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GEOLOGY OF THE KUKPOWRUK-NUKA RIVERS REGION, NORTHWESTERN ALASKA

By

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This report is preliminary and has not been edited or reviewed for conformity to Geological Survey standards and nomenclature.

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FOREWORD

The information contained in this report was collected during field investigations between 1947 and 1953. The text was written in 1957, and the generalized geologic map that accompanies the report (fig. 1) was compiled at that time. Although some of the statements or conclusions contained herein may seem outdated when compared to modern theories, the report contains information that has not been published elsewhere, together with early interpretations that support the current hypotheses regarding the development of the Brooks Range orogen.

Names and inferred age designations of stratigraphic units have been changed from the original report to correspond with current usage. Locations of sections that are given by geodetic coordinates are from planimetric maps used in mapping and compilation during the original work during the 1950's. Discussion of the Nuka Formation does not consider the much-studied section at Nuka Ridge (Tailleur, Mamet, and Dutro, 1972), and the Nuka Formation as described herein probably includes Lower Mississippian, Permian, and Triassic strata of the Nuka Ridge exposures. The pelecypod _Buchia_ reported herein was previously assigned to the genus _Aucella_. Both are considered to be of Early Cretaceous (Neocomian) age, but in earlier reports, fine-ribbed _Aucella_ was considered to be of Valanginian age and coarse-ribbed _Aucella_ was thought to be Berriasian. In the section entitled "Structural Geology", the "Overthrust belt" is generally equated with the "Disturbed belt" of later writers (Tailleur and Brosgé, 1970).

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INTRODUCTION

Location, Size, and Accessibility of Region

The Kukpowruk-Nuka Rivers region includes more than 3,200 square miles in the western part of the DeLong Mountains, a part of the Brooks Range province, and in the Arctic Foothills province north of the mountains. Most of the region lies in the Southern Foothills section and a lesser part in the Northern Foothills section. The northern part of the area overlaps with the Utukok-Corwin region (Chapman and Sable, 1960) and the eastern part lies within Naval Petroleum Reserve No. 4. Explorations during the years 1947 through 1953 were undertaken as a part of the U.S. Geological Survey's program of investigations for the U.S. Department of the Navy in Naval Petroleum Reserve No. 4 and adjacent lands.

The Kukpowruk-Nuka region can be reached by air from Kotzebue, Point Hope, and Point Lay, the nearest permanent settlements. Distances to the center of the region from these towns are about 130, 130, and 80 miles, respectively. In the winter season ski-airplane landings are possible at many places. During the summer only a few lakes are known to be suitable for float-airplane landings; these include Lake Noluk, Kokolik Lake, and the large lake 5 miles south of Igloo Mountain.

Smaller lakes, mostly suitable only for emergency landings, are scattered in the southern foothills and along the mountain front. A gravel airstrip, along the east side of the Utukok River 4 miles north of Driftwood Creek was constructed in 1950, but because of the low position near the river it may now be unsuitable for wheel landings.

Foot travel in the foothills and mountains is not difficult except in the swampy lowlands of the foothills. Although the east- and northeast-trending ridges afford the best foot travel, they are mostly discontinuous. Tracked vehicle travel is easily accomplished throughout the foothills and along most stream valleys to the mountain divide. Routes must be selected with care through low swampy terrain, for example, the area east of Lake Noluk and along the Colville River. Streams flowing south from the divide are deeply incised, strewn with large boulders and, in some places flow over small waterfalls. In these valleys, vehicle travel is difficult or impossible. The divide was crossed in one place with tracked vehicles, at Weasel Pass between the Utukok and Kuguroruk Rivers. No suitable route over the divide is known in the region east of this pass.

Major rivers are navigable to within 10 miles of the divide by boats having a draft of less than one foot. During low water, however, shallow channels and riffles make boat travel almost impossible. In the mountains even the major streams can be crossed easily on foot at selected places.

Previous Investigations

Following the establishment of Naval Petroleum Reserve No. 4 by Executive Order in February, 1923, a part of the Kukpowruk-Nuka region was first explored in August and September of 1924. A U.S. Geological Survey party under William T. Foran ascended the Utukok River and Disappointment Creek in search of a route through the DeLong Mountains. The party crossed the Colville River, traveled southward to Lake Noluk, portaged across the divide to the Nimiuktuk River, and continued down the Noatak River to its mouth. Very little geologic work was accomplished on this trip because of logistic difficulties.

In April and May, 1925, a U.S. Geological Survey party under Gerald Fitzgerald, topographic engineer, with Walter R. Smith, Geologist, ascended the Kugururok River by dog team from the Noatak River, portaged across the divide to Utukok River drainage, and reached the upper Colville River. The geology and topography along the route were mapped, and the party continued down the Colville River by canoe.

In May and June, 1926, a U.S. Geological Survey party under Phillip S. Smith made an overland journey by dog team from Kivalina, crossing the headwaters of the Kukpowruk River to the upper Kokolik River. The party then canoed down the Kokolik River. Geology and topography along the route were mapped.

More detailed accounts of these expeditions and results of the investigations are presented by Smith and Mertie (1930).

Nature and Scope of the Investigation

Field studies in the Kukpowruk-Nuka region were undertaken during 1947, 1949, 1950, 1951, and 1953, as parts of the U.S. 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 produce a geologic map, to

study the stratigraphy and structure, and to evaluate the petroleum possibilities of the area. The region had been only partly covered by rapid geologic reconnaissance during the earlier explorations of 1924-1926.

The project was supervised by George O. Gates in 1947, by Ralph L. Miller in 1949-1950, and by George Gryc from 1951 to 1953.

During field studies which covered about 70 percent of the area, the geology was mapped on available aerial photographs, taken by the U.S. Air Force. These cover the entire map area and consist of trimetrogon photographs flown in 1943, 1947, and 1949, and vertical photographs of approximately 1:20,000 scale flown in 1948 and 1950. Low-angle oblique photographs along portions of the upper Kukpowruk, Kokolik, Utukok, Colville, and Nuka Rivers were taken by the U.S. Navy in 1949. In addition, the photographs were used for photogeologic interpretation beyond the limits of field control and, to some extent, to calculate structural and stratigraphic measurements. Data were transferred from photographs to 1:48,000- and 1:96,000-scale planimetric maps compiled by the U.S. Geological Survey mostly from the trimetrogon photographs and from older sources. Because modern topographic maps of the area are now available, geology was transferred to these 1:63,360-scale maps. As a result of these transfer procedures, the resulting positions of geologic features are not of the highest degree of accuracy.

