures in that province, and the most northerly in the entire region, are in the axial zone of Snowbank anticline, along the Kukpowruk River.

The southernmost exposures of the Kukpowruk formation lie along a roughly east-northeastward-trending line north of lat 68°45' N., and include, from east to west, the isolated mesas of Meat Mountain, Poko Mountain, Igloo Mountain, and Dugout synclines. The formation is also believed to be present in the coastal bluffs in the vicinity of Eesook, west of Corwin Bluff. (See p. 71.) The northernmost exposures in the northern foothills lie along a roughly eastward-trending line, west of the Utukok River at lat 69°28' N., near the Kokolik River at lat 69°22' N., and along the Kukpowruk River at lat 69°16' N. On the Arctic coast, rocks of the Kukpowruk formation are believed to be exposed only as far north as Punak Creek at lat 68°57' N., although they probably occur within 2 miles of the coast near Kahgeatak Creek, north of Cape Beaufort.

High ridges, formed by resistant clastic rocks of the Kukpowruk formation, can be traced for many miles along the limbs of synclines in the northern foothills section (fig. 16). The slopes of the ridges rise from the lowlands underlain by the Torok formation at angles estimated to be from 15° to 25° and are broken by numerous closely spaced rubble traces and bedrock ledges of hard sandstone and siltstone (fig. 15). These beds constitute a thick resistant unit which is persistent throughout the outcrop area and upholds the prominent mesas and cuestas. The upper part of the Kukpowruk formation, having fewer resistant beds, weathers to topography of lower relief. Individual traces and ledge-forming outcrops are common, however, and many can be traced for long distances. Intervals of rock between ledges or traces of resistant strata are covered by vegetation or frost heavings of less resistant strata, such as shale and thin-bedded siltstone, bedrock exposures of which are rare and confined almost entirely to cutbanks. Weathered outcrops of the formation have a yellowish-brown to dark-brownish appearance as contrasted with the yellow and orange hues of the Corwin formation. On aerial photographs, traces of resistant rock appear as light-colored straight or evenly curving lines alternating with darker tundra-covered bands, which produce a striking banded effect. In foothills anticlines and synclines, the banding resembles a concentric series of elliptical or circular racetracks (fig. 16).

Most areas in which the Kukpowruk formation crops out are well drained because of their relatively high topographic position. The cuesta tops provide the best overland travel routes, especially to the east and west; and, like hills of the Fortress Mountain formation, afford good observation points overlooking large areas of tundra-covered lowlands.

CHARACTER

Rocks of the Kukpowruk formation represent mostly marine inshore facies, possibly some offshore facies, and include sequences transitional to nonmarine coastal facies in the uppermost part. Silty shale, siltstone, and sandstone are the predominant rocks of the formation; clay shale and claystone, conglomeratic sandstone, conglomerate, and carbonaceous shale occur in subordinate quantities. The rocks vary in abundance both laterally and vertically, and in general interbedded shale, claystone, and thin siltstone beds constitute

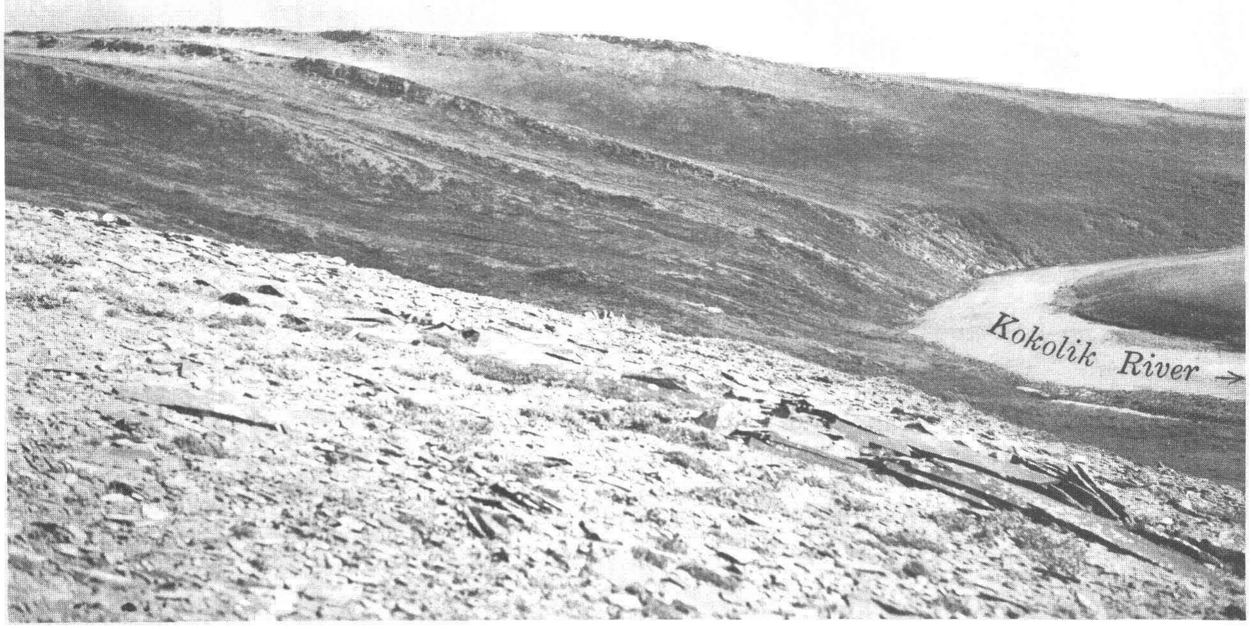


FIGURE 15.—View showing typical weathering and topographic expression of Kukpowruk formation, north limb of Flintchip syncline, Kokolik River. Sandstone and conglomerate form ledges and joint blocks in talus, and shaly units occupy covered intervals of rock between ledges.

about 65 to 80 percent of the formation, and thick-bedded sandstone, conglomeratic sandstone, and siltstone (in beds or sets of beds more than 5 feet thick) make up from 20 to 35 percent of the formation. The percentage of the coarser clastic rocks decreases markedly northward, and at Kaolak test well 1 (p. 96) the section probably equivalent to the Kukpowruk formation contains less than 10 percent of sandstone and siltstone.

The silty shale is medium dark to dark gray, weathers yellowish gray and is rarely iron stained, noncalcareous to moderately calcareous, uniform in texture, and fissile, blocky, or nodular. Interbedded siltstone beds, mostly less than 2 feet thick, are medium to dark gray, olive gray and yellowish gray, weather yellowish gray to yellowish brown, are commonly iron stained, generally more calcareous than the shale, very hard, are platy to blocky, and exhibit graded bedding and fine crossbedding within thin layers. Siltstone also occurs in lenses and nodular bodies. Both the silty shale and siltstone contain carbonaceous and micaceous flecks and laminae, woody and coaly fragments, ripple and mud markings, and worm trails. Interbedded silty shale and siltstone are as much as several hundred feet thick; the silty shale in most of these units is dominant. Fossils were found in these rocks in a few localities and include pelecypods and gastropods.

The sandstone and thicker sandy siltstone beds are light to medium gray, light olive gray, and yellowish gray; they weather to light to dark yellowish brown and less commonly to yellowish and yellowish orange. The sandstone is mostly fine to very fine grained, and less commonly medium to coarse grained, is commonly of salt-and-pepper type, and ranges from subgraywacke type to relatively clean and well sorted. Most of the sandstone and siltstone is very hard and of low porosity, but some is slightly friable. They are platy to blocky or massively conchoidal in fracture, occur in beds as thick as 20 feet, and in sets of beds as thick as 100 feet (fig. 17). Many sandstones weather in massive joint blocks tens of feet thick, and some fractures contain veins of calcite. Most of the sandstone and sandy siltstone is calcareous, some contains small lenses of conglomeratic sandstone, and is otherwise similar in depositional features to the above-described siltstone. However, the thicker sandstone and siltstone beds are commonly massive and lenticular and contain numerous subround clay pellets. Their primary features are also larger than those in the thinner siltstone beds; they include massive crossbedding with foreset beds inclined to 25° and involving several feet of section. They also have current and oscillation ripple marks ranging from 1 to 7 inches in wavelength and $\frac{1}{4}$ to $1\frac{1}{2}$ inches in amplitude. Oscillation ripple marks

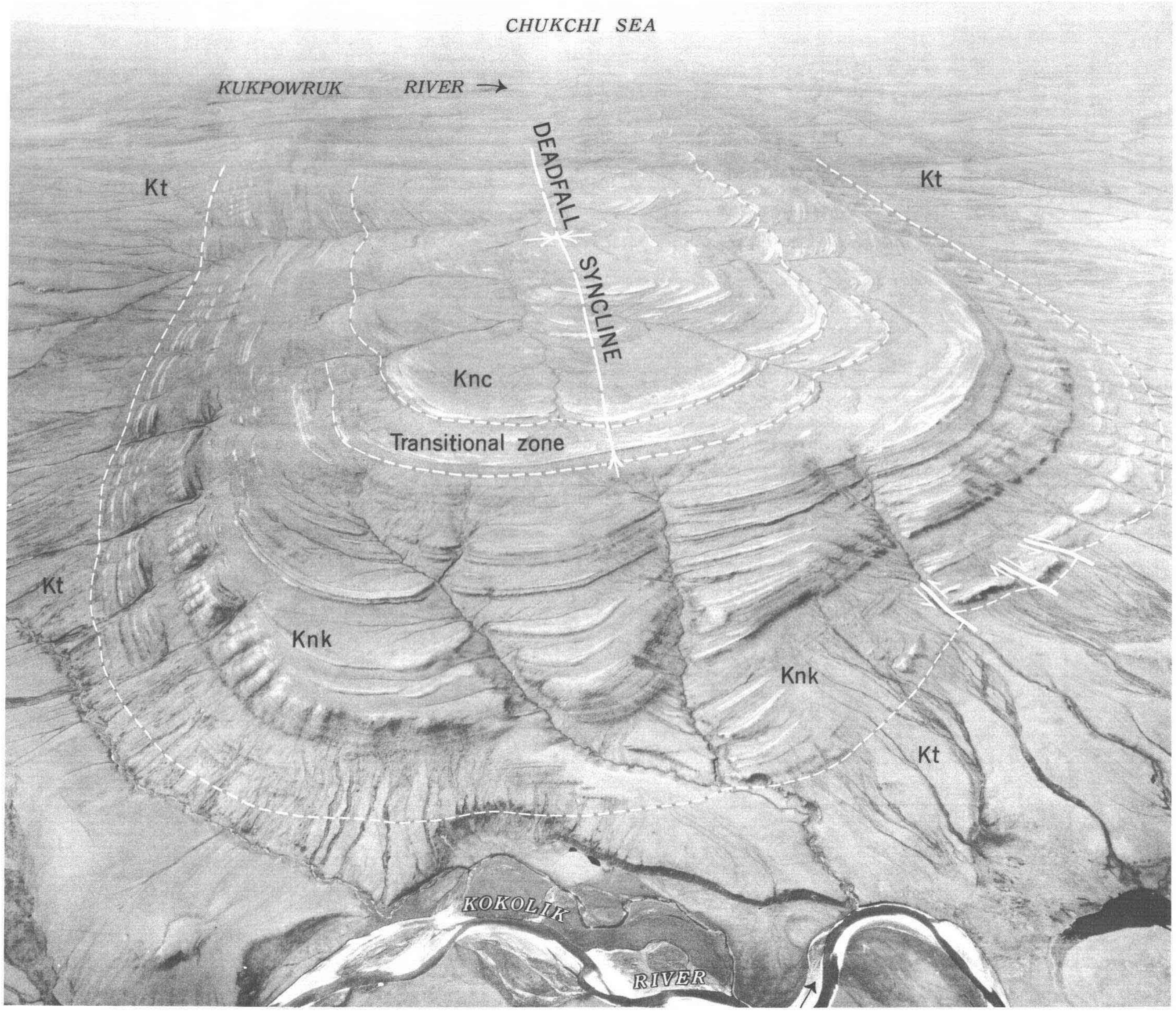


FIGURE 16.—Aerial view of Deadfall syncline looking west from Kokolik River toward Kukpowruk River, Utukok-Corwin region, Alaska. Deadfall syncline is typical of northern foothills synclines which expose the Nanushuk group. Torok formation (Kt) in lowland areas surrounding the syncline is poorly exposed. The darker appearance and abundance of sandstone beds distinguishes Kukpowruk formation (Knk) from the overlying Corwin formation (Knc). The transitional zone contains rocks gradational between the marine and nonmarine facies. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force, approximate altitude 12,000 feet.

FIGURE 17.—Massive and platy sandstone of the Kukpowruk formation near top of Poko Mountain, showing typical mechanical weathering. Shale underlies rubble in foreground.

appear to be the prevailing type, and about 30 readings indicate that they trend most commonly northwestward. Megafossils are common in some sandstones and include pelecypods, starfish, and the worm tube *Ditrupa.*

Conglomeratic sandstone and lenses of conglomerate which occur within and at the base of some thick sandstone beds contain smooth subround pebbles and small cobbles of black, gray and greenish chert, white quartz, mafic igneous rock, quartzite, ironstone, and angular coaly wood fragments in a matrix of fine- to coarse-grained sandstone. They are most abundant in the southern part of the region, as in Coke basin and Tupikchak syncline on the Kukpowruk River, and are present as far east as Foggy syncline, north of the Colville River. In the northern part of the region conglomeratic beds are absent or rare and are confined to the uppermost part of the formation.

Clay shale and claystone are believed to constitute a minor part of the Kukpowruk formation. Where exposed, they are interbedded commonly with silty shale but also with siltstone and sandstone. The clay shale and claystone are medium to dark gray and rarely olive gray, fissile to blocky, soft, and in part laminated. They commonly contain scattered nodules of dark-gray, argillaceous, and siliceous ironstone up to a few inches in diameter that weather buff to reddish orange. These nodules also occur in sandstone and siltstone but are not as common as in the overlying Corwin formation.

Medium- to dark-gray and olive-gray calcareous claystone is rare; where seen it is less than 1 foot thick and usually occurs in the upper part of the formation. Carbonaceous shale and very thin coaly beds likewise are not common except in the southernmost exposures of Coke basin and Tupikchak syncline. In these structural features, the Kukpowruk formation contains a greater percentage of nonmarine rocks than in more northern and eastern exposures.

Two kinds of graded bedding were observed in some rock units of the Kukpowruk formation, and involve sequences ranging from a few feet to tens of feet in thickness, which include conglomerate, sandstone, siltstone, silty shale, and clay shale. The first kind of graded bedding in the Kukpowruk formation is similar to that described for the Fortress Mountain formation (p. 72), except that the large mudflow features, which are abundant in the Fortress Mountain formation, are not as common in the Kukpowruk, and the coarse clastic beds in the Kukpowruk contain large-scale crossbedding which is absent in the Fortress Mountain formation. The second kind of graded bedding sequence is a reversal of the first, although of similar magnitude. It includes clay or silty shale abruptly overlying a scoured surface of sandstone and grading upward through siltstone into sandstone and conglomerate. Because graded bedding sequences were not carefully studied during fieldwork, their extent, relative positions in the section, and exact significance are not known. They may represent transgressive and regressive fluctuations in deposition, and if they are laterally persistent, future fieldwork may show them to be valuable aids in correlation of parts of the formation which are otherwise indistinguishable.

In summation, the lithologic features which distinguish the Kukpowruk formation from the Torok formation are the abundance and individually greater thicknesses of coarse clastic rocks in the Kukpowruk. In comparison with the overlying Corwin formation, the Kukpowruk formation contains more fossil faunal remains; more clay pellets in sandstone and siltstone; a greater abundance of coarse clastic rocks, especially in the lower part of the formation; more brown and gray compared with yellow and orange colors in the Corwin; and less ironstone, coal, and coaly or carbonaceous shale.

The type section of the Kukpowruk formation along the Kukpowruk River on the south flank of Kasegaluk syncline is described in the following tabulation and is shown on plate 10. The contact with the Corwin formation, above which nonmarine rocks are dominant, is at the base of a 70-foot sandstone bed. The rocks in the upper part of the Kukpowruk formation section appear to be transitional between marine and nonmarine. The base of the formation is not exposed.

Type section of the Kukpowruk formation, measured by R. M. Chapman and E. G. Sable, July 1949

Base of Corwin formation:
Kukpowruk formation (2,865± feet):

	Thickness (feet)
1. Siltstone, silty shale, clay shale; interbedded; shale medium dark to dark gray; siltstone olive gray to dark yellowish brown, blocky; carbonaceous shale at top	13
2. Sandstone, light-olive-gray, very fine grained, massive, moderately calcareous; contains carbonaceous fragments	6
3. Siltstone, dark-yellowish-brown, blocky, platy, and massive; with carbonaceous partings, carbonized wood fragments, and thin interbeds of silty shale. Asymmetrical ripple marks (onehalf an inch amplitude, 1-in. wavelength)	30
4. Silty shale and clay shale, with interbedded claystone and siltstone; dark-gray to moderate-yellowish-brown shale, 80 percent of unit; siltstone mainly in lower 15 ft, grades upward to coaly shale with coal beds to one-half of an inch thick; nodula claystone at top of unit	31
5. Sandstone, medium-gray to moderate-yellowish-brown, weathers moderate-yellowish-orange, very fine to fine-grained, massive to platy, laminated and coarsely crossbedded	22
6. Siltstone and silty shale; interbedded; siltstone dark-yellowish brown, blocky, highly calcareous; contains lens of calcareous claystone in upper 2 ft. Microfossil sample 49ASa111 (includes unit 7): *Trochammina* eilete ? Tappan, *Tritaxia manitobensis* Wickenden	13
7. Shale, silty, and clay shale interbedded	20
8. Shale, silty, and siltstone interbedded	5
9. Covered	15
10. Siltstone, moderate-yellowish-brown, blocky; with interbeds of silty shale near base; contains abundant leaf impressions and carbonaceous fragments. Resistant unit	28
11. Siltstone, platy to massive, moderately calcareous; contains plant fragments	7
12. Covered	5
13. Siltstone and shale interbedded	12
14. Covered	10
15. Sandstone, medium-gray, very fine to fine-grained, very massive, noncalcareous; hard to friable; grades upward to sandy siltstone containing a few poorly defined pelecypod molds	11
16. Siltstone and shale, interbedded	12
17. Sandstone, medium-gray, fine-grained, massive, noncalcareous; contains carbonaceous fragments and clay pellets. Resistant unit	6
18. Clay shale, silty shale, claystone, and siltstone; interbedded, medium-dark- to dark-gray, nodular to platy. Poorly resistant unit. Microfossil sample 49ASa109 (includes units 19, 20, 21, 22). Barren	29±
19. Covered	14
20. Silty shale, siltstone, and sandstone. Medium-dark- to dark-gray shale grades upward to blocky siltstone to 2-ft massive sandstone	40
21. Sandstone and siltstone interbedded, medium-dark-gray, slightly calcareous, somewhat friable; with vague ripple markings; contains pelecypod shells and molds in layer at base and scattered throughout, associated with coaly wood fragments, worm trails, and ironstone-filled tubes (*Ditrupa* n. sp). Sample 49 ASa110f: *Entolium* n. sp. *Camptonectes* n. sp. *Tancredia* sp	3
22. Silty shale, with minor amounts of interbedded clay shale and siltstone; carbonaceous and fissile in upper 1 ft with ½-in. coal bed and plant fragments. Reddish iridescent bedding surfaces in shale	35
23. Covered	9
24. Sandstone, moderate-yellowish-brown, very fine grained, massive to platy; contains irregular ripple marks	12
25. Clay shale, silty shale, claystone, and siltstone, interbedded; nodular to platy, moderately calcareous	12
26. Sandstone and sandy siltstone; medium-gray to pale-olive-gray, very fine grained, moderately calcareous; with 4- to 6-in. platy partings; contains 2-ft layer of irregular, nodular, and concretionary sandstone; concretions as much as 2 ft in diameter covered with thin layers of mudstone. Remainder of unit contains irregular ripple marks, worm trails, mud lumps, and carbonaceous fragments	7

	Thickness (feet)
27. Partly covered. Siltstone and silty shale, medium-dark-gray, platy to nodular	7
28. Snow covered	18
29. Sandstone, medium-light-gray to pale-yellowish-brown, very fine to medium-grained, slightly calcareous to noncalcareous, very resistant; lower third of unit massive to platy; middle third flaggy with shaly layers and carbonaceous partings; upper third massive to flaggy and coarser grained. Sample 49ASa108; porosity 6.2 percent, permeability 5 millidarcys	49
30. Siltstone and silty shale interbedded, medium-dark-gray, blocky to platy to nodular; with abundant plant fragments	13
31. Sandstone, light-gray, fine-grained, noncalcareous; contains few carbonaceous fragments and poorly defined pelecypod molds	3
32. Covered. Few traces in hillside. Poorly resistant unit, probably interbedded siltstone and shale	200
33. Covered along river, resistant trace along hillside probably sandstone or siltstone. Thickness estimated	30
34. Covered. Poorly resistant unit, probably siltstone and shale	160
35. Mostly talus covered. Includes in descending order: light-olive-gray to medium-gray platy siltstone with ½- to 4-in. partings; carbonaceous cross-bedded ripple-marked siltstone; light-olive- to light-gray hard platy to massive siltstone; interbedded siltstone, silty shale, and clay shale	265
36. Covered	92
37. Silty shale, olive-gray, fissile to blocky	12
38. Siltstone and silty shale interbedded	5
39. Siltstone, light-olive- to olive-gray, blocky to nodular, gnarled, lenticular	3–5
40. Siltstone and silty shale; interbedded; similar to units 35 and 37	5
41. Siltstone; as in unit 39, but massive	2
42. Siltstone and some clay shale; siltstone light olive gray to olive gray, fissile to blocky, with some thin nodular beds, gnarled appearing, irregular and lenticular	25
43. Siltstone, light- to light-olive-gray, sandy in part, slightly calcareous, hard; platy to massive irregular beds and lenses 2 to 14 in. thick; iron stained in part	3
44. Siltstone, light-olive-gray, shaly, noncalcareous, poorly consolidated; contains carbonaceous fragments	3
45. Covered	50
Fault. Displacement probably small	(?)
46. Sandstone and sandy siltstone, light-gray, slightly to moderately calcareous, well indurated; platy to massive beds 1 to 6 ft thick; contains a few ironstone nodules and clay pellets, very little carbonaceous material, lenticular, with low to moderate porosity. Sample 49ACh112; porosity 11.2 percent, permeability 5 millidarcys	30
47. Partly covered; mostly fissile silty shale, with some nodular iron-stained claystone, and hard siltstone beds 2 to 8 in. thick and lenses 3 to 12 in. thick; several nodular siliceous ironstone layers 2 to 4 in. thick near top of unit. Sample 49ACh111: *Tritaxia manitobensis* Wickenden	110
48. Siltstone, light-olive-gray, sandy, thin-bedded, hard, slightly calcareous, micaceous, contains minute crossbedding with carbonaceous laminae; some interbeds of silty shale. Grades downwards into unit below	22
49. Sandstone, light- to yellowish-gray, very fine grained, massive, hard, slightly calcareous; contains carbonaceous fragments and laminae, iron-stained patches, and crossbedding	2–3
50. Covered by frost heavings of silty shale and clay shale	15
51. Sandstone; similar to unit 49	4
52. Covered; probably shale	10
53. Siltstone, light-olive-gray, massive, well-indurated, highly calcareous, somewhat iron-stained	4
54. Mostly covered; talus of light-olive-gray to dark-gray thin-bedded siltstone, dark-gray silty shale and clay shale, and some medium-gray sandy siltstone containing coaly fragments	50
55. Sandstone, light-gray, very fine grained to silty, massive, hard, micaceous, lenticular, slightly calcareous; with abundant carbonaceous layers	3–4
56. Covered; probably siltstone	10
57. Siltstone, light-olive-gray, moderately hard, irregularly bedded; with carbonaceous and micaceous laminae	15
58. Siltstone; as in unit above	4
59. Covered; probably shale	20
60. Sandstone as in unit 55	2–4
61. Siltstone, silty shale, and clay shale; interbedded; siltstone as in unit 57, in irregular beds 1 to 12 in. thick; shale units 4 to 12 in thick	16
62. Covered; float of siltstone, silty shale, and clay shale. Poorly preserved pelecypods. Sample 49ACh108f: *Arctica* sp., *Panope* sp., *Solecurtus* n. sp., *Tancredia* n. sp	90
63. Mostly covered. Few resistant traces of sandstone and siltstone	1, 100
Total thickness	2, 865±

Covered. Inferred contact with Torok formation.

Although the upper part of the type section is well exposed, a largely covered and poorly exposed interval of rock occurs in the middle part of the section. On the south limb of Barabara syncline, 11 miles north of the type section, rocks of the middle and upper parts of the Kukpowruk formation are well exposed along the Kukpowruk River at lat 68°24′ to 68°25′ N. This section, measured by E. G. Sable in July 1949, is described below and shown on plate 10.

Base of Corwin formation.
Kukpowruk formation (2,567+ ft):

	Thickness (feet)
1. Siltstone and very fine grained sandstone interbedded; massive to flaggy, moderately calcareous	6
2. Shale and siltstone interbedded; siltstone predominant, contains mud lumps and worm trails; some carbonaceous shale	67
3. Sandstone, medium-light-gray, very fine grained, moderately calcareous; contains coaly wood fragments	22
4. Sandstone and siltstone interbedded	16

	Thickness (feet)
5. Poorly exposed. Siltstone, silty shale, and clay shale interbedded; siltstone beds 2 to 3 ft thick in lower 60 ft, shale dominant in upper 60 ft	120
6. Sandstone, conglomeratic, gray with yellowish discoloration, fine-grained, friable, noncalcareous; contains scattered chert and ironstone pebbles. Sample 49ASa139; porosity 11.3 percent, impermeable	41
7. Mostly covered. Siltstone and silty shale in lower third of unit; shale and siltstone float in upper part	110
Note: The above 383 ft are considered transitional between marine and nonmarine rocks of the Kukpowruk and Corwin formations and are here included in the Kukpowruk formation.	
8. Silty sandstone, blocky to platy; oscillation ripple marks trend N. 60° E	12
9. Siltstone, silty shale, and clay shale interbedded, medium-dark-gray to dark-yellowish-brown; siltstone weathers dark yellowish orange	170
10. Silty shale, clay shale, and claystone, light-olive-gray, weathers dusky yellow, highly calcareous, fissile to blocky	5
11. Sandstone and silty shale; sandstone dominant, very fine grained, hard, and laminated; beds as much as 20 ft thick, contains wood fragments and mud lumps on bedding planes. Resistant unit	51
12. Siltstone and sandstone interbedded; contains poorly preserved single shells of pelecypods associated with worm trails and mud lumps	66
13. Clay shale and claystone	10
14. Sandstone and sandy siltstone, with thin interbeds of silty shale; sandstone medium gray with yellowish discoloration, constitutes upper 50 ft of unit	150
15. Poorly exposed. Silty shale and clay shale in lower 100 ft; interbedded sandy siltstone and shale in upper part; minor amounts of carbonaceous shale	230
16. Sandstone and siltstone, medium-gray, platy to blocky, slightly calcareous, slightly friable; contains scattered ironstone pebbles	57
17. Siltstone and shale interbedded; clay shale predominant	89
18. Sandstone, medium-gray, fine-grained, blocky, moderately friable; contains poorly preserved pelecypod impressions of single and opened shells	7
19. Siltstone, clay shale, and silty shale interbedded; shale dominant in lower 20 ft	26
20. Silty sandstone, medium-gray; contains pelecypod shell impressions and shells, with mud markings and clay pellets. Sample 49ASa138f: *Tancredia stelcki* McLearn, *Arctica* sp., *Entolium* sp	5
21. Siltstone, silty shale, clay shale, and claystone; interbedded; siltstone in 1- to 2-ft beds, contains oscillation ripple marks and fine crossbedding; shale and claystone 70 percent of unit, nodular to fissile. Sample 49ASa137 (includes unit 23): *Milliamina manitobensis* Wickenden, *Gaudryina*? sp	81
22. Covered by shale and siltstone talus	64
23. Siltstone, very fine grained sandstone, and silty shale interbedded; sandstone has yellowish discoloration, contains clay pellets, moderately friable, occurs in 5- to 20-foot layers	40
24. Covered. Some siltstone and silty shale	78
25. Sandstone; medium-dark-gray, fine-grained, noncalcareous, salt-and-pepper type, uniform texture; contains scattered clay pellets and ironstone nodules. Sample 49ASa136, porosity, 9.43 percent, impermeable	60–65
26. Covered	10
27. Sandy siltstone; contains carbonaceous partings, clay pellets	16
28. Covered	30±
29. Poorly exposed. Siltstone and silty shale	12
30. Covered	30
31. Sandstone, medium-gray, fine-grained, moderately friable, contains coaly wood fragments near base. Sample 49ASa135	25–30
32. Heavings of sandstone and clay shale	130
33. Sandstone, as in unit 31 but darker gray and hard	4
34. Heavings of clay shale and silty shale	43
35. Siltstone	4
36. Covered	55
37. Siltstone and sandstone interbedded	10+
38. Heavings of clay shale and silty shale	31
39. Sandstone, as in unit 31	3
40. Heavings of siltstone and shale	56
41. Sandstone, moderate-yellowish-brown, fine-grained, platy, noncalcareous	15
Covered to anticline axis	500±
Total thickness	2, 567±

Bottom of formation not exposed.

STRATIGRAPHIC RELATIONS

The contact between the Kukpowruk formation and the underlying Torok formation is gradational and intertonguing. It is mapped at the base of the lowest laterally persistent sandstone traces assigned to the Kukpowruk formation or at the break in slope which denotes the presence of resistant units of the Kukpowruk. Where the contact between the Kukpowruk and the overlying Corwin formation is exposed, it is also gradational and intertonguing. (See p. 94.)

Within the Kukpowruk formation, bed relations are in most places conformable, but evidence of at least local discordance has been observed. Within single outcrops, contacts between some units are angular and show evidence of erosional unconformity. In a south-facing cutbank of the Kukpowruk River at lat 69°02' N., several discordant contacts occur between sandstone beds in the basal part of the formation, and dips above and below the contacts differ by as much as 30°. At one contact, V-shaped fractures 1½ feet deep are present in the underlying sandstone and have been filled by deposition of the overlying bed. In another exposure along the west bank of the Kukpowruk River at lat 69°14'30" N., underlying beds of olive-gray clay-

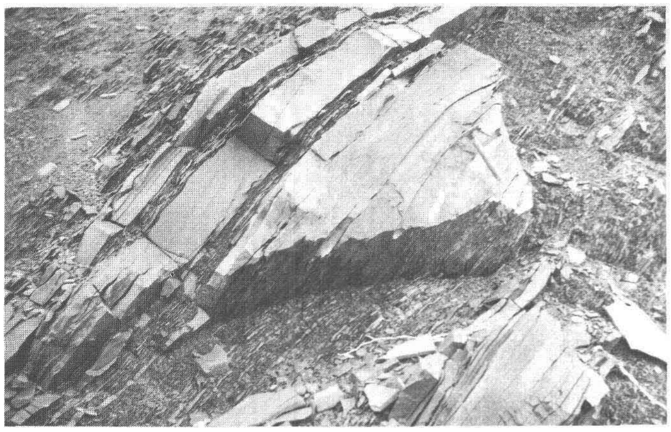


FIGURE 18.—Wedge-shaped massive siltstone interpreted as channel fill in shale and siltstone of the Kukpowruk formation. Overlying lenticular siltstone shows small-scale crossbedding. Exposure is along Kukpowruk River on south limb of Kasegaluk syncline.

stone are truncated by dark-gray shale, with 15° to 30° difference in their strikes. In many other outcrops, usually at the base of or within thick sandstone units, discordance of lesser amounts was observed. It was nowhere possible to determine the significance of such breaks in the sections; they could not be traced beyond the outcrop in which they occurred. Some bedding relations (fig. 18) may be the result of subaqueous erosion and deposition that resulted in channel filling.

Other angular relations within the Kukpowruk formation, which appear to be of greater magnitude, were located on aerial photographs of two localities and are mapped on plate 8. On the south limb of Coke basin, 2 to 3.5 miles northeast of the Kukpowruk River, about 1,000 feet of section is missing in the lower middle part of the formation. The lower part of the formation is discordantly overlain by a resistant unit in this vicinity, but elsewhere in the formation, the angular relations are not evident. On the south limb of Flintchip syncline, 4 to 5 miles west of the Kokolik River, there appear to be diverse structural trends in the general vicinity of Angle Creek, 2 miles downstream from its headwaters. Here, the apparent angular relations occur in the upper part of the Kukpowruk formation, and the stratigraphic thickness of the Kukpowruk formation, computed along Angle Creek, seems to be excessive in comparison to sections in Tupikchak basin, further south. These and other more obscure relations could not be traced for more than a mile along strike. Although the beds which show these angular relations are not contorted, the presence of unrecognized faults in these localities is not ruled out.

Still other observations of relations in the Kukpowruk formation may indicate the presence of erosional breaks in the section. In some places, if individual traces are followed completely around a synclinal structure, the traces do not return to their point of origin, but are offset as much as several hundred feet. This is particularly noticeable in the southern part of the area, in Tupikchak syncline, Flintchip syncline, and in Coke basin. As previously stated, unrecognized faults may partly or wholly account for these discrepancies. Another feature, difficult to ascribe to faulting, is the variations in thickness of the Kukpowruk formation between adjoining limbs of structural features, as discussed on pages 96–97. Thickness differences are most pronounced in the southern part of the region, mainly in Coke and Tupikchak basins and Tupikchak syncline.

Although the presence of one or more extensive erosional and tectonic hiatuses within the Kukpowruk formation has not been proved, at least local erosional breaks are believed to be present, as shown by the evidence cited above. More detailed field studies would be necessary to delineate these breaks and to establish their regional significance.

Facies changes.—Studies of the contact between the Kukpowruk and the Torok formations reveal that it changes in its stratigraphic position throughout the outcrop area. The character of the exposures permits mapping of the contact on aerial photographs of an area of more than 3,000 square miles in the northern foothills section. If the contact is traced in the field or on aerial photographs, the basal sandstone beds of the Kukpowruk formation apparently disappear under the tundra cover at numerous localities, as on the limbs of Folsom Point syncline (fig. 19). In some localities the disappearance is abrupt; in others the sandstones gradually lose their surface expression. The amount of stratigraphic section involved in these localities ranges from a few tens to several hundred feet. A significant fact in regard to the disappearance of these resistant beds is that they commonly lose their surface expression in an easterly or northerly direction and rarely in a southerly or westerly direction. Although in a few localities the apparent loss of a sandy bed can be ascribed to transverse faulting or merely to local tundra cover, many observations of outcrops along streams show that most of the resistant beds have graded laterally into shaly sections. The evidence obtained supports the conclusion that in general, northeastward facies changes from coarsely clastic units to shaly units occur in basal sections of the Kukpowruk formation; that the facies change is cumulative in this direction; and that it extends at least over the entire area of this report wherever the lower contact of the Kukpowruk formation can be

FIGURE 19.—Aerial view of Folsom Point syncline looking east, Utukok-Corwin region, Alaska. Intertonguing contact of Torok formation (Kt) and Kukpowruk formation (Knk) shown on both limbs of the syncline, and on north limb of Foggy syncline at upper right. Basal sandy sections in Kukpowruk formation grade eastward to shale mapped as Torok formation. Corwin formation occupies the axial area of syncline. Photograph by Air Photographic and Charting Service (MATS), U.S. Air Force; approximate altitude 12,000 feet.

traced. The localities where facies changes have been observed are shown by the steplike nature of the contact as mapped on plate 8.

Quantitative studies of the amount of section affected by facies changes in the Utukok-Corwin region have been made from aerial photographs in conjunction with field data. This region is unique in that it is the only large region known in northern Alaska where rocks in the basal part of the Nanushuk group are well enough exposed to permit this type of study. The conclusions drawn from the study are that basal parts of the Kukpowruk formation are equivalent to successively younger sequences of the Torok formation to the north and east, and that, cumulatively, several thousand feet of sandy section of the Nanushuk group grades to shale in those directions.

The methods used in these studies included tracing on vertical aerial photographs a resistant sandstone unit around the limbs of a large simple structural feature, measuring the stratigraphic interval between the unit and the mapped contact of the Kukpowruk and Torok formations at selected localities, thereby determining the relative stratigraphic positions of the contact along the limbs in different parts of the area. Measurements on photographs were made whenever possible in localities of good field control. If field information was lacking, dips and section thicknesses were computed by photogrammetric methods, including the solution of three-point problems by the parallax method and estimating with a visual-aid device. The limit of error of these studies is believed to be within 15 percent.

In order to determine the amount of section affected by facies change in an easterly direction, a bed in the Kukpowruk formation was chosen at a point near the east end of a syncline; the stratigraphic interval between it and the contact was determined, and the bed was then traced westward several miles along a flank of the syncline to a point at the same latitude, where the interval between the bed and the contact was again measured. In this way the relative stratigraphic positions of the contact at the two points were determined. These were plotted graphically against the lateral distance between the two points, resulting in a line that shows the average rate and direction of rise of the contact over the distance. Similar measurements were made where possible on synclines in the northern foothills and resulted in 19 individual lines which slope upward from west to east at gradients ranging from less than 1 foot per mile to 190 feet per mile. Locations of the gradient lines are shown on figure 20.

Where several individual lines lie along the same general latitude, they have been connected and plotted as sets of lines. These sets of lines show gradients sloping upward from west to east at 22 to 84 feet per mile, and they establish an average eastward-rising gradient of the Torok-Nanushuk contact of 58 feet per mile in the northern foothills. The graphic results of these studies are shown in figure 21*A*.

Similar studies along northward-trending lines established individual gradient lines sloping upward from south to north at rates ranging from less than 1 foot per mile to 350 feet per mile, and sets of gradient lines at 40 to 155 feet per mile, with an average gradient in the northern foothills of 97 feet per mile. These results are shown in figure 21*B*, and the geographic positions of the northward-trending lines are shown in figure 20.

The gradient lines and sets of lines represent the eastward and northward rates of rise of the base of the Kukpowruk formation in most of the northern foothills of this region. They also give some idea of the amount of section involved in terms of feet. Although the average gradients are about 1° or less, they indicate the "shaling" of nearly 4,000 feet of the lower part of the Nanushuk group in a northerly direction and nearly 5,000 feet in an easterly direction. If the north and east average gradients are plotted as vector quantities, the resultant or maximum gradient is 110 feet per mile at N. 30° E., as shown in figure 21*C*. This indicates that more than 10,000 feet of the lower part of the Nanushuk group grades into shaly rocks of the Torok formation from Coke basin in the extreme southwestern part of the region to Carbon Creek anticline in the extreme northeastern part.

Because the maximum gradient shows the direction of maximum facies change, the gradient lies at right angles to the direction of minimum facies change, which may be interpreted to have been the strike of belts of similar facies during deposition of the sediments. Thus the depositional strike or general shoreline direction for sediments of at least the upper part of the Torok formation and lower part of the Nanushuk group would have been N. 60° W. This is in accord with the interpretation by Payne (1951) who states that "The lithologic facies pattern of the Nanushuk and Colville groups indicates . . . west and northwest strike of belts of similar facies. . . ."

Although the resultant total footages shown from these studies may seem excessive, they represent the total amount of the section of the Nanushuk group which is lost by facies change. The footages do not represent the total of the section of the Torok formation which is equivalent to the Nanushuk group. Dominantly shale sections might be expected to be considerably thinner than their sandy equivalents, but the

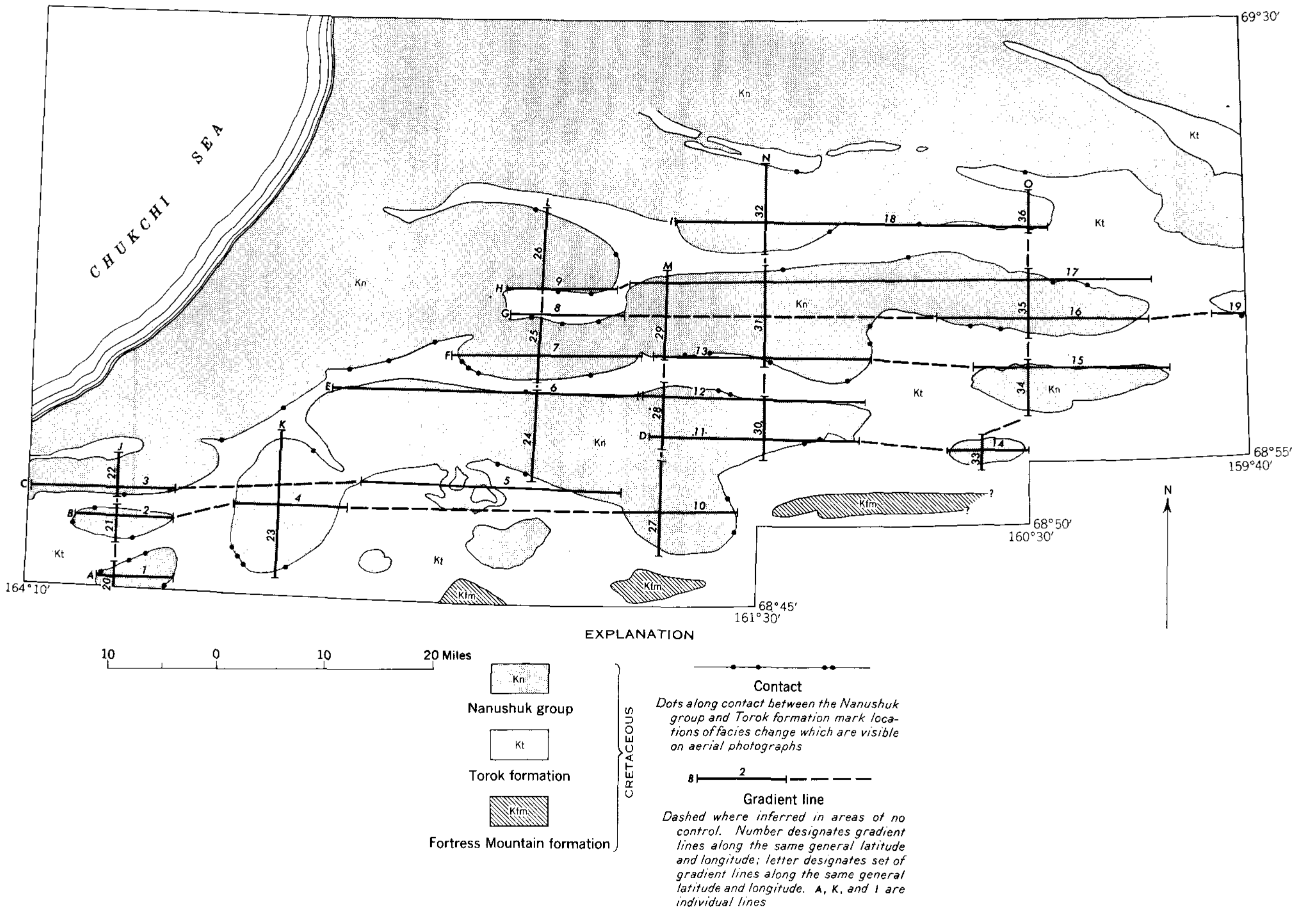


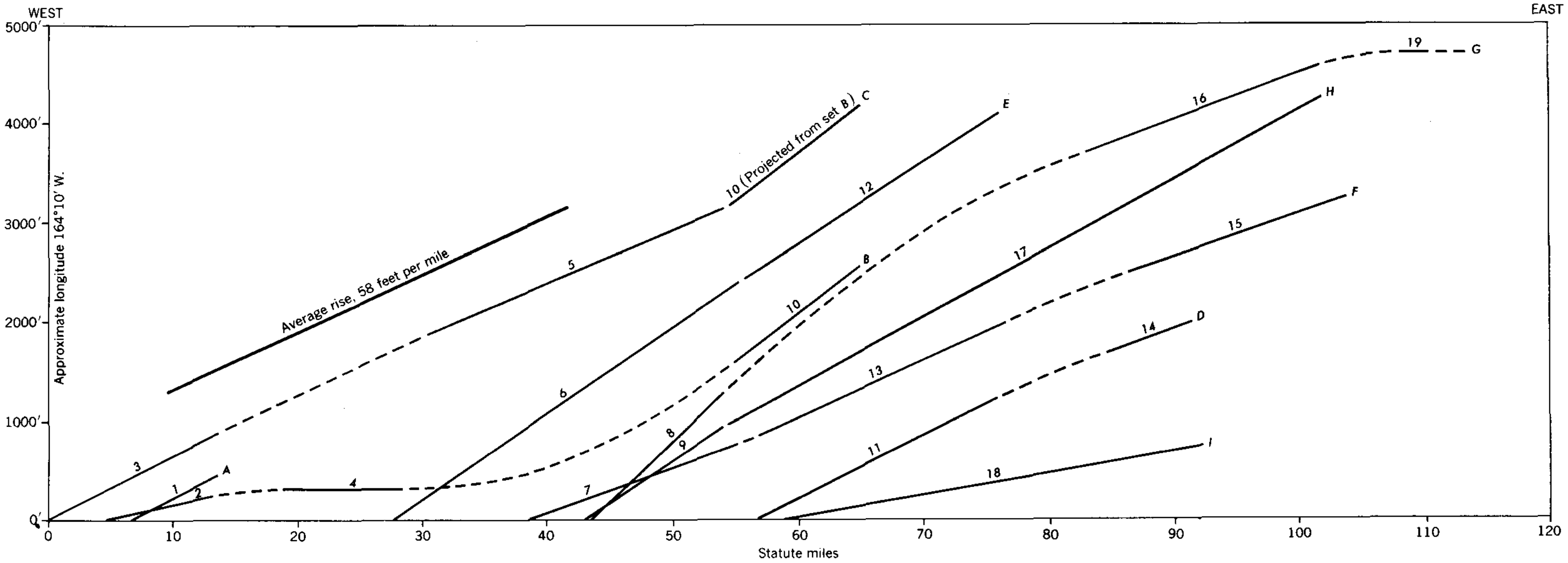
FIGURE 20.—Map showing location of gradient lines used in facies study of the contact between the Nanushuk group and Torok formation, Utukok-Corwin region.

numerical equivalence between the two facies in this region is not known.