During field work, vertical elevation control was achieved mostly by use of airplane altimeters. Elevations were tied in a few places to triangulation nets of fourth-order accuracy established in 1947 and 1949 along the Utukok and Kokolik Rivers and, in 1950, in the vicinity of the Driftwood anticlinal area. A topographic map of the Driftwood anticlinal area was prepared from the 1950 triangulation net and altimeter traverse data. Approximate altitudes, with respect to mean sea level, were obtained by a combination of the U.S. Geological Survey triangulation nets and level-lines established by the United Geophysical Company Inc. during seismic surveys.

Field Operations, 1947-1953

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 single-engined, ski-equipped airplane near the Utukok River about 8 miles north of its headwaters. A geologic reconnaissance was made in the vicinity of, and about 7 miles upriver from, 1947 camp 1. A downriver traverse was begun on May 26 in three 18-foot folding canvas boats to the northern limit of the Kukpowruk-Nuka region, and the party continued its work northward into the Utukok-Corwin area (Chapman and Sable, 1960). A triangulation net was established over some of the route. The geologic work in the Kukpowruk-Nuka region was of general reconnaissance nature and was mostly restricted to the vicinity of the river valley.

The Kukpowruk and Kokolik Rivers were traversed in a similar fashion in 1949. On May 17 and 27 the field 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 S. Solecki, archeologist, Smithsonian Institution, was landed by single-engined ski-equipped airplane near the Kukpowruk River about 16 miles from its headwaters. A triangulation net was begun at 1949 camp 1 and extended downriver; and a geologic reconnaissance was made in the vicinity of camp 1 and southward to the head of the Kukpowruk. The downriver traverse, in three 18-foot folding canvas boats, was begun on June 13, and mapping was carried along the river northward into the Utukok-Corwin region. 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. A triangulation net was established at 1949 camp 17 and carried northward. Geologic reconnaissance in this part of the area was mainly limited to the vicinity of Kokolik Lake and the outcrops along the river north of the lake. The downriver boat traverse, begun on August 11, also continued into the Utukok-Corwin region.

The bulk of geologic work in the Kukpowruk-Nuka region was done in 1950 and 1951. On May 29, 1950, a party consisting of Edward G. Sable, geologist and party chief, Marvin D. Mangus, geologist, Charles L. Hummel and Paul H. Shannon, field assistants, Robert D. Gerard, cook, and Lloyd E. Hall, Arctic Contractors mechanic, landed on Lake Noluk by twin-engined ski-equipped airplane. On June 2 and 4 the party was transported by a single-engine airplane on wheels to the Utukok River north of its junction with Driftwood Creek. After careful mapping of the Driftwood anticlines, a detailed geologic reconnaissance in the southern foothills and DeLong Mountains was undertaken. About 600 square miles was mapped between the Kokolik River and Driftwook Creek. Amphibious full-tracked vehicles, "weasels", were used for transportation. The party concluded the field season on September 3, Allan N. Kover and George Gryc, Survey geologists, spent several days examining rock exposures south of Lake Noluk during the summer of 1950.

Between May 29 and September 2, 1951, a party consisting of Edward G. Sable, geologist and pary chief, J. Thomas Dutro, Jr., geologist, Robert H. Morris, geologist, Harald R. Drewes and Robert H. Meade, field assistants, William L. Nystrom, cook, and Leo C. Sutliff, Arctic Contractors mechanic, extended the 1950 work eastward from Driftwood Creek to the Nuka River, and mapped about 700 square miles of country. The party was landed on a gravel airstrip prepared by Arctic Contractors in 1950 along the Utukok River north of Driftwood Creek. "Weasels" were again used for transportation during field work, and one boat traverse was made down the upper part of the Colville River.

In August, 1951, exposures along the upper Colville River were examined by George Gryc, geologist, and Lloyd A. Spetzman, field assistant. A canvas boat was used for transportation, and the work included reexamination of cutbank exposures near the mouth of Reynard Creek which had been studied on August 2, 1948, by Edward J. Webber, U.S. Geological Survey geologist.

In June and July, 1953, Sable and Irvin L. Tailleur, geologists, and H. Glenn Richards, field assistant, extended earlier mapping by Tailleur westward into the Kukpowruk-Nuka region, mainly along the middle and lower parts of the Nuka River. "Weasels" were used for transportation, and a tie-in with geologic mapping in the Kiligwa River area to the east was effected.

All the above parties were flown from Umiat, the main base for field operations 200 miles east of the mapped area. Food and some supplies were cached by ski-equipped airplane at prearranged locations during April and early May. This hazardous operation, handled in 1947 by R. F. Thurrell and Sable, in 1949 by Mangus and E. Lebert, in 1950 by Tailleur and A. S. Keller, and in 1951 by Mangus and R. L. Detterman, was carried out with complete success. The food was cached in 55-gallon steel drums to protect it from bears. Mail and a few additional supplies were dropped to the parties from airplanes during the field season, except where suitable float landings were possible. The parties maintained daily communication with Umiat by two-way radio.

Seismic work by United Geophysical Company Inc., in the vicinity of the Driftwood anticlines consisted of refraction studies in 1950 and refraction and reflection studies in 1952 (Woolson and others, 1962, p. 22).

Acknowledgments

In a program of the size and scope of the Naval Petroleum Reserve No. 4 explorations, many people contributed to the completion of the geologic work. Navy, Arctic Contractors, and U.S. Geological Survey personnel in Fairbanks and on the Reserve all

provided helpful support without which the parties could not have worked effectively.

Fossil identifications include those of post-Triassic Mesozoic invertebrates by Ralph W. Imlay, Triassic invertebrates by Bernhard Kummel and J. B. Reeside, Jr., Paleozoic brachiopods and miscellaneous fossils by J. Thomas Dutro, Jr., with preliminary identifications by Arthur L. Bowsher, corals by Helen M. Duncan, and cephalopods by MacKenzie Gordon, Jr. Most of the microfossils were identified by Harlan R. Bergquist, some by Helen L. Tappan, and the conodonts were restudied by W. H. Hass. Finally, the work of the earlier geologists, P. S. Smith, W. R. Smith, W. T. Foran, and others was very helpful in the planning and compilation of the fieldwork.

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

GEOGRAPHY

Archeology, Vegetation, Wildlife, Climate

No settlements, roads, or established trails are present in the Kukpowruk-Nuka region. Some of the coastal Eskimos hunt in the area during the winter, as is evidenced by the recent campsites seen along all of the major rivers. Flint-chipping sites are fairly common on hilltops in the foothills, and most of the chippings and projectile points are probably of recent Eskimo origin. Ralph S. Solecki, Smithsonian Institution archeologist, accompanied the 1949 field party and gathered data along the Kokolik

and Kukpowruk Rivers (Solecki, 1950a, 1950b).

The vegetation in the area, dwarfed by climatic conditions and typical of tundra regions, has few plants exceeding 1 foot in height. Willows are usually less than 5 feet high, and, although they are relatively scarce, enough wood can be gathered along the larger streams to provide several days firewood for small camps. In the foothills, tufted cottongrass is the dominant evident form of vegetation in interstream areas where it is associated with sedges, grasses, mosses, and heath communities. In the mountains, mosses, lichens, and flowering plants provide a partial covering.

The most abundant animal is the caribou, several thousand of which were seen each summer by the field parties. Ground squirrels are ubiquitous. Wolves, grizzly bears, red and cross foxes, wolverines, small rodents and hoary marmots were occasionally seen. Dall mountain sheep are present in the DeLong Mountains in the headwaters of the Utukok and Nuka Rivers. The Arctic grayling and small trout were the only fish noted in the streams, and larger trout are present in some of the small mountain lakes. Ptarmigan, hawks, falcons, jaegers, plovers, and many song birds are abundant during the summer months; a few eagles, owls, and water fowl were observed. Mosquitoes are very abundant and annoying during late June, July, and early August; flies and gnats are common during the same period.

The climate is arctic and semiarid. Only general weather observations were made by the field parties from June through August in 1950 and 1951. In 1950, temperatures averaged about 50°F., with highs of

82°F. and lows of 26°F. Precipitation in the form of rain squalls, drizzle, snow and, rarely, hail was usually of short duration; prolonged rains lasting more than a day occurred only twice. Strong winds, estimated to be at least 40 miles per hour with gusts probably as much as 80 miles per hour, were predominantly from the south and east and were most common in June. In 1951, temperatures averaged about 45°F., with highs of about 72°F. and lows of 25°F.; precipitation was much more frequent and in periods of longer duration than in 1950; strong winds, most common in June and August, were predominantly from the south. The northern foothills and the south side of the DeLong Mountains could often be seen to have clear weather while storms, overcast, conditions and precipitation were occurring in the southern foothills and along the north side of the mountain divide. Thunderstorms were infrequent and usually resulted in little rainfall.

The area lies in the zone of continuous permafrost (Péwé, 1954, p. 317, fig. 69). The permafrost table lies at 1 foot or more in depth in late summer, depending on factors such as the amount of vegetation cover and drainage. Soil creep and flow features are common on hill slopes. Abundant talus along the valley sides and rock rubble on hills and mountains attests to the importance of mechanical weathering in the area.

Topography and Drainage

The Kukpowruk-Nuka region lies in the Arctic Foothills and Brooks Range physiographic provinces, the former being divided into the Northern Foothills and Southern Foothills sections, as

defined by Payne and others (1951). Within the mapped area, the Brooks Range province consists of the northwestern part of the DeLong Mountains. Physiographic boundary divisions are shown on the index map.

The Northern Foothills section is characterized by belts of prominent cuesta-ridges and mesas, with as much as 1,500 feet of relief, separated by wide lowland belts. The lowlands are almost entirely covered by tundra and are underlain mostly by shale. The ridges and mesas contain good rock outcrops and traces which reflect siltstone and sandstone.

The northern part of the Southern Foothills section, separated from the northern foothills by a belt of lowlands, is largely a lowland region interrupted by rounded hills and whaleback ridges with relief of about 1,000 feet. Cutbank rock exposures are most abundant along the Colville, Nuka, and Utukok Rivers, Adventure Creek, and parts of the Tingmerkpuk and Kukpowruk Rivers. Altitude increases southward, and the southern part of the southern foothills is characterized by discontinuous, mostly north-facing hogback ridges, rounded rubble-covered hills, and whaleback ridges. The ridges, composed largely of sandstone, conglomerate, and chert are separated by nearly exposureless lowlands. Relief is as much as 1,800 feet, and altitude ranges up to about 4,500 feet. Cutbank exposures are most numerous along the Nuka River, Thunder, Driftwood, and Iligluruk Creeks, and parts of the Kukpowruk River.

The northwestern part of the DeLong Mountains is characterized by high north-facing hogback ridges of limestone, chert, sandstone, and conglomerate striking east and northeast. Irregularly shaped rounded hills and mountains are mostly of sandstone and conglomerate. The massive, precipitous mountains south and east of the Utukok River headwaters consist largely of igneous rocks and chert.

In the Kukpowruk-Nuka region, altitudes increase southward and eastward and the highest peaks, about 5,000 feet in altitude, lie between the Kokolik River and Storm Creek. Relief is as much as 2,000 feet west of the Kokolik River, and 3,000 feet in the headwaters of the Utukok and Colville Rivers. Although altitudes in the DeLong Mountains are less than those in the central part of the Brooks Range, weathering and erosion of widely different and well exposed rock types in the DeLongs produces a variety of topographic features and color patterns of considerable scenic interest.

Major north-flowing river systems with headwaters in the Kukpowruk-Nuka region are the Colville, Utukok, Kokolik, and Kukpowruk. Major tributaries of the Colville River are the Nuka River, Storm and Thunder Creeks; of the Utukok, Driftwood Creek; of the Kokolik, Iligluruk Creek; and of the Kukpowruk, Eagle Creek, and an unnamed creek. The major rivers rise in the DeLong Mountains at altitudes of about 2,000 to 2,500 feet. From the drainage divide to the northern limits of the southern foothills, the gradient of the Utukok River averages 30 feet per mile, that of the Kukpowruk River about 36 feet per mile, and the gradients of the Kokolik, upper part of the Colville, and the Nuka Rivers are roughly 25 to 30 feet per mile. The Utukok and Kokolik are shallow with numerous braided areas; main channel depths at low water are estimated to range from 6 inches to 5 feet. The Kukpowruk, Colville, and Nuka Rivers are more noticeably incised and contain fewer braided areas. Stream widths range from 50 to 100 feet and flood plains are as much as 2,000 feet wide.

Spring breakup of the rivers occurs about mid-May, after which the streams drop several feet and are clear and very low during most of the summer. Prolonged or, more rarely, sudden rainfall brings the stream levels up several feet, but flash floods are unknown.

The major rivers appear, for the most part, to be antecedent streams in the southern foothills and mountains; they commonly flow transverse to the east- and northeast-trending topographic features which parallel the structural grain. The major tributaries also flow across the grain over most of their courses but, in part, they cut against and parallel certain high bedrock ridges. Drainage patterns of Storm Creek, Driftwood Creek, Iligluruk Creek, Eagle Creek, and the uppermost part of the Kukpowruk River show a striking similarity, are nearly parallel, and flow generally northwest. The Nuka River and its major tributaries flow northeast.