Conclusions drawn from the facies studies are further borne out by thickness comparisons and direct correlations between sections of the Kukpowruk formation throughout the region as shown on plates 11–16 and discussed on page 97.

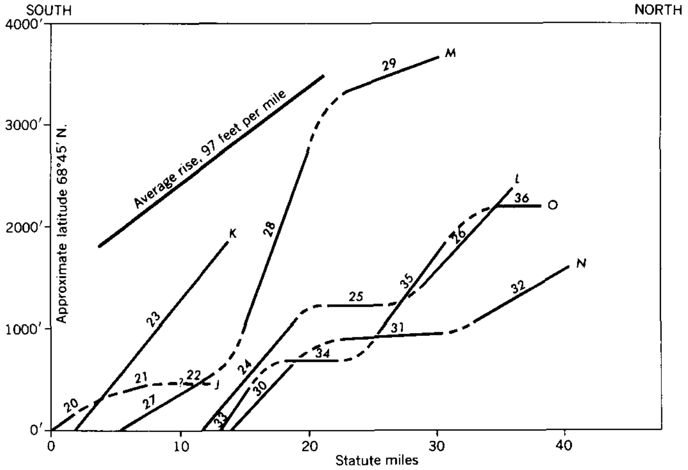
THICKNESS AND CORRELATION

The Kukpowruk formation is the only stratigraphic unit on which total thickness measurements can be made throughout most of the Utukok-Corwin region. The measurements, however, are complicated by the scarcity of good exposures and by gradational contact zones including as much as several hundred feet that occur in the basal and uppermost parts of the formation. These gradations between the Torok, Kukpowruk, and Corwin formations make the placing of contacts between these formations largely arbitrary. The lower contact of the Kukpowruk formation is placed at the base of the lowest thick relatively persistent sandstone bed, or set of beds, which is visible above the lowlands underlain by the Torok formation; or if these resistant units are not exposed, then it is placed at the bottom of the break in slope above the lowland areas which indicate the presence of the resistant units. The upper contact of the Kukpowruk formation is placed approximately where nonmarine rocks become dominant in the section and in many places is arbitrarily placed at the base of a thick sandstone or conglomerate unit in the transitional zone. Transitional zones are not shown on the map of the region (pl. 8) but are delineated in the columnar sections (pls. 11–16). These sections show thicknesses of the Nanushuk group computed from data from the large synclines in the area, as well as the position of mapped contacts, the local thickness variations, and the overall northeastward thinning of the formation. In some localities the position of contacts will vary several hundred feet depending upon the interpretation used, and this is considered in the discussion on thickness which follows. In addition to lithologic correlations, equivalent parts of the sections were correlated wherever possible by tracing rock units on aerial photographs. These cor-



A.—LINES SHOWING EASTWARD RISE OF BASE OF KUKPOWRUK FORMATION OWING TO FACIES CHANGE OF BASAL SANDSTONE UNITS

Datum is base of Kukpowruk formation at west end of Sea View syncline



B.— LINES SHOWING EASTWARD RISE OF BASE OF KUKPOWRUK FORMATION OWING TO FACIES CHANGE OF BASAL SANDSTONE UNITS

Datum is base of Kukpowruk formation on south limb of Pitmegea syncline

EXPLANATION

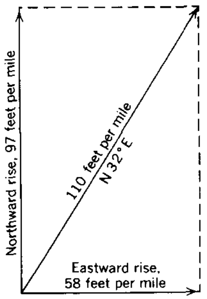
Gradient line

- - - - - ———

*Solid lines (***1–19***, eastward;* **20–36***, northward) represent rise of base of the Kukpowruk formation computed in individual structures. Sets of lines,* **A–O***, represent the rise of base of the Kukpowruk formation along different latitudes or longitudes. Dashed lines represent inferred rise in areas of no control*

Approximate positions and average rate of rise of sets of lines are as follows:

Set	Approximate latitude	Rise Feet per mile
A	68°45′	66
B	68°48′	42
C	68°50′	64
D	68°56′	55
E	69°00′	84
F	69°03′	50
G	69°06′	70
H	69°09′	73
I	69°13′	22
Set	Approximate longitude	Rise Feet per mile
J	163°50′	40
K	163°15′	155
L	162°20′	97
M	161°50′	144
N	161°28′	61
O	160°30′	86



C.—DIAGRAM SHOWING AVERAGE EASTWARD AND NORTHWARD RATES OF RISE AND MAXIMUM COMPONENT OF RISE OF BASE OF KUKPOWRUK FORMATION

Figure 21.—Lines showing eastward and northward rises of base of Kukpowruk formation owing to facies change of basal sandstone units and diagram showing average eastward and northward rates of rise and maximum component of rise of base of Kukpowruk formation.

relations show the true relative stratigraphic relations of the sections, and to some degree, thickness variations between the sections.

Table 7 shows the thicknesses of the Kukpowruk formation computed from synclines along the Utukok, Kokolik, and Kukpowruk Rivers. The table includes thicknesses of the formation as mapped on plate 8, and the possible maximum and minimum thicknesses if addition or subtraction of sections in transitional zones are considered. Thickness data that are given result from field studies in the region but should not be construed as precise figures. Although computations were carefully made, errors in planimetry and the presence of many large exposureless intervals of rock have affected results, so that computed thicknesses may be in error by as much as several hundred feet in any thick section. The computations of overall thickness are believed to be accurate within 10 percent.

Thicknesses of the Kukpowruk formation not shown in table 7 include an estimated total thickness of 4,000 to 5,000 feet in Pitmegea syncline, and an estimated partial thickness of 1,300 feet in Igloo Mountain syncline. Measured partial thicknesses include 1,700 feet in Poko Mountain syncline, 2,300 feet in Meat Mountain syncline, and 900 to 1,000 feet in Foggy syncline.

The Kukpowruk formation varies considerably in its thickness throughout the region, as shown on the columnar sections (pls. 11–16). Although the thickness variations are locally irregular, they show a pronounced northeastward thinning of the formation from more than 5,000 feet to about 2,000 feet. This thinning is believed to be due to the facies change of sandy sections to shale in basal parts of the formation (p. 91–94). From this evidence, it might be expected that the formation is represented by a predominantly shale section in the coastal plain north of the Utukok River, and such appears to be the case in Kaolak test well 1, 37 miles northeast of Carbon Creek anticline (Collins, 1958). Here the Kukpowruk formation is virtually indistinguishable as a lithologic unit, and although several sandstone units as thick as 25 feet occur below the coaly sequence in the interval from 4,600 to 6,750 feet in the well, the section is about 90 percent shale.

If only thicknesses delimited by mapped contacts are considered (table 7), rapid and erratic variations of thickness are apparent in many parts of the region. If maximum limits of thicknesses are compared, however, the variations are greatly reduced although some anomalous changes still exist. These thickness variations may be due to erosional and tectonic breaks in the sequence or may be caused by depositional conditions affected by preexisting structural features or sudden changes in the strand line.

The greatest local variations of thicknesses in the Kukpowruk formation occur in the southern part of the region, south of Blizzard anticline. Northward thinning is especially marked in Tupikchak syncline and Tupikchak basin. Even when possible maximum and minimum thicknesses are compared, the Kukpowruk formation exhibits northward thinning of more than 900 feet in these synclines over distances of a few miles. Between Tupikchak basin and Flintchip syncline, however, the formation thickens northward more than 1,300 feet in a few miles. A northward thickening of at least 400 feet and possibly as much as 1,500 feet in 10 miles also occurs in Coke basin. At

TABLE 7.—*Measured thicknesses of the Kukpowruk formation showing possible maximum and minimum limits where exposed in synclines along major rivers*

Kukpowruk River					Kokolik River					Utukok River				
Structural feature	Limb	Mapped thickness (feet)	Max. possible thickness (feet)	Min. possible thickness (feet)	Structural feature	Limb	Mapped thickness (feet)	Max. possible thickness (feet)	Min. possible thickness (feet)	Structural feature	Limb	Mapped thickness (feet)	Max. possible thickness (feet)	Min. possible thickness (feet)
Coke basin	South	[1] 4,509	6,370	3,467	Tupikchak basin	South	[1] 2,749	4,420	2,749	Meat Mountain syncline.	South	2,288+	--------	--------
Do	North	[1] 5,993	7,548	4,127	Do	North	[1] 1,750	3,020	1,750					
Tupichak syncline.	South	[1] 4,824	6,031	4,126	Flintchip basin	South	[1] 3,781	4,693	3,113	Flintchip syncline.	South	[1] 1,923±	--------	--------
Do	North	[1] 3,700	5,030	3,210	Do	North	[1] 3,431	4,131	3,012					
Kukpowruk syncline.	South	[1] 4,382	5,190	4,160	Kokolik Warp syncline.	South	[1] 3,461	4,051	3,036	Kokolik Warp syncline.	South	1,820	2,250	--------
					Do	North	[1] 4,208	4,708	4,038					
Deadfall syncline.	West	[1] 3,478+	3,478+	3,367	Deadfall syncline.	East	[1] 2,756	3,266	2,596	Folsom Point syncline.	South	[1] 2,129	2,431	--------
Howard syncline.	South	[1] 2,865+(?)	2,865+	2,675+	Howard syncline.	South	[1] 2,380	2,812	1,952	Lookout Ridge syncline.	South	[1] 1,994	2,084	--------
Do	North	1,479+	1,848+	971+	Do	North	[1] 2,074	2,652	1,970					
					Oxbow syncline	South	[1] 1,844	2,363	1,782	Oxbow syncline	North	[1] 2,040	2,620	--------
Barabara syncline.	South	2,567+	2,783+	2,185+						Elusive Creek syncline.	South	[1] 2,001	2,280	987

[1] Total thickness.

least local angular relations between rock units of the Kukpowruk formation have been observed in the south limbs of both Coke basin and Flintchip syncline (p. 91) and one or more erosional breaks may be responsible for the anomalous northward thickening in these localities. The amount of eastward thinning of the Kukpowruk formation south of Blizzard anticline is at least 1,300 feet and more likely as much as 3,000 feet in 45 miles.

Farther north, in the group of synclinal structures between Blizzard anticline and Archimedes Ridge anticline, the formation thins at least 800 feet northward between the Kukpowruk and Deadfall synclines on the Kukpowruk River and at least 800 feet between the Kokolik Warp and Deadfall synclines on the Kokolik River. The eastward thinning of the formation between the Blizzard and Archimedes Ridge anticlines is about 1,300 feet in 55 miles.

North of Archimedes Ridge anticline the formation thins eastward about 800 feet in 60 miles, but northward changes in thickness between the maximum limits shown in table 7 appear to be relatively small. The thickness of the Kukpowruk formation in the Elusive Creek syncline as mapped is about 2,000 feet but mght be interpreted to be as little as 987 feet. The lower 1,014 feet of the formation is predominantly shale with a few resistant sandstone units at the base and could be mapped in the Torok formation on a lithologic basis. This lower section is overlain by 987 feet of sandstone and shale typical of the Kukpowruk formation. The high percentage of shale in the lower section is due to a northward facies change from an equivalent but more sandy section in the lower part of the Kukpowruk formation exposed 4 miles south on the north limb of Lookout Ridge syncline.

Correlations, made by tracing rock units on aerial photographs, indicate that the base of the Kukpowruk formation rises northward and eastward relative to given datum horizons. The rates of rise compare generally with the results obtained from the facies change studies discussed on pages 91–94. The correlations northward along the major rivers are shown on plates 11, 12, and 13, and the correlations eastward within 3 structural belts are shown on plates 14–16. The correlations are limited in scope, as beds can seldom be traced between structural features because of intervening exposureless areas underlain by the Torok formation or because of complexly folded anticlines. Consequently, correlations along each river are not continuous, and eastward correlations are possible only under the most favorable structural conditions. The correlated sections along the Kukpowruk River (pl. 11) indicate that the base of the Kukpowruk formation rises northward at the rate of at least 3,500 feet in 40 miles relative to its datum, the base of the formation on the south limb of Coke basin. On the Kokolik River (pl. 12) the base of the formation rises northward more than 3,800 feet in 37 miles, relative to the base of the formation on the south limb of Tupikchak basin. It was possible to make only local correlations along the Utukok River (pl. 13). The rise of the base of the formation from a section in the Kokolik Warp syncline to one in the Folsom Point syncline, 5 miles to the northeast, appears to be relatively small and totals about 300 feet. Likewise, its rise between sections in the Lookout Ridge and Oxbow synclines amounts to about 200 feet in a northwest distance of 12 miles.

Eastward correlations of sections by direct tracing of beds were made along the Tupikchak–Flintchip syncline belt (pl. 14), the Kokolik Warp–Folsom Point syncline belt (pl. 15), and along the south limb of the Kasegaluk and Howard synclines (pl. 16). In the Tupikchak–Flintchip belt, the apparent rise of the base of the formation is more than 6,000 feet in 43 miles. In the Kokolik Warp–Folsom Point or more northerly belt, the rise is at least 1,800 feet in 26 miles; and in the northernmost Kasegaluk and Howard synclines, it is more than 2,300 feet in 54 miles.

As previously discussed, the Kukpowruk formation thins northeastward. The rate of northeastward thinning, however, is considerably less than the rate of rise of the base of the formation as determined from the studies of facies change. The formation is therefore believed to rise northeastward relative to its stratigraphic position in the southwestern part of the region, and therefore, to cross depositional time lines. From this evidence, and assuming that deposition of the upper part of the Torok formation and the Nanushuk group was essentially continuous, at least the lower part of the formation is therefore equivalent in a time sense to part of the Torok formation, and at least the upper part is equivalent to part of the Corwin formation. In the correlated columnar sections of the Kasegaluk and Howard synclines (pl. 16), it is clearly shown that the lower part of the Corwin formation on the Kukpowruk River is equivalent to part of the Kukpowruk formation on the Utukok River. If significant erosional unconformities exist within the Nanushuk group throughout the region, however, this interpretation would be invalid. No unconformable relations have been recognized in northern parts of the region, such as in Howard syncline, and most of the evidence favors the interpretation made above.

As a lithologic unit, the Kukpowruk formation is similar to the Grandstand formation of the Chandler

River and adjoining areas of northern Alaska (Bickel, oral communication, 1952). It differs from the Tuktu formation of those areas in the generally cleaner character of the sandstones, the absence of dominantly greenish sandstones and siltstones, and the less abundant marine fauna.

FOSSILS AND AGE

The most abundant fossils in the Kukpowruk formation are pelecypods, with fewer gastropods, worm tubes, and trails. Brittle stars, starfish, and ammonites are relatively rare. Fossils are most common in sandstone and siltstone and are rare in shale beds. Most of the pelecypods are scattered or sparsely distributed in layers as molds or casts in sandstone beds, although shell material is also present. Closed and open shells, single valves, and fragmental remains are common. In shale samples the mollusks are nearly unaltered, and the chitinous outer shell layer is still preserved. Starfish are preserved as obscure impressions on the surfaces of sandstone beds, and some are associated with pelecypods.

Megafossils collected in 1947, 1949, and 1950 were identified by Ralph W. Imlay. Collections made by W. T. Foran in 1923, W. R. Smith in 1925, and P. S. Smith in 1926, previously identified by J. B. Reeside, Jr., were reexamined by Imlay, whose identifications are shown in table 8. Fifteen genera and questioned genera are present in 47 samples from the Kukpowruk formation.

The most abundant pelecypods include *Arctica* (in 22 samples), *Tancredia* (21 samples), *Entolium* (14 samples), and *Panope?* (14 samples), all of which range through most or all the Kukpowruk formation. *Arctica* sp. and *Panope? kissoumi* (McLearn) (7 samples) range downward into the upper part of the Torok formation. *Tancredia stelcki* McLearn (6 samples), *Tancredia* n. sp. (8 samples), and *Entolium* n. sp. (11 samples), have been found only in the Kukpowruk formation. Less abundant faunas include *Camptonectes* n. sp. (5 samples) from the Kukpowruk formation, *Flaventia?* n. sp. (3 samples) from the Torok and Kukpowruk formations, and brittle stars and starfish (5 samples) in the Kukpowruk formation. The genus *Oxytoma* (5 samples) is present in the Kukpowruk formation; and two species, *O.* cf. *O. pinania* McLearn and *O. camselli* McLearn, are represented by single samples in the lower part of the formation. The genus *Thracia* (3 samples) from the Kukpowruk formation includes *T. stelcki* McLearn and *T.* cf. *T. stelcki* McLearn, both from the upper part of the formation. Forms represented by 1 or 2 samples each include *Inoceramus* sp. juv. and *Pleuromya* sp. from the upper part of the Torok formation; *Ditrupa cornu* Imlay (worm), from the Torok and Kukpowruk formations; *Panope elongatissima* (McLearn), *P.* cf. *P.* McLearn, and *Hamulus?* sp. from the Kukpowruk formation; *Isognomon?* sp. from the Kukpowruk; *Kirklandia?* (jellyfish), *Solecurtus* n. sp., and echinoid spines, all from the lower part of the Kukpowruk formation; and *Cultellus?* n. sp., "*Unio*," and natacoid gastropods, all from the upper part of the Kukpowruk.

Knowledge of the geographical distribution of megafossils in the Kukpowruk formation is poor because of the widely spaced and limited rock exposures. More samples of fossils were collected in the northern part of the outcrop area of the formation, generally north of lat 69°05', and a greater abundance of forms and a wider variety of individual species are known from these northern collections. These include *Entolium* n. sp., found on the Utukok and Kukpowruk Rivers; *Tancredia* n. sp., found mostly in the northeastern part of the area along the Utukok River; *Camptonectes* n. sp., and *Thracia stelcki* McLearn and *Thracia* cf. *T. stelcki* McLearn, both from the Kukpowruk River.

Based on samples collected, the upper part of the Kukpowruk formation is more fossiliferous than the lower part along the Kukpowruk River, but most of the collections from the formation on the Utukok River are from the lower part of the formation. The collections along the Kokolik River whose stratigraphic position are known lie in the middle and lower parts of the formation.

An ammonite fragment collected by P. S. Smith (Smith and Mertie, 1930, p. 224), probably from the Kukpowruk formation in the north limb of Deadfall syncline on the Kokolik River, was identified by Imlay as *Gastroplites* sp. *Gastroplites* is found in the upper part of the Torok formation and in the Tuktu and Grandstand formations in northern Alaska, east of the Utukok-Corwin region (Imlay, written communication, 1956). Another ammonite, collected from rocks in the upper part of the Kukpowruk formation along the Utukok River, was identified by Imlay as *Paragastroplites spiekeri* McLearn, and it is probably of middle Albian age.

General correlations of these faunal assemblages with those from other areas of northern Alaska and Canada have been made by Imlay (1956, written communication). As a result of these correlations, the Torok formation and the Kukpowruk formation are assigned to the Lower Cretaceous series and are not older than the late Lower Cretaceous (middle and upper? Albian).

Microfossils in shale samples from the Kukpowruk

TABLE 8.—*Megafossils collected from the Torok and Kukpowruk formations, Utukok-Corwin area, Alaska*

[Fossils identified by R. W. Imlay. A, Kukpowruk River collections; B, Kokolik River collections; C, Utukok River collections]

Mesozoic locality	Field collection	*Arctica?* sp.	*Panope? kissoumi* (McLearn)	*Flaventia?* n. sp.	*Ditrupa cornu* Imlay	*Inoceramus* sp. juv.	*Pleuromya* sp.	*Panope?* sp.	*Panope? elongatissima* (McLearn)	*Oxytoma camselli* McLearn	Echinoid spine	Brittle star	*Oxytoma* cf. *O. pinania* McLearn	*Kirklandia?* sp. (jellyfish)	Starfish undet.	*Solecurtus* n. sp.	*"Unio"*	*Gastroplites* sp.	*Hamulus?* sp.	*Thracia* sp.	*Entolium* n. sp.	*Paragastroplites spiekeri* McLearn	*Tancredia stelcki* McLearn	*Tancredia* n. sp.	*Camptonectes* n. sp.	*Oxytoma* sp.	*Tancredia* cf. *T. stelcki* McLearn	*Tancredia* sp.	*Entolium* sp.	*Isognomon?* sp.	*Thracia stelcki* McLearn	*Cultellus?* n. sp.	Natacoid gastropods	*Thracia* cf. *T. stelcki* McLearn	*Panope?* cf. *P. elongatissima* (McLearn)
Kukpowruk formation (upper part)																																			
24482	49ASa96																				A														
24466	49ACh99	A																			A	C													
24455	49ATm10 (bed 29)																							C		C									
24485	49ASa138	A																					A						A						
24481	49ASa88	A																																	
24483	49ASa110																				A				A			A							
24484	49ASa121																						A												
24467	49ACh102																														A				
24480	49ASa73	A																									A								
24465	49ACh87	A																																	
24471	49ACh120																																		A
24478	49ASa71																						A												
24479	49ASa72	A																																	
24470	49ACh117		A																												A				
24488	49ASa187	B																														B	B		
24476	49ASa60																						A		A					A				A	
Kukpowruk formation (middle part)																																			
12178	23AF100, 101	A																						A											
13310[1]	25ASmF6	C																																	
13720	26AS45														B																				
13721	26AS48	B						B												B	B														
13723	26AS49	B						B																				B							
13728[1]	26AS60																	B																	
13729	26AS61	B																										B							
13730	26AS66																		B																
24457	47ATm12																				C														
Kukpowruk formation (lower part)																																			
24472	49ACh153																B																		
24468	49ACh108	A						A								A								A											
24454	47ATm10 (bed 16)	C											C								C			C	C										
24451	47ATm5							C																					C						
24458	47ATm13	C																			C		C	C						C					
25306	50ASv11																				C														
25918	53ABi64				C									C																					
25809	50AWh10											C																							
25810	50AWh9																				C														
24461	49ACh54	A																																	
24473	49ACh176			B																							B								
24474	49ACh177	B																																	
24464	49ACh71																																		
24469	49ACh115	A	A	A							A	A									A					A		A							
24460	47ABa52																				C			C	C	C									
24452	47ATm9	C								C														C											
24456	47ATm11								C																										
24459	47ABa34	C						C																					C						
24453	47ATm10 (bed 10)																						C	C	C										
24462	49ACh61																																		
24486	49ASa165	B	B																									B							
24487	49ASa165A		B																		B														
Torok formation																																			
24477	49ASa65		A																																
24475	49ACh182			B																															
24463	49ACh62		A																																
13717[1]	26AS37				C																														
24480	50ASa32	A	A			A	A																												
Total number of samples that contained fossils		22	7	3	2	1	1	5	1	1	1	2	1	1	3	1	1	1	1	1	12	1	6	8	5	3	2	5	3	1	2	1	1	1	1

[1] Exact position not known; Torok or Kukpowruk formations.

TABLE 9.—*Known occurrences of microfossils on the north limb of Carbon Creek anticline, Utukok River*

[Fossils identified by H. R. Bergquist. Abundance of fossils as indicated by number of specimens per sample: F, 1-6; R, 7-12; C, 13-25; A, more than 25. Samples collected by R. S. Bickel in 1953]

Field collection	Foraminifera																																Other fossils					Approximate stratigraphic position (in feet above base of section)
	Barren samples (x)	*Haplophragmoides topagorukensis* Tappan	*Tritaxia manitobensis* Wickenden	*Trochammina* sp.	*Pallaimorphina ruckerae* Tappan	*Miliammina awunensis* Tappan	*Verneuilinoides borealis* Tappan	*Glomospira corona* Cushman and Jarvis	*Astacolus incrassatus* (Reuss)	*Saracenaria* sp.	*Globulina lacrima* Reuss	*Eurycheilostoma grandstandensis* Tappan	*Saccammina lathrami* Tappan	*Gaudryina canadensis* Cushman	*Marginulina planiuscula* (Reuss)	*Dentalina* sp.	*Nodosaria* sp.	*Rectoglandulina* sp.	*Globulina* sp.	*Ammobaculites wenonahae* Tappan	*Lenticulina macrodisca* (Reuss)	*Gavelinella stictata* (Tappan)	*Bathysiphon brosgei* Tappan	*Ammodiscus rotalaria* Loeblich and Tappan	*Psamminopelta bowsheri* Tappan	*Astacolus* sp.	*Saracenaria spinosa* Eichenberg	*Vaginulina* sp.	*Conorboides umiatensis* Tappan	*Miliammina manitobensis* Wickenden	*Gaudryinella irregularis* Tappan	*Spiroplectammina ammovitrea* Tappan	*Inoceramus* sp.	*Ditrupa cornu* Imlay	Crinoids	Spores	Ostracodes	
Kukpowruk formation (upper part, 220 ft exposed)																																						
53ABi72	X																																					1,219-1,249
53ABi71		F																																				1,123-1,183
53ABi70		F	C	C	F	F?																																
53ABi69	X																																					
53ABi68		C					F																															
53ABi67		F																																				
53ABi66		F				F																																1,090-1,105
Kukpowruk formation (lower part, 1,020 ft thick)																																						
53ABi65		C			F			F	F	F?	F	F																						F?		F	F	539-1,067
53ABi64		C			A	F	R				F	A	F	F	R	F	F	F															F					
53ABi63		C					F					F	F	F	F				F?																			
53ABi62		R			F		F			F		F								F?																		
53ABi61					F															F																		
53ABi60		C			C		R				F		F		F					R?	F	F	F															
53ABi59		R			F		F			F?					F		F							F	F													
53ABi58		F			F								F																									
53ABi57		C			R		C				F				F					F?		F		F	F?	F									F			
53ABi56		R			R		F					F	F								F																	
53ABi55		C			R		C				F				F									F			F?	F?										
53ABi54		F			F		R																						F									
53ABi53		R			R		F																	F			F											
53ABi52		R			R		F?						F							F?				R			F											
53ABi51		F					F																F															
53ABi50		C											F										F						F	F								
53ABi49		C	F		F								F						F	F?			F	R							F?							
53ABi44–53AB148	X																																					400-539
53ABi43		F			F		F																	F														
53ABi42		F					F																															
53ABi41		R	F				R																F	R														
53ABi40		R					F						F										F	R								F?						
53ABi39		R	R				R						F							F?				C								F						
53ABi38		F					F						F																									
53ABi37		F																																				193-208
53ABi36	X																																					53-75
Torok formation (upper part 90 ft exposed)																																						
53ABi35	X																																					0-53
53ABi34													F											F														
53ABi33		F											F							F?																		
53ABi32		F											F																									

formation consist of about 30 species of Foraminifera, a few charophytes, and rare occurrences of ostracodes and Radiolaria. Fragments of *Inoceramus* sp., *Ditrupa cornu* Imlay, and crinoids are also rare. Samples were collected from scattered exposures along the Utukok River (table 3), the Kokolik River (table 4), and the Kukpowruk River (table 5). The section on the north flank of the Carbon Creek anticline was sampled more intensively than the other sections and contained the most fossiliferous samples and greatest number of species in the Utukok-Corwin area (table 9). H. R. Bergquist states:

> The fauna of the Kukpowruk formation is a part of the *Verneuilinoides borealis* faunal zone, which is present in the upper part of the Torok formation, the overlying Tuktu and Grandstand formations, and much of the Topagoruk formation (in the Colville River region of northern Alaska). Species of Foraminifera found in the Kukpowruk formation constitute about half of the total known in the *Verneuilinoides borealis* faunal zone. Charophytes were found in a few samples.
>
> Besides *Verneuilinoides borealis* Tappan, the fauna of the Kukpowruk formation is characterized by *Haplophragmoides*

topagorukensis Tappan, *Ammobaculites wenonahae* Tappan, *Tritaxia manitobensis* Wickenden, *Gaudryina* sp., *Pallaimorphina ruckerae* Tappan, *Gavelinella stictata* (Tappan), *Conorboides umiatensis* Tappan, *Eurycheilostoma grandstandensis* Tappan, *Marginulina planiuscula* (Reuss), *Lenticulina macrodisca* Reuss, and *Globulina lacrima* Reuss. The latter three, although relatively rare, are important in helping affix an Albian age for the fauna. A species such as *Saccammina lathrami*, though common in some samples, has no significance in the fauna as it ranges throughout the entire Cretaceous sequence in northern Alaska. Specimens of *Haplophragmoides topagorukensis*, however, are found throughout the Albian strata of northern Alaska; but the species is an integral part of the *Verneuilinoides borealis* fauna, and in the Kukpowruk it is the most numerous one.

In general the specimens of Foraminifera from the Kukpowruk formation are more poorly preserved than is usually true for the *Verneuilinoides borealis* faunal zone from most other areas in northern Alaska. Identification is thus sometimes rather difficult. Almost all the arenaceous specimens are distorted by compression, and many are flattened and rolled out. Most of the specimens are dark tan or brown. Some specimens, such as those of *Verneuilinoides borealis*, seem to be dwarfed as compared to the robust specimens frequently found in samples from other areas. Calcareous specimens have escaped distortion, as they are filled with calcite and more rarely with pyrite, but all have a weathered or frosty appearance.

The specific stratigraphic range and lateral distribution of most of the microfossil species in the Utukok-Corwin region are not known from present information. Many of the species, as shown on the accompanying tables, range upward into the Corwin formation and downward into the Torok formation. Others which may be restricted to the Kukpowruk formation were found only in a few localities. The authors feel that the number of samples collected in the region is insufficient to provide a representative coverage, and that more intensive sampling is required to evaluate the range and distribution of the fossils properly.

CORWIN FORMATION

NAME AND DEFINITION

One of the names used in the early classification of rock sequences in northern Alaska was the Corwin series, proposed for a series of sedimentary rocks along the northwest coast of Alaska from Wainwright Inlet nearly to Cape Lisburne (Schrader, 1901, p. 72–74). The name was taken from Corwin Bluff "where rocks typical of the series are exposed." Relations to rocks observed inland in northern Alaska were uncertain, but the series was suggested by Schrader to be correlative with coal-bearing rocks in the Colville River valley and was believed to be of Jurassic and Cretaceous age. Following later studies of the rocks in the Corwin Bluff area, a Jurassic age was assigned to the Corwin series, and it was renamed the Corwin formation by Collier (1906, p. 27–30). As a result of the present investigations, the Corwin formation was redefined and restricted to the predominantly nonmarine facies of the Nanushuk group which overlies and intertongues with the Kukpowruk formation, and which underlies rocks mapped as the Prince Creek formation of the Colville group in this region (Sable, 1956). The type locality of the Corwin formation is in the Corwin Bluff vicinity and is defined as the rocks exposed from a point 0.6 mile west of Thetis Creek 11 miles westward to Risky Creek and thence about 0.3 mile upstream along Risky Creek. This section is lithologically similar to the nonmarine sequence of the Nanushuk group farther inland and is also thought to be correlative because it contains a like flora.

DISTRIBUTION AND OCCURRENCE

The Corwin formation is exposed in the axial areas of all the major synclines in the northern foothills section that are cut by the Utukok, Kokolik, and Kukpowruk Rivers, with the exception of the Foggy, Meat Mountain, Poko Mountain, and Igloo Mountain synclines. It is also believed to be present in synclines in the vicinity of the Pitmegea River, with the possible exceptions of the Dugout and Seaview synclines, and has been recognized along the northwest coast from Cape Beaufort to the vicinity of Ikikileruk Creek, and from the mouth of the Pitmegea River to a point about 1½ miles west of Risky Creek. The absence of the formation in the synclines named above is due to erosion and not to nondeposition. Sediments of the Corwin formation are believed to have been deposited everywhere in the region discussed in this report. The present southern limits of exposures of Corwin formation lie within this region, with the excepton of some rocks in the Pitmegea syncline and in the belts of exposures that extend southeast from Corwin Bluff. However, these belts probably do not extend more than a few miles south of the mapped region. Exposures of the Corwin formation cover about 30 percent of the northern foothills section in the Utukok-Corwin region.

Most exposures of bedrock in the coastal plain belong to the Corwin formation, and it is believed to be the most widespread formation underlying the surficial cover of that province in the mapped region. A coal-bearing section, believed to be correlative with the Corwin formation, is present under unconsolidated surficial deposits between depths of 113 and about 4,600 feet in Kaolak test well 1.

The Corwin formation produces topographic features similar to those developed on the Kukpowruk formation, but the topography is more subdued and lacks the high persistent ridges of the Kukpowruk. Locally, relief is usually less than in areas where the

Kukpowruk formation is exposed. In interstream areas the resistant sandstone and conglomeratic units form ledges, low cliffs, and rubble traces, many of which can be followed for several miles along strike. These are separated by units of less resistant rocks, which are predominantly tundra-covered but locally exposed by frost heaving. Typically, a series of dip slopes broken by resistant ledges and traces slope toward the axial zone of a syncline, and flat-lying beds in the axial zone commonly form terraced buttes. Weathering of sandstone and conglomerate forms some rock spires and pedestals as high as 50 feet, but these are not as common as rock traces, ledges, and cliffs. Many of the massive resistant units have well-developed joint sets and joint blocks as much as 40 feet across that litter the slopes in these localities, as in Tupikchak basin.

Stream-cut exposures are restricted to the major rivers and their larger tributaries and rarely are more than a few hundred feet long. Larger stream cuts include the nearly continuous exposures along the lower Kukpowruk River in the Howard and Deep synclines. Rocks in the wave-cut cliffs in the vicinity of Corwin Bluff are also almost totally exposed, but inland exposures there are limited almost entirely to resistant units.

CHARACTER

The Corwin formation is distinguished from the Kukpowruk formation by the presence of coal, coaly shale, and abundant ironstone; the greater abundance of plant remains; a higher percentage of iron-weathering products; the general absence of fossil fauna; and the presence of bentonite in the upper part of the formation. In general, rocks of the Corwin formation are less calcareous than rocks of the Kukpowruk formation. One of the most distinguishing features of rock traces and rubble hills of the Corwin formation are the orange-, reddish-, and yellowish-weathering colors in contrast to the darker yellowish-brown and brownish hues of the Kukpowruk formation. This is a conspicuous gross feature when viewed from a distance. The difference in weathering color facilitates general delineation of the 2 formations, but in detailed mapping the contact between the 2 formations is more difficult to recognize. On black and white photographs the formations are difficult to distinguish, but traces and heavings of the Corwin formation generally appear to be much lighter in tone and contain many whitish areas of mud heavings and fewer closely spaced resistant beds and traces.

Rocks of the Corwin formation are almost entirely of nonmarine coastal facies, although some thick conglomerate beds may represent an inland facies, and at one locality fossiliferous rocks of marine inshore facies were recognized. (See p. 124.) Interbedded silty shale, clay shale and claystone, siltstone, sandstone, coaly shale, coal, ironstone, conglomerate, clay, and bentonite, in approximate decreasing order of abundance, constitute the rock types of the Corwin formation (fig. 22). The relative percentages of these rocks can be compared in only a few localities where they are well exposed, such as along the Kukpowruk River in Kasegaluk and Barabara synclines and in the Corwin Bluff locality. Shale, claystone, and thin-bedded siltstone and sandstone make up about 80 percent of the section in Kasegaluk syncline, 90 percent in Barabara syncline, and 70 percent in the Corwin Bluff locality. Sandstone, siltstone, conglomerate, and conglomeratic sandstone beds more than 5 feet thick constitute 15, less than 10, and 25 percent, respectively, of these 3 sections. Coal constitutes less than 5 percent of the 3 sections but is locally more abundant in parts of the formation. Other rocks constitute less than 1 percent of the sections, with the exception of ironstone which is estimated at about 2 percent.

The silty shale, clay shale, and claystone of the Corwin formation are like those in the Kukpowruk formation but include yellowish-brown and yellowish-gray color phases as well as the more abundant neutral gray hues common to both formations. They also bear more numerous carbonaceous plant remains and ironstone, are more ferruginous, and weather dull to bright yellowish orange and yellowish gray. The shales and claystone occur in beds as much as several inches thick and in sets of beds as much as several hundred feet thick.

Siltstone and sandstone beds not more than a few feet thick are mutually interbedded, or interbedded with other rocks, in resistant units as much as 90 feet thick. Although these rocks resemble those of the Kukpowruk formation, they also have many nonmarine features. Conglomeratic sandstone and conglomeratic lenses are more abundant in the Corwin formation, as are carbonaceous and coaly fragments and partings, coaly "vugs," plant remains, and ironstone nodules. Ironstains are also more common in the Corwin formation and extend as deep as one-half of an inch below the rock surface. Common weathering colors are light brown, dark and pale yellowish orange, gray, and more rarely yellowish brown and grayish yellow, although colors of fresh rock surfaces do not differ markedly from those in sandstones of the Kukpowruk formation. Clay pellets and ripple marks are less abundant in the Corwin formation, and ripple marks, where observed, were of smaller dimensions than those in the Kukpowruk formation. Thick sandstone beds commonly contain massive crossbeds with foreset beds as much as 3 feet thick inclined as much

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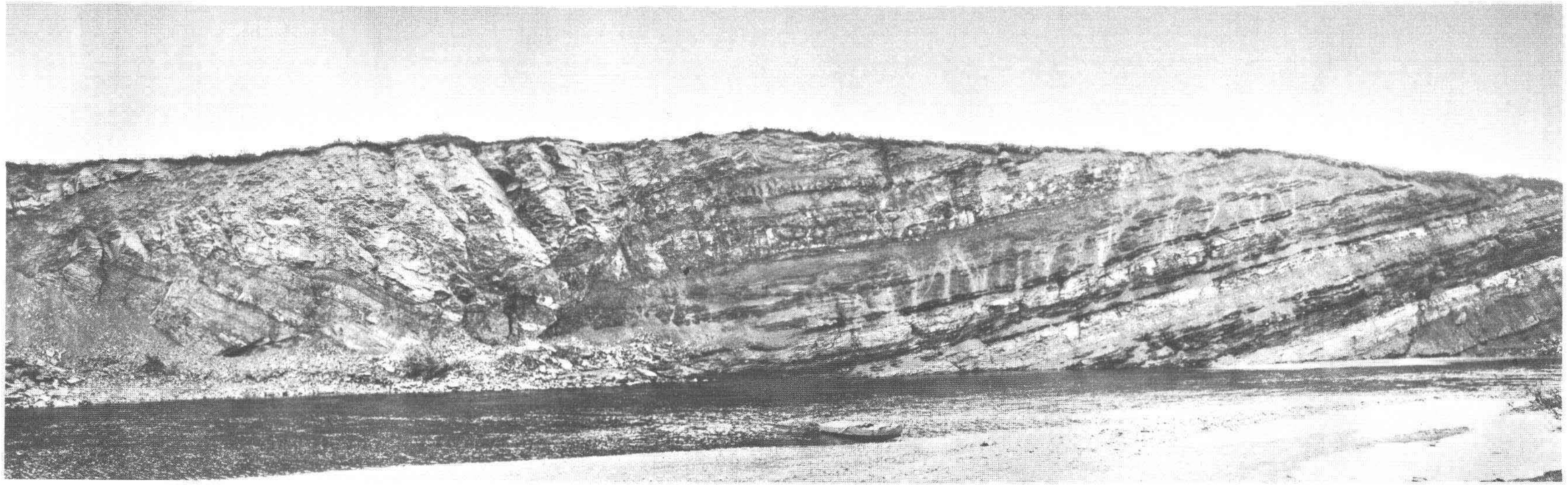

FIGURE 22.—Interbedded shale, sandstone, siltstone, and coal of the Corwin formation, south limb of Coke basin, Kukpowruk River. Small-scale faults in left part of picture.

as 25° from the topset beds. These rocks range from very hard to friable, and some sandstone in the uppermost part of the formation in Barabara syncline is nearly unconsolidated. The more friable types commonly weather to spheroidal blocks. Sandstone in the southern part of the area is in general more abundant and contains more coarse-grained phases than that in the northern part. Other features are identical with those in sandstone and siltstone of the Kukpowruk formation.

As in the Kukpowruk formation, many sandstone and siltstone beds in the Corwin formation are highly lenticular and in single outcrops can be seen to pinch out abruptly or thin and grade laterally to shale. This is a common feature in the type section of the Corwin, and many of the coarser clastic beds thin and grade eastward to shale and siltstone. Although the main source of sediments for the Corwin formation in most of the region is believed to have been to the south, the above feature suggests that the source area of the sediments in the southwestern part of the region was mainly to the west.

Bituminous coal, bone coal, and coaly shale, in beds ranging from a fraction of an inch to more than 12 feet thick, are present throughout the Corwin formation; but the thickest and most abundant coal beds are restricted to the upper part of the formation in the inland areas and in the upper middle part in the type section. The coal is shiny to dull with prismatic fracture and fissile iron-stained partings. It is normally associated with ironstone and gray plastic clay which is in part bentonitic.

Argillaceous, silty, and more rarely, siliceous and calcareous ironstone occur as lenticular and irregular beds as much as 4 feet thick and in nodular or concretionary form scattered or in layers as thick as 1.5 feet but mostly less than 6 inches. The ironstone is medium to dark gray, olive gray, and dark yellow brown; commonly weathers dark yellowish orange, light brown, and less commonly dark reddish brown, dusky red, and yellowish gray. It is dense, has conchoidal fracture, contains plant remains and leaf imprints, and is most abundant in the most coaly parts of the formation.

Conglomerate and conglomeratic sandstone, in beds and lenses as much as a few feet thick, occur at irregular intervals throughout the formation but generally are not laterally persistent. At Corwin Bluff, however, several thicker units of conglomerate with interbeds of sandstone form the prominent point and overhanging cliff. The largest of these units, estimated to be 60 feet thick, can be traced more than 16 miles inland, where it is truncated by a fault. The conglomerate constituents in the Corwin Bluff vicinity include randomly distributed subround to subangular pebbles and cobbles as much as 10 inches in diameter, which make up about 50 to 75 percent of the rock; and they can be dislodged easily from the sandy and silty matrix. Rock types represented in the pebbles and cobbles include, in approximate decreasing order of abundance, black, gray, grayish-green, and grayish-red chert; white quartz; ironstone; coal; gray sandstone; black, gray, greenish-gray, and reddish-gray quartzite; greenish argillite; and light-gray and grayish-green igneous rock. Conglomerate and conglomeratic sandstone in the inland part of the region contain the same constituents, which vary greatly in their relative abundance.

Claystone or mudstone, somewhat different from the claystone associated with shale, occurs in beds mostly less than a foot thick throughout the formation. In the type section it occurs in massive beds as much as 30 feet thick. It is commonly silty, medium to medium dark gray, olive gray, and dusky yellowish brown, weathers to bright orange hues, has irregular blocky fracture, and is soft to moderately hard and partly laminated; some units contain thin sandstone and coal interbeds and abundant plant fragments.

Beds of light- to medium-dark-gray clay are restricted to the middle and upper parts of the formation and are associated with abundant coal. Because of their plastic nature, the clay beds are rarely seen in place but are recognized by the presence of mudflow and slump. Both bentonitic and nonbentonitic clays are present, but it is difficult to distinguish the two. Clays that are known to be bentonitic, because of their swelling properties and jellylike consistency when wet, are light gray and yellowish gray and occur in beds ranging from a few inches to as much as 2 feet in thickness. Some of these are apparently nearly pure bentonite. Soft shale, sandstone, and siltstone associated with known bentonitic clay beds probably also contain bentonite, but this could not be proved by field tests. Other harder clays of a darker hue do not show appreciable swelling when immersed in water. Many of these directly underlie coal beds, and they are not known to be more than a foot thick.

Uncommon rock types noted only in a few exposures of the Corwin formation include siliceous claystone, limestone, silty claystone with cone-in-cone structure, septarian concretions, coal-fragment conglomerate, and asphaltic sandstone. A 2-inch bed of siliceous claystone was seen in the type section 3,163 feet above the base, and is black, with conchoidal fracture. Limestone, seen at several inland and coastal localities, is dark gray, with lithographic texture, weathers yellowish orange and grayish yellow, and occurs in beds less than 6 inches thick. The silty claystone with well-developed cone-in-cone structure, which has cones ½–1 inch in diameter and about 1 inch in height, is associated in rubble with sandstone and ironstone on the Utukok River, a mile north of 1947 camp 15, and probably occurs in the upper part of the formation. Septarian concretions made up of silty material and containing vein calcite are associated with clay and ironstone in rubble in two localities: on the Utukok River 4 miles southwest of 1947 camp 12, where it is believed to lie in the upper part of the formation; and on the Kukpowruk River 2 miles southeast of 1949 camp 13, where it lies about 7,250 feet stratigraphically above the base of the Corwin formation. Coal-fragment conglomerate was seen 2 miles southeast of 1949 camp 13 in the stratigraphically highest section exposed along the Kukpowruk River. The coal fragments are subround and of pebble to cobble size and are either concentrated along bedding planes or randomly scattered in several friable sandstone beds from 7,550 to 7,700 feet above the base of the formation. At least one sandstone bed, exposed 45 miles above the mouth of the Kokolik River, contains abundant asphaltic material. (See p. 154.)

Large plant fragments, tree trunks, and logs as much as 1.5 feet in diameter and 5 feet in length, were observed at several localities in shale, siltstone, and sandstone. Some tree trunks, including partly preserved root systems, are perpendicular to the bedding, apparently in their original attitudes of growth. All these have coaly surfaces, and the cellular woody structure is evident from ironstained outlines. Their interiors are commonly made up of silty claystone, some of which is calcareous.

Sandstone, shale, and ironstone, altered by the combustion of an associated coal bed, crop out on the north limb of Howard syncline near the Kukpowruk River, midway between 1949 camps 10 and 11. The sandstone weathers moderate reddish orange and orange pink, the shale is slaty, and the ironstone is a deep red. "Clinkers" several inches across occur with these rocks. This altered unit, which is about 4,800 feet above the base of the formation, is exposed in two hilltop localities 2 miles apart, separated by the Kukpowruk River valley, where it was not exposed.

Rocks of marine inshore facies containing fossils similar to those in the Kukpowruk formation were recognized in the lower part of the Corwin formation at one field locality and in Kaolak test well 1. (See p. 124.) Although they are minor parts of the Corwin formation and grade into nonmarine rocks, they are significant in that they are evidence of the intertonguing of the marine and nonmarine sediments.

The type section of the Corwin formation was measured by E. G. Sable and H. G. Richards between July 29 and August 16, 1953, along the ocean cliffs from a point 0.6 mile west of Thetis Creek to Risky Creek and 0.3 mile upstream along Risky Creek. The lowermost and uppermost 500 feet are poorly exposed. The remainder of the section is more than 90 percent exposed but is not everywhere accessible. Neither the top nor the bottom of the formation was recognized. The top of the section is known to be cut by faults, and the bottom may be faulted, although it appears to grade downward into a dominantly shale section. The well-defined and accessible units were measured with a tape, the poorly defined and partly accessible units were measured by pacing and estimate, and inaccessible units were estimated.

The type section of the Corwin formation has been divided into seven parts, here called members, for purposes of comparison with sections in the inland part of the region. The characteristics which typify each member are the abundance of one or more rock types in contrast with the relative scarcity of these types in other members. No significant breaks in sedimentation are known to occur between the members, and the divisions, made following compilation of field data, are subjective. Generalized descriptions of these members are given in the following table, and their apparent relations to other sections of the Corwin formation

General description of members of the Corwin formation

Member	Thickness (in feet)	Generalized description
Top of section. Fault.		
Upper sandstone	11, 353–15, 494	Thick sandstone beds interbedded with shale and siltstone. Scattered coal beds.
Bentonitic clay	8, 586–11, 353	Bentonite and bentonitic clay common. Coal abundant. Largely interbedded shale, siltstone, and sandstone.
Conglomerate	7, 951–8, 586	Thick conglomerate and sandstone beds dominant. Minor amounts of coal and shale. Exposed at Corwin Bluff.
Coal and sandstone.	6, 544–7, 951	Coal abundant. Scattered massive sandstone beds. Largely shale and sandstone.
Shale	5, 306–6, 544	Clay shale and claystone dominant. Scattered coal beds. Minor amounts sandstone and siltstone.
Lower sandstone	2, 621–5, 306	Similar to upper sandstone unit.
Silty shale	0–2, 621	Silty shale and thin-bedded siltstone dominant. Few massive sandstone beds. Minor amounts of coal.
Base of section. Fault (?)		

are included under "Thickness and correlation" (p. 122). The members are shown in the stratigraphic columns of the type section (pl. 17).

The type section of the Corwin formation, which is 15,494 feet thick, is described from top to bottom as follows:

Top of section. Fault.

Upper sandstone member:

	Thickness (feet)
1. Sandstone and siltstone, fine-grained, scattered exposures. Float of shale, mud, and carbonaceous shale	470±
2. Silty shale and siltstone, medium-dark-gray, platy to blocky, carbonaceous; contain plant fragments and coaly vuglike cavities; thin bed of coal and coaly shale at base	16
3. Bentonitic(?) mud, light-gray	1
4. Silty shale, 80 percent; with thin interbeds of platy to blocky siltstone as much as 2 ft thick, minor amounts of carbonaceous shale, and scattered ironstone nodules; weathers bright orange	40
5. Coaly shale, coal, and silty shale; coal beds as much as 6 in. thick in lower 6 ft	8
6. Partly covered. Interbedded siltstone and silty shale. Coaly shale and coal float in upper 5 ft	20±
7. Sandstone, very fine grained	2
8. Silty shale, clay shale, and coaly shale, interbedded	17±
9. Sandstone, silty to very fine grained	1.5
10. Clay shale, silty shale, coaly shale, and siltstone; interbedded; 80 percent soft highly ironstained shale in upper part; siltstone beds as much as 2 ft thick	20±
11. Clay shale, silty shale, and coaly shale, interbedded and intergraded	21
12. Coal	.3
13. Silty shale and clay shale	2.5
14. Coal	.7
15. Poorly exposed. Coaly shale and soft clay shale; weathers yellowish orange	5
16. Coal and coaly shale; 60 percent is coal in beds as much as 6 in. thick	7
17. Silty shale and clay shale	2.5
18. Siltstone, dark-olive-gray, moderately hard, platy to blocky; contains ironstone nodules; thickens westward to 17 ft in 200 horizontal ft	8+
19. Coaly shale and clay shale, interbedded. One-inch coal bed near top	2
20. Claystone, finely crossbedded and laminated; contains ironstone nodules	4
21. Silty shale; contains ironstone nodules concentrated along bedding planes; grades downward to coaly shale in lower 2 ft	11
22. Siltstone, nodular to blocky; weathers in spheroidal blocks	4
23. Silty shale, carbonaceous and coaly; fractures in small blocky fragments. Coal and bone coal in lower 4 in	4
24. Siltstone and silty shale, interbedded	3.5
25. Sandstone, massive, very fine grained to silty, uniform; weathers dark yellowish orange; contains plant fragments at base	4
26. Clay shale and silty shale, dark- to medium-dark-gray, soft; contains scattered ironstone nodules, interbeds of siltstone as much as 2 ft thick, and thin coal beds and lenses	31±
27. Siltstone and clay shale, interbedded; contains ironstone lenses and nodules as much as 10 in. long. One-inch coal bed at top	6
28. Claystone and siltstone, interbedded; 80 percent is medium-dark-gray soft blocky claystone in beds 6 in. to 3 ft thick; siltstone is medium dark gray and blocky, weathers light brown, is in beds as much as 1 ft thick, and contains coaly vuglike cavities	14
29. Sandstone, medium-gray, light-olive-gray, and yellowish-gray, ironstained, fine-grained, salt-and-pepper type, blocky to massive, moderately hard; coarsely crossbedded with as much as 15° difference between foreset and topset beds; contains carbonaceous laminae, plant remains including large tree trunk; ironstone lenses. Grades into unit below	70
30. Sandstone, as in unit 29, but fine- to coarse-grained, more friable, and more massive. Lower 3 ft contains conglomerate lenses as much as 3 in. thick containing subround to subangular granules and pebbles of chert. Abrupt and irregular lower contact with unit below	5
31. Siltstone, hard; beds to 2 in. thick; thins westward to less than 10 in. within a distance of 200 ft. Thinning believed due to erosion prior to deposition of unit 30	15
32. Coal and bony coal; interbedded; 40 percent is good coal. Bony coal is grayish black, dull, with prismatic fracture, laminated. Clay shale in upper 1 ft	4
33. Siltstone and shale interbedded; 90 percent is thinbedded siltstone	14
34. Siltstone, massive	6
35. Siltstone and shale; in thin interbeds	5±
36. Sandstone, very fine grained to silty, very massive	4.5
37. Shale and sandstone interbedded; 50 percent is fine-grained sandstone in beds to 2 ft thick	9
38. Sandstone, fine-grained	4
39. Shale and siltstone, interbedded; shale dominant. One 6-in. coal bed near top	11±
40. Coal, coaly shale, and clay shale, interbedded	2
41. Sandstone, very fine grained; in beds as much as 4 ft thick; interbedded with siltstone and shale	12
42. Siltstone, very massive; weathers yellowish orange	15
43. Siltstone and shale interbedded; 50 percent is siltstone, in beds as much as 5 ft thick	30±
44. Siltstone, clay shale, and claystone; interbedded; siltstone is in beds as much as 4 ft thick; claystone is in beds to 6 ft thick. Thin coal beds in upper 2 ft	40
45. Siltstone, massive	13
46. Clay shale, coal, and coaly shale; interbedded; many thin coal beds in lower 2 ft	4
47. Siltstone and very fine grained sandstone; massive unit; *Asplenium foersteri* Debey and Ettingshausen	9
48. Bony coal and coaly shale	7

	Thickness (feet)
49. Siltstone; weathers in spheroidal fragments; thickens westward to 7 ft within a distance of 100 ft	4
50. Clay shale; contains few siltstone and ironstone lenses	19
51. Siltstone lens; thickens westward	7±
52. Silty shale and siltstone, in thin interbeds	8
53. Siltstone, sandstone, and silty shale; interbedded; beds 1 to 3 feet thick; 20 percent is shale; contains 8-in-diameter coaly tree trunk perpendicular to bedding	34
54. Clay shale; contains thin coaly beds and ironstone nodules. Thickness ranges from 11 to 25 ft	18±
55. Sandstone, very fine grained, massive	5. 5
56. Clay shale; contains siltstone lenses throughout, and 6-in. coal bed at base	18
57. Siltstone, massive	4
58. Clay shale	6
59. Silty shale, and distinctive cream-colored sandstone; contains bright orange-weathering ironstone concretions	2. 5
60. Siltstone, silty shale, claystone, and clay shale; interbedded; 80 percent is shale and claystone, in beds as much as 3 ft thick; siltstone is in beds as much as 2 in. thick	9
61. Siltstone, massive to platy, finely crossbedded	14
62. Silty shale and siltstone, interbedded; contain ironstone nodules	8
63. Clay shale and claystone; fractures in large blocky fragments; contains silty ironstone nodules and few siltstone beds	13
64. Coaly shale	. 5
65. Coal	2. 2
66. Clay shale and coaly shale, interbedded	3
67. Sandstone, very fine grained, massive	6
68. Shale, claystone, and siltstone: interbedded; claystone in beds as much as 4 ft thick; 40 percent is siltstone, in beds as much as 2 ft thick	15±
69. Siltstone, with thin shale interbeds in upper 3 ft	11±
70. Shale	6±
71. Sandstone	5±
72. Silty shale; contains thin coal beds less than 1 in. thick and minor amounts of clay shale	5
73. Sandstone, medium-dark-gray, fine-grained; grades upward into siltstone in upper 2 ft	8
74. Clay shale; contains few coaly beds as much as 6 in. thick	5
75. Siltstone, platy and with shale interbeds in lower part, massive in upper 6 ft	11
76. Coal, poor quality	1
77. Clay shale and coaly shale	8
78. Siltstone and sandstone; in beds to 2 ft thick, with interbedded shale as much as 1 ft thick. Resistant unit	26±
79. Sandstone, siltstone, and conglomerate, massive, resistant. Sandstone yellowish gray, fine to medium grained, salt-and-pepper type; contains carbonaceous laminae and fine crossbedding, becomes finer upward, and intergrades with siltstone in upper part. Coarse phase 10 to 20 ft above base, includes conglomerate lenses 3 to 6 in. thick with subround pebbles and cobbles as much as 3 in. in diameter of chert, white quartz, and ironstone. Abundant coaly fragments and laminae, and coarse crossbedding in lower 6 ft	33
80. Coal; with prismatic fracture, some fissile partings	1. 5
81. Coaly shale	1
82. Clay shale, claystone, silty shale, and siltstone; interbedded; 80 percent is shale; siltstone is mostly thin bedded and grades eastward to shale. Medium-gray soft clay in upper 1 ft, grades upward into coaly shale	16
83. Clay shale, claystone, and silty shale; nodular to blocky; somewhat lighter gray than most shale in section. Few coal interbeds less than 2 in. thick	11
84. Coal	. 5
85. Shale and claystone, as in unit 83	11
86. Sandstone and siltstone	4±
87. Shale	3±
88. Siltstone and very fine grained sandstone, interbedded, massive; contain scattered ironstone lenses, numerous carbonaceous reedlike fragments, and thin shale partings; abundant coaly fragments in lower 5 ft	16
89. Clay shale with coal beds and lenses to 1 ft thick and ironstone nodules as much as 6 in. in maximum length	7
90. Clay shale, siltstone, and silty shale; contain few ironstone nodules; grade upward to coaly shale in upper 3 ft; 80 percent is shale	20
91. Mostly covered. Shale with interbeds of very fine grained sandstone and siltstone as much as 4 ft thick. About 70 percent is shale	29
92. Mostly covered. Shale	20±
93. Siltstone lenses, massive; with thin shale interbeds; weather light yellowish orange; contain numerous plant fragments; *Cladophlebis browniana* (Dunker) Seward	5
94. Siltstone and sandstone interbedded; massive with few shale partings	10
95. Siltstone and shale, interbedded; about 70 percent is shale	11±
96. Siltstone, silty shale, and clay shale; interbedded; siltstone is in beds and lenses as much as 2½ ft thick; contains some sandstone lenses	17
97. Siltstone, medium-dark-gray, massive, finely crossbedded, weathers yellowish orange	4
98. Siltstone, clay shale, and claystone; interbedded; 60 percent is siltstone, in platy to massive 3- to 8-in. beds; 30 percent is clay shale	44
99. Sandstone, lenticular, massive, salt-and-pepper	6±
100. Clay shale	8
101. Sandstone, lenticular, salt-and-pepper; in massive beds 6 in. to 3 ft thick, crossbedded, weathers yellowish gray, contains coaly fragments	5
102. Clay shale; with minor amounts of interbedded siltstone and claystone	59. 3
103. Sandstone, as in unit 79; massive beds 1 to 8 ft thick in lower part, thin bedded in upper part; contains lenses of pebble- and cobble-sized chert and white quartz conglomerate 4 to 8 in. thick near base, and coal lenses as much as 7 in. thick and 3 ft long. Siltstone interbeds near top of unit, with scattered ironstone nodules as much as 10 in. long and 6 in. thick	78

	Thickness (feet)
104. Sandstone, siltstone, clay shale, and coal; interbedded; sandstone is as in unit 79, in massive beds 6 in. to several ft thick; contains about 5 percent of coal in beds as much as 1 in., and 25 percent is siltstone in beds as much as 3 in.	42
105. Clay shale and claystone, with siltstone lenses; 70 percent is clay shale; 25 percent is claystone	59.3
106. Siltstone, medium-dark-gray; in massive lenticular beds several feet thick; finely crossbedded; weathers yellowish gray	10
107. Clay shale, with thin coal interbeds	3
108. Coal	1.4
109. Clay shale, 60 percent; interbedded claystone, 20 percent; siltstone lenses, 20 percent	75
110. Siltstone similar to unit 106, but sandy	21
111. Clay shale, 70 percent; interbedded claystone, 20 percent; some siltstone lenses	84.8
112. Clay shale, 50 percent; interbedded claystone in massive beds as much as several ft thick, 35 percent; interbeds of siltstone, carbonaceous shale, and coal at base	34
113. Siltstone, dark-gray, soft; 70 percent is in massive beds as much as several ft thick, interbedded with dark-gray silty shale in beds as much as one-half inch thick	74
114. Clay shale	14.9
115. Siltstone, similar to unit 106, gradational upward into claystone and interbedded with clay shale and few thin coal beds; 50 percent is siltstone; 30 percent is claystone; *Podozamites lanceolatus* (Lindley and Hutton) Braun, *Ginkgo digitata* (Brongniart) Heer	48.6
116. Clay shale	12
117. Siltstone, as in unit 106, hard; in beds as much as 4 ft thick	4.9
118. Claystone and clay shale, interbedded; 70 percent is massive nodular claystone, in beds 2 to 3 ft thick	17
119. Coal, blocky	.8
120. Clay shale and claystone, interbedded, with thin lenses of coal and ironstone; 50 percent is shale, in beds less than one-quarter inch thick; 45 percent is claystone, in beds less than 1 ft thick	55
121. Carbonaceous shale, black, fissile; with coal interbeds less than one-half of an inch thick; contains ironstone nodules; 75 percent is shale	4.6
122. Coal, blocky	.5
123. Clay shale and claystone, interbedded; 80 percent is platy to fissile shale, in beds about one-quarter of an inch thick; 15 percent is claystone, in beds as much as 3 in. thick. Contain scattered medium-gray orange-weathering ironstone nodules	12.5
124. Scattered exposures of clay shale, silty shale, carbonaceous shale, and siltstone	220
125. Sandstone, medium-dark-gray with bluish cast, fine-grained, hard; weathers bright yellowish orange	2
126. Mostly mud covered. Scattered exposures of siltstone, silty shale, and coaly shale	20±
127. Coaly shale	1
128. Sandstone, medium-dark-gray with bluish cast, weathers yellowish-brown to light-brownish-gray, very fine to fine-grained, massive to platy; contains coaly fernlike impressions. Thin silty fragments, small tree trunks, and shale interbeds give banded appearance to outcrop. Grades into unit below	32
129. Silty shale, clay shale, and claystone, with lesser amounts of siltstone and coaly shale interbedded. Shale is medium dark to dark gray nodular to blocky, with partings ¼ to 1 in.; contains scattered ironstone nodules and coaly wood fragments; weathers bright yellowish orange; contains interbeds of siltstone as much as 2 ft thick, and coaly shale as much as 4 in. thick	44
130. Siltstone, sandstone, and silty shale, interbedded; shale 60 percent, weathers bright yellowish orange, contains thin coaly lenses less than one-half inch thick	6
131. Siltstone, medium-dark-gray, massive, finely crossbedded; contains plant fragments; in beds 3 in. to 1 ft thick	7
132. Silty shale and clay shale; as in unit 129, but with bluish-white efflorescence on weathered surfaces	2.5
133. Coaly shale, bone coal, and coal beds as much as 2 in. thick	3.5
134. Coaly shale and shale	2
135. Siltstone and shale, thin-bedded; 70 percent is siltstone	40±
136. Siltstone, massive	5
137. Coal, poor grade	.9
138. Siltstone, massive	3
139. Siltstone and shale, interbedded	4±
140. Coaly shale and coal	1.5±
141. Shale and siltstone, interbedded; 70 percent is shale	5±
142. Shale, siltstone, and coaly shale interbedded	10±
143. Shale	4±
144. Siltstone, thin-bedded; grades downward into unit below	20
145. Sandstone, medium-gray, fine- to coarse-grained, salt-and-pepper, laminated and crossbedded, friable to moderately hard; weathers yellowish brown to light brown; contains scattered conglomerate lenses in lower 6 ft containing cobbles as much as 6 in. in diameter of green-gray quartzite, medium-light-gray chert or silicified limestone, greenish-gray igneous rock, dark-bluish-gray chert, ironstone, and coaly wood fragments. Large coaly wood fragments and current(?) markings at base. Abrupt contact with	60±
146. Sandstone, conglomeratic, similar to unit 145, but medium-grained, friable; contains pebbles and cobbles to 10 in. diameter. Some pockets of bright-grayish-yellow material	2
147. Clay shale, soft	6
148. Siltstone and coaly shale	3
149. Clay, light-gray; grades into unit below	1
150. Claystone, medium-dark-gray, weathers bright-yellowish-orange, silty, finely crossbedded	6
151. Coaly shale	3

	Thickness (feet)
152. Silty shale and siltstone, interbedded; 70 percent is nodular shale, in sets of beds as much as 3 ft thick	27
153. Sandstone, fine-grained, massive, finely cross-bedded; in spheroidal-weathering beds as much as 2 ft thick separated by thin shale interbeds; contains few ironstone nodules	6
154. Siltstone, very fine grained sandstone, and shale; interbedded; minor amounts of ironstone and coaly shale; 40 percent is siltstone and sandstone; shale as much as 8 ft thick; *Asplenium foersteri* Debey and Ettingshausen, *Ginkgo digitata* (Brongniart) Heer	70
155. Sandstone, very fine grained, massive	15
156. Silty shale	3
157. Coaly shale; contains one 8-in. coal bed	2
158. Siltstone, very fine grained sandstone, and shale; interbedded; 50 percent is siltstone and sandstone, in massive spheroidal-weathering beds as much as 5 ft thick	47
159. Bony coal, coaly shale, and ironstone	2.5
160. Siltstone and silty claystone, massive to platy, 70 percent; with interbeds of shale and coaly shale, 30 percent	65
161. Sandstone, fine-grained, very massive; contains numerous coaly plant fragments	11
162. Siltstone and shale, interbedded	9
163. Silty shale and clay shale, interbedded, with thin coal beds in upper 10 ft	40
164. Claystone and siltstone, dark-gray, massive; contain large coaly wood fragments; *Cladophlebis browniana* (Dunker) Seward	25±
165. Clay shale and silty shale, interbedded; with minor amounts of coaly shale and ironstone nodules; grades upward to siltstone in upper 3 ft	18
166. Claystone and siltstone, as in unit 164, but with interbeds of fine-grained sandstone	10
167. Claystone and siltstone	19
168. Coaly shale	.5
169. Siltstone and silty shale, interbedded; with minor amount of clay shale; siltstone massive; in beds as much as 3 ft thick	15
170. Siltstone and very fine grained sandstone, interbedded; includes 1 ironstone lens, 4 in. thick	10
171. Siltstone and silty shale, interbedded; with thin coal beds in upper 3 ft; contains ironstone nodules	26
172. Sandstone and siltstone, interbedded, massive to platy; with thin shale beds at intervals of 2 in. to 1 ft	40±
173. Sandstone and conglomeratic sandstone, as in unit 146, but moderately hard; contains pebbles in lower 2 ft, including clay galls	19
174. Siltstone and silty shale, interbedded; siltstone increases westward to as much as 90 percent	11
175. Siltstone and very fine grained sandstone, interbedded and interlensing, medium-gray, hard; weather dark yellowish orange; abundant plant fragments including broad-leaved and reedlike varieties	11
176. Silty shale and clay shale, with thin interbeds of siltstone; 70 percent is shale	13
177. Siltstone, sandstone, and shale; interbedded; coarser clastic rocks constitute 60 percent, in massive lenticular beds	27
178. Coaly shale, with thin coal bed	2
179. Siltstone, silty shale, and clay shale; interbedded; 70 percent is siltstone. Abrupt contact at base	23
180. Silty shale, clay shale, and coaly shale; interbedded. Grades into unit below	7
181. Siltstone, massive	8
182. Clay shale and silty shale, with 1-ft coaly shale at base	7
183. Sandstone and conglomeratic sandstone, with siltstone interbeds; sandstone similar to unit 145, yellowish gray, contains subround pebbles and cobbles of gray chert and white quartz, weathers yellowish orange	4
184. Silty shale and clay shale	7
185. Siltstone, massive; contains ironstone nodules and lenses, plant fragments, and coaly lenses	22
186. Siltstone, silty shale, clay shale, and claystone; interbedded; siltstone in massive 10-ft beds; claystone nodular to blocky. Numerous coal beds ½ to 2 in. thick in upper 10 ft	50
187. Siltstone, medium-gray, laminated; weathers bright yellow orange	2
188. Silty shale, in part carbonaceous	7
189. Siltstone, very massive; weathers light brown; contains ironstone nodules and 1-ft thick thick shale bed	15
190. Clay shale and claystone, nodular to blocky; contains ironstone nodules	20
191. Coal, good grade. Abrupt contact with unit below	.9
192. Siltstone and very fine grained sandstone, interbedded, medium-dark-gray, hard; in beds as much as 3 ft thick; contain shale beds as much as 1 ft thick	38
193. Siltstone and shale, interbedded; 50 percent is medium dark gray siltstone that weathers light brown to dark yellowish orange, in massive beds as much as 12 ft thick; contains plant fragments	60±
194. Siltstone, clay shale, coaly shale, and sandstone, interbedded; 60 percent is dark-gray siltstone, in conspicuous massive beds as much as 15 ft thick, with thin interbeds of sandstone. Minor clay ironstone lenses and silty ironstone nodules	120±
195. Sandstone, medium-grained, salt-and-pepper, massive; occurs mainly in lower 10 ft and grades upward to interbedded siltstone and silty shale. Abrupt erosional contact with unit below	30
196. Sandstone and siltstone, interbedded; with thin interbeds of shale; contain coaly wood fragments and carbonaceous partings; gradational upward into silty shale and coaly shale. Lenticular unit, appears to thicken to 50 ft and to contain more coarse-grained phases eastward	28±
197. Shale, sandstone, siltstone, and ironstone; interbedded; contain coaly beds as much as 1 ft thick and abundant coaly wood fragments; 40 percent is sandstone and siltstone, in beds as much as 5 ft thick	120±

	Thickness (feet)
198. Siltstone and silty shale, interbedded, with minor amount of coaly shale; siltstone beds as much as 4 ft thick	40
199. Clay shale with coaly partings	40±
200. Sandstone and shale, interbedded	4
201. Silty shale, dark-gray, blocky, hard; grades upward to clay shale and coaly shale	18±
202. Siltstone, massive; grades into unit below	3
203. Ironstone, medium-gray, silty; weathers dark yellowish orange	1
204. Silty shale and clay shale	9
205. Sandstone	1
206. Covered	25±
207. Inaccessible. Appears to be 70 percent shale, 30 percent siltstone, with ironstone lenses	37
208. Sandstone and shale, interbedded; contain ironstone lenses	20±
209. Silty shale, with thin siltstone beds in lower 5 ft	23
210. Siltstone and shale, interbedded; siltstone beds as much as 4 in.; 50 percent; carbonaceous plant fragments common	9
Total thickness	4,141±
Base of member.	
Bentonitic clay member:	
1. Mostly covered by float of clay shale, siltstone, coal, and bentonitic(?) mud	45±
2. Coal	1.8
3. Clay shale and claystone, medium-dark-gray, very soft, blocky, even-bedded; weathers to mud	5±
4. Siltstone, medium-dark-gray, weathers yellowish-gray	1.5
5. Clay shale and claystone, as in unit 3; contains thin coal lenses	8
6. Coal	1.5
7. Clay shale and claystone, as in unit 3	15±
8. Coaly shale, black, fissile	1
9. Clay shale and claystone, as in unit 3	10±
10. Coaly shale and siltstone, interbedded	5±
11. Clay shale and claystone, as in unit 3; contains coaly shale beds to 6 in. thick	17±
12. Coaly shale, with thin coal lenses	3.5
13. Clay shale and claystone, as in unit 3	3
14. Coal	2(?)
15. Clay shale and claystone, similar to unit 3; but contains ironstone nodules and coaly lenses	15
16. Sandstone, yellowish-gray, weathers yellow brown, fine- to medium-grained, salt-and-pepper, moderately hard to hard; beds ½ in. to 2 ft thick; massive and crossbedded in lower half; contains scattered ironstone nodules; current(?) markings alined in easterly direction; gradational upward into very fine grained sandstone, siltstone, and coaly shale	27
17. Sandstone and shale, interbedded; shale grades westward into sandstone and siltstone	163±
18. Shale	15±
19. Coal and shaly coal	4±
20. Sandstone, uniform medium-dark-gray, medium-grained, carbonaceous, platy, laminated and crossbedded	5±
21. Clay shale and coaly shale, with thin coal interbeds	30±
22. Coal and shaly coal	3±
23. Siltstone and shale, interbedded. Thin coal beds	12±
24. Mostly snow covered. Clay shale with thin interbeds of siltstone or sandstone in upper part; ironstone in float	50±
25. Coaly shale and hard clay ironstone, interbedded	2
26. Coal and shaly coal; includes one 1.4-ft good-grade coal bed and thickens westward to 3.5 ft, including 3 ft of good coal	1.8±
27. Siltstone and shale; interbedded; 50 percent is siltstone, in beds as much as 1½ ft thick; contains lenses of crossbedded sandstone	7
28. Clay shale, claystone, and clay; shale and claystone is medium to medium dark gray, nodular and blocky, very soft; clay possibly bentonitic; scattered small ironstone nodules	35
29. Clay shale and claystone, as in unit 28	7
30. Coal	.5
31. Clay shale, claystone, and clay, as in unit 28	22±
32. Bony coal and coaly shale	1
33. Clay shale, medium-gray; weathers dark yellowish orange and moderate yellowish brown, with interbeds of coal and coaly shale about 1 in. thick	7
34. Coaly shale and bony coal	.5
35. Clay shale, claystone, and clay, as in unit 28; grade into unit below	3
36. Sandstone, yellowish-gray, fine-grained, salt-and-pepper, coarsely crossbedded	5
37. Clay shale, with thin coal and sandstone interbeds and ironstone nodules	15±
38. Coal	.5
39. Clay shale	3±
40. Coal and carbonaceous shale; includes three 8-in. coal beds	3±
41. Clay shale, with large ironstone lenses	3±
42. Coal	1±
43. Clay shale	6±
44. Ironstone, nodular; weathers yellowish orange; with thin interbeds of clay shale	1.5
45. Coaly shale	1
46. Clay shale and claystone, medium-dark-gray, nodular to blocky, soft; contains ironstone nodules and coal fragments	6
47. Sandstone, medium-dark-gray, very fine grained to silty, massive; with thin shale interbeds; grades to silty shale within 50 ft eastward	8
48. Sandstone, siltstone, and shale, interbedded; 50 percent is medium-dark-gray very fine grained sandstone, in beds and lenses as much as 3 ft thick; contains current(?) markings alined N. 80° W. Clay shale and silty shale interbeds to 1 ft thick, and scattered ironstone nodules	30±
49. Sandstone, light-olive- to olive-gray, fine- to medium-grained, salt-and-pepper; laminated and coarsely crossbedded with foreset beds dipping 15°; massive in lower half, platy in upper half, contains numerous ironstone nodules and few thin shaly partings. Grades into unit below	21±

	Thickness (feet)
50. Sandstone and shale, interbedded; similar to unit 48; sandstone beds as much as 2 ft thick	35±
51. Shale, siltstone, and sandstone, similar to unit 48; about 70 percent is clay shale. Coaly shale and 6-in. coal bed in upper 10 ft	54
52. Sandstone, as in unit 49; contains limy ironstone lenses as much as 10 in. thick	35±
53. Shale	8
54. Coal	1. 9
55. Covered. Talus of mud, coal, sandstone, and ironstone	32±
56. Sandstone, fine- to medium-grained	3. 9
57. Shale, with thin ironstone lenses	1. 7
58. Coal, vitreous, with prismatic fracture	1. 4
59. Clay shale, dark-gray, with thin interbeds of siltstone	10±
60. Clay, light-gray, bentonitic	1. 5
61. Clay shale and siltstone, interbedded; 70 percent is shale; contains ironstone nodules and thin coal beds	30
62. Sandstone, siltstone, and silty shale interbedded; 70 percent is medium-gray very fine grained argillaceous finely crossbedded sandstone, in beds as much as 2 ft thick, with plant fragments. Siltstone is medium dark gray, platy to blocky, micaceous	7. 8
63. Shale and claystone, blocky	10±
64. Coal	1. 2
65. Clay shale, dark-gray	5±
66. Coal, vitreous, prismatic fracture	1. 2
67. Mostly covered by mud. Scattered exposures of shale, siltstone, and sandstone; heavings of coal and gray clay	99
68. Shale, dark-gray. Grades into unit below	10
69. Sandstone and silty shale, interbedded; 60 percent is medium-gray fine-grained salt-and-pepper moderately hard sandstone, in platy beds as much as 2½ ft thick; contains ironstone pebbles	46
70. Poorly exposed. Siltstone, sandstone, silty shale, clay shale, and ironstone; interbedded; sandstone and siltstone as in unit 62; silty ironstone beds as much as 2 ft thick, contain plant fragments; 60 percent is dark-gray soft clay shale, with thin interbeds of coaly shale	21
71. Siltstone, sandstone, silty shale, clay shale, and ironstone; interbedded, as in unit 70	19. 6
72. Clay shale, siltstone, and sandstone, interbedded, as in unit 70; but 80 percent is shale. Coaly shale in upper 1 ft. Abrupt contact with unit below	17. 4
73. Sandstone, medium- to olive-gray, fine- to medium-grained, weathers yellowish-orange to light-brown, blocky, laminated and crossbedded, carbonaceous and micaceous; friable and platy in lower 1 ft, hard and massive in upper 4 ft	5. 2
74. Silty shale and sandstone, interbedded	1. 9
75. Sandstone, as in unit 73; beds as much as 4 in. thick	3. 6
76. Silty shale	2. 9
77. Sandstone, as in unit 73	1. 4
78. Silty shale, siltstone, sandstone, and ironstone; interbedded; siltstone and sandstone as in unit 62; shale is dark gray to olive gray, dense, noncalcareous and contains plant fragments and ironstone nodules; minor amounts of carbonaceous shale	25. 5
79. Claystone, slightly calcareous	1
80. Mostly covered by slump of medium-gray mud. Includes float of coal and siltstone, and 1-ft coal bed	31±
81. Siltstone and ironstone, thinly bedded	5
82. Covered by mud slump. Mud appears to be bentonitic	25±
83. Sandstone and siltstone, with thin interbeds of shale and ironstone nodules; 70 percent is sandstone, in beds as much as 1½ ft thick	8±
84. Clay shale and coaly shale, interbedded	1. 7
85. Coal, good grade	. 6
86. Clay shale; varies in hardness; some interbeds of siltstone less than 1 ft thick; ironstone nodules as much as 6 in. in diameter	21
87. Sandstone, light-olive-gray, weathers pale yellowish brown, fine-grained to very coarse grained, salt-and-pepper; becomes finer upward. Lower 20 ft coarsely crossbedded, consists of massive lensing beds including granule to pebble chert-conglomerate lenses. Scoured surfaces 5 to 20 ft above base. Gradational upward into thinner beds of interbedded siltstone, silty shale, and clay shale	70±
88. Shale and siltstone, interbedded; shale dominant. Lenticular unit	6±
89. Siltstone, brownish-gray, blocky, laminated, and finely crossbedded	3. 5
90. Clay shale, silty shale, siltstone, and ironstone; interbedded; coal beds about 1 in. thick	10
91. Siltstone, as in unit 89	4. 5
92. Clay shale and silty shale, interbedded; contain ironstone lenses as much as 3 in. thick, and plant fragments	6
93. Siltstone and sandstone, as in units 87 and 89, interbedded	7
94. Mostly mud covered. Dark-gray very soft clay shale, coaly shale, bentonitic(?) shale, and siltstone interbedded in upper part of unit	25±
95. Bentonitic mud	1±
96. Clay shale; with few interbeds of siltstone as much as 1 ft thick, and nodular ironstone in upper part	18
97. Coaly shale, coal, and clay shale; interbedded; includes one 6-in. coal bed	1. 5
98. Clay shale and siltstone, as in unit 96	29
99. Siltstone and silty shale; interbedded, with few clay shale interbeds. Grades into unit below	17
100. Sandstone and conglomerate, similar to unit 87; contains large coaly fragments. Abrupt and irregular contact with unit below	35
101. Clay shale, silty shale, and coaly shale; interbedded; includes coal beds as much as 8 in. thick, and bentonitic (?) shale; *Cladophlebis browniana* (Dunker) Seward, *Ginkgo digitata* (Brongniart) Heer	7

	Thickness (feet)
102. Siltstone, massive	4
103. Clay shale, very soft; contains abundant ironstone nodules, plant fragments, and one 2-ft siltstone bed	4.5
104. Siltstone and clay shale; interbedded; includes one 8-in. coal bed	2.5
105. Clay shale; with thin siltstone interbeds less than 1 ft thick, minor amount of coaly shale, and numerous ironstone nodules	17
106. Coal, hard, massive, good grade	1.8
107. Clay shale, coaly shale, and siltstone; interbedded; ironstone nodules in upper part	5.5
108. Sandstone, very fine-grained, massive; abrupt contact with	5.5
109. Silty shale and clay shale, interbedded; numerous thin ironstone lenses in upper part. Unit thins westward to 2 ft in 30 horizontal ft. Abrupt contact with unit below	4.5±
110. Coal, massive, prismatic fracture, good grade	5.5
111. Clay shale, very soft, with thin ironstone lenses	4.5
112. Coal and coaly shale; includes one 1-ft coal bed of good grade	2
113. Siltstone, and very fine grained sandstone, massive to blocky	4
114. Silty shale and clay shale; with thin interbeds of coal, and ironstone nodules at base; *Cladophlebis septentrionalis* Hollick, *Cephalotaxopsis magnifolia successiva* Hollick	3
115. Sandstone, very fine-grained, massive; grades upward into siltstone	2
116. Mostly mud covered. Clay shale, coal, ironstone nodules, bentonitic clay; clay increases in upper part of unit	14
117. Clay, medium-light-gray, clean, bentonitic; weathers yellowish gray	2
118. Coal, coaly shale, and clay	1
119. Siltstone, silty shale, and clay shale; interbedded; includes some thin coaly shale beds	9
120. Siltstone, and very fine grained sandstone; with thin coal and shale interbeds, lenticular	8±
121. Clay shale and silty shale; with siltstone interbeds as much as 2 ft thick; 70 percent is shale	21
122. Clay shale, soft, hackly; with ironstone lenses as much as 2 in. thick. Brownish-gray dense noncalcareous ironstone with conchoidal fracture	7
123. Coal and clay shale, interbedded; coal beds 2 to 8 in. thick. Unit thins and grades westward into 0.8 ft coal bed	1.5
124. Siltstone, clay shale, and silty shale; interbedded; 50 percent is siltstone, in beds as much as 2½ ft thick	14±
125. Coaly shale and clay shale, interbedded	.5
126. Coal, good grade	.8
127. Coaly shale, clay shale, and coal	1.5
128. Clay shale, very soft, probably bentonitic	2
129. Sandstone, very fine grained, massive	4
130. Siltstone and silty shale, interbedded; carbonaceous shale in lower 1 ft	2.5
131. Clay shale, claystone, siltstone, sandstone, and silty shale; interbedded; sandstone very fine-grained, in beds as much as 3 ft thick; 60 percent is shale and claystone, in beds 2 ft thick	31±
132. Clay shale, soft, probably bentonitic; contains ironstone lenses	6±
133. Carbonaceous shale	1
134. Coal, good grade	.7
135. Silty shale, brownish-gray	1
136. Sandstone, very fine grained; contains coaly wood fragments perpendicular to bedding	3
137. Inaccessible. Shale and siltstone, interbedded; about 80 percent is shale	10±
138. Coal and bony coal	.5
139. Silty shale, clay shale, and siltstone; 90 percent is shale	3.5
140. Coaly shale, with coal interbed 10 in. thick	3
141. Sandstone, medium-light- and light-olive-gray, very fine to medium-grained; weathers yellowish brown to bright yellowish orange, massive and hard in lower 7 ft, platy and moderately friable in upper part; siltstone interbeds in upper 2 ft, very soft, possibly bentonitic; ironstone lenses in lower 15 ft	40±
142. Siltstone; platy with spheroidal weathering in lower part, grades upward to more massive type. Sandstone and shale interbeds in upper part, with ironstone nodules in shale	17
143. Clay shale	1
144. Coal, good grade	2±
145. Coaly shale and clay shale	.8
146. Coal, good grade	1
147. Siltstone and silty shale, interbedded	2
148. Clay shale, silty shale, and siltstone; interbedded; 80 percent is iron-stained shale	14
149. Siltstone and silty sandstone; massive unit, weathers light brown	5
150. Coaly shale and clay shale	1.4
151. Coal	1
152. Siltstone	.5
153. Coal and coaly shale	2
154. Silty shale	1.5
155. Sandstone, yellowish-gray, very fine grained, laminated and crossbedded; gradational to siltstone in upper 1 ft	6
156. Sandstone, as in unit 155; gradational to siltstone and interbedded silty shale in upper 3½ ft. Abrupt contact with unit below	8
157. Siltstone, claystone, and clay shale; interbedded; 50 percent is siltstone, in beds as much as 1½ ft thick	16
158. Coaly shale	1
159. Clay shale, with thin siltstone interbeds	4
160. Siltstone, massive	4
161. Clay shale, silty shale, and siltstone; interbedded; 80 percent is shale; siltstone beds as much as 2 ft thick	11
162. Clay shale; contains ironstone nodules and one 2½-ft siltstone bed	10
163. Sandstone, light-olive-gray, very fine grained to silty, massive, finely crossbedded; contains coaly fragments	3
164. Siltstone, claystone, and clay shale; interbedded; 60 percent is siltstone; ironstone nodules common	4
165. Sandstone, as in unit 163; with carbonaceous partings	5

	Thickness (feet)
166. Siltstone and silty shale, interbedded; grades downward to sandstone as in unit 163 but fine grained	5. 5
167. Siltstone and silty shale, interbedded; 70 percent is siltstone, in beds as much as 2½ ft thick	4. 5
168. Siltstone and shale, interbedded; shale very soft	4. 5
169. Siltstone, medium-dark-gray, massive in lower part, nodular in upper part	5
170. Clay shale, dark-gray, weathers medium to medium dark gray, fissile to blocky, beds usually less than 1 in., and commonly ¼ to ½ in. thick	21
171. Coal, good grade, thin partings	. 6
172. Clay shale, as in unit 170; but with thin coal lenses and coaly shale in lower 1 ft. Grades downward into unit below	40
173. Coal, blocky, good grade	. 9
174. Claystone, massive, soft; with conchoidal fracture	4. 5
175. Coal, blocky, good grade	2. 6
176. Clay shale, as in unit 170; with 20 percent interbedded claystone	80±
177. Coal	2±
178. Clay shale and claystone, as in unit 176	38
179. Coal, blocky, good grade. Not entirely accessible	9±
180. Clay shale and claystone, as in unit 176	9
181. Coal, blocky, good grade	1. 1
182. Clay shale, as in unit 170	16
183. Coal, blocky, good grade	3. 5±
184 Clay shale, as in unit 170; with 10 percent claystone occurring as lenses	50±
185. Coal, blocky, fair to poor grade	1. 4
186. Clay shale, as in unit 170	35
187. Coal, blocky, fair to good grade	2. 8
188. Clay shale, as in unit 170; but with 20 percent interbedded siltstone	30
189. Sandstone, medium-gray, medium-grained, salt-and-pepper, blocky, finely crossbedded; weathers yellowish-gray; lenticular unit	4±
190. Clay shale, as in unit 170	21. 5
191. Sandstone, as in unit 189	3. 5
192. Clay shale, as in unit 170	7
193. Sandstone, as in unit 189	10
194. Clay shale, as in unit 170	3
195. Siltstone, medium-dark-gray, weathers medium-gray, soft to hard, platy, finely crossbedded; contains plant fragments and fucoidal markings at base	4
196. Coal, blocky, good grade	. 5
197. Clay shale, as in unit 170	. 5
198. Coal, blocky, good grade	. 5
199. Clay shale, as in unit 170; interbedded with 10 percent siltstone lenses	41
200. Coal, blocky, good grade	2
201. Clay shale, as in unit 170; orange weathering in part	16
202. Coal, blocky, good grade	2
203. Clay shale, as in unit 170; but very fissile	5
204. Siltstone, as in unit 195; interbedded with fine-grained salt-and-pepper sandstone. Beds 6 to 10 in. thick, separated by thin shale partings	27
205. Silty shale, medium-gray; weathers medium-light-gray, fissile; contains ironstone nodules	24
206. Sandstone, as in unit 189; but pale yellow brown and fine to very coarse grained, moderately friable, slightly calcareous; gradational downward into unit below	15±
207. Siltstone, platy; beds 1 to 6 ft thick	13±
208. Shale and carbonaceous shale	6±
209. Siltstone	1±
210. Shale	7±
211. Siltstone	1±
212. Shale	2±
213. Sandstone, massive	3±
214. Mud covered. Float of shale and coaly shale	6±
215. Siltstone and shale, interbedded; beds as much as 1 ft thick	5±
216. Shale, with coaly shale and thin beds of coal at 7 to 10 ft above base	17±
217. Sandstone, massive	3. 5±
218. Coaly shale	4±
219. Coal, massive; prismatic fracture; good grade	7±
220. Coaly shale, with ironstone nodules	2±
221. Siltstone or sandstone, massive; beds as much as 2 ft thick, with shale interbeds to 6 in. thick	6±
222. Shale	13±
223. Siltstone, massive	4±
224. Coaly shale and coal; about 70 percent is shale; coal beds less than 1 ft thick	7±
225. Siltstone and shale, interbedded; siltstone beds massive, less than 1 ft thick	4±
226. Shale	18±
227. Sandstone or siltstone, massive	4±
228. Shale, with coaly shale in upper part	13±
229. Siltstone, massive; appears to thicken westward to 2 ft	1±
230. Clay shale with ironstone nodules, 90 percent; light-gray bentonitic(?) mud about 15 ft above base; coaly shale in upper part	35±
231. Sandstone or siltstone, massive	1. 5±
232. Shale, and mud flow	11±
233. Siltstone and sandstone, with interbeds of shale; beds as much as 6 ft thick; resistant unit	16±
234. Shale; grades upward to siltstone	5±
235. Coal	1±
236. Siltstone and shale, interbedded	2. 5±
237. Siltstone, massive	2. 5±
238. Shale	4±
239. Siltstone(?), massive	1±
240. Shale	13±
241. Coal, with prismatic fracture, good grade	2±
242. Coaly shale and bony coal; may include some thin coal beds of good grade	4±
243. Bentonitic(?) claystone; light-gray clay in upper 6 in	3±
244. Clay shale, very soft	5±
245. Siltstone, massive	5±
246. Clay shale; contains 1 ironstone lens 6 in. thick	7±
247. Sandstone or siltstone, massive	4±
248. Shale, with interbeds of ironstone	12±
249. Sandstone	4±
250. Shale	2±
251. Siltstone and shale, interbedded; siltstone is in beds about 1 to 8 in. thick	4±

	Thickness (feet)
252. Shale, with light-gray bentonitic(?) mud in middle part	13±
253. Sandstone, salt-and-pepper	2. 5±
254. Coaly shale	1±
255. Shale, with thin siltstone interbeds	5±
256. Sandstone, fine- to coarse-grained, salt-and-pepper, massive to flaggy; beds as much as 4 in. thick	12±
257. Siltstone and silty shale, blocky	8±
258. Siltstone, massive to blocky	5±
259. Mostly mud covered. Shale, with 20 percent of thin siltstone interbeds	15±
260. Coal	1. 5±
261. Coaly shale and shale, interbedded	3±
262. Sandstone or siltstone lens; thickens westward to 7 ft	2±
263. Shale, siltstone, and coaly shale; interbedded; 80 percent is shale; siltstone beds less than 1 ft thick; scattered ironstone nodules	17±
Total thickness	2, 767±

Base of member.