The present major tributaries between the Kukpowruk and Nuka Rivers were probably parts of the ancient east-flowing Colville; they were subsequently captured by the present north-flowing major rivers. This is indicated by the fact that west-flowing streams west of the Colville are enlarging their drainage areas eastward by headward erosion. Driftwood Creek, which lies at a much lower altitude than the Colville, is capturing Colville drainage. Pleistocene(?) gravel deposits, which lie well above present stream levels, extend from at least Driftwood Creek to the Colville River and indicate that Colville drainage once extended farther west than it does today. Tributary streams of the Utukok, Kokolik, and Kukpowruk Rivers in the Utukok-

Corwin region (Chapman and Sable, 1960) are also enlarging their drainage areas eastward by headward erosion. Thus, the northwest directions of the streams west of the Colville appear to have been the result of relatively recent uplift along a north- or northeast-trending line in the eastern part of the Kukpowruk-Nuka region and east of the Utukok-Corwin region, and the tributaries are in part consequent streams flowing away from the line of uplift. North of the Kukpowruk-Nuka region high-level gravel deposits of Pleistocene age are known to slope westward (Chapman and Sable, 1960); the slope may reflect regional structural tilting like that indicated in the western part of the Kokpowruk-Nuka area.

South of the mountain divide, only headwater portions of the major south-flowing streams, the Kelly, Kugururok, and Nimiuktuk Rivers, lie within the Kukpowruk-Nuka region. Their headwater tributaries are deeply incised and lie several hundred feet below the level of north-flowing drainages which they head against. They are actively capturing the north-flowing streams by headward erosion. The lower portions of the main tributaries, and the valleys of the major rivers which they enter, have undergone extensive valley glaciation. During Pleistocene glaciations, the DeLong Mountains divide was south of its present position. The active headward cutting of south-flowing streams probably resulted from the deepening of the major river valleys by glacial action and the consequent steepened headwater gradients.

Glaciation

Extensive valley glaciation along the south side of the DeLong Mountains is reflected by wide U-shaped valleys, cirques, arête ridges, and extensive deposits of glacial origin in the major river valleys. On the north side of the mountains, however, there is little fresh evidence of glacial activity except in the highest portions near the mountain divide. At these higher altitudes, small abandoned cirques are present in the headwaters of the Nuka, Colville and Utukok Rivers at altitudes of about 3,500 to 4,000 feet. One small cirque glacier, less than 1,000 feet in diameter, lies at about 4,000 feet near the divide between Storm Creek and Nimiuktuk River drainages. Terminal moraines, identified on aerial photographs, lie along the small tributaries which head in the cirques. These moraines represent relatively late stages of glaciation in the area and may correspond to the Alapah Mountain and Fan Mountain glaciations recognized by Detterman, Bowsher, and Dutro (1958) in the central Brooks Range.

On the north side of the mountains, older glacial features have been greatly modified by erosion and solifluction. No erratics, till, or morainal deposits were recognized with certainty anywhere in the area. Unconsolidated deposits are either of fluvial origin or consist of rubble derived from nearby bedrock. Nevertheless, the valleys of some major north-flowing streams within the DeLong Mountains show a modified U-shaped cross-section and rock benches into which the streams have been incised. The upper parts of Driftwood Creek, Storm Creek, and Kidney Creek show these features. Small north-facing cirques, also considerably modified, occur at many localities between altitudes of 2,500 and 3,000 feet. One such is occupied by the lake along a tributary of Driftwood Creek. Cirques at this general altitude

were observed as far west as the headwaters of the Kukpowruk River. In addition, modified arcuate drainage patterns of certain tributary streams in the mountains and the southern part of the foothills, may reflect initial control by morainal deposits.

These features point to one or more ice advances considerably older than the later stages. Valley glaciers probably extended into the southernmost part of the foothills in the area between the Nuka and Utukok Rivers. Farther west, glacial extent may have been more restricted. The apparent absence of ice-contact deposits may mean that the ice transported a relatively small amount of material or that the deposits may have been removed subsequently by erosive agents. The widespread high-level gravel deposits along the Colville River may contain reworked glacial and glaciofluvial material derived from older glacial advances.

GEOLOGY

Devonian System

Rocks of known Devonian age crop out in four widely separated localities in the Kukpowruk-Nuka region. They occur on a tributary of Iligluruk Creek, at approximate lat. 68°35'40" N., long. 161°37' W.; in the headwaters of Iligluruk Creek at lat. 68°36'15" N., long. 161°17'00" W.; along the upper Nuka River, at lat. 68°40' N., long. 160°09' W., and in Mount Bastille and vicinity south of the upper Kugururok River at lat. 68°28' N., long. 160°53' W. The Iligluruk Creek exposures consist of a narrow, east-trending band not more than a few hundred feet wide and 1½ miles long; the exposures on the upper Nuka River occur in a southwest-trending band about 1 mile long and a quarter of a mile wide; in contrast, those at Mount Bastille make up the main mass of the mountain and can be traced on aerial photographs for at least 6 miles east and 2 miles west of the mountain.

Kugururok Formation

Distribution and outcrop

The Kugururok Formation, typically exposed in Mount Bastille (map, fig. 1) and adjacent mountainous areas, was named for the Kugururok River (Sable and Dutro, 1961). The formation can be traced for several miles east and west of the type locality in outcrops south of the Kugururok River. Rocks in part similar to those in the type section are exposed on the west side of the Kugururok River valley about 25 miles to the southwest beyond the limits of the map area.

Character and thickness

The Kugururok Formation in the type section is largely dolomite and limestone, with shaly to conglomeratic clastic rocks in the lower part. At the type locality, three informal lithologic members are recognized. The lower member is dominantly clastic (shale with interbedded sandstone, granule conglomerate, siltstone, and limestone) and is about 380 feet thick: the upper member is light-colored, laminated to cross-bedded dolomite. The yellowish-weathering ("creamy") color of the dolomite is a distinctive gross feature of the formation.

Section 1. Kugururok Formation, type section, exposed on north side of Mount Bastille, approximately lat. 68°28' N., long. 160°50' W. Measured by E. G. Sable and J. T. Dutro, Jr., July 14, 1951 (see fig. 1)

Unit	Thickness in feet
Top of section. Shales of probable Jurassic or Early Cretaceous age.	
1. Dolomite, light gray, very fine grained, saccharoidal texture, massive; partly rubble covered.	235+
2. Dolomite, yellowish gray to light brownish gray, medium grained, weathers dark yellowish orange to dark yellowish brown; beds 2-6 inches thick, mostly cross bedded with conspicuous black bands produced by weathering along bedding planes; laminated in upper part; cliff-former	25

3. Dolomite, light gray to light brownish gray, weathers pale orange to grayish orange, saccharoidal texture. Blocky irregular fracture with partings 4-6 inches apart; talus has conspicuous creamy color; lower part massive with beds as much as 6 feet thick. . . . 120+

4. Limestone and sandstone (dolomitic?), interbedded in platy beds 1/2 inch to 4 inches thick. Limestone, 50 percent of unit, is medium dark gray, very fine grained, laminated; about 50 feet of bioclastic limestone in upper part of unit contains a few lenses of chert and poorly preserved horn corals and brachiopods. Sandstone is dark gray, very fine grained; weathers moderate yellowish brown, finely cross bedded; contains poorly preserved brachiopods (<u>Atrypa</u> sp. and spiriferoid types). . 350+

Fault?