Conglomerate member:

	Thickness (feet)
1. Sandstone, salt-and-pepper; massive beds as much as 5 ft thick in lower part, 15 ft thick in middle part, and flaggy or platy beds as much as 1½ ft thick in upper part. Interbedded lenses of chert conglomerate and ironstone conglomerate	50±
2. Coaly shale and coal. Coal includes 5 beds estimated to be 1 to 3 ft thick, of good grade	28±
3. Conglomerate and sandstone; conglomerate in lenticular beds, estimated to compose 75 percent of unit, contains subround to subangular pebbles, granules, and cobbles as much as 4 in. in diameter of gray, black, grayish-red, and grayish-green chert, white quartz, coal, ironstone, hard gray sandstone, coaly wood fragments, black, gray and grayish-red quartzite, and light-gray silicic(?) igneous rock. Matrix of siltstone and sandstone, estimated 30 percent of rock, moderately hard to friable. Sandstone lenses of salt-and-pepper, medium-gray, massive to blocky, weathers yellowish gray. Massive unit	60±
4. Sandstone, coarse-grained, salt-and-pepper similar to that in unit 3. Massive unit	50±
5. Inaccessible. Shale, possibly including coal beds; appears to thin eastward	10±
6. Sandstone, similar to unit 3. Massive unit	60±
7. Conglomerate and sandstone, interlensed, as in unit 3	28
8. Siltstone, medium-dark-gray, hard, finely crossbedded; weathers medium gray, in massive beds as much as 8 ft thick; contains shale interbeds in upper part, including coaly shale at top	26
9. Coal, blocky, good grade	. 4
10. Siltstone, massive	6
11. Siltstone and shale, as in unit 8, but lighter in color	22
12. Siltstone and clay shale, interbedded; 70 percent is siltstone, as in unit 8	62
13. Clay shale, grades downward to siltstone; 60 percent is shale; contains ironstone nodules	12
14. Pebble conglomerate, as in unit 3	26
15. Covered	50
16. Siltstone and clay shale, interbedded	20
17. Siltstone, as in unit 8; laminated, with carbonaceous partings near top	7
18. Clay shale, dark-gray, weathers medium-gray, fissile, soft; contains few lenses of ironstone; brownish-weathering clay shale at top	70
19. Conglomerate and sandstone; interbedded; similar to unit 3, but conglomerate constituents mostly pebbles and include grayish-green igneous rock. Some thin coaly beds	24
20. Pebble conglomerate as in unit 19, but with thin coal interbeds. Abrupt lower contact	24
Total thickness	635±

Base of member.

Coal and sandstone member:

	Thickness (feet)
1. Clay shale, dark-gray, fissile to blocky, soft; beds average ¼ to ½ in. but maximum is 1 in.; weathers medium to medium dark-gray	48
2. Clay shale, as above; includes lens of sandstone and conglomerate with yellowish-gray fine- to coarse-grained moderately hard to friable salt-and-pepper matrix and pebble- to small boulder-size constituents of chert, white quartz, coal, ironstone, hard sandstone, and coaly wood fragments	30±
3. Sandstone, medium-gray, coarse-grained, subgraywacke, massive, laminated and cross-bedded; with thin carbonaceous shale partings; weathers yellowish gray and yellowish orange; thin bedded in upper part	84
4. Coal, blocky, good grade	1. 8
5. Clay shale, as in unit 1; interbedded lenses of yellowish-gray siltstone, weathering yellowish orange; some coaly shale and claystone. Grades into unit below	55
6. Coal, blocky, good grade. Grades into unit below	1. 8
7. Clay shale and siltstone, as in unit 5	4
8. Coal, with thin shale partings; poor grade	1. 8
9. Clay shale and siltstone, as in unit 5	12
10. Coal, blocky, good grade	2. 5
11. Clay shale and siltstone, as in unit 5; 70 percent shale	70
12. Clay shale, as in unit 1	67
13. Siltstone, sandstone, and conglomerate; siltstone is medium dark gray, soft to hard, platy, finely crossbedded, weathers medium gray; occurs in upper 15 ft and grades downward into massive sandstone as in unit 3, with thin interbeds of coal and conglomerate lenses as much as 4 in. thick and 2 ft long. Conglomerate, as in unit 2, in basal 3 ft of unit	58
14. Clay shale, coaly shale, and coal; interbedded; 80 percent is fissile shale; coal beds about one-quarter inch thick	40±
15. Clay shale, and claystone, interbedded; some coaly shale	30
16. Coal, blocky, good grade	1. 9
17. Clay shale, as in unit 1	3
18. Siltstone, as in unit 13; thin bedded in upper part	4
19. Clay shale, as in unit 1, but fissile	7
20. Siltstone, as in unit 13, but massive	4

	Thickness (feet)
21. Clay shale, coaly shale, and coal; interbedded; 60 percent is clay shale, as in unit 1; coal beds about one-half of an inch thick	10
22. Clay shale, as in unit 1, with 20 percent of coaly shale and claystone	22. 5
23. Sandstone, medium-gray, weathers medium light gray to yellowish gray and yellowish orange, crossbedded, platy to nodular; contains thin coal lenses near base	48
24. Clay shale, as in unit 1	12±
25. Sandstone, medium-dark-gray, weathers light and yellowish gray, salt-and-pepper, hard; one lenticular bed	5±
26. Clay shale, as in unit 1	25
27. Coal and coaly shale, poor grade	9. 2
28. Clay shale, as in unit 1; includes few lenses of siltstone	34
29. Coal, blocky, good grade	1. 5
30. Clay shale, as in unit 1, fissile	10. 5
31. Claystone and clay shale, interbedded; massive appearance	4
32. Coal, blocky, good grade	1. 3
33. Siltstone and salt-and-pepper sandstone, interbedded; medium-dark-gray; weather yellowish gray; lenticular, hard	8±
34. Clay shale, as in unit 1; with 10 percent interbeds of siltstone and carbonaceous shale	40. 4
35. Coal, blocky, good grade; some coaly shale at top and bottom	. 8
36. Clay shale, with thin coal interbeds and one ironstone lens	5. 1
37. Coal, blocky, good grade	1. 4
38. Clay shale, medium-gray, weathers medium light gray and yellowish orange; contains 10 percent of carbonaceous black fissile shale	34. 7
39. Siltstone, as in unit 13, blocky, hard; in beds as much as 1 foot thick	11. 5
40. Clay shale, claystone, and carbonaceous shale; interbedded; 70 percent is shale	75
41. Coal, blocky to fissile	. 9
42. Clay shale, fissile	3. 3
43. Sandstone, coarse-grained, salt-and-pepper, finely laminated and crossbedded, massive to blocky; weathers grayish yellow; ironstained on fracture surface, with thin shale and siltstone partings	10
44. Clay shale and claystone, nodular to fissile; with 20 percent interbeds of siltstone as in unit 13	37. 4
45. Coal, blocky, good grade	2. 8
46. Siltstone, as in unit 13; but weathers grayish yellow, and with few interbeds of coal about one-half inch thick	18. 7
47. Clay shale and sandstone; sandstone is fine grained, massive, crossbedded, mostly in lower part of unit, in lenses from 1 to 6 ft thick; 60 percent is shale	95
48. Clay shale and claystone, interbedded; 80 percent is shale	40. 8
49. Siltstone, as in unit 13, but weathers grayish yellow; beds 6 in. to 2 ft thick	11
50. Clay shale	8
51. Coal, blocky, good grade	1. 6
52. Clay shale, claystone, and siltstone; interbedded; 20 percent is siltstone, as in unit 13, lensing; 70 percent is shale	54. 6
53. Coal and carbonaceous shale, interbedded	1. 5
54. Clay shale, fissile; weathers grayish yellow	1. 9
55. Sandstone, yellowish-gray, weathers grayish yellow, fine-grained, well-sorted, crossbedded, moderately hard to friable; contains plant fragments and ironstone nodules; thin bedded with shaly interbeds near top, and grades downward to massive at base. Lenticular unit	14±
56. Clay shale, as in unit 1	20. 1
57. Siltstone, as in unit 49, lenticular; interbedded with clay shale as much as 6 in. thick	15±
58. Clay shale, claystone, and siltstone; interbedded; 85 percent is shale with claystone beds as much as 3 in. thick and siltstone lenses as much as 4 in. thick	19
59. Siltstone lens, as in unit 49; beds average 4 in. thick	6. 6
60. Clay shale and claystone; 90 percent is shale	29. 9
61. Sandstone, as in unit 55	9. 6
62. Clay shale and siltstone, interbedded; 70 percent is shale; siltstone as in unit 49 but in thinner beds	22
63. Coal, blocky, good grade	. 9
64. Clay shale and claystone, interbedded; 80 percent is shale	12. 5
65. Sandstone, as in unit 55; beds 6 in. to 3 ft thick	10±
66. Shale and clay shale carbonaceous; with coal interbeds as much as 3 in. thick; 75 percent is shale	5
67. Clay shale, as in unit 1	30
68. Coal, blocky, good grade	. 9
69. Clay shale and siltstone, interbedded. Siltstone as in unit 49; 80 percent is shale	13. 3
70. Sandstone, similar to unit 55, but friable; contains thin beds of medium-gray sandstone	25±
Total thickness	1, 407±

Base of member.

Shale member:

1. Clay shale and claystone, interbedded, dark-gray, fissile to blocky; weathers yellowish orange, contains scattered plant fragments; a few thin lenses of yellowish-gray fine-grained moderately hard sandstone; contains coaly fragments; 80 percent is shale	85
2. Coal, blocky, good grade	1. 3
3. Clay shale and claystone, interbedded; 75 percent is shale	39
4. Sandstone, coarse-grained, salt-and-pepper, uniform, hard; weathers grayish yellow; lenticular unit	5±
5. Clay shale and claystone, interbedded, 90 percent is shale	52
6. Sandstone and siltstone, interbedded; sandstone is similar to unit 4, with interbeds of medium-dark-gray soft to hard platy finely crossbedded siltstone containing plant fragments and thin interbeds of shale. Lenticular unit	20±
7. Clay shale and claystone, dark-gray, weather medium to medium dark gray, fissile to blocky; beds usually less than 1 in. thick and averaging one-half inch	10

	Thickness (feet)
8. Coal, with few thin interbeds of clay shale	1. 5
9. Carbonaceous shale, clay shale, and coal; interbedded; 90 percent is shale; coal in thin lenses	10
10. Siltstone; similar to that in unit 6 and highly iron-stained, with beds 6 to 10 in. thick. Lenticular unit	12±
11. Clay shale and claystone, interbedded; shale weathers yellowish orange in part	150
12. Coal, blocky to fissile, fair to good grade	1. 4
13. Sandstone, as that in unit 1	15. 8
14. Clay shale and claystone, interbedded as in unit 1; 80 percent is shale, with few thin coal lenses and scattered plant fragments	150
15. Coal, blocky	. 4
16. Clay shale and claystone, interbedded, as in unit 1	229
17. Coal, blocky to platy, fair to good grade	1. 4
18. Clay shale and claystone, interbedded, as in unit 1; but 70 percent is shale	148
19. Coal, as in unit 17	1. 3
20. Clay shale and claystone, interbedded, as in unit 1; but with 10 percent of scattered interbeds of of siltstone; 70 percent is shale	215. 3
21. Siltstone, similar to that in unit 6, but finely laminated	8. 9
22. Clay shale, claystone, and coal; interbedded; 80 percent is shale; coal restricted to middle part; lower part heavily iron stained	81. 2
Total thickness	1, 238±

Base of member.

Lower sandstone member:

	Thickness (feet)
1. Sandstone, medium-light-gray, weathers light olive gray, medium- to fine-grained, salt-and-pepper, hard, crossbedded and laminated, massive to blocky. Contains carbonaceous fragments	25±
2. Clay shale, claystone, and siltstone; interbedded; 80 percent is fissile to nodular shale, in beds ¼–½ in. thick, locally iron stained. Few scattered coal beds, one-quarter inch thick	68
3. Claystone, in upper part; grades downward to clay shale and to massive siltstone in lower part. Yellowish-orange weathering throughout unit	11. 8
4. Clay shale and siltstone, interbedded; 70 percent is fissile shale, in ½-inch uniform beds. Siltstone is medium-dark gray, hard, micaceous, carbonaceous, with irregular splintery fracture	73. 8
5. Sandstone, similar to unit 1, massive, hard; contains conglomerate lenses and large coaly wood fragments at base. Highly fractured	60±
6. Clay shale, claystone, and siltstone; interbedded; siltstone as in unit 4; claystone and shale nodular to fissile, locally iron stained, 80 percent of unit. One coal interbed 1.4 ft thick 4 ft below top	18
7. Siltstone, as in unit 4, highly fractured	17. 7
8. Clay shale and claystone, nodular; grades into unit below	8
9. Sandstone, as in unit 1; grades upward into siltstone	13. 4
10. Sandstone, as in unit 1; contains large coaly wood fragments and prominent crossbedding. Grades upward into siltstone	24
11. Clay shale, claystone, and siltstone; interbedded; 70 percent is shale and claystone fissile to nodular; thin interbeds of coal and carbonaceous shale	139. 5
12. Sandstone, similar to unit 1; grades upward into siltstone with few shale partings. Massive unit	12
13. Clay shale, claystone, and coal; interbedded; shale and claystone beds to one-half inch thick, nodular, iron stained, make up 80 to 90 percent of section; coal in scattered beds less than one-half inch thick	7. 6
14. Siltstone, as in unit 4, but weathers grayish yellow	3. 2
15. Clay shale and claystone, interbedded; claystone is massive to nodular; beds as much as 5 in. thick	14. 2
16. Siltstone, as in unit 4, highly fractured	5. 2
17. Clay shale, fissile, highly fractured. Thin coal beds near base	4. 2
18. Sandstone, as in unit 1; one massive bed	3. 3
19. Silt shale and siltstone, interbedded; 40 percent is siltstone as in unit 4; beds as much as 4 in. thick. One interbed of fissile coal 6 in. thick; thin clay shale bed at base	24. 5
20. Sandstone, medium-gray, very fine grained to silty, micaceous, carbonaceous; with conglomerate lens 6 in. thick 15 ft below top that contains pebbles and cobbles of chert, white quartz, sandstone, coal, and ironstone. Unit thickens westward from 50 to 75 ft	65±
21. Coal and carbonaceous shale; coal at base, thickness poorly defined	3. 8
22. Siltstone, as in unit 4	4. 8
23. Shale and siltstone interbedded 60 percent is shale, siltstone similar to unit 4. Upper 20 ft not accessible	74±
24. Not accessible. Siltstone (?), blocky	5±
25. Not accessible. Shale and siltstone, interbedded	25±
26. Not accessible. Siltstone (?)	8±
27. Silty shale, fissile beds less than one-half inch thick	25
28. Siltstone, as in unit 4; with thin interbeds of fissile shale	18
29. Siltstone, as in unit 4, but in single bed	5. 2
30. Shale and siltstone, interbedded; mostly shale; siltstone is thin bedded; 1 coal bed 1 in. thick	12
31. Siltstone, as in unit 4, but in one massive bed; plant fragments common	4. 1
32. Siltstone, similar to unit 4; but thinner bedded and with interbeds of coal about one-half inch thick and medium-light-gray siltstone as much as 6 in. thick	20
33. Siltstone, as in unit 4, but without plant fragments; thin shale beds throughout. Massive	3. 2
34. Siltstone and coal, as in unit 32	34. 9
35. Sandstone, as in unit 1; contains pebble conglomerate in lower 6 in., and few thin siltstone interbeds and lenses	4. 1
36. Siltstone, as in unit 4, highly fractured	4. 5
37. Carbonaceous shale, with coal interbeds less than one inch thick	6

	Thickness (feet)
38. Coal, good grade	1.3
39. Siltstone and silty shale, interbedded; 50 percent is siltstone, as in unit 4; grades into unit below	10.5
40. Siltstone, as in unit 4; with very fine-grained sandstone interbeds	8.7
41. Clay shale, silty shale, siltstone, and sandstone; interbedded; 80 percent is shale, includes 50 percent medium-gray soft clay shale that weathers yellowish orange, with whitish efflorescence on some surfaces; sandstone in beds as much as 3 ft thick; minor amounts of coaly shale	40±
42. Coal and coaly shale	.5
43. Silty shale, clay shale, siltstone, and sandstone; interbedded; 60 percent is shale, in interbedded units as much as 10 ft thick; siltstone as beds and lenses as much as 4 ft thick, with shaly interbeds; one 2-ft bed of sandstone	18
44. Coal, fair grade	.6
45. Silty shale, clay shale, siltstone, and sandstone, as in unit 43	53
46. Silty shale and siltstone, interbedded	7±
47. Sandstone, very fine grained to fine-grained; partings at intervals of less than 1 ft; some interbedded siltstone	7
48. Silty shale and clay shale	12
49. Siltstone	3
50. Silty shale and clay shale, interbedded	10
51. Silty shale, with thin interbeds of siltstone; 70 percent is shale	7
52. Bony coal and coaly shale	1
53. Clay shale	1.5
54. Siltstone and sandstone, massive; medium-dark-gray very fine grained to fine-grained sandstone in upper 15 ft, grades downward to siltstone	25±
55. Clay shale and silty shale; interbedded; contain ironstone nodules, one 3-ft thick siltstone interbed, and one coaly tree trunk 5 ft long, 8 in. in diameter, perpendicular to bedding	20
56. Siltstone, massive, with conchoidal fracture	2.5
57. Bony coal	.7
58. Clay shale, silty shale and siltstone; interbedded; grades downward into	2
59. Siltstone, massive; weathers yellowish gray in lower 2 ft; abrupt contact with unit below	8
60. Clay shale, with thin siltstone lenses; grades downward into unit 61	7
Note: Units 61 through 65 form resistant section.	
61. Siltstone, thin-bedded; with interbeds and lenses of very fine grained to medium-grained sandstone and coaly beds and lenses as much as 6 in. thick	22
62. Sandstone and siltstone, as in unit 61, but sandstone dominant	25
63. Sandstone, fine- to medium-grained, weathers yellowish-orange; platy beds less than 1 ft thick and minor amounts of siltstone in upper part; grades downward to massive beds and lenses in lower part	27
64. Sandstone, medium- to olive-gray, medium-grained, salt-and-pepper, hard, very massive; single bed, grades into unit below	8
65. Sandstone and conglomerate; sandstone as in unit 64, contains pebble- to cobble-conglomerate lenses as much as 1 ft thick, lenses of ironstone nodules, and lenses of coaly material	7
66. Clay shale, olive-gray	4
67. Coal, good grade	1
68. Siltstone, nodular to platy, with interbeds of silty ironstone	4.5
69. Silty shale, siltstone, and very fine grained sandstone interbedded in beds as much as 6 in. thick; 50 percent is shale; coaly shale and clay shale in upper 6 in	14
Note: Units 70–72 form resistant section.	
70. Siltstone and fine-grained to very fine grained sandstone; interbedded; similar to unit 61; 70 percent is siltstone; appears to grade eastward in part to shale	29
71. Silty shale	1
72. Sandstone, similar to units 63 and 64; but fine grained in upper part, becoming coarse grained downward; beds 1 in. to 5 ft thick, crossbedded and laminated; contains fine carbonaceous material, large plant fragments, and ironstone nodules. Lower contact abrupt and irregular on what appears to be scoured surface of unit below	30
73. Clay shale and silty shale, interbedded; contain abundant ironstone nodules	6
74. Sandstone, as in unit 72. Lower contact abrupt and irregular	45
75. Coaly shale	1
76. Silty shale, grades downward into clay shale; weathers yellowish orange; contains ironstone nodules and one 2-ft siltstone lens. Abrupt contact with unit below	17
77. Sandstone, very fine grained, massive; grades downward into unit below	9
78. Silty shale	10
79. Siltstone, weathers dusky-yellow, laminated and crossbedded	3
80. Silty shale and clay shale	28
81. Siltstone and fine-grained sandstone, interbedded	15
82. Mostly inaccessible. Shale, siltstone and sandstone, interbedded; 60 percent is shale; siltstone and sandstone beds as much as 2 ft thick, more abundant in upper part of unit	40
83. Siltstone, sandstone, and silty shale; interbedded. 40 percent is medium dark gray crossbedded laminated siltstone; 30 percent is fine-grained medium-gray salt-and-pepper sandstone and medium-dark-gray uniform-textured sandstone	24±
84. Silty shale	8±
85. Inaccessible. Shale with 3 coal interbeds ½ to 1 ft thick	4±
86. Mostly inaccessible. Interbedded, silty shale, clay shale, and siltstone, and few thin sandstone beds and coal lenses. Unit weathers light brown to yellowish orange, contains plant fragments; 50 percent is siltstone, in beds less than 2 ft thick	47±
87. Bony coal	.8

	Thickness (feet)
88. Silty shale, clay chale, siltstone, and sandstone, interbedded, as in unit 86, but shale constitutes 80 percent	65±
89. Coal, with bony coal and coaly shale in upper 6 inches	1.5
90. Siltstone, in upper part; grades downward to fine- to medium-grained moderately hard sandstone; sandy shale in middle part	9
91. Inaccessible. Shale	15
92. Siltstone, massive, with few interbeds of silty shale	19
93. Coaly shale, clay shale, and silty shale; coaly shale in lower 1 ft	2
94. Inaccessible owing to snow banks. Shale weathers dull dark gray; contains thin coal and siltstone beds; upper 10 ft appears to grade west to siltstone	42±
95. Siltstone, and fine-grained sandstone with few interbeds of shale; grades into unit below	20
96. Silty shale and siltstone, interbedded; clay ironstone lenses in lower 20 feet	23
97. Siltstone and very fine grained sandstone, interbedded; massive to thin platy beds; contains plant fragments in upper 5 ft; *Asplenium foersteri* Debey and Ettingshausen, *Cladophlebis browniana* (Dunker) Seward, *Nilssonia serotina* Heer	30
98. Coal and coaly shale; includes one 8-in. bed of good coal	1
99. Inaccessible. Siltstone or sandstone, appears to grade into shale eastward	6±
100. Inaccessible. Shale, weathers bright yellowish orange	22±
101. Largely sandstone, as in units 63 and 64; interbedded with siltstone and silty shale in upper part, grades downward to massive and thick bedded in lower 15 ft; large clay ironstone lenses and nodules at base and near top. Abrupt contact with unit below	35
102. Siltstone, massive; contains scattered ironstone nodules	11
103. Silty shale, with small amounts of coaly shale interbedded	13
104. Coal, fair to good grade	.7
105. Silty shale, clay shale, and carbonaceous shale; interbedded	14
106. Coaly shale and bony coal	1
107. Siltstone, massive	11
108. Silty shale	3
109. Siltstone and very fine grained sandstone, interbedded	5
110. Silty shale; contains 1-ft bed coaly shale 2 ft below top	10
111. Sandstone, very fine grained	6
112. Silty shale	8
113. Sandstone, medium-dark-gray, very fine grained to fine-grained; in massive regular beds 6 in. to 2 ft thick with few thin shale partings. Abrupt contact with unit below	11
114. Coaly shale, with one 6-in. coal interbed	1
115. Silty shale, weathers dark-yellowish-orange	9
116. Siltstone and very fine grained sandstone, interbedded; 20 percent is shale in thin interbeds	24
117. Silty shale and clay shale	8
118. Siltstone	4
119. Siltstone, sandstone, and silty shale; 70 percent is siltstone, interbedded with shale and grades downward into lower 5 ft of fine- to medium-grained sandstone	34
120. Silty shale	2
121. Siltstone	5
122. Silty shale, with some clay shale interbeds and silty ironstone nodules	24
123. Siltstone	5
124. Silty shale; grades into unit below	8
125. Resistant unit. Siltstone in upper 10 ft; grades downward to very fine-grained to medium-grained laminated crossbedded platy to massive lenticular sandstone that grades downward to coarse-grained salt-and-pepper sandstone in lower 2 ft, with abundant coaly material and large ironstone nodules. Abrupt contact with unit below	25
126. Siltstone and silty shale; 70 percent is siltstone; grades into unit below	10
127. Silty shale and siltstone, interbedded; 70 percent is shale; siltstone in beds and lenses as much as 1½ ft thick; grades into unit below	18
128. Sandstone, medium-dark-gray, very fine grained, dirty appearing, massive; grades into unit below	7
129. Siltstone and silty shale, interbedded; 70 percent is siltstone	10
130. Silty shale, clay shale, and coaly shale; interbedded; includes very thin coal beds	2.5
131. Siltstone, massive	3
132. Silty shale	3
133. Sandstone and siltstone, interbedded; mostly siltstone in upper part grading down to massive fine-grained medium-dark-gray sandstone in lower 5 ft	18
134. Silty shale	9
135. Siliceous claystone, black, very hard, dense; with conchoidal fracture, medium-brown streak. Persistent bed along more than 200 ft of exposure	.2
136. Claystone, dark-gray, weathers light brown to dark yellowish orange, silty, hard, massive to blocky; with conchoidal fracture; constitutes 70 percent of unit; contains thin interbeds of siltstone and very fine grained sandstone, coaly lenses, and clay ironstone nodules	55
137. Siltstone, blocky; with thin, fine-grained salt-and-pepper sandstone lenses; grades into unit below	19
138. Claystone, as in unit 136	20
139. Bony coal and coal	1
140. Clay shale, claystone, and carbonaceous shale, weathers yellowish orange, fissile to nodular; contains small plant fragments	4
141. Siltstone, clay shale and clay ironstone lenses interbedded	4
142. Carbonaceous shale, fissile	3.5
143. Massive unit. Silty shale and siltstone interbedded in upper 9 ft; siltstone increases downward with interbeds of sandstone; mostly sandstone in lower 35 ft becoming more massive	

	Thickness (feet)
downward; lower 5 ft very massive hard medium-grained medium-light-gray salt-and-pepper sandstone	54
144. Silty shale, blocky	5
145. Siltstone, massive to platy, with very fine grained sandstone lenses at base and near top	14
146. Silty shale, hard	6
147. Siltstone, in upper 4 ft; lower part is medium-gray very fine grained massive hard, carbonaceous sandstone that weathers reddish brown	5
148. Silty shale and clay shale, with plant fragments	7
149. Siltstone	6
150. Silty shale and nodular siltstone; includes one interbed of medium-dark-gray lithographic limestone with conchoidal fracture, which weathers grayish yellow to yellowish orange and contains reedlike fragments	3. 5
151. Clay shale, soft	1
152. Coal, bony	. 5
153. Clay shale, claystone and silty shale, nodular to blocky fracture	11
154. Siltstone and silty shale, interbedded; contain ironstone nodules; 70 percent is siltstone	13
155. Siltstone, medium-dark-gray, massive to platy; upper 5 ft coarsens westward to fine- to medium-grained medium-gray massive sandstone; grades into unit below	10
156. Silty shale and carbonaceous shale	. 5
157. Coal and bony coal	1. 5
158. Silty shale and clay shale, with siltstone lenses	6. 5
159. Siltstone, massive	5
160. Coal	. 2
161. Silty shale; contains small plant fragments	4
162. Sandstone, medium-gray, fine- to medium-grained, salt-and-pepper; contains coaly wood fragments. Abrupt contact with unit below	3
163. Siltstone, medium-dark-gray, laminated and cross-bedded; weathers light brown and yellowish orange; contains large coaly wood fragments resembling tree branches in upper 5 ft. Massive unit	21
164. Silty shale and clay shale	12
165. Siltstone and silty shale, with plant fragments; 80 percent is siltstone	12
166. Coal	. 1
167. Siltstone, with few shale interbeds	23±
168. Clay shale and silty shale	4
169. Siltstone and silty shale, interbedded; 80 percent is siltstone in beds 1 to 2 ft thick	15
170. Shale, with two 3-ft interbeds of siltstone; few ironstone nodules	16
171. Siltstone, medium-dark-gray, massive; contains numerous coaly plant fragments	7
172. Silty shale	4
173. Siltstone, massive, crossbedded	5
174. Clay shale, claystone, and silty shale, dark-gray, nodular to blocky; contain ironstone nodules	21
175. Coal and coaly shale	1. 5
176. Silty shale, blocky fracture; grades into unit below	5
177. Sandstone, medium-dark-gray, very fine grained to fine-grained, massive. Abrupt contact with unit below	4
178. Silty shale, in upper 10 ft; grades downward to interbedded sandstone and siltstone; 4 in. coaly shale at top of unit; grades downward into unit below	28
179. Massive unit. Siltstone, sandstone, and conglomeratic sandstone; fine-grained to very fine grained medium-dark-gray platy sandstone and siltstone in upper part that weathers light brown; grade downward to medium-grained platy to massive cross-bedded laminated moderately hard sandstone with coaly lenses and fragments; grades downward to lower 12 ft of medium-gray massive conglomeratic salt-and-pepper medium- to coarse-grained sandstone that weathers moderate yellowish brown and yellowish orange and light brown; contains large coaly lenses and plant fragments and subround to subangular pebbles as much as 2 in. in diameter of black, gray, and grayish-red chert, gray sandstone, grayish-green argillite ironstone, white quartz, and grayish-green quartzite. Abrupt lower contact with unit below	39
180. Silty shale, with coal interbeds to 1 in. thick	5
181. Coal and coaly shale, interbedded. Abrupt lower contact with unit below	2
182. Massive unit similar to unit 179. Interbedded siltstone and sandstone in upper 10 ft; conglomeratic sandstone and conglomerate in lower 10 ft	54
Total thickness	2, 685±

Base of member.

Silty shale member:

1. Silty shale and siltstone; with interbedded coal lenses and ironstone nodules	12
2. Shale; coarsens westward and intertongues with very fine-grained sandstone	8
3. Claystone and shale, interbedded, olive-black, olive-gray, and dusky-yellow-brown; weathers bright orange. Claystone is silty and massive	12
4. Sandstone, very fine grained and siltstone; interbedded; massive unit	16
5. Claystone, as in unit 3; *Nilssonia serotina* Heer, *Ginkgo digitata* (Brongniart) Heer	30
6. Shale, as in unit 3	16
7. Siltstone, massive	52
8. Silty shale and clay shale, interbedded	20
9. Coal, poor grade; beds about one-quarter of an inch thick	1. 7
10. Clay shale, silty shale, siltstone, and sandstone; interbedded; 65 percent is shale in sets of beds as much as 20 ft thick; sandstone is medium- to very fine-grained, salt-and-pepper type, hard and in beds as much as 8 ft thick but averaging less than 5 ft; siltstone beds as much as 5 ft thick; some thin interbeds of ironstone; plant fragments in lower 10 feet include *Cladophlebis browniana* (Dunker) Seward, *Ginkgo digitata* (Brongniart) Heer	175. 3
11. Coaly shale and coal; includes one 11-in. bed of good grade coal	2

	Thickness (feet)
12. Sandstone and siltstone, interbedded; 10 percent is shale interbeds. Sandstone is very fine grained and in beds as much as 4 ft thick. Massive unit	50
13. Coal, vitreous, good grade	1
14. Coaly shale	1
15. Sandstone, medium-gray, very fine grained to medium-grained, massive to platy; with interbeds of siltstone	18
16. Sandstone, siltstone, silty shale, and clay shale; interbedded as in unit 12; but 40 percent is shale in sets of beds as much as 3 ft thick	63
17. Siltstone and shale, interbedded; 80 percent is siltstone, medium dark gray and blocky to massive in beds as much as 12 ft thick; shale is dark gray interbedded, as much as 4 ft thick	41
18. Siltstone and very fine-grained sandstone; contains plant fragments, thins eastward to 1 ft in thickness	7.5±
19. Siltstone, as in unit 17, massive; contains carbonaceous reedlike fragments	5
20. Silty shale	7
21. Siltstone, as in unit 17, massive	4.5
22. Siltstone and clay shale, interbedded, ironstone nodules in upper 5 ft	15
23. Coal and coaly shale	.5
24. Siltstone and shale, interbedded; 80 percent is siltstone in beds as much as 1 ft thick	20.5
25. Sandstone, medium-gray to pale-yellowish-brown, fine- to medium-grained, uniform	2.5
26. Siltstone, as in unit 17	17.5
27. Coal, vitreous, good grade	1
28. Silty shale	4
29. Sandstone, as in unit 25, but very fine grained	4.5
30. Siltstone and clay shale, interbedded; 80 percent is siltstone as in unit 17	8
31. Sandstone, fine-grained, salt-and-pepper; interbedded with siltstone	4
32. Silty shale; contains 1 ironstone bed 6 in. thick. Plant fragments common	6
33. Siltstone, as in unit 17	18
34. Shale	2
35. Siltstone, as in unit 17	4
36. Shale	4
37. Silty shale, clay shale, and claystone; interbedded; nodular to blocky	4
38. Sandstone, siltstone, and shale; interbedded. Mostly pale-yellowish-brown to light-olive-gray fine- to medium-grained massive to platy laminated and crossbedded sandstone that weathers moderate yellowish brown; grades upward to siltstone and shale in upper part. Unit appears to thin eastward	31
39. Silty shale, clay shale, siltstone, and sandstone; interbedded; 50 percent is shale; 20 percent is salt-and-pepper sandstone. Plant fragments scarce	90
40. Poorly exposed. Clay shale, silty shale, siltstone, sandstone, and ironstone; interbedded. Beds as much as 5 ft thick	35±
41. Ironstone, dark-yellowish-brown; weathers dark-yellowish-orange and light-brown; contains abundant plant fragments	4
42. Silty shale, clay shale, siltstone, and sandstone; interbedded; 65 percent is shale, 15 percent is sandstone in beds as much as 5 ft thick. Scattered ironstone nodules and lenses with plant fragments; *Podozamites lanceolatus* (Lindley and Hutton) Braun, *Ginkgo digitata* (Brongniart) Heer	46
43. Sandstone, siltstone, and silty shale; interbedded; includes one medium-gray very fine grained to fine-grained quartzitic sandstone bed 15 ft thick with 2-in. to 1½-ft partings; weathers pale brown and reddish brown. Ironstone nodules in siltstone, few coal beds as much as 6 in. thick. Sequence somewhat contorted, thickness estimated	100±
44. Silty shale and clay shale, interbedded; contain ironstone nodules, plant fragments; whitish efflorescence on fractured surfaces; few siltstone and thin coal interbeds. Some contorted bedding, unit highly fractured. Estimated thickness	45±
45. Coaly shale, with ironstone nodules	1±
46. Siltstone, silty shale, and sandstone; interbedded; 50 percent is siltstone; 20 percent is sandstone	50±
47. Sandstone, medium-gray, salt-and-pepper, laminated and crossbedded; contains lenses of ironstone. Abrupt contact with unit below	4
48. Siltstone and silty shale, interbedded; mostly shale in upper part of unit	43
49. Coal, fissile, highly fractured	2.5
50. Siltstone, silty shale, and clay shale; interbedded; contains ironstone nodules and plant fragments, becomes coarser grained downward and grades downward into unit below	40
51. Sandstone, yellowish-brown, fine- to medium-grained, carbonaceous, moderately hard, subgraywacke-type; massive in lower 7 ft, becoming platy, laminated, and crossbedded in upper part	24
52. Coal and coaly shale, highly fractured; includes 8-in. coal bed	1.3
53. Silty shale and siltstone, interbedded; with thin interbeds of clay shale and coaly shale, and few lenses of very fine grained sandstone as much as 1½ ft thick; 70 percent is shale; contains ironstone nodules. Numerous plant fragments 10 ft below top include *Ginkgo* leaves, ferns, and reeds	88
54. Silty shale, siltstone, clay shale, and sandstone; interbedded; as in unit 53	26
55. Coal and carbonaceous shale	.5
56. Silty shale and siltstone interbedded; includes one 2-ft sandstone bed 10 ft below top	52
57. Silty shale, siltstone, and sandstone; interbedded; as in unit 53. Siltstone is medium-dark-gray platy to blocky beds as much as 2 ft thick	73±
58. Silty shale and clay shale, interbedded	45±
59. Sandstone, medium-grained, salt-and-pepper; contains abundant ironstone lenses and plant fragments at base. Siltstone in upper part	5
60. Silty shale and siltstone, interbedded	10
61. Sandstone, very fine grained	4

	Thickness (feet)
62. Siltstone, blocky fracture; with thin interbeds of coal and coaly shale	29
63. Siltstone, sandy, platy	13
64. Silty shale	7
65. Sandstone, medium-dark-gray, fine-grained	10
66. Silty shale and clay shale, interbedded	2
67. Siltstone	11
68. Silty shale and clay shale, interbedded	5
69. Siltstone, blocky; contains ironstone nodules	15
70. Silty shale and siltstone, interbedded, with abundant ironstone nodules; 85 percent is shale	37
71. Coaly shale	. 5
72. Coal	. 7
73. Silty shale and siltstone, with few interbeds of very fine-grained sandstone	14
74. Covered	6
75. Siltstone and shale, interbedded	25
76. Silty shale, hard; 20 percent is interbeds of clay shale	16
77. Coal	1. 3
78. Silty shale and siltstone, interbedded, with few interbeds of sandstone; abundant plant fragments	67
79. Covered	5
80. Siltstone and silty shale interbedded; whitish efflorescence on fracture surfaces	14
81. Sand, moderate yellow-brown; contains granules of reddish, black, gray, and orange chert at base	. 8
82. Bony coal	. 7
83. Siltstone, sandstone, and silty shale; interbedded; contain plant fragments and ironstone; 60 percent is shale	10
84. Silty shale and siltstone, interbedded; contain ironstone nodules; 80 percent is shale; siltstone beds as much as 2 ft thick	25
85. Siltstone; contains abundant plant fragments	1. 5
86. Shale, dark-gray to dark-olive-gray; contains ironstone nodules	8
87. Siltstone, medium-dark-gray, hard, platy, cross-bedded	5
88. Silty shale, clay shale, and coaly shale; interbedded; contains abundant ironstone nodules with plant fragments	10
89. Sandstone, silty	1
90. Shale	7
91. Sandstone, medium-gray, platy, salt-and-pepper	2
92. Ironstone, dark-olive- to dark-gray; weathers light brown; contains abundant plant fragments; *Equisetum* sp., *Nilssonia serotina* Heer, *Ginkgo digitata* (Brongniart) Heer	1
93. Shale	1
94. Sandstone, very fine grained, with thin interbeds of shale	9
95. Silty shale and siltstone, medium-dark-gray; interbedded ½–10 in. thick; contain plant fragments and ironstone nodules	72
96. Mostly covered. Scattered exposures of siltstone, sandstone, and silty shale	15
97. Silty shale, with interbedded lenses and nodules of ironstone	28
98. Silty shale and siltstone, interbedded, with some interbeds of very fine grained sandstone; 70 percent is hard shale, with hackly fracture	15
99. Sandstone, medium-dark-gray, fine-grained, platy partings	15
100. Covered	12
101. Coaly shale	4
102. Sandstone, medium-gray, salt-and-pepper, coarse- to fine-grained, platy to blocky; beds as much as 6 in. thick; contains scattered pebbles and cobbles of chert and ironstone, grades into unit below	17
103. Conglomerate; silty matrix, subround to round, pebbles and cobbles of black chert, light-gray and white quartz, and coal	. 5
104. Carbonaceous shale, coaly shale and silty shale; interbedded; with few siltstone beds and ironstone lenses as much as 2 in. thick	42
105. Siltstone, silty shale, and sand stone; interbedded; shale contains ironstone lenses and nodules with plant fragments	17
106. Mostly covered. Scattered exposures of siltstone, silty shale, and very fine grained sandstone	122
107. Siltstone and very fine-grained sandstone, interbedded, platy; with ½-in. partings, scattered carbonaceous fragments	30
108. Mostly covered. Scattered exposures of medium-dark-gray siltstone and silty shale	48
109. Siltstone and silty shale interbedded, medium-dark-gray; beds less than 1 in. thick	15
110. Covered	41
111. Silty shale and clay shale, dark- to olive-gray. Includes one 4-in. bed of medium-dark-gray brownish-weathering soft silty limestone	1
112. Scattered exposures. Silty shale, siltstone, and lenses of very fine grained sandstone. Ironstone nodules and lenses in shale	190
113. Clay shale, silty shale, and coaly shale; interbedded; fissile, soft	24
114. Siltstone, medium-dark-gray, thin-bedded	21
115. Shale, siltstone, and sandstone; interbedded; poorly exposed; 70 percent is shale	10
116. Sandstone, medium-dark-gray, weathers olive-gray, coarse-grained, laminated, and cross-bedded; contains scattered pebbles of light-gray quartzite, ironstone nodules, and large carbonaceous fragments	17
117. Clay shale, silty shale, and sandstone; interbedded. Poorly exposed	25
Total thickness	2, 621 ±

Base of type section. Underlying rocks mostly covered by mud slump, tundra, and sand. Includes one 3-ft bed of medium-dark-gray medium- to coarse-grained hard to moderately friable highly carbonaceous laminated sandstone. Scattered rubble of dark-gray clay shale. These rocks appear to be transitional between nonmarine and marine rock types and may be equivalents of the Kukpowruk formation. They are mapped as Nanushuk group undifferentiated on plate 8.

STRATIGRAPHIC RELATIONS

The contact of the Corwin formation with the underlying Kukpowruk formation appears to be conformable and gradational. No exposed contact with the overlying rocks of the Prince Creek formation was seen during field studies in the region, and study of aerial photographs that cover the inferred contact area failed to yield more information. In the central areas of northern Alaska the Prince Creek formation overlies the Seabee formation of the Colville group which in turn unconformably overlies the Nanushuk group (Whittington, 1956, p. 244–253). In the region of this report, the only evidence that might indicate an unconformable relation is the rapid eastward thinning of the Corwin formation at the south edge of the coastal plain and the apparent absence of the Seabee formation. No large-scale stratigraphic breaks are known to occur within the Corwin formation, although some sections known to be equivalent differ considerably in thickness. These variations are not well understood, and with present data they can be demonstrated in only a few places. They may be due to erosional breaks, such as are locally exposed within the formation, where thick sandstone and conglomeratic beds lie upon irregular surfaces of the underlying rocks and in some places truncate the underlying beds. Several such breaks were recognized in the type section and in some cutbanks along the rivers, and they are similar to those previously described in the Kukpowruk formation. One such angular unconformity is exposed in a bluff on the east bank of the Kukpowruk River at lat 68°51'30" N., and long 163°09'30" W., in the south limb of Coke basin. Here, 10 feet of irregularly bedded sandstone, part of which contains 6 to 12 inches of pebble conglomerate at its base, overlies more than 30 feet of interbedded siltstone, shale, and ironstone with an apparent angular discordance of as much as 55° (fig. 23). No evidence of faulting was seen. Because of lack of exposures away from cutbanks, the lateral extent and significance of such breaks is not known.

THICKNESS AND CORRELATION

Nearly all measured thicknesses of the Corwin formation in the Utukok-Corwin region are incomplete; erosion has cut deeply into the sequence, so that most preserved sections represent only part of the original thickness. One measurement giving the complete thickness of the formation was obtained in the northern part of the foothills along the Utukok River, between Carbon Creek anticline and Westbend syncline. There the Corwin formation is about 4,500 ft thick. Table 10 shows the measured thicknesses of the Corwin formation in the major synclines of the area and the minimum and maximum possible thicknesses, including allowance for the transitional zone at the base of the formation. The thickness of the one complete section discussed above also includes allowances made for the covered interval between uppermost exposures of the Corwin formation and the lowest exposures of the Prince Creek formation in Westbend syncline.

Four sections of the Corwin formation indicate a northward and eastward thinning of the formation. The thickest section of the formation is at the type locality in the southwestern part of the mapped region, where almost 15,500 feet is present and where neither the top nor the bottom are exposed. Northeast of the type section, relatively thick sections of Corwin formation are preserved north of Archimedes Ridge anticline on the Kukpowruk and Kokolik Rivers and north of Carbon Creek anticline on the Utukok River. In this northern belt there is good evidence that the Corwin formation thins eastward. In Barabara syncline, along the Kukpowruk River, an incomplete section of the Corwin formation includes more than 7,600

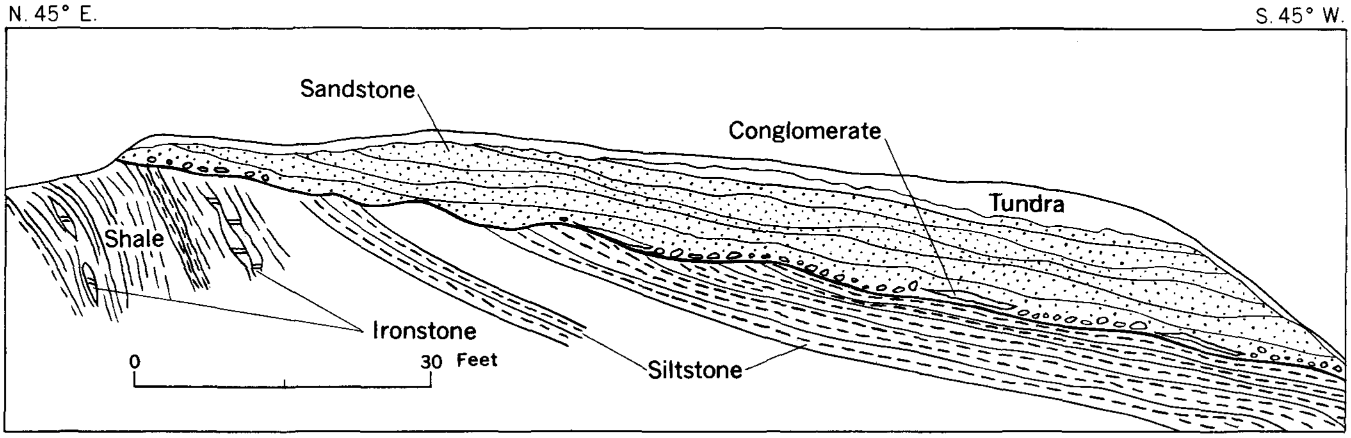

FIGURE 23.—Field sketch of cutbank on Kukpowruk River, lat. 68°51'30" N., long. 163°69'30" W., showing unconformable relations within the Corwin formation.