5. Limestone, light brownish gray to medium dark gray, weathers light bluish gray; medium grained; calcarenite, with some conglomeratic phases containing small limestone pebbles which are generally darker than the matrix; a massive unit. 230+

Fault?

6. Limestone, dark gray in lower part, weathers medium gray, very fine grained to sublithographic; medium gray in upper part, weathers pale yellowish orange; beds mostly 2-3 inches thick, but as much as 8 inches thick. 30

7. Interbedded shale, sandstone, conglomerate, and limestone. Shale, black, silty, noncalcareous, fissile to hackly; in sets of beds as much as 10 feet thick; 60 percent of unit. Sandstone and granule conglomerate, 20-30 percent of section, are medium dark gray; medium- to coarse-grained calcareous matrix, with granules of dark gray siltstone(?), pelletal grains, and crystalline calcite; weather pale reddish brown to grayish red; some elongate concretions of ferruginous claystone as much as 2 inches long and half an inch thick. Limestone, medium dark gray, very fine grained; contains shell fragments aligned parallel with bedding . . . . 380+

Thickness measured. . . . . 1,370+

Fault

<u>Stratigraphic relationships</u>

The type section is in a thrust plate that overlies probable Mississippian carbonate rocks and is unconformably overlain by dark shales of possible Mesozoic age. On the Kugururok River 25 miles southwest of the type locality, the Devonian sequence is separated by faults from underlying Triassic rocks and overlying Mississippian rocks (J. T. Dutro, Jr., oral commun., 1962). The lithologic character and fossils in that section of the

Kugururok Formation, suggest that the total thickness of the formation exceeds 2,000 feet. A 400-foot-thick basal unit of dolomite, perhaps equivalent to the upper 380 feet of the type section is overlain by 30 feet of beds transitional to 100 feet of dark-gray to brownish-gray, medium- to very fine grained limestone. This is succeeded by more than 400 feet of thick-bedded, light-gray, aphanitic limestone which is a cliff-forming unit overlain by 15 feet of thin-bedded, brownish-gray, medium-grained calcarenite. The uppermost unit is an 80-foot thickness of brownish-gray coarse calcarenite which, in places, is a nearly solid brachiopod coquina.

Fossils and age

Fossils from unit 4 of the type section, identified by Dutro, include: cystiphyllid corals, undet., *Thamnopora* sp., *Gypidula*? sp., *Atrypa* sp., *Euryzone* sp., *Strobeus*? sp., and orthoceratid and cyrtochoanitic cephalopods.

51ASa210f (USGS locality 3512-SD) (Collected from limestone and conglomerate in unit 7, section 1)

Ambocoelia? sp.

Dechinella (*Dechinella*) sp.

ostracode fragment, indet.

The gastropods were identified by J. Brooks Knight (oral commun., 1952) who indicated that the genera are present in the European Middle Devonian. The faunal assemblage suggests an approximate correlation with limestones in the western Brooks Range which have yielded coral faunas of Givetian or early Frasnian age. The trilobite *Dechinella*

(*Dechinella*) ranges from Early Devonian through early Late Devonian. The two collections from the Mount Bastille section are of either latest Middle Devonian or earliest Late Devonian age.

Fossils from high in the sequence in the Kugururok Valley are considered to indicate a Famennian age and include brachiopod assemglages rich in *Cyrtiopsis*? and *Cyrtospirifer*. The Kugururok Formation is a time equivalent of a part of the Upper Devonian rocks in the Shainin Lake area (Bowsher and Dutro, 1957). Lithologically, it appears more closely related to the unnamed sandstone and shale formation than to the probably nonmarine Kanayut Conglomerate of the Shainin Lake area.

Mode of deposition

Rocks of the Kugururok Formation suggest marine inshore deposition in their basal part; upper beds may represent shallow offshore platform conditions. Within a probably east-trending Late Devonian seaway, the depositional basin of Kugururok sediments may have bordered a large-scale deltaic outpouring of clastic rocks (Kanayut) which crop out to the east. The locations of source areas for Upper Devonian clastic rocks are not known, but distributional patterns suggest a northerly or northeasterly source. A positive area, perhaps with an extension as a south-trending peninsula in the vicinity of the present Alaska-Yukon boundary, may have shed clastic debris both southwestward (Kanayut Conglomerate) and southeastward (Imperial Formation equivalent) during the Famennian (see also Martin, 1959, especially p. 2442-2445).

Undifferentiated Devonian Rocks

The Devonian rocks on a tributary of Iligluruk Creek consist of two 6-inch beds of medium-light-gray to medium-gray, finely to coarsely crystalline limestone which protrude through vegetation and mud-cover on the west side of the creek. The total possible thickness of Devonian section at this locality, including the covered intervals, is 45 feet. Devonian rocks are faulted over rocks of probably Mesozoic age and are overlain by fossiliferous black chert, shale, and limestone of probable Mississippian age. These exposures lie in a complexly folded and faulted belt at the mountain front. Although they are, in general, along strike with the Devonian rocks exposed in the headwaters of Iligluruk Creek, they cannot be traced into these exposures.

Fossils from the limestone beds were identified by J. T. Dutro, Jr.:

USGS loc. 4740-SD (50ASa67):

Yunnanella sp.

Parapugnax sp.

Sinotectirostrum cf. *S. nordeggi* (Kindle)

Cyrtospirifer aff. *C. animasensis* (Girty)

Section 2. Devonian rocks, undifferentiated. Section of Devonian rocks exposed in the headwaters of Iligluruk Creek; measured by E. G. Sable on August 9, 1950.