TABLE 10.—*Measured thicknesses of the Corwin formation showing maximum and minimum limits where exposed in synclines along major rivers*

Kukpowruk River and west				
Structural feature	Limb	Mapped thickness (feet)	Maximum possible thickness (feet)	Minimum possible thickness (feet)
Coke basin	South	3, 487	4, 529	2, 746
Do	North	3, 943	4, 729	2, 868
Tupikchak syncline.	South	2, 099	2, 792	887
Do	North	1, 917	2, 407	887
Kukpowruk syncline.	South	1, 140	1, 362	732
Do	North	1, 140	1, 344	841
Deadfall syncline	West	320	650	320
Howard syncline	South	5, 595	5, 785	5, 087
Do	North	5, 531	4, 214	3, 337
Barabara syncline.	South	7, 683	8, 065	7, 467

Kokolik River				
Structural feature	Limb	Mapped thickness (feet)	Maximum possible thickness (feet)	Minimum possible thickness (feet)
Tupikchak basin.	South	2, 200	2, 200	929
Do	North	2, 192	2, 192	922
Flintchip syncline.	South	2, 046	2, 715	1, 684
Do	North	1, 499	1, 818	1, 299
Kokolik Warp syncline.	South	475+	900	475
Do	North	475+	643	475
Deadfall syncline.	East	760+	920	450
Howard syncline.	South	1, 320	1, 748	1, 188
Do	North	1, 714	1, 818	1, 306
Oxbow syncline	South	4, 387	4, 449	4, 086
Oilsand syncline.	South	2, 375+		
Do	North	3, 147+		

Utukok River				
Structural feature	Limb	Mapped thickness (feet)	Maximum possible thickness (feet)	Minimum possible thickness (feet)
Meat Mountain syncline.		Formation not present.		
Flintchip syncline.		do		
Kokolik Warp syncline.	South	1, 020		
Folsom Point syncline.	do	939	939	637
Lookout Ridge syncline.	do	453	453	363
Oxbow syncline	North	1, 960	1, 960	1, 480
Elusive Creek syncline and north.	South and north.	[1] 4, 446	[1] 4, 564	[1] 4, 079

[1] Total thickness.

feet of strata. On the Kokolik River, 32 miles east of the above section, Oxbow syncline exposes an incomplete section of 4,400 feet; and an estimate of the total thickness of the formation, based upon projection of the Oxbow syncline section northward to the exposures of Prince Creek formation, is not more than 6,000 feet. Thirty miles farther east the complete section of the Corwin formation measured in the Elusive Creek syncline and north along the Utukok River is about 4,500 feet thick. These thicknesses indicate that the formation thins eastward at a rate of at least 50 feet per mile.

The apparent northeastward thinning of the Corwin formation may be due to actual differences of depositional thicknesses in the basin of deposition that deepened progressively southwestward. It may also be due to a hiatus between deposition of the Corwin and Prince Creek formations, during which time the upper part of the Corwin formation may have been removed by differential erosion. Evidence supporting the first explanation is the northeastward thinning of the Kukpowruk formation and the thickness variations within the Corwin formation, most of which indicate a northward thinning. Some of these thickness variations are due to intertonguing at the contact of the Corwin and Kukpowruk formations and are not significant in that they are due to facies differences and do not necessarily represent true thickness changes. More significant, however, are the changes of thickness between equivalent sections of the formation when compared on opposite limbs of a single syncline. In Tupikchak syncline, on the Kukpowruk River, equivalent sections in the lower part of the Corwin formation show a northward thinning of about 400 feet in 3 miles (pl. 12). Sections in Flintchip and Kokolik Warp synclines, on the Kokolik River, likewise show an apparent northward thinning but of lesser amount (pl. 13). One known exception, a southward thinning from about 3,950 feet to 3,500 feet in 6 miles is shown by equivalent sections in Coke syncline, on the Kukpowruk River (pl. 11). This exception suggests that although the basin of deposition did in general deepen southwestward, other factors, such as local differences in depositional conditions caused by unevenness of the basin floor, or intraformational unconformities, may have been responsible for the thickness change.

The type section of the Corwin formation is correlated with inland exposures in this region mainly on a lithologic basis, and it is fairly certain that prior to faulting, rocks of the type section were structurally continuous with the inland rocks. It has not been possible to satisfactorily correlate all seven units of the type section (p. 105) with the more poorly exposed inland sections of the Corwin formation. The lower part of the formation in most inland localities, however, resembles the silty shale member of the type section and is about 1,900 to 2,000 feet thick in Howard syncline on the Kukpowruk River, where it underlies sandy, coaly and bentonitic(?) sections. These include a section with numerous thick coal beds that are associated with clay believed to be in part bentonitic, which begins 3,300 feet above the base of the formation. Similar clays associated with thin coal beds were seen as low as 1,960 feet above the base. This section is tentatively correlated with the Bentonitic clay member and the Coal and sandstone member of the type section. In Barabara syncline, thick coal beds are exposed as low as 1,830 feet above the base of the formation, and bentonitic beds were observed at about 5,000 feet and 7,550 feet above the base; but the exposures between 3,100 feet and the top of the section at 7,700 feet are so scattered that definitive correlations with the type section are not possible. As in Howard syncline, the exposed parts of the section resemble the Bentonitic clay member and Coal and sandstone member. Other sections in the inland area are too poorly exposed to permit correlation. In conclusion, it is not certain whether the thickest sections in the inland area represent most of the type section, with overall thickness changes accounting for the differences between them, or whether the upper part of the Corwin formation in the inland part of the region is missing, owing either to nondeposition or to post-Corwin erosion.

Bentonitic rocks exposed along the coast west of Cape Beaufort, including those in the type section of the Corwin formation, were previously thought to be correlative with the Colville group (Payne and others, 1951, sheet 1). These rocks are not like the Prince Creek formation in the inland part of the region and are placed by the authors in the Corwin formation.

The Corwin formation is similar to the Chandler formation of the Nanushuk group in more easterly areas of northern Alaska (Detterman, 1956, p. 237–239), but where it can be measured, it is considerably thicker than the Chandler formation. It is also tentatively correlated with the strata in the interval from 113 to about 4,600 feet in Kaolak test well 1.

FOSSILS AND AGE

Nearly all fossils observed in the Corwin formation are plant remains. Indeterminate pelecypods were found in only one field locality, on the south limb of Tupikchak syncline on the Kukpowruk River 1,760 feet above the base of the formation. The presence of this fauna in the Corwin formation is attributed to minor tongues of marine rocks deposited in the lower part of the formation. Pelecypods identified as *Entolium* sp. were also found at a depth of 3,996 feet in Kaolak test well 1, in the coaly section correlated with the Corwin formation.

Collections of fossil plant remains from coastal exposures of the Corwin formation were made as early as 1885 by Woolfe and others, noted by Schrader (1904, p. 74), and in 1904 by Collier and party (1906, p. 28). Ages of these respective collections were indicated to be Early Cretaceous or possibly Late Jurassic by Lesquereux and Newberry, provisionally Jurassic and Cretaceous by Fontaine and Ward and finally Jurassic by F. H. Knowlton (1914, p. 39–64); and Collier (1906, p. 28–31).

Collections from inland localities in this region include those made in 1923 by Foran along the Kukpowruk and Utukok Rivers. Those known to be collected from rocks now mapped as Corwin formation had been determined to be Jurassic to Early Cretaceous in age by Knowlton (Smith and Mertie, 1930, p. 226), but they were not specifically correlated with the Corwin formation as it was then known. Plant collections made by P. S. Smith in 1926 were examined by Hollick, who identified them as Jurassic or possibly Cretaceous in age (Smith and Mertie, 1930, p. 225–226). In stating Jurassic age it was Hollick's intention to identify the flora of these samples with the "Cape Lisburne-Corwin flora" (Smith and Mertie, 1930, p. 219). However, because the inland rocks from which these samples were collected overlie fossil faunal-bearing rocks of Early and Late Cretaceous ages, the age of the plant-bearing rocks in the inland areas was thought to be Late Cretaceous by Smith and Mertie (1930, p. 222). The sequence in and near Corwin Bluff was also suggested to be of Late Cretaceous age on the basis of the lithologic similarity and apparent structural continuity of these rocks with inland exposures, although this was not supported by paleobotanical evidence (Smith and Mertie, 1930, p. 218–219, 231).

The type section in the vicinity of Corwin Bluff is lithologically like and, prior to faulting, was structurally continuous with the inland exposures mapped as Corwin formation. On this basis the inland exposures are considered to be, at least in large part, of the same age as exposures in the Corwin Bluff vicinity.

Collections of plant fossils made in the Corwin Bluff vicinity in 1947 and 1953 and in inland areas in 1947 and 1949 were examined and identified by Roland F. Brown as follows:

Corwin Bluff vicinity, Arctic coastline from a point 0.6 mile west of Thetis Creek to 2 miles west of Aknasuk Creek

[Stratigraphic positions are shown on the columnar section (pl. 17) except where noted]

53ASa204:
  Equisetum sp.
  Nilssonia serotina Heer
  Ginkgo digitata (Brongniart) Heer
53ASa209:
  Podozamites lanceolatus (Lindley and Hutton) Braun
  Gingko digitata (Brongniart) Heer
53ASa214:
  Nilssonia serotina Heer
  Ginkgo digitata (Brongniart) Heer

- 53ASa221:
  - *Cladophlebis browniana* (Dunker) Seward
- 53ASa223:
  - *Asplenium foersteri* Debey and Ettingshausen
  - *Ginkgo digitata* (Brongniart) Heer
- 53ASa232:
  - *Asplenium foersteri* Debey and Ettingshausen
  - *Cladophlebis browniana* (Dunker) Seward
  - *Nilssonia serotina* Heer
- 53ASa240 (stratigraphic position unknown):
  - *Podozamites lanceolatus* (Lindley and Hutton) Braun
  - *Ginkgo digitata* (Brongniart) Heer
- 53ASa1012:
  - *Podozamites lanceolatus* (Lindley and Hutton) Braun
  - *Ginkgo digitata* (Brongniart) Heer
- 53ASa1018A:
  - *Cladophlebis browniana* (Dunker) Seward
- 53ASa1021:
  - *Asplenium foersteri* Debey and Ettingshausen
- 53ASa1027:
  - *Cladophlebis septentrionalis* Hollick
  - *Cephalotaxopsis magnifolia successiva* Hollick
- 53ASa1030:
  - *Cladophlebis browniana* (Dunker) Seward
  - *Ginkgo digitata* (Brongniart) Heer

Comment: The presence of the fern *Cladophlebis browniana*, the abundance of *Nilssonia serotina*, and the fact that the ginkgo is predominantly digitate, points to a late Lower Cretaceous age for all these collections.

- 47ATm C-1, Corwin Bluffs. Corwin formation type section, stratigraphic position unknown:
  - *Asplenium johnstrupi* (Heer) Heer
- 47ATm38, Utukok River. Probably upper part of Corwin formation.
  - *Ginkgo laramiensis* Ward
- 49ASa68, Kukpowruk River. Near base of Corwin formation.
  - *Ginkgo laramiensis* Ward

Comment: From the few specimens submitted, the age of the strata at each of the localities appears to be Upper Cretaceous.

Although the last 3 samples were referred to as Upper Cretaceous, after examination of the Corwin samples, Brown suggested that the 3 samples might be of Early Cretaceous age, as they do not represent suitable collections for specific age determination (R. W. Brown, oral communication, 1954).

Fossil plants collected from inland localities in the 1920's, and which are still available, include National Museum numbers 7840, 7843, 7845, 7849, 7852, 7641, 7647, 7650, and 7665 (Smith, 1930, p. 225–227). These were reexamined by Brown who made the following comment:

> The other locality numbers . . . are represented by only 1 or 2 specimens each. All of them are Cretaceous, except probably 7668. [See p. 127 this report.]

On the basis of the above paleobotanical evidence and from the identifications of fossils in the underlying Kukpowruk formation, the Corwin formation in this region is here assigned to the Lower Cretaceous and possibly Upper Cretaceous series, not older than the Albian stage of the Lower Cretaceous. Exact age relations to the Chandler formation of the Nanushuk group are not known. The age of the Chandler formation is believed to be late Early and early Late Cretaceous (Albian and Cenomanian stages) (Imlay, written communication, 1956).

Lowther, who collected and described 16 collections of fossil plants from rocks mapped here as Corwin and Prince Creek formations, is of the opinion that the plants indicate an early Early Cretaceous (late Neocomian) age (Lowther, written communication 1957). This age designation is based on the character of the plant assemblages as compared to better known Mesozoic assemblages from boreal and temperate zones, on the relatively small percentage of angiosperms in the collections, and on the strong similarity between the northern Alaska material and that from the upper Neocomian of Svalbard. A late Neocomian age for rocks of the Nanushuk group, however, conflicts with the age of these rocks based on the invertebrate fossils reported on by Imlay (p. 98–99) and the plant fossils reported on by Brown. The apparent discrepancy in age designation is as yet unresolved.

Shale samples were collected for microfossils from the Corwin formation at localities scattered along the Utukok River (table 3), Kokolik River (table 4), Kukopowruk River (table 5), and in the type section of the Corwin. These were examined by H. R. Bergquist who states:

> Of the few samples from the Corwin formation along the Utukok, Kokolik, and Kukpowruk Rivers submitted for microfossil examination, nearly 45 percent had a few arenaceous Foraminifera or charophytes. The species of Foraminifera constitute less than a quarter of the number found in the Kukpowruk formation, but they are nevertheless part of the *Verneuilinoides borealis* faunal zone. These include the following: *Verneuilinoides borealis* Tappan, *Miliammina awunensis* Tappan, *Tritaxia manitobensis* Wickenden, *Gaudryina* sp., *Psamminopelta bowsheri* Tappan (in one sample), and *Saccammina lathrami* Tappan. *Saccammina lathrami* Tappan, though most frequent in occurrence, is a long-ranging species that has no significance. Specimens of all species have been greatly distorted by compression and are indistinguishable from those found in the Kukpowruk formation. Only a couple of fragments of a calcareous foraminifer (*Dentalina*?) were found.
>
> The microfossils from the Corwin and Kukpowruk formations indicate that these lithologic units are part of the same faunal zone; further sampling may reveal characteristic paleontological differences.

Of 59 samples from the type section of the Corwin formation, only 13 were fossiliferous; these contained 6 occurrences of charophytes, 3 of *Haplophragmoides topagorukensis*, 2 of *Trochammina*? sp., and 1 each of *Ammodiscus rotalaria* Loeblich and Tappan, *Glomospira*? sp., and *Miliammina*? sp.

UPPER CRETACEOUS SERIES—COLVILLE GROUP

PRINCE CREEK FORMATION

The Colville group includes marine and nonmarine rocks of Late Cretaceous age that overlie and are separated from rocks of the Nanushuk group by a major unconformity (Gryc, Patton, and Payne, 1951, p. 164–167). The only rocks that are believed to represent the Colville group in the Utukok-Corwin region are mapped as Prince Creek formation (pl. 8).

The Prince Creek formation in the Colville River region includes all the nonmarine beds of the Colville group; it intertongues with the marine Schrader Bluff formation and overlies the marine Seabee formation (Gryc and others, 1956, fig. 4, p. 214). The rocks mapped as Prince Creek formation in the Utukok-Corwin region are lithologically similar to rocks of that formation in the Colville River region, and they overlie the Corwin formation. In earlier studies of the Utukok-Corwin region, these rocks were included in the Upper Cretaceous series along with rocks now mapped as Nanushuk group and Torok formation. (Smith and Mertie, 1930, p. 212–213).

DISTRIBUTION AND OCCURRENCE

Exposures of the Prince Creek formation in the Utukok-Corwin region are restricted to isolated cutbanks in the Arctic coastal plain province and the north edge of the northern foothills section along the Utukok and Kokolik Rivers, where they form dark-gray vertical cliffs. No rocks of this formation were recognized along the Kukpowruk River, or along the Arctic coast.

This formation, where it underlies the tundra in the northern part of the northern foothills section, has a distinctive surface expression that can be identified on aerial photographs. Large whitish patches of mud heavings occur on the low hilltops, and a streaked appearance, probably caused by mudflow, is common on hillsides. The drainage pattern is dendritic; swampy land is common in interstream areas; and minor washes have a featherlike appearance. Rock traces are rare. These surface features differ from those in areas underlain by the Nanushuk group where linear rock traces are common; streams show strong structural control; interstream areas are better drained; and the tundra surface appears more even-textured.

CHARACTER AND THICKNESS

The Prince Creek formation in this region includes sandstone, conglomeratic sandstone, conglomerate, ironstone, coal, bentonitic clay, shale, and claystone (given in approximate order of abundance). The sandstone and conglomerate are distinctive, not resembling those in the Nanushuk group of this area; and the apparent abundance of bentonite, as inferred from numerous muddy areas, further distinguishes the formation from other rock sequences.

In the sections exposed along the lower Utukok and Kokolik Rivers, sandstone constitutes 80 percent of the formation. It is medium to dark gray, weathers gray to moderate brown, is fine to very coarse grained with rapid lateral and vertical gradations in grain size, and is commonly very poorly consolidated, although well-indurated phases are also present. It is of salt-and-pepper type and is massive to platy, highly carbonaceous, locally ferruginous, and rarely calcareous, and it occurs in sets of beds 5 to 40 feet thick. A conspicuous feature of the sandstone is the massive cross-bedding, which includes foreset beds ranging from 1 to 3 feet in thickness and at angles of as much as 30° from topset beds. Thin lenses and irregular beds of ironstone, ironstone nodules, and concretions as much as 12 inches in diameter, lenses of subround coal pebbles, and a few carbonaceous logs as much as 2 feet in diameter are included in the sandstone. A few thin beds of hard sandstone resembling Corwin formation types are also associated with the above-described sandstone.

Conglomerate forms lenses within sandstone beds that range from 1 inch to 3 feet in thickness. A relatively high percentage of white quartz pebbles gives it a distinctive character not seen in the Nanushuk group of the Utukok-Corwin region. The well-rounded pebbles range from ¼ inch to 3 inches in diameter and include about 50 percent white quartz, as well as ironstone, black, gray, and green chert, green aphanitic igneous rock with tiny phenocrysts, light-gray quartzite, limestone, and carbonaceous fragments. Although the coarse sand matrix is generally poorly indurated, shear planes have developed along which many of the pebbles break. Some of the conglomerate locally contains lenses and nodules of reddish- to dark-brown ironstone or ferruginous claystone. These contain plant impressions and carbonaceous fragments and occur commonly in layers as much as 1 foot thick. Coal conglomerate is also fairly common and consists of subround coal fragments of pebble to cobble size. The presence of white quartz conglomerate and the generally poor induration are characteristic of the coarse clastic rocks in the formation.

Comparatively little coal is associated with the above rocks. A few thin beds of poor-grade coal less than 1 foot thick were observed, and one 4-foot bed of bony coal below a conglomeratic bed is present 2 miles above 1947 camp 16 on the Utukok River.

Bentonitic clay and clay are commonly associated with ironstone and coal. They are light to medium gray, rarely bluish gray or dark gray green, and tough to plastic. Slump and mudflows obscure most of these units, and the few exposed beds are only a few inches thick.

Dark-gray to black silty shale and coaly shale form a minor part of the exposures and occur in units less than 5 feet thick.

The total thickness of the Prince Creek formation in this area is not known. The rock sections exposed along the rivers are relatively thin and are believed to all represent approximately the same horizon, as a result of undulatory folds. The maximum measured section is about 93 feet thick and is exposed on the north bank of the Utukok River, north of 1947 camp 12. The section, described from top to bottom is as follows:

Prince Creek formation

[measured by R. M. Thompson, July 1947]

	Thickness (feet)
1. Sandstone, dark-gray, very fine-grained, hard to quartzitic, massive; weathers dark brown to rusty	8
2. Shale, bentonitic(?) and carbonaceous	(?)
3. Sandstone and conglomerate, medium- to coarse-grained, salt-and-pepper; contains white-quartz pebble conglomerate locally along bedding planes	15
4. Shale, coal, and yellow bentonitic claystone containing plant fragments; poorly exposed. *Asplenium foersteri* Debey and Ettingshausen	50±
5. Sandstone, dark-gray, very fine-grained, very argillaceous and ferruginous, thin-bedded	20
Total thickness	93+

The thickest exposure of Prince Creek formation along the Kokolik River, 3 miles south of 1949 camp 28, is described from top to bottom as follows:

Prince Creek formation

[measured by E. G. Sable, September 1949]

	Thickness (feet)
1. Clay, medium-gray, sticky, sandy	(?)
2. Sandstone, interbedded with conglomerate; sandstone is dominant and is medium gray, fine to very coarse grained, mostly very friable to moderately indurated, moderately porous, platy to massive, and weathers light gray to moderate brown; contains common ironstone nodules and carbonaceous fragments in massive lenses thinning laterally from 1½ ft to 6 in. or less in 20 ft, gives oily scum in water. Conglomerate lenses as much as 6 in. thick with sandstone matrix contain abundant well-rounded pebbles of white quartz and dark chert, light-gray quartzite, clay ironstone. One 6- to 8-in. lens of medium-gray nodular to bedded dense ironstone about 5 ft above base	40
Total thickness	40+

The Prince Creek formation overlies the Corwin formation; the contact may be unconformable but is not exposed in the Utukok-Corwin region. (See p. 142.) The Prince Creek formation is unconformably overlain by unconsolidated deposits of Quaternary age in the mapped region.

AGE

In central areas of northern Alaska, east of the Utukok-Corwin region, the Prince Creek formation is assigned a Late Cretaceous age on the basis of its equivalence to the marine Schrader Bluff formation, which ranges from the lower Turonian into the Campanian of the Upper Cretaceous series (Whittington, 1956, p. 251–253). The Schrader Bluff formation is not known to be present in the Utukok-Corwin region and evidence for the age of the Prince Creek formation in this region was obtained from two collections of plants from the Utukok River. One collection, 47ATm32, collected near 1947 camp 12 on the north bank of the river, contains *Asplenium foersteri* Debey and Ettingshausen; and according to Roland W. Brown ". . . the age of the strata . . . appears to be Upper Cretaceous." The other collection, made by W. T. Foran in 1923, is believed to have been from rocks of the Prince Creek formation, although the location is not precisely known. This was identified by Knowlton as follows (Smith and Mertie, 1930, p. 227):

> 7668, Foran, Station Z, Utukok River, 43 miles above mouth.
> *Oleandridium* sp.
> *Onychiopsis* sp.
> *Cladophlebis* sp.
> Apparently new fern
> Some coniferous leaves
>
> The age appears to be Lower Cretaceous, in the approximate position of the Kootenai or Wealden.

The collection was reexamined by Hollick who made the following report (Smith and Mertie, 1930, p. 227):

> 7668. This collection, consisting of a single piece of matrix, contains plant remains, mostly fragments of ferns, among which are specimens of *Oleandridium* sp. and *Cladophlebis* sp. The age appears to be Lower Cretaceous and equivalent to the Kootenai formation.

In reexamination of the above collection in 1953, Brown states: "This has a good specimen of *Metasequoia occidentalis* (Newberry) Chaney, and appears to be Tertiary in age."

It appears that the collections are inadequate to give a positive age determination to the above flora, and more collections are needed to solve the age problem of these rocks. The Prince Creek formation in the Utukok-Corwin area is tentatively assigned to the Upper Cretaceous series.

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT

During fieldwork in the Utukok-Corwin region, emphasis was given to the older sedimentary rocks of the area, and very little specific work was done on Pleistocene and Recent deposits. The discussion of these sediments is based upon field observations of isolated exposures and augmented by photogeologic studies. Doubtlessly all these deposits were not recognized and mapped, and detailed or extensive correlations are not possible with present information.

In the Utukok-Corwin region the Pleistocene and Recent sediments represent two depositional types, inshore marine and fluviatile. The marine and nonmarine deposits, excluding the Recent fluviatile and beach deposits, which mantle the Cretaceous rocks in the coastal plain, are termed the Gubik formation. Two general levels of fluviatile and beach sediments in the foothills province of this region are mapped on plate 8. The lower level includes all Recent deposits in the flood plains of present streams, low gravel terraces along the flood plains as high as about 15 feet above stream level, and low-level beach deposits. The high-level gravel terraces and beach deposits include Pleistocene deposits lying 15 feet or more above present stream and ocean levels.

The unconsolidated deposits are essentially flat lying and overlie Cretaceous rocks with pronounced angular unconformity. The marine and fluviatile facies of the Gubik formation of Pleistocene age probably interfinger with the fluviatile facies of some of the high-level terrace deposits, as they apparently do along the west bank of the Kukpowruk River near the foothills-coastal plain boundary. However, knowledge of exact relations between these units awaits further study.

Alpine glaciation occurred in the De Long Mountains during Quaternary time, but no glacial deposits have been recognized in the Utukok-Corwin region; it is believed that the glaciers did not reach this far north. The fluviatile sediments cover relatively large parts of the region, however, and their deposition was probably in part related to the increased volume and carrying capacity of streams during melting of the glaciers.

ARCTIC FOOTHILLS PROVINCE

South of the coastal plain, Pleistocene and Recent fluviatile sediments consist of gravel, sand, silt, clay, and organic material and contain ground ice. The poorly sorted coarse-sand- to cobble-size constituents are derived from consolidated rocks within the drainage areas; chert is dominant, and sandstone, siltstone, shale, mafic igneous rocks, quartzite, limestone, argillite, coal, and ironstone constitute the remainder. Some of these constituents were derived from conglomerates of Mesozoic age, and those in the youngest deposits were derived in part from older high-level terrace gravels. These deposits rest unconformably upon the eroded surface of Mesozoic rocks in this area and on Paleozoic and Mesozoic rocks south of the area. The positions of the high-level terraces indicate considerable uplift of one or more stages since their deposition, but apparently they were not affected by tectonic forces other than epeirogenic movement.

HIGH-LEVEL TERRACE DEPOSITS

The high-level gravels occur in prominent terraces 20–500 feet above present stream levels. The most extensive deposits occur in the southeastern and northern parts of the Utukok-Corwin region. In the northern foothills section they are confined to the lowland areas between the higher mesa- and cuesta-forming units of the Nanushuk group and to interstream areas along the edge of the coastal plain where they probably merge into at least part of the Gubik formation. In the southern foothills section, high-level terraces blanket a large area between Driftwood Creek and the Colville River and occur as small remnants at least as far west as Poko Mountain. Rock constituents of the high-level gravels are the same as those of the lower gravels but appear to be somewhat better sorted and of pebble to cobble size. Finer grained constituents, however, have probably been removed by wind and runoff, leaving the coarser material to uphold the distinctive terrace forms.

Although the high-level gravel deposits are nearly everywhere covered by vegetation in this area, they can be discerned in photogeologic studies as terraces, by a sudden break in slope along their edges and by the minor drainage patterns developed on them. Small areas of gravel show little or no drainage pattern, and the surface appears nearly featureless. In more extensive deposits swampy areas with ponds and small lakes occupy the top of many terraces; and small featherlike drainages in a radial pattern lead to the larger streams.

As many as 3 levels of high terraces were observed on the Utukok River: 2 were recognized in some localities along the Kokolik River, and only 1 at any locality along the Kukpowruk River.

The southernmost belt of high-level terraces includes the prominent terrace 500 feet above Driftwood Creek at 1,950 feet altitude. This terrace consists of 15–20 feet of gravel, covers more than 30 square miles, and is believed to be correlative with the larger gravel-covered areas mainly south of the Colville River which are at about 1,950 feet altitude and 110 feet above the Colville at Meridian Creek. West of Driftwood Creek only a few scattered remnants of high terraces remain at about 1,200 feet altitude and 220 feet above Iligluruk Creek southeast of the Iligluruk high and at 1,200 feet altitude and 300 feet above the Kokolik River south of Poko Mountain. The relation between these remnants and the Driftwood-Meridian Creek terraces is not known.

Along the Utukok River, between 1947 camps 4 and 5, isolated remnants of 3 high terrace levels were noted; 2 are at 900 and 950 feet altitudes, about 20 feet and 70 feet above the river, and the third is at a higher undetermined altitude, more than 100 feet above the present stream. These may be correlative with terraces farther north along the Utukok in the lowland belt between 1947 camps 6 and 7. Here 3 terrace levels occur at approximate altitudes of 600, 670, and 720 feet about 20, 90, and 140 feet, respectively, above the present stream. A fresh-appearing mammoth tusk and large tree trunks were found imbedded in the lowest of these deposits. Forty miles west and in the same lowland belt, a high terrace consisting of about 25 feet of gravel occurs at an altitude of about 600 feet, 180 feet above the Kokolik River. This terrace is discussed by Smith and Mertie (1930, p. 248). Lower deposits of gravels and mud were seen 15 to 20 feet above the river in this locality; a fresh mammoth tusk was found on the present flood plain near these deposits and is believed to have washed out of the lower deposits. If the highest and lowest terraces along each river are correlative, they may represent the depositional remnants of a major stream which flowed along the lowland belt, transverse to present drainages. It is uncertain whether the apparent westward gradient of the highest level terraces represents the initial gradient of an ancient westward-flowing stream or is the result of differential uplift since deposition.

No measurements were made of the high-level terrace deposits along the Utukok River in the vicinity of Elusive Creek. They are estimated to be 75–100 feet above present stream level and about 400 feet in altitude. Along the same general latitude, similar deposits covering more than 50 square miles occur between the Kokolik and Kukpowruk Rivers; they are as much as 25 feet thick, occur 110 feet above the Kokolik River at altitudes of about 370 feet near camp 25, and slope northward. They can be traced 24 miles westward and are believed to be correlative with high-level terrace deposits along the Kukpowruk River which occur about 40 feet above the river, to altitudes of 200 feet. The southwestward-trending outcrop pattern of the terrace deposits and the presence of highland areas south and north of them suggest that they were deposited by an ancient westward- or eastward-flowing stream. The westward and northward slopes of the terrace surfaces may not represent the initial gradients of deposition but may be due to differential uplift following deposition of these sediments. Elsewhere in northern Alaska, north of the Sadlerochit Mountains, a gravel terrace overlying Pliocene rocks has been uplifted and gently folded (Morris, oral communication, 1952). Such may be the case in the Utukok-Corwin region, and the northward and westward slopes of the high-level terraces may represent relatively recent uplift which culminated east of this area, possibly along the Meade arch (Payne, 1951, sheet 1).

Organic remains found in high-level gravel deposits on the Utukok River 6½ miles east of 1947 camp 6 included a mammoth tusk measuring 8 feet 3 inches along the compound curve and 15½ inches in maximum circumference. This tusk was imbedded 4 feet above the base of a 16-foot gravel deposit in a cutbank 35 feet high. In the same gravel deposit a few hundred yards upstream, large logs, believed to be balsam poplar, as much as 1½ feet in diameter and 10 feet in length, were imbedded 8 feet above the base.

A mammoth tusk, measuring 5 feet along the compound curve and 25 inches maximum circumference, was found on a Recent river gravel bar, between 1949 camps 22 and 23 on the Kokolik River, and was probably derived from nearby older gravels and silts, which lie about 20 feet above the river in this vicinity.

No fossil remains were found in gravel terraces that are higher than the lowest high-level terraces, which are assigned a Pleistocene age on the basis of the mammoth remains. The higher terraces are older, and although here assigned to the Pleistocene epoch, may have been deposited earlier.

LOW-LEVEL DEPOSITS

The low-level deposits of Recent and possibly in part Pleistocene age contain poorly sorted angular to rounded sand- to cobble-size rock fragments similar to those in the high-level deposits, associated with clay and silt. Angular sandstone boulders derived from nearby outcrops are locally abundant on gravel bars in the northern foothills. Four or five low terrace levels were recognized in some localities along the rivers and differ in altitude by only 3 or 4 feet. Organic remains, found on Recent gravel bars along the Utukok and Kokolik Rivers and probably originating in older deposits included mammoth teeth and tusk fragments and a musk-ox skull.

ARCTIC COASTAL PLAIN PROVINCE

GUBIK FORMATION

The Gubik formation of Pleistocene age, as defined by Gryc, Patton, and Payne (1951, p. 167) includes largely marine unconsolidated deposits which mantle the older rocks in much of the coastal plain of northern Alaska.

In the coastal plain of this region gravel, sand, and silt of the Gubik formation cap numerous bedrock cutbanks along all major rivers. Between 1947 camps 12 and 14 on the Utukok River, these deposits cap bluffs 50–100 feet high; they also occur more than 50 feet above the Kokolik River, and cap 35- to 40-foot cutbanks along the Kukpowruk River. Scattered cutbank exposures of silt, clay, and organic matter, with associated ground ice, are also present in the coastal plain.

During recent explorations, recognizable marine sediments of the Gubik formation were seen in only one inland locality on the Kukpowruk River, although they probably underlie a considerable part of the tundra-and-lake-covered coastal plain and are present as elevated beach deposits along the Arctic coast (Paige, Foran, and Gilluly, 1925, p. 20). The Gubik formation marine section is exposed in a cutbank on the north side of the Kukpowruk River at lat 69°31′ N., and long 162°43.5′ W. The base of the section is 35 feet above the river at an altitude of about 50 feet. The deposit consists of 68 feet of unconsolidated very fine grained sand, silt, and clay, with scattered granules and pebbles of chert, white quartz, quartzite, and argillite. The color ranges from yellowish brown to dark gray and black owing to concentrations of carbonaceous material. Pebbles are more numerous in the upper part of the section. Some silt layers resemble loess in their absence of bedding, and some sand grains are frosted, possibly indicative of eolian origin. Unaltered shells of pelecypods and gastropods are common throughout the sequence. This flat-lying section overlies rocks of the Corwin formation with pronounced angular unconformity.

The gastropods and pelecypods collected in the marine Gubik formation exposure on the Kukpowruk River were identified by F. Stearns MacNeil as follows:

Field number 49ASa143f (U.S.G.S. D–2)

[Lithology: unconsolidated gray silty sand]

Gastropoda:

Buccinum angulosum Gray (Point Barrow to Bering Strait).

Volutopsius sp. cf. *V. stefanssoni* Dall (*V. stefanssoni* is living from Point Barrow to the Pribilof Islands).

Neptunea ventricosa soluta (Heermann). (MacKenzie River to Bering Sea.)

The fragments so identified are close to *Neptunea mesleri* (Dall) but have weaker axial ribs and stronger and more elongate nodes on the periphery of the young whorls. (*N. mesleri* is known only as a fossil in the Intermediate Beach, Nome.)

Natica clausa Broderip and Sowerby (Arctic Ocean and Bering Sea and in deep water to San Diego, Calif).

Pelecypoda:

Saxicava pholadis (Linnaeus) (Arctic Ocean to Panama).

Age: Pleistocene.

R. F. Black (written communication Feb. 1954) reports on one exposure of Gubik formation in a cutbank of the Kokolik River at about lat 69°40′ N., and long 161°55′ W. Here, faintly stratified dark-blue-gray to black massive clayey silt is exposed 8 feet above river level and is capped by 12 feet of fluvial-lacustrine(?) mud and organic matter with much ice. A sample of the silt contains clay, clay-sized minerals, quartz, and calcite as dominant constituents, and also chlorite, muscovite, zircon, sphene, magnetite-ilmenite, and other minerals. Black states that the silt texture and mineral content resembles similar silts of the Gubik formation at other localities along the Arctic coast. At Kaolak test well 1 (Collins, 1958) the top 113 feet of unconsolidated surface deposits regarded as Gubik formation include, from top to bottom: 30 feet of silt with loose unconsolidated mantle; 40 feet of light-gray soft clay shale; 43 feet of sand and gravel with well-rounded black, yellow, and red chert, coarse sand size to ¼-inch pebbles.

Ground ice, an important constituent of parts of the Gubik formation throughout the coastal plain, is discussed on pages 65–67.

RECENT DEPOSITS

Fluviatile deposits along present streams in the coastal plain are similar to those in the foothills province but contain a greater proportion of fine sand, silt, and mud. Ice-rafted boulders, mostly of sandstone derived from rocks in the northern foothills, are fairly common. Where the major rivers empty into Kasegaluk Lagoon, wide deltaic flats, consisting mostly of mud and silt, are exposed at low water, and contain well-formed ripple and current markings, oriented wind scour depressions, worm trails, scattered pebbles and a few ice-rafted boulders, and plant fragments. On the offshore bar west of the lagoon, deposits are of sand- to pebble-sized material. Southeast of the lagoon, beach deposits are generally coarser and include some cobble-size shingle types.

One valve of a brachiopod was found on present beach sands near Point Lay. This has been identified as *Hemithyris psittacea* (Gmelin) by G. A. Cooper, of the U.S. National Museum.

COASTAL AREA WEST OF CAPE BEAUFORT

The Pleistocene and Recent deposits of the coastal area west of Cape Beaufort have been described by Collier (1906, p. 32–34), and they have been mapped on plate 8 from these data as well as a few observations made in 1953. The elevated Pleistocene deposits vary greatly from place to place in composition and consist of gravel, sand, silt, clay, and ice. They were assigned to the group of beds called the Kowak clays and ground ice by Dall and others (Collier, 1906, p. 33) and may be partly equivalent to the Gubik formation. Mammoth remains derived from these deposits were found by Collier at two localities. The Recent deposits consist mostly of coarse alluvial and beach deposits, still in the process of construction. A collection of marine invertebrate remains from the present beach deposits near Corwin Bluff was made in 1953 and identified by Harald A. Rehder, of the U.S. National Museum as follows:

Identifications of invertebrates from beaches near Corwin Bluff (53ASa265f)

	Number Specimens
Mollusks:	
Mytilus edulis Linné	2
Astarte arctica Gray	1
Cerastoderma californiensis (Deshayes)	2
Tellina (Angulus) lutea Wood	2
Macoma planiuscula Grant and Gale	3
Siliqua media (Gray)	3
Mya japonica Jay	1
Trichotropis bicarinata Sowerby	2
Natica (Cryptonatica) clausa Broderip and Sowerby	1
Natica (Cryptonatica?) aleutica Dall	1
Velutina coriacea (Pallas)	1
Colus spitzbergensis (Reeve)	1
Neptuna sp. (immature)	1
Buccinum normale Dall	1
Buccinum glaciale Linné	2
Buccinum angulosum transliratum Dall	1
Hydroids:	
Hydractinia species	1
Sponges:	
Myxilla incrustans (Johnston)	2
Phakellia beringensis Hentschel	1
Octocoral:	
Eunephthya rubiformis (Ehrenberg)	1
Crab:	
Hyas coarctatus alutaceus Brandt (fragment)	1

PETROGRAPHY

THIN SECTIONS

Ten thin sections of rocks from the inland part of the Utukok-Corwin region were examined under the petrographic microscope. One section of sandstone is from the uppermost part of the Torok formation, 5 sections of sandstone and 1 section of ironstone are from the Kukpowruk formation, and 3 sections of sandstone are from the Corwin formation.

The sandstone from the Torok formation, sample 49ASa61, in hand specimen is very fine grained and calcareous and has numerous white grains and fewer black grains in a light-olive-gray matrix. In thin section it is intermediate between subgraywacke sandstone and calcarenite (after Pettijohn, 1949). The cement, predominantly quartz with some calcite, and minor amounts of clayey material and chlorite, is about 20 percent of the rock. Subangular to subround, mostly equidimensional grains from 0.05 to 0.48 millimeter in diameter with a modal size of 0.24 millimeter are closely packed. The grains consist of clear quartz (estimated to be 40 percent of the total), chert and devitrified glass (?) (30 percent), calcite (12 percent), feldspar (10 percent), and ferromagnesian minerals, rock fragments, and opaque grains (8 percent). Quartz is present as single crystal grains with wavy extinction, single crystal grains with apatite and other inclusions, and composite grains. Carbonates are clear and occur both in granular and prismatic form. Siderite may be associated with calcite, and some of the carbonates appear to have replaced ferromagnesian minerals. Plagioclase feldspars, probably andesine and labradorite, are fresh in appearance. A mineral of fibrous texture with moderate birefringence, possibly muscovite, occurs as elongate fragments. Black opaque grains include ore minerals and what appears to be carbonaceous material. A minor amount of chlorite replaces ferromagnesian minerals. Grain boundaries of major constituents against the cement are mostly irregular as if the grains had been incipiently replaced. Limonite is common along intergrain contacts as cement and as a coating on some minerals.

The sandstone samples from the Kukpowruk formation (samples 47ABa11, 47ABa18, 47ABa25, 49ASa192, and 49ACh53) in hand specimen are all salt-and-pepper type, ranging in grain size from very fine to medium grained. In thin section they resemble the sandstone described from the Torok formation except that most of these contain more calcite, particularly as cementing material and also replacing the feldspars. Grain size ranges from 0.04 to 0.56 millimeter, with modal sizes from 0.12 to 0.4 millimeter. One thin section from a sample near the base of the Kukpowruk formation contains pore space estimated at 10 percent, in the other samples pore space is nearly absent. Cementing material in the 5 sections range from 20 to 40 percent of the rock; the cryptocrystalline quartz cement is usually coarser in texture than the chert constituents. The constituents are quartz (estimated to be 40–55 percent of the total grains); chert (15–35 percent), calcite (5–25 percent), feldspars (2–10 percent), and ferromagnesian minerals, rock fragments, and opaque grains (5–10 percent). Chlorite as a replacement of ferromagnesian minerals is present in most samples. Several spheroidal black particles, possibly carbonized spores or seeds, are present in some sections. Limonite and other iron oxides are common, imparting a reddish or yellowish color to the weathered rock. Two of the samples may be classified as between subgraywacke sandstone and calcarenite, 2 between subgraywacke and calcarenite, and 1 as subgraywacke.

One thin section of an ironstone nodule from the upper part of the Kukpowruk formation (sample 49ACh103) was examined. In the hand specimen it is dark gray, exceedingly fine grained and dense, and hard and weathers yellowish orange. In thin section the rock is very fine grained. The texture is amorphous to slightly granular; the groundmass is clayey material and probably siderite, with tiny scattered grains most of which are probably quartz.

The three sandstone samples from the Corwin formation, (samples 49ASa54, 49ASa55, and 49ACh126) in hand specimen appear similar to those in the Kukpowruk formation except that the ferric-oxide weathering colors are somewhat brighter. In thin section they are seen to differ from the Kukpowruk formation samples in that the cement is predominantly calcite and that the feldspars and ferromagnesian minerals are extensively replaced by calcite. There is also a larger percentage of black opaque grains, probably carbonaceous fragments. Cement ranges from 30 to 60 percent of the rocks. Grain size ranges from 0.04 to 0.72 millimeter, with modal sizes of the 3 samples 0.16, 0.20, and 0.40 millimeter. Constituent minerals include quartz (estimated at 25–45 percent of the total grains), chert and devitrified glass (?) (20–40 percent), calcite (minimum of 10–20 percent), and unaltered plagioclase (from less than 1 percent to 10 percent). Chlorite, ferromagnesian minerals, rock fragments, and zircon are present in small amounts. Limonite is common along intergrain contacts, and it is associated with calcite and with carbonaceous and woody fragments. The 3 sections may be classified between subgraywacke sandstone and calcarenite.

HEAVY MINERALS

In the Utukok-Corwin region, numerous samples of sandstone were taken for heavy-mineral study. In this study the minerals having a specific gravity of 3.0 or more were examined, and their usefulness for stratigraphic correlation was determined. From the Torok, Kukpowruk, Corwin, and Prince Creek formations 173 samples were collected by Barksdale and Thompson during the 1947 field season and by Sable and Chapman in 1949. Heavy-mineral concentrates of the samples were prepared in the laboratory of the Geological Survey, in Fairbanks, Alaska. The slides were examined by R. H. Morris, of the Geological Survey, whose report submitted to the authors in 1954 is included in the following modified form. The term "zone" used by Morris implies a stratigraphic interval of rock characterized by the presence of 1 or more diagnostic heavy minerals; in the Utukok-Corwin region only 1 such zone, the zoned zircon zone, is named.

The various accessory minerals occurring in samples from the Utukok-Corwin area include andalusite, augite, biotite (two forms), chloritoid, epidote, garnet, glaucophane, hornblende, muscovite, picotite, tourmaline, and many varieties of zircon, including crystals with zonal growth markings. The opaque minerals magnetite, ilmenite, leucoxene, and authigenic pyrite were found to be nondiagnostic for zonation purposes. Of the nonopaque minerals, zoned zircon grains persist from the upper part of the Torok formation, throughout the Kukpowruk formation, to the top of the Corwin formation. This persistence and the lack of other criteria for more restricted zoning is the basis for establishing the zoned zircon zone. East of the Utukok-Corwin area, the zoned zircon zone is characteristic of the upper part of the Torok formation, the Tuktu formation, the Chandler formation, and the lower part of the Ninuluk formation. Within the zoned zircon zone, there is considerable variation in the relative abundance of the constituent minerals. None of these variations appears to be systematic except for the abundance of muscovite which occurs at the contact of the Torok and Kukpowruk formations and again in the basal part of the Corwin formation.

The four heavy-mineral samples obtained from the Prince Creek formation are inadequate to use for zonation. However, one sample (47ATm42) contains an abundance of fresh dark- to rust-brown subhedral biotite plates. Biotite of similar form occurs in many samples from the test wells and in outcrop samples from the Umiat and Maybe Creek area associated with bentonitic deposits in the lower part of the Prince Creek formation.

The character of the heavy minerals found in the strata in the Utukok-Corwin region indicates that the sediments were derived from a source area rich in metamorphic rocks but also containing igneous and sedimentary rocks. The subround tourmaline grains and well-rounded zircon grains are probably at least second generation and were supplied by older sedimentary rocks. The fresh biotite plates occurring in the Prince Creek formation were probably derived from volcanic ejecta.

STRUCTURAL GEOLOGY

The major structural element of the Utukok-Corwin region is a basin which deepens westward and, to some extent, northward and opens into the Chukchi Sea. The basin includes two negative tectonic elements—the Colville geosyncline of Mesozoic age and the Chukchi Basin of Mesozoic and Cenozoic ages (Payne, 1955). As shown by Payne, these negative elements are at least in part flanked on the north by the Barrow arch, north of the Utukok-Corwin region; on the east by the Meade arch, east of the region; on the south by the Brooks Range geanticline; and on the southwest by the Tigara uplift at Cape Lisburne.

Patterns of folding and faulting superimposed upon the major basin element include large isolated synclinal folds, relatively persistent complex anticlines, and thrust faults (pls. 8 and 9). These features form two distinct structural provinces which are approximately separated by the lower Pitmegea River and which are here referred to as the eastern and western structural provinces. The eastern province consists of generally westward-to-northwestward-trending folds, including prominent simple synclines and several long complex anticlines. The anticlines are possibly related to major thrust faults. The western structural province is characterized by thrust faults that strike northwest and dip southwest. Rocks between the faults include southwest-dipping sequences which generally strike parallel to the strike of the faults and which in part represent faulted limbs of synclines.