Unit	Thickness in feet
Top(?) of section - Overlying rocks consist of black to dark-gray siltstone, shale, chert, and limestone, in part of Mississippian age.	
1. Clay shale, moderate yellowish brown, fissile	10
2. Rubble of clay shale, as above.	7
3. Clay shale as above, contains a few siltstone nodules . .	20
4. Covered	20
5. Clay shale, dark gray to grayish brown, soft, fissile; contains nodules and lenses of reddish-brown weathering, calcareous claystone and siltstone as much as 5 feet long and 1 foot thick; one 2-inch bed of coaly shale; contains conodonts	130±
6. Shale and limestone, interbedded. Shale grayish brown, fissile; limestone, olive-gray to light greenish gray, fine grained, soft, in lenses and beds as much as 4 feet thick, locally coquinoid; contains spiriferoid and rhynchonelloid brachiopods and conodonts	15
Thickness measured.	202±
Fault	

These Devonian rocks are interpreted to lie in the south-dipping north limb of an overturned anticline. A high-angle fault cuts the anticline so that south-dipping Triassic and Permian(?) rocks overlie the Devonian sequence.

Fossils from unit 6 include brachiopods and conodonts. Collection

USGS 4749-SD (50ASa163) contains:

Schizophoria sp.

Productella sp.

? *Yunnanella* sp.

Cyrtospirifer sp.

? *Strophopleura* sp.

In addition to more specimens of the *Schizophoria*, collection USGS 4748-SD (50ASa164) also has a small indeterminate ambocoelid brachiopod. Conodonts from units 5 and 6 consist only of fragments of bladelike and barlike forms that are of no value in precise age designation (W. H. Hass, written commun., 1957).

Half a mile east of, and along strike with, the above section, limestone rubble similar to that in unit 6, section 2, contains the following fossils, identified by J. T. Dutro, Jr.:

USGS 4739-SD (50ASa192)

Schizophoria cf. *S. simpsoni* Merriam

chonetid, indet.

productellid, indet.

? *Strophopleura* sp.

Athyris cf. *A. angelicoides* Merriam

"*Cleiothyridina*" sp.

ambocoelid, indet.

The Devonian exposures along the Nuka River consist of tightly folded and sheared limestone and shale which have been intruded by

mafic igneous rocks and faulted against Jurassic(?) and Mississippian(?) rocks. The Devonian limestones are medium gray and light olive-gray, weather yellowish brown, are finely crystalline to silty, platy, in part ripple marked, and appear to be interbedded with black calcareous shale with thin beds of dark-gray to black siltstone, quartzite, and chert. The limestones are locally coquinoid and include the following fossils, according to J. T. Dutro, Jr.:

USGS 3366-SD (51ASa1061)

inadunate crinoid, undet.

Schizophoria sp.

Productella sp.

Tenticospirifer? sp.

Strophopleura cf. *S. notabilis* (Kindle)

"*Cleiothyridina*" sp.

Parapugnax sp.

Eoparaphorhynchus cf. *E. maclareni* Sartenaer

Sinotectirostrum sp.

Aviculopecten? sp.

orthoceratid cephalopod, undet.

Cyrtoclymenia aff. *C. plicata* Münster

?*Dinichthys herzeri*

The fish fragments were identified by David Dunkle of the U.S. National Museum; the brachiopod identifications were verified by Paul Sartenaer; the goniatite was identified by Michael House.

All the collections from the undifferentiated Devonian rocks probably represent parts of a single Late Devonian (Famennian) fossil assemblage. The brachiopods are similar to those found in the upper part of the Palliser Formation of the Rocky Mountains of Alberta (McLaren, Norris and McGregor, 1962) and also contain elements of high Devonian assemblages from the western United States. According to Michael House, *Cyrtoclymenia plicata* is characteristic of the middle Famennian Clymenia Zone of the Upper Devonian in western Europe.

Devonian rocks on the Nuka River, together with the associated igneous rocks, are interpreted as a klippen from a thrust plate which has overridden Jurassic(?) and Mississippian(?) rocks at this locality. The Devonian limestones are lithologically similar to those exposed along Iligluruk Creek but do not resemble the Devonian rocks exposed at Mount Bastille.

Mississippian System

Mississippian rocks exposed in the Kukpowruk-Nuka region were first reported by Smith and Mertie (1930, p. 168, 171-172). In the headwaters of the Utukok River, light-colored limestone containing "a considerable amount of silica" was called the Lisburne formation (Schrader, 1904, p. 63) by Smith and Mertie. The Lisburne was reported to overlie a sandstone believed to represent the Noatak formation (Smith, 1913, p. 69-75). Cream-colored limestone, called Lisburne limestone or Lisburne formation, was also reported to be exposed south and southwest of the Kukpowruk-Nuka region, in the hills near the Kukpuk-Kukpowruk

divide, along the Noatak River and its tributaries, in the Kivalina valley, and in the Cape Lisburne region (Smith and Mertie, 1930, p. 168-169). Subsequently, the Lisburne was raised to group status by Bowsher and Dutro (1957, p. 3).

Lisburne Group

The Lisburne Group in the Shainin Lake area, about 250 miles east of the Kukpowruk-Nuka region, was defined by Bowsher and Dutro (1957) to include rocks of Mississippian age which overlie the Kayak Shale of Early Mississippian age and underlie the Siksikpuk Formation of Early Permian(?) age. In the Kukpowruk-Nuka region, a sequence of Mississippian rocks believed possibly to be at least 4,500 feet thick and consisting largely of limestone, sandstone, chert, shale, and quartzite, underlies rocks ranging from probable Permian to Early Cretaceous age. The Kayak Shale is not known to be present. Identifications of megafossils indicate that most or all of this sequence is probably equivalent to part of the Lisburne Group of Bowsher and Dutro, and the sequence is here included in the Lisburne Group.

Mississippian rocks of the Lisburne Group in the Kukpowruk-Nuka region are divided into three named formations and dark-colored cherty units whose precise correlation to the Mississippian rocks of the Shainin Lake area is not known. The three formations, from oldest to youngest, have been named the Utukok, Kogruk, and Tupik Formations (Sable and Dutro, 1961). Other rocks of Mississippian age consist largely of black and dark-gray chert, shale, limestone and siltstone are mapped as the dark-colored cherty units, and rocks of probable

Permian age as undivided cherty units, and with the Nuka Formation. Positions of outcrop belts and relationships of Mississippian rocks reflect overthrust faulting with the resultant juxtaposition of strata of the same general age but of different rock facies.

Utukok Formation

The Utukok Formation is named for the Utukok River near which well-exposed sections of this formation occur. The type section of the formation is exposed in the headwaters of the Utukok River, on the north face and along the top of Tupik Mountain about 2 1/2 miles northwest of the junction of Tupik and Kogruk Creeks.