The eastern structural province, which includes most of the region, can be subdivided into two structural belts. One belt lies within the southern foothills physiographic section, and the other lies within the northern foothills section and Arctic coastal plain province. Structural features in the southern foothills, along the south boundary of the Utukok-Corwin region, consist of complex anticlinal structures in which the Fortress Mountain formation is exposed along the axes and is surrounded by belts of highly folded Torok formation, the structural features of which are not well understood. In the northern foothills, exposures are mainly of the Torok, Kukpowruk, and Corwin formations but include some rocks of the Prince Creek formation in the northeastern part of the region. Here, broad, simple synclines and basins are separated by relatively narrow complex anticlines which connect in an anastomosing pattern and isolate the prominent synclines. In the coastal plain, rock exposures are not common, but the surface structural pattern appears to be similar to that in the northern foothills.

South of the Utukok-Corwin region, in the southern foothills and De Long Mountains, Early Cretaceous and older rocks are tightly folded and cut by numerous faults. There, the structural grain strikes N. 50°–70° E., between the Kukpowruk and the Utukok Rivers and is at considerable variance to the general westward strike of structural features in the mapped region. West of the region, rocks of early Mesozoic age and older are present on the Cape Lisburne Peninsula, where the structural grain is north to northwest.

Rock structures in the Utukok-Corwin region are shown on the geologic map (pl. 8), the generalized geologic map (pl. 9), and on the structure sections (pl. 18). Vertical aerial photographs were used to extend the structural data into interstream areas and to the coast, and they also were used as base maps for structural computation. Much difficulty was encountered in transferring structure-section data from the photographs to the planimetric maps used in this report, and the difficulty is believed to be due to variations in the map scale. In many places it was not possible to maintain both the correct structural configuration and the thickness of rock units when data were transferred. As a result the structure sections are somewhat generalized and do not everywhere show true unit thicknesses, although the structural features are not exaggerated.

EASTERN STRUCTURAL PROVINCE

SOUTHERN FOOTHILLS SECTION

The structural features along the south boundary of the Utukok-Corwin region and within the southern foothills section, lie between the southernmost synclines of the northern foothills and the tightly folded and faulted anticlines and synclines in the southern foothills and mountains south of the region. The structural pattern resembles in part that in the northern foothills, but it also includes structural features similar to those south of this region.

All structural features in which the Fortress Mountain formation is exposed in the southern foothills of this area appear to be anticlinal and considerably more complex than structural features in the northern foothills. Of the three general areas of Fortress Mountain formation, the structural features of the East and West Driftwood anticlines have been examined in most detail; field studies in the Iligluruk high were limited because of poor exposures, and aerial photographs were used to aid in the interpretation; the Tingmerkpuk high has not been visited in the field.

East and West Driftwood anticlines have been interpreted as two major westward plunging en echelon anticlines which trend N. 70° E. to east. East Driftwood anticline is separated from the West Driftwood anticline by a northeastward-trending reverse fault with the south side upthrown. The apparent displacement along the fault is small at its southwest end but increases northeastward to 1,200–1,500 feet at the Utukok River. The East Driftwood anticline appears to be of greater amplitude than the West Driftwood anticline. Rocks in the axial zone of the East Driftwood anticline are overturned at the Utukok River. The east end of this anticline is not exposed; thus, eastward plunge or closure could not be determined.

The area of the Iligluruk high, north of 1949 camp 17 on Iligluruk Creek, includes several prominent rubble-covered hills with few good bedrock exposures. Fieldwork and photogeologic interpretation indicate that it is in general anticlinal, complexly folded, and includes several smaller folds trending slightly north of east. Cutbanks along Iliguruk Creek show numerous reversals of dip and some anomalous northward-trending strikes. It is doubtful whether further surface geologic work would clarify the interpretation of these structural features.

The Tingmerkpuk high is topographically expressed by rounded hills that, from distant field observation, are believed to be made up of Fortress Mountain formation rocks. Photogeologic interpretation shows the high to be anticlinal, and a complex domelike structure is inferred at its apex. Dips appear to be steep, and the northeast side of the high is probably faulted. Several eastward-striking folds south of the high also expose rocks thought to be of the Fortress Mountain formation.

Belts of the Torok formation lie south of the main areas of the exposed Nanushuk group and surround the anticlinal structures in the Fortress Mountain formation. The structural features of these belts are not well understood. Outcrops are limited to scattered stream cuts, and rock traces in interstream areas are rare. Structural features in the stream-cut exposures generally reflect the anticlinal nature of the Fortress Mountain formation, but many of these contain anomalous trends and other indications of complex structural features that are undecipherable with present information. Some outcrops show several tight overturned folds at various degrees of inclination, which are truncated by faults of undetermined displacement, as on the Kokolik River between 1949 camps 18 and 19. Highly complex structural features are also common in the Torok formation in the northern foothills. They may be the results of large-scale rock flowage in the incompetent shale of the Torok formation, or they may reflect belts of intense structural deformation accompanying faulting. Another possibility is that they may be in part the result of severe near-surface frost action, similar to structural features in unglaciated areas in the British Isles (Kellaway and Taylor, 1952). Frost heaving of this type, however, apparently has not affected Pleistocene and Recent surficial deposits which overlie some of the highly contorted strata of the Torok formation, and it is the opinion of the authors that these complex features are largely the results of shale flowage during tectonic movement.

NORTHERN FOOTHILLS SECTION AND ARCTIC COASTAL PLAIN PROVINCE

In the northern foothills and coastal plain of the eastern structural province, northward tangential forces have affected the Cretaceous rocks, resulting in structural features that are generally simpler than those in the southern foothills section (fig. 24). Broad simple synclines and basins, as single structural features or in groups of several en echelon, lie between several persistent complex anticlines which extend across the area and which in part may be surface expressions of thrust faults. Many of the en echelon synclines are separated by relatively short anticlines that appear to branch from the persistent anticlines. Such groupings may represent the later stages of folding of larger parent synclines which formerly existed between the persistent anticlines.

Synclines and basins are the dominant structural features in this part of the area. In the northern foothills, 20 major synclines are well exposed and stand out in strong relief above the relatively exposureless valleys which occupy the major anticlines. The lack of heavy vegetation and the persistence of thick sandstone traces provide unusual opportunities for structural delineation. Most of the synclines are simple folds with some minor transverse faults on the limbs and small-scale normal and reverse faults in some axial areas. Their axial traces strike west to northwest throughout most of the area except in the western part, where northeast strikes are dominant. Although the axial traces can be easily mapped within areas underlain by rocks of the Nanushuk group, in only a few synclines can they be accurately extended into the upper part of the Torok formation. Most synclinal structures are relatively short and nonpersistent and range from 4 to 25 miles in length, although 7 persistent synclines extend for more than 30 miles. The southernmost 4 of these, the Tupikchak, Kokolik Warp, Folsom Point, and Deadfall synclines, are mappable for 36–40 miles. The 3 northernmost synclines, Howard, Lookout Ridge, and Elusive Creek are even more extensive and can be mapped for distances of 46–64 miles. Parts of the Lookout Ridge and Elusive Creek synclines extend east of the mapped area.

Unlike the synclines and basins, most of the anticlines in this province cannot be delineated because their axial areas are breached to relatively exposureless lowlands underlain by the Torok formaton. Where exposed in the axial areas, the beds are irregularly and steeply dipping, form two folds or more and are cut by faults of unknown displacement. The few anticlines in which detailed relations of the opposite flanks can be determined are relatively minor folds such as the Kokolik anticline, and even these cannot be mapped for more than a few miles before they open into exposureless areas or become complexly folded. The presence of major thrust faults in some anticline axial areas is inferred from the results of seismic work, as interpreted by the United Geophysical Co., Inc. The above evidence indicates that these structural features may not be simple anticlines despite the simple aspect of the limbs of adjoining synclines. However, they are referred to as named anticlines in the discussion which follows, and on the geologic map (pl. 8) they are also mapped as named anticlines, although the locations of their axial traces indicate only the suggested position of axial crest lines.

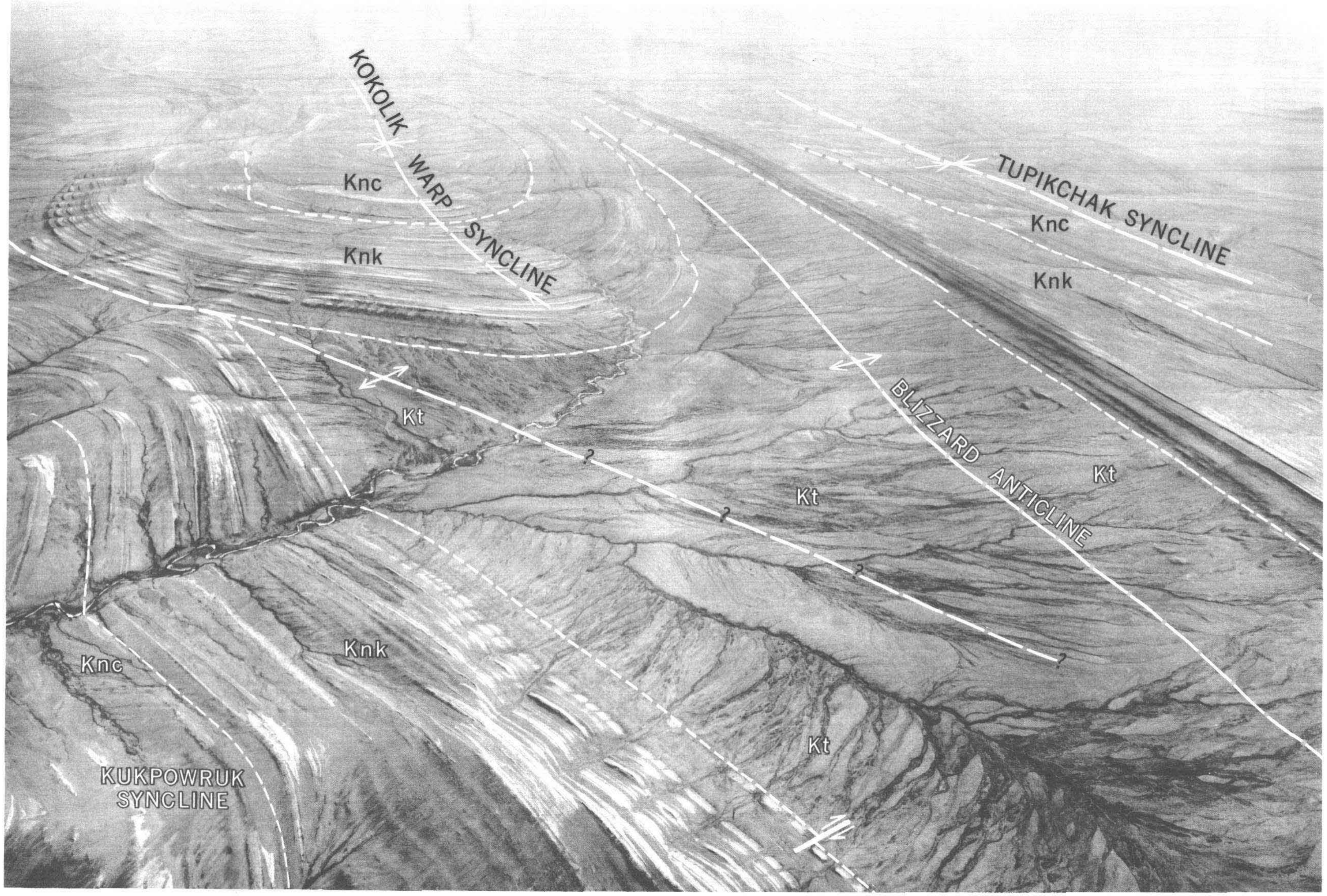

FIGURE 24.—Aerial view of typical structural features in northern foothills, looking east toward Kokolik River, Utukok-Corwin region, Alaska. Relatively persistent anticlinal structures are believed to bifurcate (as Blizzard anticline and anticline in left center of picture) and isolate shorter en echelon major synclines. Most anticlines are breached to Torok formation (Kt); Kukpowruk (Knk) and Corwin(Knc) formations are exposed in the synclines. U.S. Air Force Air Photographic and Charting Service (MATS), approximate altitude 12,000 feet.

East of the Kukpowruk River the persistent anticlines strike essentially west or northwest; and west of the Kukpowruk, mostly northeast. The longest include Carbon Creek, Archimedes Ridge, and Blizzard anticlines, which are more than 100 miles long and extend east of the mapped region. Shorter anticlines such as Snowbank and Token appear to branch from the more persistent anticlines.

In accordance with the westward deepening of the regional basin in this area, synclines are progressively more deeply folded westward, and the thickest sections of the Nanushuk group are preserved in the western part of the area. A maximum total thickness of 5,700 feet is exposed in Elusive Creek syncline on the Utukok River; 6,200 feet is present in Flintchip and Oxbow synclines on the Kokolik River; more than 10,000 feet is preserved in Coke basin on the Kukpowruk River; and an incomplete section of nearly 15,500 feet was measured in the Corwin area in the western structural province. Similarly, a thickening of the Kukpowruk formation from a maximum thickness of 2,100 feet on the Utukok River to more than 5,000 feet on the Kukpowruk River indicates that the most active sinking of the basin of deposition of the Nanushuk group occurred in the western part of the area which is also the present structural low.

In a northward direction, the depth of folding is more irregular, although the regonal component of dip of Cretaceous rocks appears to be north at least as far as lat 69°35′ N. Two positive and two negative structural elements are present in the northern foothills. A positive element containing the thinnest erosional remnants of the Nanushuk group is present along an east-northeastward-trending belt between Igloo Mountain and Foggy syncline. Between this belt and Blizzard anticline a negative element is present in the deeply folded structural features of Coke basin and the Tupikchak and Flintchip synclines. North of the Blizzard anticline a positive element in which the structural features are relatively shallow is present as far north as Archimedes Ridge anticline on the Kukpowruk River, Snowbank anticline on the Kokolik River, and Carbon Creek anticline on the Utukok River. North of these structural features the synclines are deeply folded and contain the thickest preserved sections of the Nanushuk group in this structural province. This negative element strikes east-northeast, about parallel to the south edge of the coastal plain; and although it is not associated with any single persistent structural feature, its southern boundary may reflect lines of flexture or faulting of a hinge line type, northwest of which depth of folding increases under the coastal plain. Northeast of the Utukok River, however, seismic data show that the rock sequence has a regional south dip and rises in a northward direction beyond the limits of the mapped region. (See p. 146.)

At least two structural features, here called salients, are present in the map area as indicated by a northward bowing of the axial traces of major structural features. The largest, or Kukpowruk salient, lies about west of the middle course of the Kukpowruk River, and its northward extension strikes northeast into the coastal plain between the Kukpowruk and Kokolik Rivers, parallel to the Arctic coastline. Several structural highs lie along the apex of the Kukpowruk salient south of Howard syncline, and the salient also appears to be related to a northward bulge in older rocks along the upper Kukpowruk River, south of this area. The salient may therefore be an expression of a northeastward-striking positive element, or it may represent an area of warping between the northward-directed forces from the Brooks Range geanticline and the eastward forces from the Tigara uplift. Another smaller salient is present between the Utukok and Kokolik Rivers. It also appears to strike northeast and is represented by the northward bowing of axial traces in Oxbow syncline, Carbon Creek anticline, and possibly Snowbank anticline and Howard syncline.

In the ensuing discussion of individual structural features, those in the northern foothills are discussed from south to north in relation to the persistent anticlines which cross the region. In the coastal plain, where rock exposures are not abundant and extensions of axial traces across interstream areas cannot be mapped, structural features are discussed from south to north in relation to the major rivers.

STRUCTURAL FEATURES SOUTH OF BLIZZARD ANTICLINE

Six of the twenty synclines in the eastern structural province lie at the southern limit of exposures of the Nanushuk group and include Pitmegea, Dugout, Igloo Mountain, Poko Mountain, Meat Mountain, and Foggy synclines. They are deeply eroded remnants topographically expressed as mesas and surrounded by broad lowland areas. Poko Mountain, Meat Mountain, and Foggy Mountain synclines have been studied in the field, and the remaining three have been mapped by photogeologic methods. With the possible exception of Pitmegea syncline, which probably contains some Corwin formation in the axial area, surface rocks in these synclines are restricted to the Kukpowruk and Torok formations. Rocks in Pitmegea, Dugout, and Igloo Mountain synclines are estimated to have dips of less than 15°. Poko Mountain syncline appears to be structurally symmetrical, with dips not exceeding 10° in rocks of the Nanushuk group. Meat

Mountain syncline is a slightly asymmetrical fold, with dips in the Nanushuk group not exceeding 20° on the south flank and estimated to be less than 10° and on the north flank. The syncline axis extends eastward from Meat Mountain at least to the Colville River. West of Meat Mountain, bedding traces are rare, but they indicate that the axis of Meat Mountain syncline generally parallels the trend of the East Driftwood anticline. An angular break is evinced in the Torok formation about 4,000 feet above its base between Meat Mountain and Seismo Creek, and may be the expression of an angular unconformity or a fault. (See p. 76.) Foggy Mountain syncline appears to be symmetrical, and dips of rocks of the Nanushuk group do not exceed10° although beds in the Torok formation dip as much as 60° on the south limb north of the Colville River.

Structural features north of the above synclines include Coke basin, Tupikchak syncline, Tupikchak basin, Squeeze anticline, Kokolik anticline, and Flintchip syncline. Coke basin is unusual in that it is the most deeply folded structural feature in the southern part of this structural province and because of its structural position. It is a slightly elliptical basin with steeply dipping beds on its flanks that flatten abruptly near the center. No axial trend can be mapped, although the longest dimension of the basin trends north-northeast. This basin lies between northeastward-trending structural features west of the Kukpowruk River and the essentially westward- to northwestward-trending structural features east of the Kukpowruk. Its structural configuration is probably the result of a squeeze by differential tangential forces from two directions.

North of Coke basin, beds of the Torok formation are tightly folded where exposed along the Kukpowruk River in the axial zone of the Squeeze anticline. About 2 miles east of the river, at least one small anticline is parallel to the trend of the Squeeze anticline for a short distance but is not present near the river. The Squeeze anticline may connect with Blizzard anticline west of the river, but its eastward extension is not known.

Tupikchak syncline extends from the Kukpowruk to the Kokolik River, and its axis is continuous with the axis of Tupikchak basin, a circular structural feature lying east of the Kokolik River. A small northeastward-trending high lies along the Kokolik and separates the 2 basins, but they are here treated as 1 structural unit. Both Tupikchak syncline and Tupikchak basin appear symmetrical in cross section, with dips of beds not exceeding 39° in the former and 25° in the latter. An anticlinal area between the south limb of Tupikchak syncline and Poko Mountain was mapped by photogeologic methods and is believed to consist of thin erosional remnants of the Kukpowruk formation in part breached to the Torok formation. Three anticlinal and three synclinal axes have been mapped in this area.

The eastward-trending Flintchip syncline, on the south limb of Blizzard anticline, is more sharply asymmetrical than other synclines in the area. Beds in the Torok formation on the outer limbs of the syncline have steep and irregular dips, probably the result of shale flowage. Several transverse faults of small displacement cut the relatively thin section of the Kukpowruk formation preserved in this syncline north of the Utukok River. East of the Utukok River the axial trace of Flintchip syncline appears to strike into the south limb of Foggy syncline. Here the direction of strike of the axial trace is at considerable variance to that of Foggy syncline, but tundra cover masks the relation of the two synclines.

Kokolik anticline.—The Kokolik anticline, which is cut by the Kokolik River between Tupikchak syncline and Flintchip syncline, was examined briefly in 1949 by a Geological Survey party and in more detail in 1952 by Andrew Milek, of Arctic Contractors, who prepared the structure-contour map (fig. 25). Although the structural interpretations of Milek and the authors agree in general, there are some differences. These include the position of the axial trace near the southwest end of the anticline and bed correlations between the limbs of the anticline.

The anticline is a sharply asymmetrical fold best exposed east of the Kokolik River. The Kokolik anticline is well exposed only on its flanks, where exposures of resistant sandstone of the Kukpowruk formation form ledges that rim the southeast side of the anticline. The axial zone, which contains a few exposures of the Torok formation, is expressed as a bowl 5 miles long and 2 miles wide, with maximum topographic relief of about 1,200 feet at the east end and about 800–1,000 feet at the west end. Because of insufficient exposure the structural configuration in the axial area is largely inferred except at the extreme southeast end of the bowl. The axial trace of the anticline strikes N. 15° W., at the northwest end and N. 65° W., at the southeast end. It is generally parallel to axial traces of the Tupikchak syncline and basin, but is at considerable variance to the trend of Flintchip syncline. Three miles east of the Kokolik River the anticline is well exposed and plunges 5°–8° E. before rising southeastward. Milek estimated that the axis plunges 50–100 feet west of its southeastward rise. North of the axis, minor folds plunge 35°–40° E., and the beds are cut

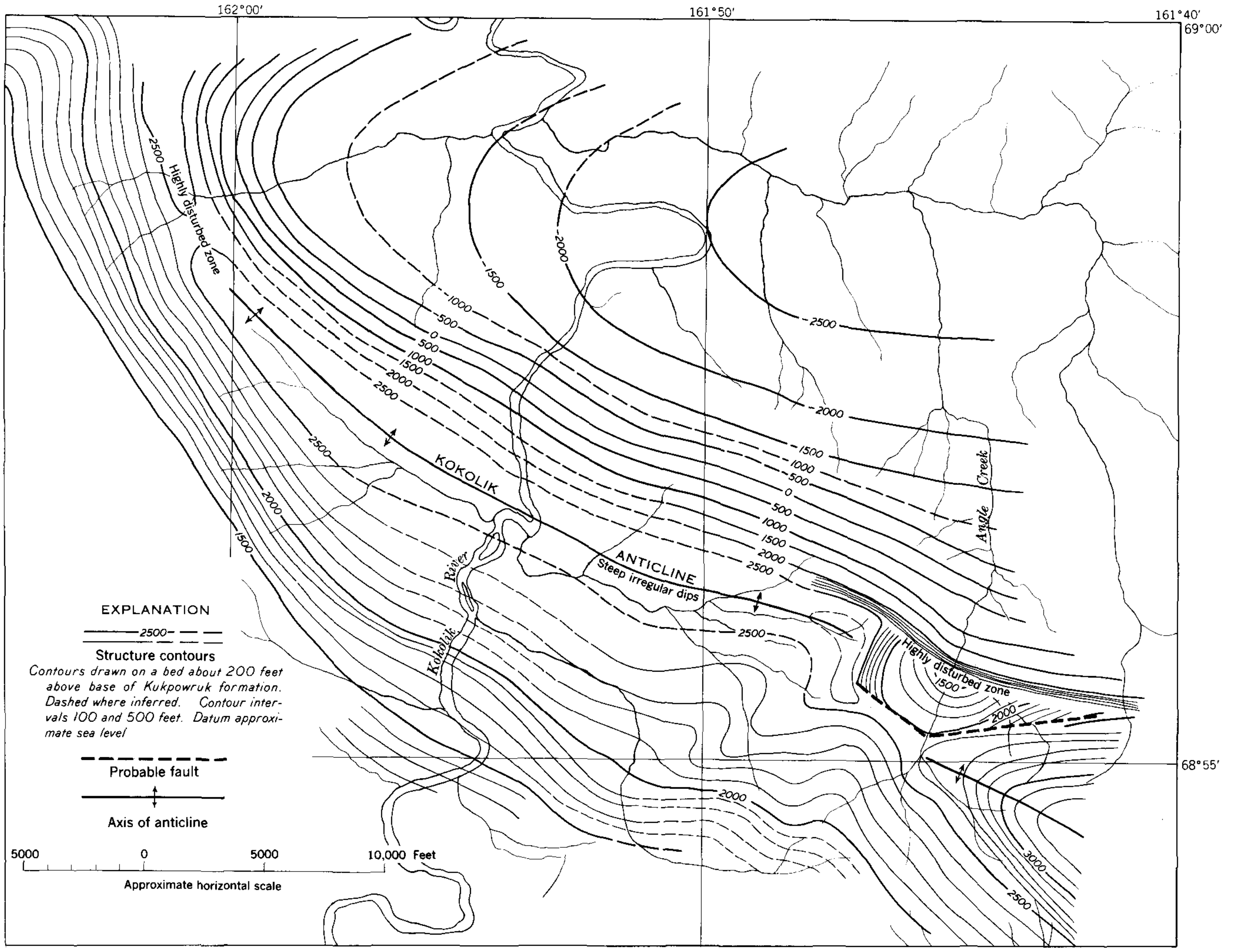

FIGURE 25.—Structure-contour map of Kokolik anticline and vicinity.

by small faults and calcite veins and are silicified. Two miles west of the Kokolik River, 2 transverse faults with apparent displacements of less than 300 feet cut the south limb, and 2 small drag folds are present in the north limb. Three miles west of the river a convergence of traces indicates a slight westward plunge. Many divergent strikes were noted here, and the surface expression of the axial area is complex. If a west plunge is present, closure on the anticline is not more than a few hundred feet. Milek (written communication, 1952) states: "At the northwest end of the Kokolik anticline the axis plunges at an estimated 200 feet shortly before the structure opens to the Blizzard anticline. * * * Thus the anticline seems rather even crested throughout most of its length."

No major faults in the Kokolik anticline were observed in the field although lack of similarity of rock sections on the south and north limbs suggests that faults may be present. The authors do not believe that sandstone beds in the lower part of the Kukpowruk formation can be directly correlated across the anticline. Several thick sandstone beds which are exposed in the lower 1,050 feet of the Kukpowruk formation on the south limb can be traced around the southwestward-plunging nose, and they appear to strike into rubble and poor exposures of shale of the underlying Torok formation. This discrepancy is probably due at least in part to facies changes in the lower sandy beds of the Kukpowruk formation northward to the shaly section (p. 91–94), but it may also be caused by unrecognized faults along or north of the anticline axis. Although no positive evidence of faulting could be obtained from field or photogeologic studies, beds north of the axial area near the west end of the anticline contain several dip reversals. These, and the marked difference in degree of dip between the two limbs of the anticline may indicate the presence of a fault with the north side upthrown.

Milek (written communication, 1952) suggests that the Kokolik anticline is a relatively small structural feature that developed in a parent syncline that is separated into the Tupikchak and Flintchip synclines which were buckled by northward compressional forces. The anticline would therefore be rootless, and it would have little or no expression in rocks below the Torok formation.

BLIZZARD ANTICLINE

This persistent anticline extends across the Utukok-Corwin region from the Pitmegea River eastward for more than 130 miles. Although this is one of the longest anticlines in northern Alaska, little is known about its configuration. It is not exposed along the Kukpowruk River, and the scattered cutbanks along the Utukok and Kokolik Rivers are too few for satisfactory structural interpretation. Beds in these exposures dip steeply and are complexly faulted and folded. Interpretation of seismic work by the United Geophysical Co., Inc., shows subsurface dips east of the Utukok River to be from 15°–30° S. beneath this anticline; it also shows a thrust fault which comes to the surface near the contact between the Torok formation and the Nanushuk group on the south flank of Folsom Point syncline, and an anticline at approximate lat 69°06′ N., below northward-dipping beds that crop out on the south limb of Folsom Point syncline. (See pl. 20.) The only surface evidence for the presence of a thrust fault along the anticline is the incongruous structural trends on opposite sides of Blizzard anticline west of the Kukpowruk River. The northwestward trend of Tupikchak syncline south of the Blizzard anticline differs considerably from the northeastward trends of Beaufort and Kukpowruk synclines. Major thrust faulting coextensive with the Blizzard anticline may be responsible for this surface expression.

STRUCTURAL FEATURES BETWEEN BLIZZARD AND ARCHIMEDES RIDGE ANTICLINES

The group of structural features in this belt includes six echelon synclines, of which the Seaview, Beaufort, and Kukpowruk synclines lie mostly west of the Kukpowruk River and strike northeast. North and east of these structural features are the Deadfall, Folsom Point, and Kokolik Warp synclines, which are more persistent and strike mostly west to northwest. The synclines are separated by relatively short anticlines including Seaview and Token anticlines.

Seaview and Beaufort synclines lie west of the Kukpowruk River, trend east to northeast, and may have developed from one parent syncline. Seaview is the westernmost syncline and is bounded on the west by northward-trending structural features and faults probably related to the thrust-fault pattern of the western structural province, and on the north by Seaview anticline and several faults of unknown displacement. These faults occur in an area where several fold axes converge, and they probably resulted from the concentration of stresses in this small area. Seaview anticline, in which the axial zone is breached to the Torok formation, plunges eastward toward this faulted area, and on its west end, strikes into a zone of highly contorted northward-striking rocks. Beaufort syncline appears to be an asymmetric fold, with the north limb steeper than the south. A steep-limbed anticline flanks the syncline on the northwest and northeast sides and may connect with the Blizzard anticline on the southeast. The Torok formation is exposed for a distance of 5 miles along the axial area of this anticline, but closure, if present, is probably not more than a few hundred feet.

Northwest of these structural features, the south limb of a large northwestward-trending syncline is exposed along the Arctic coast. This syncline, which is probably a westward extension of Deadfall syncline, was mapped mainly by photogeologic methods, and field control was limited to examination of a few exposures along the coast. If reconstructed, the axial trace would be about 16 miles long; and the south limb, about 7 miles in maximum width. Dips on the south limb appear to flatten abruptly near the axis. Both ends of the syncline near Punak and Kahgeatak Creeks are bounded by transverse faults associated with small folds. The main fault at the west end appears to have been thrust from the west, and the fault on the east end is probably a high-angle fault with the north side upthrown, caused by rupture along the small northwestward-striking anticline between this syncline and Deadfall syncline.

Kukpowruk syncline, northeast of and parallel to the structural trend of Beaufort syncline, parallels the Kukpowruk River for 5 miles N. 45° E. Two gentle anticlines and one gentle synclinal flexure separate Kukpowruk and Deadfall synclines. Dips are low and flatten progressively northward into Deadfall syncline. The larger anticline northwest of Kukpowruk syncline swings southward, parallels the syncline axis for 5 miles, and plunges southwest. Dips on the flanks are estimated to be 30°–45°, and a small area of closure about 4 miles long and less than one-quarter of a mile wide is indicated. Another anticline, echelon to but along the same trend as the above anticline, can be mapped for 7 miles southwest, but it shows no evidence of closure.

The Deadfall syncline is the southernmost syncline in the Nanushuk group that reflects the Kukpowruk salient. The axial trace of the syncline bows northward at the Kukpowruk River. West of the Kukpowruk River the syncline plunges west toward the coast near Cape Beaufort, and east of the Kukpowruk it plunges east to the vicinity of Kokolik River where the plunge reverses (fig. 16).

Little information is available on Token anticline, which lies between Deadfall and Kokolik Warp synclines; for most of its length it is breached to the Torok formation. The east end appears to join Archimedes Ridge anticline, and the west end enters a highly folded zone associated with small-scale transverse faults and apparently merges into the south flank of Deadfall syncline before reaching the Kukpowruk River. Although the axes of Token anticline and the anticline northwest of Kukpowruk syncline (p. 139) do not coincide, the anticlinal trend is essentially continuous around the Kukpowruk syncline at least as far as the Beaufort syncline.

The Kokolik Warp syncline consists of two basins separated by a northward-trending high at the Kokolik River. Along the Kokolik River the syncline is slightly asymmetrcal, and toward the Utukok River the syncline develops into a broad westward-dipping warp. The contact between the Kukpowruk and Corwin formations is quite distinct in the rubble exposures on the north limb east of the Kokolik River, but it is not as easily recognized on the south limb. On the east end of this syncline the contact between the Kukpowruk and Corwin formations was not recognized in the field, and the contact shown on the geologic map (pl. 8) was located by projecting the contact eastward from the Kokolik River exposures.

Folsom Point syncline consists of two elongated basins separated by a structural high along Disappointment Creek. The western basin is only partly separated from the Kokolik Warp syncline by a small anticlinal flexure, so that the north limbs of Folsom Point and Kokolik Warp synclines are continuous. The eastern basin resembles the western basin in shape but is probably shallower.

ARCHIMEDES RIDGE ANTICLINE

This anticline is more than 100 miles long and can be mapped from the coastal area west of the Kukpowruk River to about 18 miles east of Disappointment Creek. As in the Blizzard anticline, the axial area is breached to the Torok formation, most exposures of which are limited to river cuts and a few traces in interstream areas. Well-exposed sections of the Torok formation are present on the north limb of the Archimedes Ridge anticline, in bluffs more than 5 miles long on the west side of the Kokolik River. Near lat 69°12′ N. in the south 1.5 miles of bluffs in the axial zone of the anticline there are several folds, the limbs of which generally dip 15° but which in places dip as much as 35°. These folds include a few hundred feet of section and, near the north end of the axial zone, are associated with contorted beds which dip as steeply as 85°; this indicates possible faulting. In the northern 3.5 miles of the bluffs, northward-dipping beds on the south limb of Howard syncline generally decrease in dip from 40° to slightly less than 20°. Some beds dip locally as much as 55°, and it is possible that unrecognized folds or faults are present in covered intervals of rock in this part of the anticline.

At the Kukpowruk River the convergence of resistant bed traces suggests a west plunge of the Archimedes Ridge anticline, and west of the river a doubly plunging high extends for 7 miles. Beds exposed in the axial zone dip steeply and show evidence of shearing.

As with Deadfall syncline, Archimedes Ridge anticline bows around the Kukpowruk salient but changes its direction 7 miles west of the river and strikes northwest into the coastal plain where it is masked by surficial cover. On the east end, 6 miles east of the Utukok-Corwin region, the anticline plunges east at about 20° and merges into the south limb of Lookout Ridge syncline.

STRUCTURAL FEATURES BETWEEN ARCHIMEDES RIDGE AND CARBON CREEK ANTICLINES

Included in this group of structural features are the Howard, Kasegaluk, Lookout Ridge, and Oxbow synclines, and the Snowbank anticline. These synclines strike west to northwest, with local northeast trends reflecting the Kukpowruk salient and a salient between the Kokolik and Utukok Rivers. They are subparallel, in contrast to the shorter echelon folds farther south. The more regular pattern of subparallel folds may reflect a lesser intensity of the tectonic forces as they diminished northward from the southerly areas of greater tectonic activity.

Howard syncline extends at least from the Kukpowruk River to the Utukok River, a distance of 65 miles. Components of west plunge exceed those of east plunge along most of the syncline; the east plunge reversals occur between the Utukok and Kokolik Rivers and probably just west of the Kokolik. The syncline is asymmetrical, but unlike most of the synclines farther south, the apparent dip of the axial plane of this syncline is to the north. Kasegaluk syncline, the south limb of which is continuous with that of Howard syncline, plunges northwestward from the Kukpowruk River and strikes into Kasegaluk Lagoon.

The Snowbank anticlines consist of several echelon structural features lying north of Howard syncline and between the Kukpowruk and Utukok Rivers. They are poorly exposed, particularly just east and west of the point where the Kukpowruk River enters the coastal plain. On the Kukpowruk River a single anticline is exposed, with dips near the axis ranging from 58° to 62° on the north limb and from 49° to 56° on the south limb. A stratigraphic discrepancy at the assumed base of the Nanushuk group (pl. 18) may be due to a fault in the axial zone on which the south side is downthrown.

In the vicinity of the Kokolik River, several anticlines west of the river and one major axis east of the river were mapped by photogeologic methods, but no rocks are exposed in cutbanks of the stream. The anticline east of the river may include several reversals of plunge, and it apparently merges into the south limb of Lookout Ridge syncline. Other echelon anticlines are present between the Kokolik and Utukok Rivers, and the easternmost anticline opens toward the Utukok River between Howard and Lookout Ridge synclines. No surface expression of faulting was noted in photogeologic studies of the Snowbank anticlines, and degree of local plunge, if present, is not known.

Lookout Ridge and Oxbow synclines and Avingak anticline are best exposed between the Kokolik and Utukok Rivers, although Lookout Ridge syncline extends 68 miles southeast beyond the mapped area. These folds are related and pass southeastward into one major structure, the Lookout Ridge syncline, and are characterized by low dips except in the outer extremities of the limbs. Oxbow syncline consists of two basins whose centers lie between the Utukok and Kokolik Rivers. The axial trace trends eastward for a distance of 12 miles east of the Kokolik, then bows northward west of Elusive Creek. The Avingak anticline is about 8 miles long. It is not large in either amplitude or areal extent, but it possesses definite closure of about 300 feet. Dips in the axial zone appear to be less than 5°. The Lookout Ridge syncline lies wholly east of the Kokolik River, and the axis trends southeast to east except for a small northward bulge south of Oxbow syncline. In this area it consists of two separate basins and an intervening high 4 miles west of the Utukok River, and the eastern basin appears to be shallower than its western counterpart.

CARBON CREEK ANTICLINE

The Carbon Creek anticline is more than 106 miles long, but only the western 56 miles is discussed in this report. It can be traced from the eastern boundary to a point 8.5 miles west of the Kokolik River, where tundra cover obscures all traces. It does not appear to cross the Kukpowruk River, but it may swing southward and join the trend of the Snowbank anticlines. On the Kokolik River it is highly asymmetric with a steeper north limb. Rocks of the Corwin formation are exposed along its axis on the Kokolik. To the east it swings slightly southward and then trends northeastward to form a prominent salient between the Utukok and Kokolik Rivers. The axis may be offset by minor faults within a zone of disturbance at long 160°40' W. No indications of plunge are evident along this part of the anticline, and exposures are poor.

Between this part and the east edge of the map area the anticline is an asymmetric fold, with the north flank generally much steeper than the south flank. Although a convergence of the flanks and a narrowing of the axial lowland west of the Utukok River gives the appearance of northwest plunge, field studies show that the convergence results from a flexure on the south flank 6 miles west of the junction of Carbon Creek and the Utukok River (Whittington, written communication, 1951). Beds cannot be traced directly around the apparent west plunge, and a fault may extend along the axis in this vicinity. This may be the extension of the major thrust fault deduced from seismic data by United Geophysical Co., Inc. (See p. 147.) The structural high of the anticline is believed to be in the vicinity of the Utukok River. East of the mapped area the flanks converge and then open again to the east.

On the north limb of Carbon Creek anticline west of the Utukok River, a structural anomaly, believed to be a fault or line of flexure, parallels the trend of the anticline and can be mapped from a point 2 miles west of the Utukok River westward for at least 20 miles. No exposures along this anomaly could be seen in photographic studies, and it is expressed as a low tundra-covered belt which crosses several small streams. Seven miles west of the Utukok River, this belt marks a division between traces striking N. 60° W., on the north flank of the Carbon Creek anticline and traces striking N. 30° W., on the south flank of Elusive Creek syncline. Contorted bedding and transverse faults are present south of this belt, and at least 1,200 feet of section in Elusive Creek syncline is truncated by the belt. Other strike divergences can be seen along it and along another belt, mapped as a fault, which strikes northwest from about 5 miles west of Elusive Creek. The exact nature or extent of these faults or lines of flxure is not known from present information.

STRUCTURAL FEATURES NORTH OF CARBON CREEK ANTICLINE

KUKPOWRUK RIVER

Two major structural features are north of Snowbank anticline. The first of these, Barabara syncline, contains the thickest section of Nanushuk group in the eastern structural province—more than 9,100 feet of partly exposed section and an additional 500 feet inferred in the subsurface. Dips on the south limb decrease northward from 62° to 0°; the north limb is not well exposed, and its configuration is not known. The axial trace of the syncline appears to trend northeast.

About 7 miles northwest of Barabara syncline, scattered cutbanks reveal the axial zone of Epizetka anticline. The anticline appears to be asymmetric with the steepest dips in the north limb, and it seems to plunge east at this locality.

KOKOLIK RIVER

Oilsand syncline lies north of lat 69°30' N., and the north limb of Carbon Creek anticline. For the most part the syncline is poorly exposed. Maximum dips are 25° on the south limb and 70° on the north limb. The axis of the syncline strikes west.

North of Oilsand syncline the Norseman anticline crosses the Kokolik River at lat 69°35' N. and is about parallel to the course of the river for 7 miles before becoming obscured by surface cover west of the river. About 3 miles east of the river, the anticline appears to plunge west. Sixteen miles east of this point, an anticline strikes east for more than 5 miles and plunges steeply to the east. If these two axes are continuous, they probably represent a closed anticline of large dimensions. At least one sandstone bed with a high asphaltic content lies on the south flank of the Norseman anticline on the Kokolik River—about midway between the axes of Oilsand syncline and Norseman anticline. Drag folds on the south limb of the Norseman anticline are exposed along the Kokolik River at latitude 69°33' N., about 1 mile south of the major axis. An unusual relation was observed at the north limit of the major westward bend of the Kokolik, and also on the south limb of the anticline, where a sandstone bed dipping 7° S. lies 10 feet vertically above a bed that dips 35° S. The interval of rock between the two beds is covered. This relation may represent a tight flexure, fault, or an angular unconformity. In the area ½–2 miles north of the sandstone outcrop, a lowland ringed by hills is believed to indicate the Torok formation in the axial zone of Norseman anticline. As all rocks examined in the river cuts are assigned to the Corwin formation, this leaves less than 1,000 feet remaining for the Kukpowruk formation, which can be explained either by the northward thinning of this unit or by faulting.

The few riverbank exposures 3 miles north of Norseman anticline contain Prince Creek formation which dips uniformly 16°–18° N. No contacts between this unit and rocks of the Nanushuk group are exposed.

The northernmost outcrop on the Kokolik River, a small cutbank 7 miles northwest of 1949 camp 28 at lat 69°43'30" N., exposes rocks mapped as Corwin formation which dip about 15° S.

UTUKOK RIVER

The greatest thickness of the Nanushuk group along the Utukok River is exposed north of the Carbon Creek anticline zone in the Elusive Creek syncline and north into Westbend syncline. About 6,500 feet of section, of which about 2,000 feet is Kukpowruk formation, was measured and is believed to be the total thickness of the Nanushuk group in this part of the area.

The axial trace of Elusive Creek syncline is parallel to the Carbon Creek anticline east of long 160°20' N., but unlike the anticline, it trends northwest at least to the large northward bend of the Utukok River at the edge of the coastal plain. The syncline consists of two basins separated by a structural high north of the inferred Carbon Creek anticline high. East and west plunges of the basins appear to be less than 5°. West of the Utukok River the axial trace strikes northwest and is about parallel to the course of the Utukok River west of 1947 camp 13.

Several gently dipping structural features are present between Elusive Creek syncline and the major westward swing of the Utukok River at 1947 Camp 12. Two of these structural features, about which little is known, lie mostly east of this area. North of this area, along the river, there are several gentle folds, including the Harris anticline. West and south of the Utukok River, this anticline strikes northwest, and exposures in the axial area near 1947 camp 13 show contorted bedding, with dips ranging from 15° to 90°, and a zone of south-dipping normal faults with displacements ranging from a few feet to 100 feet. Dips in the north limb of this anticline decrease progressively northward to the flat-lying beds of the Prince Creek formation in the axial area of Westbend syncline near 1947 camp 12.

Beds of the Corwin formation exposed at 1947 camp 14 form a minor syncline and a tightly folded anticline. The north limb of the anticline is not well exposed, but an abrupt change from steeply dipping to flat-lying beds occurs north of a small covered interval of rocks. Farther downstream, the horizontal beds are displaced 100 feet by a thrust fault dipping 30° N., with the north side upthrown. The horizontal beds can be traced downstream about 2.5 miles, where they steepen to 2° S. and are displaced by a small normal fault north of which beds dip 2° N.

The remaining exposures downstream on the Utukok River are scattered cutbanks in which dips are low to horizontal, in minor flexures in rocks of the

Prince Creek and Corwin formations. Structural features include a small anticline 7 miles downstream from 1947 camp 15, dips to 30° S. in the vicinity of 1947 camp 16, and a 5° S. dip about 6.5 miles downstream from camp 16. In contrast to the west and northwest strikes of rocks south of 1947 camp 15, the few exposures north of that locality indicate that structural trends are east to northeast in this part of the coastal plain. The northeast trends may be related to the northeastward-striking structural features mapped along the lower Kukpowruk River, and they may have influenced the northeast trend of this part of the Arctic coastline.

WESTERN STRUCTURAL PROVINCE

The western structural province is roughly bounded on the east by the Pitmegea River, and it is separated from the eastern province by the complex structural area east of the Pitmegea and west of Seaview syncline. The structural pattern of the western structural province differs considerably from that of the eastern province. The general strike of rocks in the western province is northwest, in contrast to the adjacent eastward-trending structural features of the eastern province. The western province also contains several persistent fault zones which in general are parallel to the dominant northwest structural trend.

Field studies in this province have been restricted to the coastal exposures and a few outcrops less than 5 miles from the coast. Much of the area contains good rock traces, however; and structural information obtained in the field has been augmented by photogeologic studies.

West of the Pitmegea River, 6 west- and northwest-trending linear features, 8–23 miles in length, have been interpreted as major thrust fault zones. The two easternmost zones were mapped from photogeologic observations, and the others were located by ground observations along the coast and traced inland by the use of photographs. Where exposed along the coast, these faults are zones of contorted and sheared beds as much as several hundred feet wide, consisting of two or more small folds, on either side of which normal southward-dipping sequences are exposed. In the fault zones west of Risky Creek, it is obvious that the beds on the south side, which are structurally relatively uncomplicated, have been thrust over the beds on the north side of the zones. Inland from the coast, the fault zones are mostly expressed as exposureless valleys that strike across the major drainage patterns of the area. In many localities along the north side of these valleys, the bedding is contorted and strikes into the valleys. Most bedding traces south of the valleys are simple linear features parallel to the trend of the faults. Where two fault zones converge, the intervening area shows a high degree of complexity.

The amount of displacement of the thrust faults is unknown. In general, older sequences are found progressively westward; and if the stratigraphic interpretation is correct, the net slip of the faults may be several thousand feet.

Between the major fault zones, relatively uncomplicated southward-dipping sequences of rocks of the Nanushuk group probably are on the limbs of broad synclines similar to those in the eastern structural province. The axial traces of two synclines were mapped: Thetis syncline, east of Thetis Creek; and the Eesook syncline, southeast of Eesook.

The complex area between the eastern and western structural provinces contains structural features akin to both provinces. West of and adjacent to Seaview syncline, northward-trending folds and faults in the Nanushuk group and the Torok formation are nearly at right angles to the east trend of Seaview syncline. Along the coast, however, complexly folded eastward-trending rocks are parallel to the structural features in the eastern province and imply a relation to them. Between these contorted zones and the Pitmegea River, uniformly southward-dipping rocks are structurally similar to those in the western province.

In the following discussion the major structural features of the western structural province are described westward from the eastern boundary of the province.

Along the coast, between the Pitmegea River and Thetis Creek, beds in the Corwin formation dip southwest, and they are truncated by a fault zone which strikes east-southeast from the mouth of Thetis Creek to a point 3.5 miles upstream from the mouth of the Pitmegea River. The zone may continue even farther southeastward, as suggested by the straight-line course of the Pitmegea below a point 9 miles upstream from its mouth. Another fault zone which strikes southeast from the mouth of Thetis Creek, and lies south of the above-described zone, can be mapped for 25 miles southeastward and strikes into an area of intensely crumpled rocks southwest of the Pitmegea River.

The two thrust faults exposed along the coast less than 2 miles west of Risky Creek can be seen easily from the ocean. Simple sequences of sandstone and shale of the Nanushuk group, which dip 30°–45° S., overlie crumpled and contorted beds of similar rocks. The fault exposed 0.6 mile west of Risky Creek has been traced by field observations southeastward across

Risky Creek almost as far as Kookrook Creek. East of Kookrook Creek, high dips and apparent dip reversals probably reflect the fault zone as far as 6 miles east of Thetis Creek, beyond which it could not be traced. The fault exposed 1.6 miles west of Risky Creek can be traced eastward from the coast for a distance of about 10 miles and with less certainty to a point 7 miles farther southeast, where it apparently truncates the axial trace of Thetis syncline. There, the fault swings southward and for the most part parallels the axial trace of Thetis syncline for at least 7 miles.

Between a point 1.6 miles west of Risky Creek and Eesook, rocks resembling those of the Nanushuk group and the Torok formation crop out, but their relations are not well known. At least one fault zone extends southeastward from the coastline 1 mile east of Eesook, and from photogeologic studies it is inferred to continue along the north flank of Eesook syncline and southeastward at least to the vicinity of upper Thetis Creek. Reasons for extending the fault include discordance of structure trends and differences in the appearance of exposures on either side of this zone. North of the fault, and east of Eesook syncline, rocks of the Nanushuk group and probably of the Torok formation are folded in many small structural features that strike generally parallel to the regional northwest trend. Rocks south of the fault in part resemble sedimentary beds which overlie Triassic rocks in the Cape Lisburne Peninsula, and they are thought to be of Jurassic or Early Cretaceous age.

The westernmost major fault in this area extends from the west end of Ahyougatuk Lagoon eastward to the headwaters of Eesook Creek and may possibly swing southward around Eesook syncline. The presence and location of the fault is inferred from the following field relations. A steeply plunging anticline in rocks correlated with the Corwin formation is exposed in a low hill south of the lagoon. One-half mile to the south, a steep north-facing hill composed of Jurassic(?) rocks rises sharply to about 1,000 feet above the lagoon. The base of the hill lies along a nearly straight line and resembles a fault-line scarp.

The Jurassic(?) and Cretaceous rocks south of Eesook syncline are not well exposed. They display diverse strikes, tight folds, and faults of unknown displacement, and the structural relations are believed to be more complex than those described above.

INTERPRETATION OF STRUCTURAL FEATURES

The structural features in the western structural province are related to the northwest trends and thrust faults in rocks of Mesozoic and Paleozoic age exposed in the western part of the Cape Lisburne Peninsula (Collier, 1906, pl. 1, p. 18–21, 31). They are the result of eastward- and northeastward-directed tangential forces originating west of the peninsula in the Tigara uplift (Payne, 1955). The structural features of the eastern province were mainly caused by northward-directed forces originating in or south of the DeLong Mountains, in the Brooks Range geanticline (Payne, 1955). The area of contorted rocks between the two provinces may represent a marginal area where contemporaneous northeastward- and northward-directed forces impinged upon one another, or one where northeastward-directed forces affected the already existing eastward-trending structural features of the eastern province. As shown on the generalized geologic map (pl. 9), the fault pattern of the western province generally appears to truncate the fold pattern of the eastern province. Thus it would seem that the latest deformation of the Tigara uplift postdates that of the Brooks Range geanticline. This, however, is a tentative conclusion, as little work has been done along the boundary of the two provinces.

The relations between structural features of the southern and northern foothills sections in the eastern structural province are not well understood. Axial trends of the southernmost synclines in the Nanushuk group in the northern foothills at Igloo and Poko Mountains, Tupikchak basin, and Meat Mountain are west to northwest, whereas south of the mapped area the structural grain of the Fortress Mountain formation and older rocks is parallel to the DeLong Mountain front and strikes northeast between the Kukpowruk River and the Utukok River. These rocks crop out 3–15 miles south of exposures of the Nanushuk group, and the intervening area containing Torok formation and anticlinal structures of the Fortress Mountain formation possesses structural features intermediate in complexity and in directions of strike between those of the northern foothills and the mountain front. The pronounced difference in the regional trends and degrees of complexity between the structure of the Nanushuk group and the Fortress Mountain formation indicates a break between these units. Either a profound but obscure angular unconformity below the Nanushuk group and above the Fortress Mountain formation, or large-scale faulting near the boundary of the foothills sections would explain these discrepancies. Evidence for a structural or stratigraphic break within this interval of Torok formation rocks is discussed in a preceding section. Evidence supporting faulting on a large scale as an explanation of the difference in regional trends also includes the essentially straight-line character of the north-front exposures of the Fortress Mountain formation south of this area, and the inferred major thrust faults between these exposures, and the Carbon Creek anticlinal zone, as interpreted from seismic work.

The previously discussed major structural features that are present in the northern foothills and coastal plain of the eastern structural province are summarized below. Their exact nature and interrelations are not clear, and interpretations regarding them are tentative.

The general strike of surface folds is west-northwest, subparallel to what is believed to have been the trend of the Colville geosyncline, which was a depositional basin of sediments of the Torok formation and the Nanushuk group. This strike does not correspond to either the northeast strike of the DeLong Mountains front or the north-northwest strike of rocks on the Cape Lisburne Peninsula. It is believed that the interaction of forces originating in the Brooks Range geanticline and in the Tigara uplift, superimposed on the west-northwestward-trending geosyncline, has caused this west-northwest strike.

The structural salients shown by the northward bowing of the axial traces of surface folds along the Kukpowruk River and in the vicinity of Elusive Creek strike northeast. The salients, particularly the one along the Kukpowruk River, may represent northeastward-trending structural highs, caused by the interaction of compressive forces from the two major areas of uplift. The northeast strike is parallel to the general trend of the Arctic coast north of Cape Beaufort and to that of several major streams, including parts of the Kukpowruk, Kokolik, and Utukok Rivers, as well as parts of the Meade and Kaolak Rivers west and north of the Utukok-Corwin area. The significance of this parallelism is not known.

The positive and negative structural elements discussed in a preceding section strike east-northeast and are generally parallel to the front of the De Long Mountains, south of the area. They therefore appear to have been influenced more by stresses from the Brooks Range than from the Tigara uplift. These structural elements may be upthrown and downthrown blocks bounded by major faults, or they may be large folds upon which the smaller surface folds have been superimposed.

GEOPHYSICAL EXPLORATION

SEISMIC WORK

Reflection seismic work was done in parts of the Utukok-Corwin region in 1950 and 1952 by United Geophysical Co., Inc. In 1950 several reflection lines were shot in the area between the Utukok River and Wainwright and west of long 158° W. (See pl. 8.) The reflection work in 1952 by party 146 was begun on the upper Kaolak River, about 10 miles north of the Utukok River, where a tie-in with the 1950 work was made. The 1952 traverse, consisting of 3 lines that are not directly connected to each other, was extended southward along the Utukok River valley to the vicinity of Driftwood Creek at the southern boundary of the mapped area. (See pls. 19, 20.) Refraction lines and reflection lines were shot near Driftwood Creek to obtain detailed information on the structure, but only the reflection work north of Driftwood Creek is discussed here.

It is not possible to plot the positions of the seismic lines with extreme accuracy on the base map (pl. 8); however, the locations of the lines as shown are sufficiently close to their actual positions to eliminate any possibility of major discrepancies in geological correlation of surface and subsurface data. Insofar as possible the lines have been plotted in their correct relation to topographic features. The most noticeable discrepancy is the lack of tie-in between shothole 42 on line 16–50 and shothole 1 on line 1–52 (pl. 8). These shotholes were located at the same point (G. C. Donohue, written communication, 1950); but these shotholes, when plotted on plate 8 according to proper topographic positions of the rest of the seismic traverses, are about 2.6 miles apart. Errors in geodetic position on the base maps, or errors in field surveying of distances and azimuths, could account for this discrepancy; but with existing maps and field data it is impossible to determine where corrections should be made.

According to the United Geophysical Co., (H. B. Chalmers Jr., written communication, 1950), the quality of the records obtained in most of the area worked in 1950 is fair to good; but, owing to the difficulties of maintaining open shotholes in loose gravel, the quality of the records is poor in the extreme southern part of the area, near the Utukok River. The quality of the records obtained in the 1952 work is mainly good, although in several parts of the area only fragmentary or poor data were obtained, owing to surface or subsurface conditions. As a result of these gaps in the reflection records, no bed or horizon may be correlated throughout the entire length of the traverse from the upper Kaolak River to Driftwood Creek.

The part of the mapped region that lies north of Carbon Creek and the Utukok River, herein called the upper Kaolak River area, includes few surface traces of beds and few bedrock outcrops, all of which are in or adjacent to the banks of the Utukok River and Carbon Creek. The interpretations of subsurface structure and stratigraphy are based almost entirely upon the data obtained from the 1950 seismic work, from line 1 of the 1952 work, and from the log of Kaolak test well 1, which was drilled in this area. The part of the mapped region south of Carbon Creek and just east of the Utukok River is herein called the Utukok River area. Numerous outcrops and bedding traces are present. The interpretations of subsurface structure and stratigraphy in this area are based on field and aerial photograph studies made by the Geological Survey and on data from lines 2–52 and 3–52 of United Geophysical Company's 1952 party 146.

UPPER KAOLAK RIVER AREA

The upper Kaolak River area is traversed by six southward-trending lines of reflection shotholes, including line 10–50, 12–50, 15–50, 18–50, and 21–50, run in 1950; and line 1–52 in 1952. These lines were tied together by eastward-trending lines 11–50, 13–50, 14–50, 16–50, 17–50, 19–50, and 22–50 run in 1950.

The seismic data show a sequence of rocks, believed to include all or parts of the Corwin, Kukpowruk, and Torok formations, that is gently folded along nearly eastward-trending axes and that has a regional southerly dip. The thickness of this sequence is about 12,000 feet in the northern part of the area and about 15,000 feet in the southern part near the Utukok River. The underlying pre-Torok sequence, believed to include rocks of Early Cretaceous, Jurassic(?), Triassic, and possibly earlier ages, dips homoclinally southward from the Barrow arch (Payne, 1955), a high in metamorphic(?) basement rocks lying near Barrow and about 80 miles north of the mapped region. In contrast to the upper sequence, this lower sequence is not folded. The southern boundary of the upper Kaolak River area follows the surface trace of the Carbon Creek fault, a southward-dipping reverse fault of major proportions.

No faults are indicated on the seismic records within the upper Kaolak River area, but a few faults on and near the Utukok River have been mapped from field observations and interpretation of aerial photographs. A fault just north of the crest of the anticline between the Elusive Creek and West Bend synclines may be inferred to intersect line 1–52 between shot points 68 and 75, a zone of few reflections. The 2 small faults on the east bank of the Utukok River, at and 2.5 miles north of 1947 camp 14, have small displacements; and no indications of faulting are shown on the seismic profile of line 10–50. (See pl. 19.)

Two eastward-trending anticlines near the head of the Kaolak River were mapped in detail by seismic lines 10–50, 11–50, 12–50, 14–50, 16–50, 17–50, 18–50, 19–50, 21–50, and 22–50. The northern or Kaolak anticline is interpreted to have 480 feet of closure; and the southern anticline approximately at lat 69°49' N., is shown to have 160 feet of closure and possibly greater closure to the west (Chalmers, written communication, 1950). Kaolak test well 1 was drilled in 1951 near the crest of the Kaolak anticline.

Well-defined synclines, which lie 2.5–4 miles north of Kaolak anticline, are shown approximately at lat 69°58'30" N., on line 10–50 (shotholes 49–64) and on line 12–50 (shotholes 51–65). These are interpreted as parts of the same eastward-trending syncline. The first syncline south of Kaolak anticline is at about lat 69°51' N., and can be identified on line 10–50 (shotholes 92–100) and line 12–50 (shotholes 20–31). The axis trends west-northwest and seems to plunge at a low angle both east and west from line 10–50. The anticline that has 160 feet of closure lies south of this syncline. Synclines, shown on line 10–50 (shotholes 119–131) and line 1–52 (shotholes 1–6) at approximately lat 69°45' N., flank this anticline on the south. One may infer from the relations of these structural features that the synclines are parts of the same west-northwestward trending fold, although they are not connected on the subsurface maps of the United Geophysical Co.

Anticlines, shown on line 10–50 (shotholes 131–143) and line 1–52 (shotholes 5–12) at approximate lat 69°43'30" N., lie immediately south of the previously mentioned synclines. They show about 600 feet and 250 feet of structural relief, respectively. Possibly these represent a single westward-trending anticline, but surface and subsurface control is lacking in the 13-mile interval between lines 10–50 and 1–52. South of the anticline(s), synclines are present at about lat 69°41'30" N., on line 10–50 (shotholes 143–153) and line 1–52 (shotholes 12–20). Correlation of these structural features is also hypothetical.

An anticline is indicated at approximate lat 69°39' 30" N., on line 10–50 (shotholes 153–157), but surface and subsurface control is incomplete in this area, and the anticline is poorly delimited. About 400 feet of structural relief is indicated. Due east of this point, a large anticline having 1,450 feet of structural relief is outlined on line 1–52 (shotholes 20–45). These two anticlines are probably not related. The anticline on line 10–50 may correlate with the anticline between the West Bend and Elusive Creek synclines.

The West Bend syncline is outlined by some surface outcrops and traces of beds and by subsurface data on line 1–52 (shotholes 45–63). The axial trace trends west to west-northwest at approximate lat 69°36′ N.

An anticline is present at approximate lat 69°33′ N., on line 1–52 (shotholes 63–74). About 900 feet of structural relief is indicated. Outcrops and surface expression of a structural feature are lacking in this vicinity, but the subsurface structure appears to be the eastward extension of the anticline mapped from surface geology between the West Bend and Elusive Creek synclines (p. 142).

A syncline that has no recognizable surface expression is shown on line 1–52 (shotholes 74–84), at lat 69°30′20″ N. South of this syncline a subsurface anticline coinciding with the surface expression of the Harris anticline is shown on line 1–52 (shotholes 84–94). About 400 feet of structural relief is indicated. Faults or tight folds may be inferred from the sparse and discordant reflections between shotholes 9–95.

The succeeding syncline to the south, shown on line 1–52 (shotholes 94–109), is a broad, westward- to northwestward-trending syncline that coincides with the Elusive Creek syncline, which was mapped from surface data. Bedrock exposures and bedding traces, as interpreted from aerial photographs, indicate that the south limb of this syncline rises uniformly southward toward the Utukok River and the Carbon Creek anticline. The subsurface data give a pattern of erratic dips and poor-quality reflections along line 1–52 (shotholes 110–119). These reflections are indicative of close folding and faulting that does not coincide with either the surface data or the deeper seismic reflections.

This contorted zone is interpreted as the expression of a major thrust fault, the Carbon Creek fault, that comes to the surface just north of the axial zone of the Carbon Creek anticline. United Geophysical Co., Inc. (written communication, 1953) states: "The interpretation of a major thrust at Carbon Creek is reliable. The amount of throw and the angle of the thrust is conjectural because it was impossible to make a direct seismic correlation across the fault."

It is further inferred that "the Carbon Creek structure is a large thrust fault, which has a vertical displacement of the order of 10,000 feet and horizontal displacement of the order of 2 to 3 miles." The discordance of the reflecting horizons in the upper part of this faulted anticline is apparent on the profile of line 1–52 (shotholes 109–132). (See pl. 20.)

Geologic and photogeologic fieldwork in the vicinity of the confluence of Carbon Creek and the Utukok River and in the vicinity of line 1–52 does not reveal any surface expression that is indicative of a major fault. However, a fault line or flexure was mapped on the north flank of the Carbon Creek anticline between 4 and 24 miles northwest of the intersection of line 1–52 and the Utukok River. Possible faults along the axial plane of the Carbon Creek anticline between 18 and 23 miles northwest of this point are indicated by surface data. (See pl. 8.)

UTUKOK RIVER AREA

The Utukok River area was traversed from north to south in 1952 by party 146 from United Geophysical Co., and two reflection lines, 2–52 and 3–52, were shot. These lines are not tied directly to each other or to the lines in the upper Kaolak River area. Thick deposits of coarse gravel prevented the southward continuation of line 2–52 along Disappointment Creek. Rough terrain and impending spring breakup of the Utukok River prevented the field crew from making a direct tie between lines 2–52 and 3–52.

In contrast to the area north of the Carbon Creek fault, both the younger sequence and the underlying older rock units are folded; in addition, at least seven southward-dipping reverse faults that cut the Cretaceous and at least part of the older rocks are believed to be present. The top of the pre-Torok sequence, a good reflecting horizon that is conjecturally identified as Jurassic in age by United Geophysical Co., Inc., lies, according to interpretation of the seismic data, at depths ranging from 2,000 to 8,500 feet below sea level. As a result of thrust faulting, this horizon presumably is closer to the surface than it is in the upper Kaolak River area (United Geophysical Co., Inc., written communication, 1953).

On line 2–52, which was started just south of the surface position of the Carbon Creek fault as inferred from seismic records, a reflecting horizon that is believed to correlate with a horizon 12,250 feet below the surface at Kaolak test well 1 has been contoured by United Geophysical Co., Inc. It is assumed that this horizon is the top of a unit below the Torok formation, possibly of Jurassic age. This assumption is based on the character and quality of reflections from this horizon which are similar to those obtained from the pre-Cretaceous rocks in the Topagoruk area to the northeast. A reasonable correlation of the pre-Torok horizon between the upper Kaolak River area and the Utukok River area can be made in the absence of direct seismic correlation between line 1–52 and 2–52, if an assumed thickness of 7,000 feet of shale underlies the Nanushuk group at Carbon Creek (G. C. Donohue, written communication, 1952), an assumption that is in accord with the thicknesses of the Torok formation measured in the field by the Geological Survey. The pre-Torok (Jurassic?) horizon is shown on line

2–52 at a depth of 6,500 feet below sea level, and there is an indication of a slight anticlinal structure in the footwall block of the fault in this and lower horizons between shotholes 3 and 10. The axis of the Carbon Creek anticline, as mapped from surface data, crosses line 2–52 at shothole 6. In the hanging-wall block the pre-Torok sequence between shotholes 9 and 21 dips homoclinally southward from a depth of 3,800 to 7,500 feet below sea level; and it is terminated on the north by a reverse fault, not shown on the profile of line 2–52, that is inferred from the discordance in dip and scarcity of reflecting planes at this point.

No structural features or reflecting horizons are interpreted on the seismic profile of line 2–52 between shotholes 21 and 36. Several discordant dips are shown at shallow depths near shotholes 23, 24, 31, and 32. The line crosses the axial trace of Lookout Ridge syncline at shothole 33, as plotted from surface data. Reflecting horizons plotted between shotholes 23 and 36 are noticeably smaller in number than those shown on the profiles north of this area. As previously stated, this line could not be continued farther south owing to topography and weather conditions; and a direct tie with seismic line 3–52 was not made.

Line 3–52, which starts about 12.4 miles west-southwest of the south end of line 2–52, trends southward along the east side of the Utukok River valley to the vicinity of Driftwood Creek on the south boundary of the mapped area. The horizon contoured on line 3–52 is assumed to be pre-Torok (Jurassic?), and it is tentatively believed to be the same as that contoured on line 2–52. Between shotholes 1 and 15 the zone is believed to lie in the footwall block of a southward-dipping reverse fault and to dip southward from a depth of 6,500 feet to 8,000 feet below sea level. The fault is shown on plate 20 as surfacing at shothole 6. Near shothole 10, line 3–52 crosses the eastward-trending axial trace of Archimedes Ridge anticline, which is in a broad eastward-trending belt of the Torok formation that is devoid of outcrops or bedding traces in this vicinity. The shallower reflections between shotholes 6 and 20 are indicative of a complex anticline that probably is cut by several faults, which are not shown on the profile section. The pre-Torok horizon is shown at about 6,500 feet below sea level in the hanging wall, indicating a throw of about 1,500 feet on this fault. On the Kokolik River the Torok formation is exposed in bluffs several miles long where this anticline is cut by the river. Faults and complex folds are present in the axial zone of the anticline, but little deformation can be seen in the north limb.

A synclinal axis is indicated at the pre-Torok horizon below shothole 30. The axial trace of Folsom Point syncline, based on surface information, intersects line 3–52 between shotholes 36 and 37 and lies about 9,500 feet south of the trace of the axis at the pre-Torok horizon.

An anticlinal axis is indicated at the pre-Torok horizon below shothole 44. The axial trace of the Blizzard anticline is intersected by line 3–52 at shothole 53, or about 12,000 feet south of the deeper subsurface anticline. A southward dipping thrust fault associated with the Blizzard anticline apparently cuts the pre-Torok horizon between shotholes 48 and 58 and is, according to the interpretation of seismic data, 5,000 feet below sea level under shothole 53. The fault (or faults) would surface within the Torok formation in the axial zone of the anticline where no outcrops or surface expression are evident. The pre-Torok horizon under the south limb of Blizzard anticline has a uniform south dip and lies at 4,000 feet below sea level, and 6,000 feet below sea level beneath shotholes 58 and 65, respectively, as interpreted by United Geophysical Co., Inc.

The subsurface records between shotholes 65 and 88 show poor quality reflections of discordant and discontinuous dips. No horizon could be traced through this area. The axial trace of Foggy syncline, whose location is based on good surface control, is intersected at shothole 69. Only an indication of this syncline can be interpreted from the few reflecting planes shown on the seismic profile. Apparently there are faults and crumpled folds in the Torok formation at the west end of Foggy syncline that lack surface expression in the shale. Contorted folds were noted in outcrops of the Torok formation on the north limb of the syncline on the Utukok River about 4 miles west of line 3–52 and in an outcrop 2 miles east of the line. A southward-dipping thrust fault, which is not shown on line 3–52 (pl. 20), may be present below shothole 73 (G. C. Donahue, written communication, 1952).

Two thrust faults are indicated on line 3–52 between shotholes 75 and 97. The northernmost and deeper fault is projected from a depth of 9,400 feet below sea level under shothole 92 to the surface between shotholes 75 and 76. The southernmost and shallower fault extends from 6,800 feet below sea level at shothole 96 to the surface between shotholes 81 and 82. The inferred surface locations of these faults are in the area where projected axial traces of Amo Creek anticline, which lies east of line 3–52, and of Flintchip syncline, which lies between line 3–52 and the Utukok River, would intersect line 3–52. Structural complexity and possibly bifurcation of the Amo Creek anticline axis would be expected in this area. Owing to the fact that this area lies within the belt of the Torok formation, there is little surface expression that aids in interpretation of the structural features. Additional evidence of faulting or structural complexity along this structural trend can be noted just west of the Utukok River and north of Plunge Creek, and in the exposures on Angle Creek about 4 miles east of the Kokolik River (pl. 8).

Meat Mountain, which is formed by the Kukpowruk formation, lies just east of line 3–52 and is the most conspicuous surface expression of the Meat Mountain syncline. The westward projection of the axial trace is not well defined in the Torok formation, owing to the scarcity of traces of beds and the absence of outcrops; but it appears to cross line 3–52 at shothole 99. The seismic profile shows the axial plane of a deeper syncline between shotholes 94 and 95 about 6,000 feet north of the surface trace. The axial trace at the contoured pre-Torok horizon is 5,450 feet below sea level.

From shothole 98 southward to shothole 127 at the southern boundary of this map area, the seismic data are poor, and only scattered and discontinuous dips are shown. Southward-dipping thrust faults are tentatively inferred below shotholes 109 and 119. The axial trace of East Driftwood anticline is intersected at shothole 115, but the subsurface profile shows no significant indications of major structural features in this area.

INTERPRETATION OF SEISMIC DATA

In general, the seismic data and surface geologic information in the Utukok-Corwin map region correlate reasonably well, but much more geologic and seismic information is needed in order to interpret the structure and stratigraphy of this region in detail. In summary, two parts of the region have been delimited: the southern or Utukok River area and the northern or upper Kaolak River area.

In the Utukok River area, thrust faults and folds are the dominant structural features. The southward-dipping thrust faults, as interpreted from the seismic data and shown on the seismic profiles (pls. 19 and 20), are probably correct only in general. It is suggested that the fault pattern is complex and in part may be analogous to that of the foothills in Alberta, Canada (Link, 1949; Scott, 1951). The relations of the folds in the Torok formation and younger rocks to those in the pre-Torok rocks is not clear from the available information. The axial planes of folds in these two sequences apparently do not coincide. Perhaps two or more stages of folding along different axes, followed by or punctuated by faulting, have occurred. It is equally possible that complex faulting has destroyed the continuity of originally simple folds that embraced both the Torok and the younger rocks and at least part of the pre-Torok rocks. As surface evidence of major faults is almost entirely lacking and as interpretation of pre-Torok stratigraphy is based on inference and conjecture, an accurately detailed intepretation of subsurface structure and stratigraphy is difficult without additional geological data from deep drilling to depths of 10,000–15,000 feet.

As previously mentioned, the subsurface reflecting horizon in the Utukok River area that was contoured by United Geophysical Co., Inc., is only tentatively identified as the top of the Jurassic sequence. The correlation of the contoured horizon is tenuous not only between this map region and other areas in which seismic work was done but between seismic lines and between parts of the same line within the Utukok River area of the map region. The most obvious difficulties are due to the breaks in direct correlation of the subsurface horizon (such as between nonconnected seismic lines 1–52, 2–52, and 3–52, across inferred faults, and between the Utukok-Corwin and other regions). In addition, other factors (such as lateral change in facies and in the thickness of rock units, and local or regional unconformities) may materially affect subsurface correlations and age identifications in this region, much of which is many miles removed from areas of known pre-Torok rocks. Thus, the pre-Torok horizon that is tentatively identified by United Geophysical Co., as Jurassic might be as young as Lower Cretaceous or older than Jurassic. Furthermore, the horizons as shown on the various lines may not all be correlative in age. Therefore, the horizon and the sequence of rocks underlying it can be identified only as pre-Torok in age.

The axial traces of Meat Mountain syncline, Blizzard anticline, and Folsom Point syncline, as located from surface data, apparently do not coincide with axial traces on the pre-Torok horizon as inferred from seismic work. Each of these surface structural features is between 1.8 and 2.3 miles south of a similar structural feature in the pre-Torok sequence, but a genetic relationship of the surface and subsurface structural features is not necessarily implied. The other surface anticlines and synclines have no apparent counterparts in the pre-Torok sequence. An adequate explanation of these anomalous structural features cannot be made from the available data, but it is reasonable to assume that some or all of the surface folds may be rootless or complexly faulted at depths ranging from a few thousand to 8,000 feet below sea level. Simple, unfaulted major anticlines probably do not exist in this area of the map region, and many of the synclines probably have been somewhat affected by thrust faults.

Most of the faults in the Utukok River area appear to be thrust faults that dip southward at low to moderate angles. The Carbon Creek fault could conceivably be the major sole of a large thrust sheet. The other faults that lie south of the Carbon Creek fault may be subparallel to it or may branch upward from it. Probably much of the fault movement has been within shale of the Torok formation, and either complex folding and flowage of the shale or feathering of the main faults, or both, has occurred in the anticlinal zones (pl. 20, lines 2–52 and 3–52). At depth some of the faults may become bedding-plane faults and, in part at least, follow the folding in a manner similar to that known in the Alberta foothills structures (Scott, 1951).

About 6,400 feet of Torok formation, as computed from surface data, should be present between Driftwood anticline and Meat Mountain syncline. This thickness and the thicknesses of the Kukpowruk and Corwin formations that have been computed from field measurements (see tables 7 and 10) closely approximate the thickness of the section that overlies the pre-Torok reflecting horizon as it is interpreted on lines 2–52 and 3–52 (pl. 20).

In the upper Kaolak River area north of the Carbon Creek anticline, the subsurface structural characteristics are quite different from those in the Utukok River area. The approximately 10,000-foot greater depth of the pre-Torok seismic horizon, its regional uniform southward dip, and the apparent lack of faulting in the pre-Torok units indicate that little of the northward thrust stress was transmitted beyond the Carbon Creek anticline and (or) fault. The only structural feature in the pre-Torok units is a nose, the axis of which plunges southward. It is unconformable with the overlying westward-trending structural features in the younger sequence, but it closely coincides with a line of culmination through the Kaolak anticline and adjacent folds. This suggests a genetic relationship between the highs in the upper and the lower sequences.

The number and quality of reflecting horizons in the upper, predominantly shale sequence, which includes the Torok formation and the shale equivalent of part of the Kukpowruk formation, show a northward increase in the Utukok River area and a marked increase in the upper Kaolak River area. Possibly this is due to a variation in near-surface ground conditions and to shooting techniques.

The shallow seismic horizon in the upper Kaolak River area (horizon *A–1* in pl. 19) is within the upper sequence. It shows undulating, unfaulted folds that reflect much less strain than the folds in the upper sequence south of the Carbon Creek anticline. This Cretaceous horizon is traced southward from a depth of about 5,000 feet in Kaolak test well 1. At this point the horizon, as interpreted from the well data, approximately coincides with the base of the Corwin formation. (See p. 155.) The stratigraphic section in the well above the horizon is predominantly nonmarine sandstone, siltstone, and coal. Below this horizon, as far as is known, the section is probably an equivalent of the Kukpowruk formation and part of the Torok formation; and it is predominantly marine clay shale with minor amounts of sandstone and siltstone, and very little coal. The pre-Torok seismic horizon (horizon *B* in pl. 19) is about 13,000 feet below the ground surface at Kaolak test well 1. This stratigraphic interval of rock correlates closely with the combined thicknesses of the known well section, which is 6,952 feet, and the Torok formation, which is between 6,000 and 7,000 feet in the central and southern part of the Utukok-Corwin region.

The coincidence of the upper seismic horizon *A–1* and the contact of the Corwin and Kukpowruk formations in the southern part of the upper Kaolak River area is doubtful. In the axial zone of Elusive Creek syncline the seismic horizon is about 6,800 feet below the ground surface, but surface measurements show approximately 4,000 feet of Corwin formation in the south limb. Regional facies and formation thickness changes within the part of this mapped region that lacks outcrops may partly or entirely explain the apparent discrepancies in correlation. Seismic work indicates that there is an eastward thinning of 1,500 to 2,000 feet in the upper sequence between the Kaolak River area and Meade test well 1, which is nearly 70 miles east (H. B. Chalmers, Jr., written communication, 1950).

The subsurface structural trends in the upper Kaolak River area are part of the regional structural basin in the western part of northern Alaska. The regional slope and stratigraphic thickening southward from the Barrow arch have a slight westerly component in this area as a result of the regional westward slope and thickening from the Meade arch.

The areas of pre-Torok rocks that are known from either surface or subsurface information are 100 miles or more distant from the upper Kaolak River area. Thus, speculations on the age, lithologic characteristics, and thicknesses of formations within and below the limit, about 15,000 feet below sea level, of the pre-Torok acoustic sequence are purely conjectural, as unconformities, thickness variations, and facies changes, which probably are present, could materially alter the subsurface stratigraphy.

GRAVITY AND MAGNETIC WORK

Gravity work in northern Alaska was done by United Geophysical Co. as a part of the Navy's petroleum-investigations program. Gravimetric surveys cover the part of the Utukok-Corwin region that lies north of lat 69°30' N., and east of approximate long 161°50' W. A discussion of the results of the work and a map of observed gravity has been prepared by United Geophysical Co. (written communication, 1953).

An airborne magnetometer survey of northern Alaska was made by the Geological Survey in cooperation with the Navy Department in 1945. This survey covers most of the Utukok-Corwin region north of lat 69°15' N.; and one traverse line between the Kokolik and Kukpowruk Rivers extends south to approximate lat 68°50' N.

INTERPRETATION OF GRAVITY AND MAGNETIC DATA

The gravimeter results in the Utukok-Corwin region show a northwestward-trending gravity low along and just north of the Utukok River and northwest of Carbon Creek. Gravity increases markedly to the southwest on the flank of this low. The area of gravity high coincides with the area that is underlain by the Carbon Creek fault and possibly other faults. The gravity low is considered to be related to the area underlain by a thick sequence of coal-bearing Corwin formation, although this type of lithology would not alone account for the anomaly.

The magnetic data show a general southwestward decrease in magnetic intensity within most of this region. In the area just north of Carbon Creek, the magnetic intensity increases in an easterly to southerly direction. A southward increase in magnetic intensity is shown at the southern limit of the traverse between the Kukpowruk and Kokolik Rivers.

There is a general lack of conformity between the gravity and magnetic maps along the trend of the Carbon Creek fault and anticline. This is interpreted to indicate that the Carbon Creek fault "becomes a bedding-plane fault at depth and does not occur as a major fault in the rocks of high magnetic susceptibility underlying the sedimentary rocks" (United Geophysical Co., Inc., written communication, 1953).

HISTORICAL GEOLOGY

Cretaceous rocks now exposed in the Utukok-Corwin region were deposited in the western part of the Colville geosyncline and later in the Chukchi basin (Payne, 1955). Sediments were shed from the south, and source areas lay in the Brooks Range geanticline and probably in part to the southwest in the Tigara uplift. In general, Cretaceous seas receded northward and northeastward as the sedimentary basin filled, so that marine rocks give way to nonmarine rocks progressively upward in the Cretaceous sequence.

An interval of nondeposition, inferred from the absence of rocks of middle Early Cretaceous (Aptian) age, followed deposition of the Upper Jurassic and Lower Cretaceous (Neocomian) sediments, both of which unconformably overlie older Mesozoic and Paleozoic rocks south of the Utukok-Corwin region. Continued tectonic activity during lower Albian time in the Brooks Range resulted in the deposition north of the DeLong Mountains of graywacke sandstone, conglomerate, and shale of the Fortress Mountain formation as a marginal facies which grades northward into finer grained sediments. These rocks in part underlie and in part may be equivalent to the lower part of the Torok formation.

The Torok formation, a marine offshore facies mostly of shale, appears to have been deposited under relatively constant conditions. An erosional or nondepositional hiatus, possibly reflecting an orogenic interval may have preceded the deposition of the upper part of the Torok formation; but both the upper and the lower parts of this formation appear to have been deposited in similar marine environments. If such a break occurred, the upper part of the Torok formation represents a possible southward transgression of the sea during middle Early Cretaceous time, followed by a general northward regression. Thick sandstone beds appear in the uppermost part of the Torok formation and grade upward into the dominantly marine sandy inshore facies of the Kukpowruk formation.

The thick sequence of the Torok formation and the Nanushuk group represents the latter stages of the filling of the western part of the Colville geosyncline as the sea regressed northeastward. The axis of uplift in the Brooks Range geanticline may have shifted northward from its positions in Jurassic and earliest Cretaceous times, and rocks of these ages are believed to have contributed part of the source materials to the younger sequences. The axis of the basin extended west or northwest into what is now the Chukchi Sea, and the axis probably migrated northward during deposition of the Nanushuk group. The general shoreline trend during deposition of at least the basal sediments of the Nanushuk was about N. 60° W. from the Kukpowruk River east; and the thickest accumulation of sediments was in the western and southern parts of the area, west of the present Kokolik River. The general northeastward thinning of the Nanushuk group and particularly of the Kukpowruk formation, as well as other evidence, indicates that a positive area, the Meade arch (Payne, 1955), may have existed east of the Utukok River and served in part to separate the Colville geosyncline into a western basin in the Utukok-Corwin region and a basin farther east in the Colville River region. Although rocks in the two regions in part bear resemblances to one another, the Utukok-Corwin region lacks the variety of sequences, reflecting different depositional environments, found in the Colville River region.

The marine inshore facies of the Kukpowruk formation was deposited in a rapidly sinking but shallow geosynclinal sea with a constantly shifting shoreline. The uplift in the Brooks Range geanticline was probably intermittent, and the characteristics of the sediments indicate that many fluctuations of the strand line took place. Some relatively clean sands, owing to shoreline winnowing, and ripple marks indicate that many of the sands were above wave base during deposition. At times the deposits were subaerially exposed, and such breaks are now represented by unconformities. These may account for local thickness variations observed in the Kukpowruk formation, or the variations may be the result of differential sinking of local basins during deposition. Fragmental plant remains, although not as abundant or well preserved as in the overlying Corwin formation, are common in the Kukpowruk formation and attest to the presence of large quantities of vegetation in the bordering land areas. Invertebrates included mainly such bottom-dwelling forms of the littoral and neritic zones as pelecypods, starfish, gastropods.

As the sea continued its regressive trend, progressively larger areas of swampy, marshy, and lagoonal land of low relief were subaerially exposed. Reeds, ferns, and trees of considerable size growing along the shores and in the foreland area, were overwhelmed by local transgressions of the sea or by shifting deltaic deposits and formed the coaly beds in the nonmarine coastal facies of the Corwin formation. Rivers deposited gravel and sand rapidly. No evidence of faunal life other than a few pelecypods has been found in this formation, and the turbid waters were probably unfavorable to most aquatic organisms. During deposition of the upper part of the Corwin formation, ash from an unknown volcanic source was deposited and has produced the bentonite and bentonitic clay. Although much of the sediment in the Corwin formation was derived from the uplifted Brooks Range geanticline, some of it was probably also shed from the Tigara uplift, west of the mapped area. Sediments of the upper part of the Corwin formation and the Prince Creek formation were deposited in the Chukchi basin, which had resulted from the northward shifting of the western part of the Colville geosyncline. The sediments of the Prince Creek formation appear to have been rapidly deposited in a nonmarine deltaic environment; their source probably lay to the south. The presence of bentonite indicates a continuation of volcanic activity during this time. Evidence for a hiatus before the deposition of Prince Creek formation is not conclusive, but in areas farther east, marine equivalents of these rocks disconformably overlie the Nanushuk group. It is possible that some of the present structural features in the Nanushuk group and older rocks were formed earlier than or contemporaneously with the deposition of the Prince Creek formation and that sediments of this formation may represent a reworking of part of the Nanushuk group.

Continued uplift of the Brooks Range geanticline during Late Cretaceous time culminated in great deformation in Tertiary time, during which the present structural pattern in this area is believed to have developed. Deformation of the Tigara uplift also probably reached a maximum during Tertiary time, but its age relative to that of the Brooks Range deformation is not known. No Tertiary deposits have been recognized with certainty in the Utukok-Corwin region.

The sequence of Quaternary events within this region is poorly known, and much detailed work would be required in order to decipher the history of this time. During Quaternary time the extensive surficial deposits now mantling the coastal plain and the fluvial gravels that now form the high-level terraces in the foothills were deposited. Pleistocene valley glaciers were restricted to the De Long Mountains south of the region, but upon melting they contributed to the volume of the rivers flowing through the foothills and coastal plain. Pleistocene outwash material, probably mostly reworked, forms most of the present surficial deposits. In interglacial periods the vegetation probably resembled to some extent the present forest growth in interior Alaska. The trend of the seacoast in Quaternary time probably remained about parallel to the trend of the south edge of the present coastal plain, and at its maximum inland extent the strand line is believed to have closely or exactly coincided with this physiographic boundary. A general northward recession of the shoreline to its present position continued during Quaternary time; however, it probably was punctuated by temporary reversals of this trend. Permafrost development during Quaternary time probably began in the foothills and gradually extended northward into the coastal plain following the receding shoreline.

Differential uplift continued, and the present coastal plain was exposed. The land area in the foothills and coastal plain was tilted westward; existing streams were rejuvenated; and the land was eroded to its present configuration. The Utukok, Kokolik, and Kukpowruk Rivers, already well entrenched in the foothills, flowed across the coastal plain as consequent streams away from the area of maximum uplift, which probably centered in the De Long Mountains and east of the Utukok River. Uplift may yet be active in these areas, as the present coastline from the Utukok River southward appears to be one of emergence.

The present Arctic climate, initiated in the Pleistocene epoch, is a major factor affecting the physiographic features of the area. Mechanical weathering, frost action in soil and rock, and solifluction are active in the subaerial denudation of the landscape. The Arctic Ocean and coastal lagoons are receiving inshore and coastal sediments with features closely resembling those in rocks of the Nanushuk group and the Prince Creek formation. The sediments are derived from these and older rocks and from the younger unconsolidated sediments. The present basin of offshore deposition is the Chukchi Sea.

ECONOMIC GEOLOGY

PETROLEUM

In general, the Utukok-Corwin region does not appear to offer attractive possibilities for petroleum in the formations and structural features that have been observed or can be reasonably inferred. On the basis of presently available data, however, the area cannot be dismissed as having no petroleum potential. Some good potential reservoir beds are present, a few rocks containing petroliferous material are known, and some of the structural features might be favorable for the accumulation of petroleum.

The sandstone and conglomerate in the Kukpowruk, Corwin, and Prince Creek formations offer the best possibilities as potential petroleum reservoir beds in the Utukok-Corwin region; their porosity and permeability characteristics and indications of petroleum accumulation are discussed below. However, these rocks are not present in most of the anticlines in the southern part of the eastern structural province, inasmuch as the anticlines have been eroded to or nearly to the shaly sequence of the Torok formation. Structurally, this part of the region is therefore regarded as having little or no petroleum potential in rocks younger than the Torok formation. Farther north, in general, north of lat 69°15', the Kukpowruk and Corwin formations are not breached in most of the anticlines, and they would afford a suitable reservoir where structural closure exists. Geophysical studies show that at least in the northeastern part of the Utukok-Corwin region, the structural features are relatively simple. Owing to facies changes, however, the percentage of sandstone and conglomerate beds in the Kukpowruk and Corwin formations decrease from south to north, and considerably fewer reservoir beds can be expected in the northern part of the region. In the western structural province, where there are great thicknesses of sandstone and conglomerate, no structural features favorable to petroleum accumulation are known. The thrust faults appear to be nearly parallel to bedding planes at the surface, but information on their subsurface relations and possible fault traps is lacking.

In summary, the most favorable structural features for petroleum accumulation are in the northern part of the region, but the presence of favorable reservoir rocks in this part appears least promising. Surface outcrops in the northern part of the region are few and scattered, and further information on the petroleum possibilities of this area can be obtained mainly by geophysical work and drilling.

FORTRESS MOUNTAIN FORMATION

Inasmuch as very little of the Fortress Mountain formation is exposed in this region, an extensive discussion of its oil and gas possibilities is beyond the scope of this report. Although the outcrops of the formation contain thick sandstone units, they have a high percentage of shale and dense siltstone. The few samples of the sandstone that were tested have uniformly low porosity and permeability. The surface and subsurface interpretations of the Driftwood anticlinal area show a complex structural pattern, and the surface interpretations of the Tingmerkpuk high and the Iligluruk high indicate a similar complexity, although little information is available.

TOROK FORMATION

The Torok formation that occurs within this region is predominantly clay shale and silty shale with minor amounts of siltstone. No favorable reservoir rocks in this formation are known within the Utukok-Corwin region.

KUKPOWRUK FORMATION

In 54 sandstone samples of the Kukpowruk formation collected along the Utukok River porosity averages 12.6 percent and ranges from 4.2 to 22.4 percent. In 31 samples from along the Kokolik and Kukpowruk Rivers the porosity averages 6.8 percent and ranges from 1.59 to 11.2 percent. This considerable difference in porosity between samples from the eastern and western parts of the Kukpowruk formation within this area may be due in part to the selectivity of the samplers, but it is also a reflection of actual regional differences, particularly in the maximum values, as the field parties made an effort to sample sandstones that showed the best porosity. The averages are abnormally large because many of the obviously low-porosity sandstones were not sampled. The difference indicates that the sandstones in the eastern part of the area were deposited in shallower water in which winnowing was more thorough, resulting in a cleaner, more porous sandstone. It is inferred that sandstones with more favorable porosity for oil accumulation exist in the eastern part of the map area and that the sandstones in the Kukpowruk formation west of the Kukpowruk River might be even less porous. The permeability of the Kukpowruk formation samples is nil or very low, the highest being 7.5 millidarcys.

Three sandstone beds near the Utukok River in the Carbon Creek anticline contain petroleum residues. A sample (50ASv12), collected from a petroliferous sandstone bed at approximate lat 68°21'24" N., and long 160°04'30" W., or about 3.65 miles southeast of Omicron Hill, yielded a very pale-straw-colored cut and a pale-yellow residue when treated with CCl_4. A sample (50AWh7) from a petroliferous sandstone bed on a sharp north bend of the Utukok River about 6 miles west of Carbon Creek at approximate lat 68°22'54" N., and long 159°59'30" W., when treated with CCl_4 yielded a very pale-straw-colored cut and a pale-yellow residue. A sample (50AWh11) from a sandstone bed on Omicron Hill in the lowest part of the Kukpowruk formation yielded a black cut (possibly due to carbonaceous matter) and a brownish-black residue when treated with CCl_4. A small fault cuts this bed, and for a distance of 100 feet on either side adjacent to this fault the sandstone is moderately dark brownish gray. Beyond these limits the dark color is absent. All the above samples are of low permeability.

A part of sample 50AWh11 was tested by Anna Hietanen-Makela of the Geological Survey to determine the intergranular material. She reports: "The dark material which fills the cavities between the mineral grains and the cracks in them appears brown under the microscope. It burns when heated and colors the chloroform brown. W. W. Brannock tested it chemically and found it to be asphalt."