Distribution and outcrop.-- Most of the exposures of the Utukok Formation are in the DeLong Mountains, west and south of the Utukok River headwaters. The formation also extends southeastward from the Utukok River and one belt of exposures is present on Chertchip Creek, a tributary of the Nuka River. West of the Utukok River, the formation is exposed in two distinct outcrop belts which trend west to southwest and whose northern limits are nearly everywhere defined by thrust faults. In the northern belt, which is relatively narrow and discontinuously exposed from the Utukok River westward for about 12 miles, only the uppermost part of the formation is exposed on the north-facing fronts of the mountain ridges. The southern belt, which is as much as 2 miles wide, strikes west and southwest from the Utukok River to beyond the southern limits of the area. During an aerial reconnaissance south of the Kukpowruk and Kokolik Rivers in 1949, rocks which are almost

certainly Utukok Formation were seen to comprise wide belts of mountain exposures along the Kelly River and its tributaries. These rocks are exposed in the axial zones of broad anticlines and are overlain by Kogruk Formation.

East of the Utukok River, three belts of Utukok Formation strike generally east and southeast; the southernmost belt, north of Trail Creek, narrows and strikes southeastward beyond the limits of the mapped area.

The Utukok Formation along Chertchip Creek is topographically expressed as a high rubble-covered ridge about 1.2 miles long which strikes east. The formation does not extend continuously east or west of these exposures; there are, however, several small outcrops and rubble mounds of rock types like those of the Utukok that are discontinuously exposed along the same structural belt as far west as Storm Creek. These exposures may constitute isolated thrust plate remnants far north of the main outcrop of the formation.

The Utukok Formation is a resistant unit west of the Utukok River which is typically exposed in high, mostly rubble-and talus-covered, mountains. Bedrock exposures are mostly limited to ridge tops between mountain gulleys, although the resistant units uphold benches which can be traced along the mountain sides. Cutbank exposures of the formation are best exposed along Kogruk Creek. The weathering colors of outcrops and rubble of the formation are distinctive moderate to dark yellowish brown as contrasted to the grayish weathering colors of the Kogruk. On the basis of gross weathering colors, the Utukok

Formation is unlike other rock units in the area with the exception of parts of the Nuka Formation. On aerial photographs, the Utukok Formation usually appears medium to light gray with a two-toned splotchy appearance due to differential weathering.

Character and thickness.-- The Utukok Formation consists largely of medium-dark-gray silty, argillaceous, ferruginous and finely crystalline limestone which weathers distinctive dark yellowish brown, dark yellowish orange, and olive-gray. Limestone, roughly 80 percent of the formation, is fissile, platy, blocky, and massive, and occurs in beds as much as 1 foot thick. A few thin beds of dark-gray, grayish-red-weathering, silty limestone occur in the lower part of the formation. Limestone beds are locally fossiliferous and contain crinoidal debris, brachiopods, gastropods, pelecypods, cephalopods, and trilobites.

Limy siltstone, quartzitic siltstone, very fine grained limy sandstone and quartzite are interbedded with the limestone and comprise roughly 20 percent of the formation. These clastic rocks are dark gray to medium gray, in part argillaceous, and occur in platy, blocky, and massive beds which average about 1 1/2 feet thick. Quartzite beds as much as 10 feet thick are most abundant in the lower part of the formation. Weathering colors are similar to those of the limestone but are commonly lighter. Although limy shale appears to comprise a minor part of the formation, it may be more abundant than indicated here, particularly in units which are talus covered.

The Utukok differs from other units in the Lisburne Group in the silty and argillaceous character of the limestone, the presence of quartzite and other clastic rocks, the absence of chert, and in its characteristic yellowish-brown-weathering colors.

Section 3. Utukok Formation, type section. Exposed on north face and along top of Tupik Mountain, about 2.5 miles northwest of junction of Tupik and Kogruk Creeks; measured by E. G. Sable, August, 1950.

Unit	Thickness in feet
Kogruk Formation. Contact believed to be gradational.	
1. Rubble. Limestone, silty, medium to dark gray, hard to soft, weathers moderate yellowish brown to medium gray, platy to blocky	75
2. Limestone and quartzitic sandstone interbedded. Limestone similar to but more sandy than that in unit 1, about 50 percent of unit. Sandstone, medium dark gray, silty to very fine grained, platy to blocky, finely laminated and cross bedded, ferruginous, in part calcareous, weathers yellowish brown and light olive-gray. Spiriferoid and productid brachiopods in limestone. Unit exposed in wide saddle	390
3. Sandstone with interbedded limestone similar to rocks in units 1 and 2, but sandstone weathers light brown to pale yellowish brown, and comprises about 70 percent of	

unit. Exposed in ledges and small cliffs separated by talus 540

4. Sandstone and limestone as in unit 2, but sandstone about 60 percent of section. Poorly preserved and meager fauna consisting of crinoidal debris, brachiopods, and gastropods 150

5. Limestone with few interbeds of quartzitic sandstone. Similar to rocks in unit 2, but contains a few thin beds of medium-gray, finely crystalline limestone, with thin beds of coquinoid limestone throughout unit. Crinoidal debris abundant; cephalopods, spiriferoid brachiopods, and gastropods common. 60

6. Sandstone and limestone, similar to unit 2, interbedded. Sandstone about 40 percent of section, blocky in beds as much as 2 feet thick. Few spiriferoid and productid brachiopods 30

7. Covered. Rubble of platy limestone, similar to that in unit 1 10

8. Limestone, medium dark gray, weathers dark yellowish brown and reddish brown; dense, platy, in irregular beds. Lower 10 feet highly fossiliferous, contains spiriferoid and productid brachiopods 40

9. Talus-covered. Sandy limestone, medium dark gray, ferruginous, weathers light brown to pale yellow-

brown, platy, beds as much as 2 inches thick. In part fossiliferous. (Talus-covered units probably partly underlain by calcareous shale.) 25

10. Limestone and coquinoid limestone, medium to dark gray, ferruginous, weathers yellowish brown; sandy to finely crystalline, platy, beds as much as 4 inches thick. Laminated and finely cross bedded. Fossils include spiriferoid and productid brachiopods 85

11. Sandstone and sandy limestone, similar to unit 2. Few fossils like those in unit 10. 50

12. Talus. Sandstone and limestone as in unit 11. 65

13. Sandstone and limestone interbedded, similar to unit 2, but beds are lenticular. Sandstone beds as much as 3 feet thick, limestone beds as much as 3 inches thick. Abundant spiriferoid brachiopods in limestone. 20

14. Largely talus of limestone and sandstone similar to unit 2, in approximately equal amounts. Limestone, in part coquinoid, contains crinoidal debris, brachiopods, and gastropods. Limestone percentage increases in upper part of unit. Prominent rubble-covered bench occurs about 415 feet below top of unit 1,215

Fault?