CORWIN FORMATION

The Corwin formation in the outcrop area is generally less promising than the Kukpowruk formation as a reservoir for oil and gas. The porosity and permeability of sandstone and conglomerate in the Corwin formation are low, although a few beds with good porosity are present. The porosity of 22 samples collected along the Utukok River averaged 10.4 percent and ranged from 6.4 to 18.9 percent. The average porosity of 32 samples taken along the Kokolik and Kukpowruk Rivers was 9.1 percent, and the range was from 3.0 to 23.1 percent. The difference of 1.3 percent in average porosities between the samples from the eastern and western parts of the inland area is probably not indicative of any significant differences in depositional environment. As in the Kukpowruk formation, average porosity figures are a maximum, inasmuch as the obviously low-porosity sandstone beds were not sampled. Only a few porosity samples were taken in the Cape Beaufort-Corwin area, and the best of these has a maximum porosity of 14 percent.

Permeability determinations were made on some of the samples, and only 2 exceeded 5 millidarcys. These samples, which were collected from sandstone beds exposed along the Kukpowruk River about 10.75 miles upstream from the mouth, showed 15 and 450 millidarcys. These beds are about 7,700 feet stratigraphically above the base of the Corwin formation.

One 7-foot silty sandstone bed that is exposed along the Kokolik River, just north of the Oilsand syncline axial zone and about 42 airline miles upstream from the mouth of the river, has a high asphaltic content. About 6 cubic centimeters of the sample yielded approximately 1 cubic centimeter of a brownish-black tarry substance with a strong petroliferous odor. One sample of the sandstone tested has a porosity of 10.94 percent and is impermeable. This oil sand lies midway between the axial traces of Oilsand syncline and Norseman anticline. Stratigraphically the oil sand lies in a coaly sequence of the Corwin formation, possibly about 2,400 feet above the base. Several other beds of siltstone and very fine-grained sandstone, ranging from 2 to 14 feet in thickness, lie within 100 stratigraphic feet of the oil sand. A few of these have a slight petroliferous odor.

Woolfe (1893, p. 133) reported a possible oil seepage near Cape Beaufort as follows: "Between the [coal] seams bands of clear ice intervene, and I have noticed on the shelving banks of a small creek that runs through the coal lands an oily exudation resembling crude petroleum." The above locality, presumably underlain by the Corwin formation, has not been relocated, and the report is unconfirmed.

PRINCE CREEK FORMATION

The Prince Creek formation, which has been mapped on the lower Kokolik and Utukok Rivers, is not a well-defined unit in this area, owing chiefly to the limited and poor exposures. Inasmuch as its areal extent and thickness are poorly known and at best are quite limited, little consideration should be given to it as a potential oil reservoir.

The sandstone and conglomerate beds in this formation are in general poorly consolidated. A sample from a conglomeratic sandstone bed on the Utukok River about 18 miles north of Carbon Creek has a porosity of about 18.4 percent and another bed about 30 miles above the mouth of the Utukok has a porosity of about 8.5 percent. A sample from a section of sandstone and conglomerate (p. 127) on the Kokolik River 32 miles above the mouth has a porosity of 18.7 percent and an average permeability of 44 millidarcys.

KAOLAK TEST WELL 1

Kaolak test well 1 (Collins, 1958) was drilled in the extreme northern part of the Utukok-Corwin region at lat 69°56′ N., and long 160°14′51″ W., on an anticline that was located by seismic work. The drilling was accomplished by Arctic Contractors for the Navy Department between July 21 and November 13, 1951, and it reached a total depth of 6,952 feet. No commercial quantities of oil or gas were found, but 9 shows of oil and gas were noted, all between 3,184 and 6,757 feet. Good reservoir sandstone beds are conspicuously lacking throughout the well, and sandstone beds more than a few feet thick are uncommon. The average porosity of the sandstones that have been tested is 10.26 percent, and all are impermeable. The section between 113 and about 4,600 feet in the well appears to be the nonmarine coaly Corwin formation, although a pelecypod, *Entolium* sp., was found at 3,996 feet. The section between 4,600 and 4,952 feet has not been definitely correlated with surface rocks by lithologic, paleontologic, or seismic evidence. It is probably equivalent to the Kukpowruk formation and the upper part of the Torok formation. Seismic data indicate that at least 10,550 feet of sedimentary section lie between the bottom of the well and the basement complex.

COAL

The coal beds in the Utukok-Corwin region, particularly those of potential economic significance, are confined almost entirely to the Corwin formation. A few coal, bone, and coaly shale beds, most of which are thin, occur in the upper part of the Kukpowruk formation; and some coal and coaly beds are present in the Prince Creek formation. Most of the coal-bearing rocks lie north of lat 69°15′ N., in the inland part of the region and along the coast west of Cape Beaufort (Sable and Chapman, 1955).

The coal beds examined in 1947, 1949, and 1950 range from a few inches to 13 feet in thickness, but Foran in 1923 described one 18- to 20-foot bed near the Kukpowruk River about 25 airline miles from the mouth (1925, p. 27–28). This bed is almost certainly the same as the 13-foot bed that was not completely exposed when examined in 1949. The coal beds seem to be most abundant in the middle and upper parts of the Corwin formation.

Twenty-eight potentially minable coal beds were sampled in 1947, 1949, and 1950 in the inland part of the region; others were seen, and numerous traces of coal and coaly talus were noted that indicate the presence of unexposed coal beds. The cores and ditch samples from Kaolak test well 1 show that more than 4,000 feet of coal-bearing section underlies the northernmost part of this region. Locations of many of the known coal beds more than 1 foot thick are shown on the generalized geologic map (pl. 9).

The presence of coal in the Cape Beaufort-Corwin coastal area has been known since the early days of Arctic exploration, whaling, and trading. It is reported that coal for use in whaling ships was first obtained from the Corwin mines in 1879 (Schrader, 1904, p. 112). Since that time several individuals and companies have mined coal at localities on this coast for ship and local use, and some of the coal was marketed in Nome in the early 1900's. Numerous coal beds of Cretaceous age are exposed in the wave-cut bluffs between Cape Beaufort and Corwin. The first systematic coal study of this area was made by A. J. Collier (1906) in 1904. Previously this coal-bearing area had been briefly visited in 1901 by F. C. Schrader (1904, p. 110–113) and had been described by W. H. Dall (1896, p. 819–820) and A. H. Brooks (1902, p. 561–566) from information furnished by several people. A brief reconnaissance of the coastal area between Cape Beaufort and Eesook was made by the Gelogical Survey in 1947, and a more detailed examination of the coast between Thetis and Risky Creeks was made in 1953. Results of these studies indicate that these coal-bearing sections are correlative with the Corwin formation of the inland part of this area.

Detailed descriptions of the coal beds along the lower Kukpowruk, Kokolik, and Utukok Rivers, which were examined in 1923 by Foran (1925, p. 26–32), together with the data gathered by P. S. Smith in 1926 on the Kokolik River and by Foran in 1924 on the Utukok River are summarized by Smith and Mertie (1930, p. 304–308). A U.S. Bureau of Mines party examined the coal exposures along the lower 24 miles of the Kukpowruk River in 1946, and they also sampled the coal in use at Point Lay that reportedly had been mined near the Tepsako River 15 miles east of Point Lay (Toenges and Jolley, 1947). The exact location of this river or of the coal bed is not known to the present authors.

The coal ranges from subbituminous to medium-volatile bituminous, and analyses indicate that much of the coal is of the higher rank. Many of the coals resist weathering and do not slack appreciably. The results of all the known analyses of coal samples collected in the inland part of the region are shown in table 11. All the samples collected in 1947–53 were from outcrops, but an attempt was made to take the freshest material possible. However, the samples were not collected in sealed containers and were not analyzed for at least several months after the date of collection, so the samples did not contain the normal complement of bed moisture. A sample collected from the 13-foot coal bed along the Kukpowruk River (D–34610, table 11) and samples from the same bed, collected in sealed containers by the U.S. Bureau of Mines (C–61130, C–61131, and C–61132, table 11) show this moisture difference. A sample collected from almost certainly the same bed by Foran in 1923 (96821, table 11) upon analysis gave results similar to those of the U.S. Bureau of Mines samples; this and the other coal sample (96820, table 11) collected by Foran are therefore believed to have been collected in sealed containers.

The heating values of the 30 beds represented by 34 samples in table 11 average 13,144 Btu and range from 11,200–14,360 Btu on a moisture-free basis. Samples from the Kukpowruk and Kokolik Rivers in general have a higher heating value than those from the Utukok River, and a general westward increase in heating values is indicated by the fact that samples from 10 coal beds on the Utukok River average 12,863 Btu, samples from 9 beds on the Kokolik average 13,045 Btu, and samples from 10 beds on the Kukpowruk average 13,509 Btu.

TABLE 11.—*Analyses of coal samples collected from the Corwin formation along the Utukok, Kokolik, Kukpowruk, and Tepsako Rivers*

[All samples analyzed by the U.S. Bureau of Mines]

Geol. Survey sample	Bur. Mines laboratory No.	Bed thickness (feet)	Location	Condition [1]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heating value (Btu)
49ACh122	D-34610	13 exposed	Kukpowruk River	1	1.8	32.1	59.5	6.6	0.1	13,220
				2		32.7	60.6	6.7	.1	13,450
				3		35.1	64.9		.1	14,430
49ACh130	D-34611	7	Kukpowruk River	1	2.6	36.0	57.9	3.5	.2	13,320
				2		36.9	59.5	3.6	.2	13,680
				3		38.3	61.7		.2	14,190
49ASa56	D-34615	3	Kukpowruk River	1	.8	31.4	52.8	15.0	.3	12,880
				2		31.6	53.3	15.1	.3	12,980
				3		37.3	62.7		.3	15,300
49ASa113	D-34616	1.5	Kukpowruk River	1	2.1	35.8	58.5	3.6	.3	13,860
				2		36.6	59.7	3.7	.3	14,160
				3		38.0	62.0		.3	14,700
49ASa125	D-34617	2	Kukpowruk River	1	2.2	33.1	61.3	3.4	.2	13,780
				2		33.8	62.7	3.5	.2	14,080
				3		35.0	65.0		.2	14,580
49ASa126	D-34618	2	Kukpowruk River	1	2.4	37.9	57.3	2.4	.4	13,840
				2		38.8	58.8	2.4	.4	14,180
				3		39.8	60.2		.4	14,540
49ASa128	D-34619	5	Kukpowruk River	1	3.3	34.8	52.6	9.3	.3	12,170
				2		36.0	54.4	9.6	.3	12,580
				3		39.8	60.2		.3	13,920
49ASa129	D-34620	2.8	Kukpowruk River	1	3.3	33.6	58.0	5.1	.3	13,110
				2		34.7	60.0	5.3	.3	13,560
				3		36.7	63.3		.3	14,310
49ASa130	D-34621	3	Kukpowruk River	1	2.7	32.0	55.2	10.1	.3	12,520
				2		32.9	56.7	10.4	.3	12,870
				3		36.7	63.3		.3	14,350
49ACh172	D-34612	5	Kokolik River	1	1.7	34.1	46.8	17.4	.3	11,630
				2		34.7	47.6	17.7	.3	11,830
				3		42.2	57.8		.4	14,360
49ACh206	D-34613	3	Kokolik River	1	4.5	34.3	57.5	3.7	.2	12,370
				2		35.9	60.3	3.8	.2	12,950
				3		37.4	62.6		.2	13,460
49ACh209	D-34614	5	Kokolik River	1	2.8	36.5	57.6	3.1	.2	13,640
				2		37.6	59.2	3.2	.2	14,030
				3		38.8	61.2		.2	14,500
49ASa212	D-34622	4	Kokolik River	1	5.0	34.4	56.0	4.6	.3	12,320
				2		36.2	59.0	4.8	.3	12,970
				3		38.0	62.0		.3	13,630
49ASa213	D-34623	4	Kokolik River	1	7.6	33.6	56.8	2.0	.2	11,640
				2		36.3	61.6	2.1	.2	12,600
				3		37.1	62.9		.2	12,870

See footnotes at end of table.

TABLE 11.—*Analyses of coal samples collected from the Corwin formation along the Utukok, Kokolik, Kukpowruk, and Tepsako Rivers*—Continued

[All samples analyzed by the U.S. Bureau of Mines]

Geol. Survey sample	Bur. Mines laboratory No.	Bed thickness (feet)	Location	Condition [1]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heating value (Btu)
49ASa214	D-34624	2	Kokolik River	1	3.3	34.6	59.1	3.0	0.4	13,270
				2		35.7	61.2	3.1	.4	13,720
				3		36.9	63.1		.5	14,160
49ASa217	D-34625	3	Kokolik River	1	4.0	33.1	56.9	6.0	.5	12,530
				2		34.4	59.4	6.2	.5	13,040
				3		36.7	63.3		.6	13,910
49ASa219	D-34626	6	Kokolik River	1	2.8	36.1	50.3	10.8	.2	12,400
				2		37.1	51.8	11.1	.2	12,760
				3		41.7	58.3		.2	14,350
49ASa220	D-34627	5	Kokolik River	1	4.4	35.5	57.4	2.7	.3	12,910
				2		37.2	60.0	2.8	.3	13,510
				3		38.2	61.8		.3	13,900
47ATm19	C-87707	.3	Utukok River	1	3.1	29.6	48.9	18.4	.8	10,850
				2		30.5	50.6	18.9	.8	11,200
				3		37.6	62.4		1.0	13,810
47ATm24(2)	C-87708	5	Utukok River	1	6.2	37.1	53.7	3.0	.2	11,640
				2		39.5	57.3	3.2	.2	12,400
				3		40.8	59.2		.2	12,810
47ATm24(27b)	C-87709	1.3	Utukok River	1	2.7	35.0	48.9	13.4	.8	12,000
				2		36.0	50.2	13.8	.9	12,330
				3		41.8	58.2		1.0	14,300
47ATm25	C-87710	(?)	Utukok River	1	5.6	43.2	47.5	3.7	.1	12,170
				2		45.7	50.4	3.9	.1	12,890
				3		47.5	52.5		.1	13,410
47ATm29	C-87711	(?)	Utukok River	1	3.0	37.4	57.3	2.3	.6	13,460
				2		38.6	59.1	2.3	.6	13,870
				3		39.5	60.5		.6	14,200
47ATm30	C-87712	(?)	Utukok River, 4 miles upstream from 1947 camp 12	1	3.7	32.9	60.1	3.3	.2	12,950
				2		34.2	62.4	3.4	.2	13,450
				3		35.4	64.6		.3	13,930
47ATm31	C-87713	(?)	Utukok River, 1.6 miles upstream from camp 12	1	3.4	37.3	57.1	2.2	.6	13,250
				2		38.7	59.0	2.3	.6	13,720
				3		39.6	60.4		.6	14,040
47ATm34	C-87714	6	Utukok River	1	2.2	33.1	60.8	3.9	.2	13,620
				2		33.8	62.3	3.9	.2	13,920
				3		35.2	64.8		.2	14,490
47ATm40	C-87715	8	Utukok River	1	4.6	36.2	51.6	7.6	.2	11,850
				2		37.9	54.1	8.0	.2	12,420
				3		41.2	58.8		.3	13,500
50AWh8	D-60565	11	Elusive Creek, Utukok River	1	5.8	33.1	57.9	3.2	.3	11,710
				2		35.1	61.5	3.4	.3	12,430
				3		36.4	63.6		.3	12,870
	[2] C-61130	12-13 Exposed	Kukpowruk River, top 5 ft 8 in. of same 13-ft bed as sample 49ACh122.	1	8.6	29.1	58.0	4.3	.1	12,560
				2		31.9	63.4	4.7	.1	13,740
				3		33.4	66.6		.2	14,410
	[2] C-61131	12-13 Exposed	Kukpowruk River, middle 4 ft of same 13-ft bed as sample 49ACh122.	1	4.6	35.6	54.0	5.8	.2	12,820
				2		37.3	56.6	6.1	.2	13,440
				3		39.7	60.3		.2	14,310
	[2] C-61132	12-13 Exposed	Kukpowruk River, bottom 3 ft of same 13-ft bed as sample 49ACh122.	1	4.6	37.0	54.8	3.6	.1	13,300
				2		38.8	57.4	3.8	.1	13,940
				3		40.3	59.7		.1	14,480
	[2] C-61139	10	From coal sampled at Point Lay and reported to have been mined on Tepsako River.	1	10.5	37.3	49.4	2.8	.4	11,800
				2		41.6	55.3	3.1	.4	13,180
				3		43.0	57.0		.4	13,610
	[3] 96821	12-13	Kukpowruk River. Same bed as 49ACh122	1	3.9	38.6	55.5	2.0	.2	13,790
				2		40.0	57.7	2.1	.2	14,360
				3		41.0	59.0		.2	14,660
	[3] 96820	10	Kukpowruk River, 5 airline miles above mouth on east bank.	1	9.9	31.5	56.1	2.5	.4	11,910
				2		34.9	62.3	2.8	.5	13,210
				3		35.9	64.1		.5	13,600

[1] Condition: 1, as received; 2, moisture free; 3, moisture and ash free.

[2] Samples collected in 1946 by the U.S. Bureau of Mines. Analyses taken from Bureau of Mines R.I. 4150, p. 10, 12.

[3] Samples collected in 1923 by W. T. Foran, Geological Survey. Analyses taken from Geological Survey Bulletin 772, p. 31.

Fischer low-temperature carbonization assays at 500°C were made by the U.S. Bureau of Mines on the 18 samples collected in 1949 from the Kokolik and Kukpowruk Rivers (W. A. Selvig and W. H. Frederic, written communication, 1950). J. M. Schopf (written communication, 1950) has made the following comments based upon the analytical data that are available for these samples:

> From the analytical data provided, it is not safe to base an opinion about the coking properties of these Cretaceous coal

> beds. Probably all these samples had been subjected to weathering to some extent as none are indicated as coming from operating mines [this is correct]. In any case, the samples were not shipped in sealed containers and do not contain their normal complement of bed moisture. . . Coals low in the coking range are very sensitive to exposure, apparently because of surface oxidation. Either weathering near the outcrop or oxidation accompanying drying during shipment can have a materially adverse effect on results from laboratory tests of coking properties. Hence, it seems probable that whatever coking properties these coals possess it is more pronounced than the accompanying data indicate. It is virtually impossible to determine how great this difference might be, although it seems unlikely that coke of desired metallurgical quality could be prepared directly from any of them. In some instances a low temperature coke, suitable for domestic consumption, might be prepared.
>
> The most promising coal for the production of domestic coke would appear to be 49ASa56 that yielded a swollen cellular coke residue. Properties of the coal substance seem most favorable; but before commercial possibilities of this coal can be suggested, the possibility of reducing the amount of ash by simple preparation methods should be investigated. Fresh samples free of any suspicion of weathering or oxidation should be obtained and shipped in sealed containers . . . [for further testing] to assist in establishing coking properties.
>
> Sample 49ASa56 is presumably a higher rank coal than the others . . . it is of high-volatile bituminous rank. All the rest may be classified as either bituminous or subbituminous. Probably none of the nine samples yielding a loose powdery residue in the Fischer test have coking properties of any consequence. A number of these coals evidently would be satisfactory for boiler use since they have low ash and sulfur values and are of adequate thickness for mining.
>
> The coal beds represented by samples 49ASa113 and 49ASa129 are probably too thin for mining although properties of the coal, ash content, and yields of tar and light oil seem more favorable for producing a low-temperature coke than is indicated by results from most of the other coal beds.
>
> Sample 49ACh172 probably includes too much mineral matter to be considered further. Sample 49ACh209 has a good yield of tar and light oil, a low ash content, and more water of decomposition than is desirable. This seems to be the most favorable of the Kokolik River coals. Sample 49ACh122 has a low yield of tar and light oil, a moderate ash content, and a fairly low content of water of decomposition. Sample 49ASa219 has a good yield of tar and light oil, a moderately high ash content, and more than a desirable amount of water of decomposition.
>
> At best, results from this series of tests should be regarded as inconclusive. They suggest that most of the coals are not suitable for carbonization but that some of them may deserve further consideration for low-temperature coke production.

Fischer low-temperature carbonization assays at 500°C were made by the U.S. Bureau of Mines on nine coal samples collected along the Utukok River by R. M. Thompson in 1947. The U.S. Bureau of Mines (W. A. Selvig, W. H. Frederic, and W. H Ode, written communication, 1948) stated:

> One coal [47ATm24, 1.25-foot bed] formed a nonswollen coke that was very weak and friable. The carbonized residue from seven coals [47ATm24, 5-foot bed; 47ATm25; 47ATm29; 47ATm30; 47ATm31; 47ATm34; 47ATM40] showed evidence of very slight fusion. One sample [47ATm19] was noncoking, the residue being loose powder.

At the present time and in the immediate future the inland coal deposits of this region have only the limited economic value of supplying the fuel needs of the village of Point Lay and of the Eskimo hunting and trapping parties The reserves have, however, potential value. Many of the minable good grade coal beds are close to the coast, dip at relatively low angles, and are favorably located for low-cost water transportation. Because of the shallow and frequently stormy coastal waters and short ice-free season, careful planning and the proper type of shallow-draft barges would be necessary to make the mining operation economically feasible. If military or civilian installations are established in this region, these coal deposits could assume a dual importance of supplying a good fuel from a nearby source and of providing employment for the local Eskimos.

KUKPOWRUK RIVER

The southernmost occurrences of coal on the Kukpowruk River are in Coke basin, which lies about 66 airline miles upstream from the mouth of the river. The Corwin formation occupies the center of this basin and contains coaly and carbonaceous shale as well as coal beds. The thickest exposed bed of coaly and carbonaceous shale measures 12 feet in thickness and crops out in a river bluff 3.2 miles north-northwest of 1949 camp 4. A river bluff on the sharp bend about one-half of a mile north of the center of Coke basin exposes 6 beds of coal that range from 1 to 3 feet in thickness. Each bed is predominantly coal, but some grade in part to coaly shale. One 3-foot bed (D–34615) is a high-volatile bituminous coal that possesses fairly good coking properties and forms a swollen, cellular coke.

Several coal beds are exposed in the river bluffs formed by the Corwin formation 1 to 2 miles south of 1949 camp 10 and on the north flank of the Archimedes Ridge anticline. A coal bed ranging from 1 to 3 feet in thickness crops out 1.4 miles northwest of the point where the axial trace of the anticline crosses the river. A 2-foot coal and coaly shale bed, a 1-foot coal bed, and coal talus are present 2.3 miles northwest of this point. A 1½-foot coal bed (D–34616) and two 1-foot beds are exposed 1.9 miles upstream from camp 10, and a 4-foot bed of coaly shale and coal is present 1.3 miles upstream from camp 10.

Along the Kukpowruk River in the Kasegaluk syncline, Snowbank anticline, and the southern half of Barabara syncline, the rock exposures are confined almost entirely to the river banks. Along this part of the river at least 39 coal beds ranging from 1 to 13 feet in thickness, 6 or more showings of coal talus, and 1 burned coal bed were noted in 1949. Possibly some of these coal beds represent the same strata; but, owing to the discontinuity of the outcrops and the lack of recognizable marker beds, exact correlations cannot be made. The most significant of these beds is the 13-foot bituminous coal bed (D–34610) that has been sampled and described by Foran (Paige, Foran, and Gilluly, 1925, p. 28) and by Toenges and Jolley (1947, p. 9–11). Although the full thickness of the bed could not be seen, it is mined by Eskimo hunting parties and is well exposed in the east river bluff at the upstream end of a large meander 3 airline miles south of 1949 camp 11. A short distance downstream on this same meander a 4- to 5-foot coal bed, 2 coal and coaly shale beds 2 and 3 feet in thickness, and a 5- to 6-foot coal bed crop out in a section that overlies the 13-foot bed. On the west bank several hundred feet downstream from the 5- to 6-foot bed, several thinner coal beds crop out and include two 2-foot beds (D–34617, D–34618). A 7-foot coal bed (D–34611) is exposed about one-quarter of a mile upstream from camp 11. Another sequence, including a 7-foot bed, a 3-foot bed (D–34621), and a 2.9-foot bed (D–34620), crops out 1.4 miles downstream from camp 11; and a 5-foot bed (D–34619), which overlies this sequence, is 1.1 miles below camp 11. Three 4- to 7-foot coal beds are exposed in a coal-bearing section 1.2 to 2 miles south of 1949 camp 12.

In the part of the river that extends 6 airlines miles downstream from the axis of the Barabara syncline only one rock exposure is present. It is reasonably certain, however, that the coal-bearing rocks exposed in the south limb of the syncline are continuous into the north limb and are present at shallow depth under surficial deposits.

The bluff exposures in the axial zone of the Epizetka anticline are fairly good. Three coal beds, 2.5, 7, and 7–8 feet thick, are present on the south limb of the anticline; and a bed 8 feet thick, which is poorly exposed on the north limb, is possibly correlative with one of the beds on the south limb. The coal at this locality is frequently mined by the Eskimos to supply their local needs. Foran's sample (analysis 96820) was collected at this locality.

KOKOLIK RIVER

The southernmost occurrences of thick coal beds on the Kokolik River are in the Corwin formation that lies in the center of Flintchip syncline in the vicinity of 1949 camp 20. A 5±ft bed (D–34612) of subbituminous coal which is exceptionally high in ash content is exposed on the east bank of the river in the axial zone of the syncline about 1.7 miles southeast of camp 20. A coal bed that ranges from 2 to 4 feet in thickness crops out 5 miles southeast of 1949 camp 20 on a small northward-flowing tributary of the creek that enters the Kokolik about one-half of a mile below camp 20. Coal talus is present on this tributary creek about 0.7 mile north of the 2- to 4-foot bed in the bluffs at the mouth of this tributary and on the low ridge on the west side of the Kokolik River one-half a mile south of camp 20.

Coal talus is present along the river bank at two places on the south flank of the Howard syncline. One locality is 3.6 airline miles downstream from 1949 camp 23, and the other is 1.5 airline miles farther downstream.

Coal beds and coal talus are common in the Kokolik River bluff exposures in Lookout Ridge syncline and Carbon Creek anticline. At least 12 coal beds are exposed, all within the Corwin formation, in the area between the axial traces of the Snowbank and Carbon Creek anticlines. One burned coal bed crops out on the east bank of the Kokolik 4.3 airline miles south of 1949 camp 25. At least 14 shows of coal talus were observed in the Corwin formation river bluffs between the axial traces of Snowbank anticline and Oilsand syncline.

Three coal beds that are 3 (D–34613), 3.25, and 5 (D–34614) feet thick, respectively, crop out in the west bank of the Kokolik River, on the large meander 4.7 airline miles upstream from 1949 camp 25; and two 4-foot coal beds (D–34622, D–34623) that overlie these beds are exposed in the bluffs 1.2 and 2 airline miles downstream from this meander bluff. A 5- to 5.5-foot bed of good grade coal 1.7 miles north of camp 25 at the base of a bluff at the south end of a long lake, and a 2-foot coal bed (D–34624) crops out on the west bank of the river, west of the 5-foot bed.

In the area north of the axial trace of Oilsand syncline, the exposures of bedrock are not abundant and are confined to the low banks of the Kokolik River. The Corwin formation crops out to a point about one-quarter of a mile north of the axial trace of the Norseman anticline. Within this area, 15 coal beds of poor to good grade are exposed, and 6 showings of coal long lake, and a 2-foot coal bed (D–34624) crops out on the north bank 1 mile downstream from 1949 camp 26. A 6-foot bed (D–34626) of subbituminous coal is exposed about 1.8 miles upstream from 1949 camp 27, and a 5-foot bed of coal and bone (D–34627) crops out about 1.2 airline miles north of camp 27. A section containing 6 beds of coal, bone, and coaly shale, which range from 2 to 8 feet in thickness and have an aggregate thickness of nearly 25 feet, is exposed within one-quarter of a mile north of the axial trace of Norseman anticline.

UTUKOK RIVER

Workable coal beds on the Utukok River are restricted to areas northwest of Carbon Creek. South of Carbon Creek only small amounts of coal float and thin coaly layers occur in the Corwin formation where it is exposed in the axial zones of Folsom Point and Lookout Ridge synclines. One sample (C–87707) was taken from a 3- to 4-inch bed in Lookout Ridge syncline. In this part of the northern foothills section, the greater relief and shallow streams make access to coaly horizons more difficult than in areas farther north.

Many workable coal beds occur along the Utukok between 50 and 75 airline miles upstream from the mouth, in the northern foothills northwest of Carbon Creek. Coal beds ranging from 1 foot to 6 feet in thickness crop out at 15 localities in river bluffs or on low hillsides, and most of the Utukok River coal samples were collected in this area. With the exception of 2 thin beds believed to be in the Prince Creek formation, all the coal has been assigned to the Corwin formation. One 5-foot bed (C–87708) and two 2- to 3-foot beds are exposed a few hundred feet east of the river 2.5 miles south of Elusive Creek. Several coal beds on Elusive Creek include one 11-foot bed (D–60565) in a cutbank 3.5 miles west of the Utukok River. Thin beds occur at the mouth of Elusive Creek (C–87710) and 2 miles downstream from the mouth (C–87709). All the above-mentioned beds occur on the south flank of Elusive Creek syncline. Five miles north of the point where the Harris anticline axial trace crosses the Utukok, a 4-foot bed (C–87711) crops out on the north bank of the river. Five and one-half miles downstream from this exposure a 4-foot bed crops out in the east bank. A 6-foot bed (C–87714) on the north bank of the Utukok is exposed near the northern limit of the foothills province across the river from 1947 camp 13. The presence of numerous other coal beds in this part of the area is inferred from coal float in river bluffs, and a number of other beds undoubtedly underlie the large areas that are tundra covered.

In the part of the coastal plain 17 to 50 airline miles from the mouth of the Utukok River, 8 bluff exposures revealed coal beds ranging from 1 to 8 feet in thickness. Three beds, 3, 8 (C–87715), and 6 feet thick, occur in the north bank in the vicinity of 1947 camp 14. Exposures farther north are few and isolated; a 4-foot bony coal bed was seen in the north bank about 3.5 miles east of 1947 camp 16. All these beds are thought to be in the Corwin formation. As in the northern foothills, large quantities of coal are without doubt obscured by surficial cover. Kaolak test well 1, which revealed considerable coal in the upper 4,600 feet, is about 6 miles east of and along the structural trend of exposures along the Utukok River in the coastal plain. The Utukok River is relatively deep in the coastal plain and would probably accommodate a boat with a 2-foot draft for shipping coal. Also, in the northern foothills the river is generally deep, but it is interrupted by many small rapids which would confine water operations to boats of shallower draft, except during periods of high water.

CAPE BEAUFORT-CORWIN BLUFF

Some of the many coal beds in the Cape Beaufort-Corwin Bluff coastal area that are mentioned in the previously cited reports of Dall, Schrader, Collier, and P. S. Smith and Mertie are difficult to locate exactly. Accurate maps of adequate scale were not available at the time the early work was done in this area. The present authors have attempted to summarize, as accurately as possible from published material and original field notes, all the data on the coal beds and their locations that were gathered by the early geologists and by the 1947 and 1953 field parties. Results of all known proximate analyses of coal samples from this part of the area are shown in table 12.

No calorific determinations for heating values or tests for coking properties have been made on these samples. Collier (1906, p. 46) states that so far as is known, the coals of the Corwin formation along the Cape Beaufort-Corwin Bluff coast are noncoking. Coal samples, probably taken from the Corwin Bluff vicinity and upon which calorific tests were made at the Massachusetts Institute of Technology, were reported to have an average heating value of 13,600 Btu (Collier, 1906, p. 46). This value compares favorably with heating values of the coal samples from the Kukpowruk River (p. 156).

The Cape Beaufort locality, where 4 coal beds crop out on a hill about one-eighth of a mile inland and where Schrader collected sample 665 (table 12) from a 6-foot bed, is believed to be about 3.2 airline miles southwest of the mouth of Kahgeatak Creek. Collier reports that at least 6 coal beds, one of which is more than 4 feet thick, crop out 10 miles east of Cape Sabine. This locality is probably 5.3 airline miles southwest of the mouth of Kahkatak Creek.

Several coal beds described by Collier (1906, p. 40–41) are present at the Thetis mine, on the coast about 2 to 2.5 miles east of the mouth of Thetis Creek. The

Table 12.—*Analyses of coal samples collected from the Corwin formation near Cape Beaufort and Corwin Bluff*

Geol. Survey sample [2]	Bur. Mines laboratory No.	Bed thickness (feet)	Location	Condition [1]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur
47ATmC17	E-70927	Unknown	At or near Corwin mine	1	3.0	37.6	47.8	11.6	
				2		38.8	49.2	12.0	
				3		44.1	55.9		
47ATmC23	E-70928	Unknown	Between Corwin Bluff and Corwin Creek	1	3.9	36.2	54.2	5.7	
				2		37.7	56.4	5.9	
				3		40.1	59.9		
47ATmC24	E-70929	Unknown	1,000 ft east of mouth of Corwin Creek	1	5.9	28.8	58.0	7.3	
				2		30.6	61.7	7.7	
				3		33.2	66.8		
47ATmC63	E-70930	Two beds, 2 ft and 1 ft thick.	Sea bluffs between Thetis Creek and Pitmegea River	1	3.3	40.1	52.5	4.1	
				2		41.5	54.3	4.2	
				3		43.3	56.7		
53ASa216	E-70925	1.4–3	Sea cliff 1 mile west of Corwin Bluff (p. 162)	1	8.5	39.6	45.8	6.1	
				2		43.2	50.2	6.6	
				3		46.3	53.7		
53ASa1028	E-70926	5.5	Sea cliff 0.6 mile west of Corwin Bluff (p. 162)	1	7.2	34.9	40.9	17.0	
				2		37.7	44.0	18.3	
				3		46.1	53.9		
4AW7 [3]		4.5	Sea cliff 1⅜ miles west of Corwin Bluff (p. 162)	1	13.55	41.30	40.8	4.33	0.40
4AC1 [3]		5	Sea Cliff three-quarters of a mile west of Corwin Bluff (p. 162).	1	11.18	37.72	42.06	9.04	
4AC4 [3]		7+	Mined from Corwin vein, 500 ft lower than 4AC-1 (p. 162).	1	9.45	37.49	41.67	11.39	.30
4AC5 [3]		7+	Same lot of mined coal as 4AC4, after washing (p. 162)	1	9.49	39.08	47.94	3.49	
4AC6 [3]		1–7 (?)	Sample from chunk of irregular vein at Corwin Bluff (p. 162).	1	4.49	34.59	57.49	3.43	.39
4AC2 [3]		5	Sea cliff east of Corwin Bluff (p. 162)	1	12.45	33.40	48.47	5.68	
4AW20 [3]		4	Thetis mine	1	13.61	35.60	46.27	4.52	
665 [3]		6	Cape Beaufort. Collected by F. C. Schrader, 1901	1	7.18	36.38	51.23	5.21	.48
669 [3]		Unknown	Corwin mines. Collected by F. C. Schrader, 1901	1	10.47	40.12	46.16	3.25	.27
671 [3]		Unknown	Corwin mines. Collected by F. C. Schrader, 1901	1	7.23	38.68	50.05	4.04	.23
(3)		Unknown	Corwin mines(?). Submitted by Corwin Trading Co.	1	3.75	43.75	47.39	5.11	.36

[1] Condition: 1, as received; 2, moisture free; 3, moisture and ash free.

[2] Unless otherwise noted analyses are by the U.S. Bureau of Mines.

[3] Analyses from A. J. Collier, (1906 p. 47).

main bed at Thetis mine is believed to be at least 6 feet thick, and talus on the level ground above this bed indicates 2 other coal beds of considerable thickness. The 700 feet of section underlying the 6-foot bed includes 10 coal beds, 2 of which possibly have economic value. One bed (sample 4AW20) is 4 feet thick, and the other contains 3 feet of coal and 3 feet of probably worthless bony coal. Between the Thetis mine and Cape Sabine, several coal beds were noted by Collier.

West of Thetis Creek the type locality of the Corwin formation contains more than 80 coal beds that are more than a foot thick, and includes the Corwin mines. At least 17 of these beds range from 2.5 to 9 feet in thickness. The largest reserves of coal occur in the interval of rock between 6,550 and 11,350 feet above the base of the type section in the coal and sandstone, conglomerate, and bentonitic clay members of the Corwin formation (p. 105). The following discussion of coal occurrences in the type section deals with each member exposed progressively westward from Thetis Creek and includes, except where noted, only those coal beds that are more than a foot thick and contain little or no shaly material. Many thinner beds of coal and thick sections of coaly shale are also present (p. 106–121). Many previously unreported beds both east and west of the Corwin mine were noted in 1947 and 1953.

A relatively small amount of coal was seen below the coal and sandstone member. The silty shale member, intermittently exposed as far as 2 miles west of Thetis Creek, contains 7 coal beds ranging from 1.2 to 2.5 feet in thickness. The thickest bed occurs about 1,510 feet above the base of the type section. In the overlying lower sandstone member exposed between 2 and 3.3 miles west of Thetis Creek, 7 beds that range from 1.3 to 2.5 feet in thickness and at least 5 beds about 1 foot thick crop out at several locations. Some coaly shale is present in the thickest bed which lies about 3,200 feet above the base of the section. The shale member, exposed between 3.3 and 4.2 miles west of Thetis Creek, contains 5 beds that range from 1.3

to 1.5 feet in thickness; and the 1.5-foot bed lies about 6,330 feet above the base of the section.

The coal and sandstone member, exposed between 4.2 miles west of Thetis Creek and a point about 100 feet east of Corwin Creek, contains 11 beds of clean coal that are 1.3 to 2.8 feet thick and a 9.2-foot unit of interbedded coal and coaly shale about 7,290 feet above the base of the section. The 9.2-foot unit may include the same beds reported by Collier (1906, p. 39–40) to be exposed about 1,000 feet east of Corwin Bluff and described as 1 foot of clean coal, 1 foot of black shale, and 4 feet of clean coal (sample 4AC2, excluding shale). A 1.5-foot bed exposed about 35 feet below the 9.2-foot unit may be the same as Collier's (1906, p. 40) 2-foot bed 50 feet below the 4-foot bed of clean coal.

The conglomerate member, most of which is exposed west of Corwin Creek and at Corwin Bluff, was not everywhere accessible, and the number and thicknesses of coal beds were estimated. The irregular coal bed (sample 4AC6) reported to underlie a conglomerate at Corwin Bluff (Collier, 1906, p. 39) was not noted and is probably concealed by talus. At least 2 inaccessible beds estimated to be 1 and 2 feet thick are interbedded with sandstone and conglomerate. Above the thick conglomerate which upholds the highest part of Corwin Bluff, 5 beds, the thickest of which is estimated to be 3 feet and the thinnest 1 foot, are interbedded with coaly shale and constitute the 30-foot unit estimated by Collier (1906, p. 38–39).

The bentonitic clay member, overlying the conglomerate member, is exposed between Corwin Bluff and a point 0.5 mile west of Kookrook Creek and contains 32 coal beds ranging from 1.4 to 9 feet in thickness. The lower 710 feet of the bentonitic clay member, from 8,590 to 9,300 feet above the base of the section, contains 9 coal beds ranging from 1.4 to 7 feet in thickness, some of which were inaccessible in 1953. A 7-foot coal bed associated with coaly shale, a 7-foot bed of coaly shale and coal, and a 3.5-foot bed of clean coal occur at 8,850, 8,880 and 9,625 feet, respectively, above the base of the section. A 9-foot bed, which was inaccessible and whose thickness is estimated, is about 0.5 mile west of Corwin Bluff, about 9,300 feet above the base of the section. This is probably one of the Corwin mine locations reported by Collier and may be the same as the 16-foot unit containing 7 feet of clean coal described by him (Collier, 1906, p. 38) (samples 4AC4 and 4AC5). A timbered platform about 30 feet above the beach and a short adit into the bed was seen above the ice-covered base of the cliff in 1953. West of the 9-foot bed, 17 coal beds ranging from 1.2 to 5.5 feet in thickness and many units of interbedded coal and coaly shale as much as 5 feet thick are exposed to the top of the bentonitic clay member. The 5.5-foot bed (E–70926) occurs 9,840 feet above the base of the section and may be the same as the 5-foot bed said to crop out three-fourths of a mile west of Corwin Bluff (sample 4AC1) (Collier, 1906, p. 37). A 3-foot coal bed, a 1.4- to 3-foot lens of coal (E–70925), and 4 feet of coal and shaly coal occur at 10,790, 10,900, and 11,010 feet, respectively, above the base of the section. One of these beds is probably the same as that sampled by Washburn (sample 4AW7) "1⅜ miles west of Corwin Bluff" (Collier, 1906, p. 37). There is considerable variation in the relative amounts of coal and shale in some of the coaly beds in this area, and this may account for the discrepancies in thickness as measured by different investigators.

The upper sandstone member contains 8 coal beds, the thinnest of which is 1.4 feet and the thickest of which is 3 feet. These occur mainly between 12,520 and 12,870 feet and 14,095 and 14,670 feet above the base of the section. Many beds a foot thick or less occur in the lower and upper parts of the unit.

In the hills bordering the coast west of Risky Creek, many coal traces and heavings were noted as far as 5 miles from the creek, and they are present inland from the coast at least as far south as Eesook syncline.

There has been no commercial coal mining along the Cape Beaufort-Corwin Bluff coast for many years. The buildings and timbers used in early operations, where still present, are nearly useless; new operations would require the transporting of all new mining equipment, including timbers, to the area. Other deterrents to mining operations are the remoteness of the area, absence of natural harbors, and the relatively short time between mid-July and late September that the ocean is free of ice. Encouraging factors include the relatively simple structure in most of the area, the thin tundra cover, and the good quality of the coal which occurs in many beds of minable size. In the past, coal mining operations have been confined to surface digging and short adits into the ocean-cliff faces. Although the beds dips as much as 45° in the Corwin Bluff vicinity, considerable coal could probably be obtained by stripping methods. The presence of permafrost within a few feet of the surface, however, may be a further deterrent to this type of operation.

Additional geologic fieldwork in the coastal and inland parts of this area is warranted. Bedrock is well exposed and undoubtedly detailed geologic mapping would delimit substantial reserves of good coal.

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INDEX

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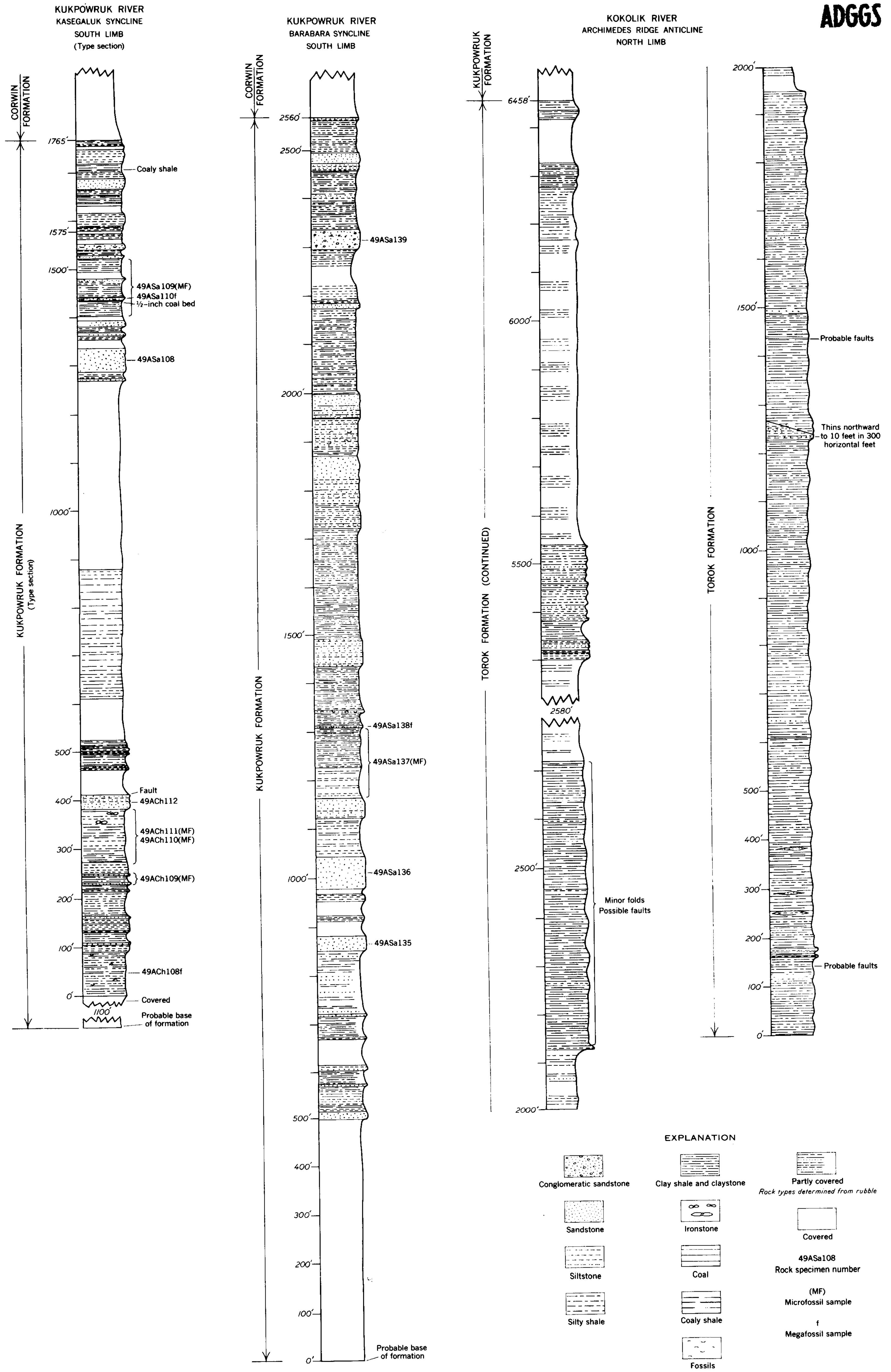
PLATE 10



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