15. Quartzitic sandstone and limestone interbedded. Limestone weathers dark yellowish orange; laminated;

	beds as much as 4 inches thick	40
16.	Covered by quartzitic sandstone and limestone rubble and talus. Prominent rubble-covered bench	20
17.	Calcareous shale with thin interbeds of silty limestone, calcareous siltstone, and quartzite. Shale dark gray, platy, hard, with a quarter of an inch partings, in sets of beds as much as 4 inches thick. Worm trails and fucoidal markings on surfaces of shale	30
18.	Covered. Quartzitic sandstone and limestone talus . . .	20±
19.	Quartzitic ferruginous sandstone and silty limestone interbedded. Sandstone 80 percent of unit in beds as much as 10 feet thick, silty to fine grained, in part slightly to moderately calcareous. Massive, cliff-forming unit . .	100
20.	Quartzitic sandstone and limestone interbedded. Ferruginous sandstone, medium light to dark gray, weathers light brown, yellowish brown, and light olive-gray; in part calcareous; finely cross bedded and laminated to blocky and massive; contains few fossils on bedding surfaces; forms about 70 percent of unit. Limestone, medium gray weathers moderate yellowish brown, in beds averaging about 4 inches thick but as much as 8 inches in upper part of unit, has irregular bedding surfaces; contains abundant brachiopods, gastropods, and pelecypods	25

Total thickness measured . . . . 2,990±

Fault

One thin section from the Utukok Formation, was examined under the petrographic microscope. In hand specimen, the rock is a medium-dark-gray to brownish-gray, silty to fine-grained sandy limestone, platy, laminated, and in part quartzitic. In thin section, it is calcareous orthoquartzite (Pettijohn). The rock has a sandy texture and granular structure. The cement, 30 to 40 percent of the thin section, is predominantly carbonate, with less than 10 percent crypto-crystalline quartz. Limonite and hematite are also present in small amounts, mostly along grain boundaries and fractures. A black opaque substance, possibly carbonaceous matter, occurs along grain boundaries of as small particles, and is less than 5 percent of the section. Subround to subangular, mostly equidimensional, grains from .02 to .16 mm in diameter with a modal size of about .08 mm are closely packed or separated from each other by as much as 0.1 mm. The grains consist predominantly of clear quartz (about 90 percent), crypto-crystalline quartz (less than 10 percent), and scattered grains of mica, zircon, and tourmaline (less than 2 percent). Edges of some quartz grains appear to have been etched by the carbonate cement, and some grains have been partially replaced by calcite. Pore space is less than 5 percent.

No structural breaks were observed in the type section of the Utukok Formation; all units appear to be conformable with little change in strike or dip. The belt of outcrop, however, narrows abruptly both east and west of the type section, and section units could not be traced across these rubble-covered bands. It is possible that a bedding plane thrust fault cuts the section at the base of, or within about 250 feet above, the base of unit 14. The presence of such a fault would result in a minimum continuous stratigraphic thickness of about 2,500 feet above the fault. Duplication of the beds above and below this questionable fault cannot be demonstrated; conversely, the upper beds do not contain some of the features found in the lower beds; for example, the distinctive 10-foot-thick quartzite beds that are conspicuous in unit 19 were not seen in the upper part of the section.

West of the type section, and about half a mile south of camp 8A, a section of Utukok Formation about 4,400 feet thick was measured by M. D. Mangus in 1950. The rocks in this section are similar to those of the type section in their character, mode of outcrop, structural conformity, and the narrowing of the outcrop belt east and west of the section where the lower beds are absent as a result of faulting. Thrust faults may cut the section at about 1,300 and 1,900 to 2,250 feet above the base, but it seems likely that the upper 2,700 feet of the section is not faulted. The total section, discounting possible faults, is the thickest known sequence of Utukok Formation in the Kukpowruk-Nuka region.

In the northern belt of Utukok Formation outcrops west of the Utukok River, only the uppermost 500 feet is exposed. A few thin

coaly beds, interbedded with crinoidal limestone and limy shale, are poorly exposed at approximately lat. 68°35' N., long. 161°33' W. These are assigned to the Utukok Formation because of the lithologic character of the limestone and shale and the apparent stratigraphic position beneath the Kogruk Formation.

A section of the upper part of the Utukok Formation, about 1,200 feet thick, is exposed in the southern belt of outcrops along Kogruk Creek about 3 miles east of the Utukok River. Other belts of exposures north and southeast of this section contain only the uppermost part of the formation. These are largely rubble covered and probably do not represent more than a few hundred feet of section. One 780-foot-thick sequence, was measured by J. T. Dutro, Jr., 7 miles east-northeast of the junction of Kogruk Creek and the Utukok River.

The exposures along Chertchip Creek, measured by Dutro in 1951, consist of about 800 feet of interbedded limestone and shale. The limestones are dark-gray, fine-grained to silty, ferruginous calcarenite and dark-gray fine- to medium-grained bioclastic calcarenite. Limestones are uniformly bedded, platy, weather dark yellowish orange and yellowish brown. Megafossils consist of brachiopods and crinoidal debris, the latter making up as much as 30 percent of some beds, and fossils occur throughout the section but are most abundant in the upper 200 feet. Interbedded black, silty shale and clay shale comprise a minor part of the section.

Stratigraphic relationships.-- No unconformities or significant depositional breaks were noted in exposures of the Utukok Formation. The base of the formation was nowhere seen; and the bases of measured sections of the Utukok are all in fault relationship with younger rock units. The uppermost part of the Utukok conformably underlies the Kogruk Formation. In the sections examined, approximately the uppermost 50 feet of Utukok consists of interbedded limestone of the yellowish-brown-weathering silty and sandy types common in the Utukok and the gray-weathering crystalline types characteristic of the Kogruk. The contact is considered to be gradational.

Kogruk Formation

The Kogruk Formation is named after Kogruk Creek, the west-flowing major headwater tributary of the Utukok River. The type section of the formation is exposed in mountain-top outcrops adjacent to and south of the Utukok Formation type section.

Distribution and outcrop.-- The Kogruk Formation in the Kukpowruk-Nuka region lies along the same belts of outcrops as the Utukok Formation. In the northern belt of outcrops west of the Utukok River, exposures of the Kogruk Formation extend at least as far as the headwaters of the Kokolik River. In this belt, the Kogruk crops out in high, discontinuous en echelon hogback ridges which strike southwest and whose steepest slopes face north. Strata are exposed mostly as ledges and cliffs on the north sides of the ridges; the south slopes are mostly rubble covered. The ridges are prominent landmarks and are conspicuous on aerial photographs because

Kogruk carbonate rocks weather chalky white to light gray in contrast to the darker weathering colors of adjacent rocks. Ridges of similar appearance can be traced along the same outcrop belt as far as 7 miles east of the Utukok River.

The southern belt of Kogruk Formation exposures, which is arcuate and convex northward in plan view, extends to beyond the east and west limits of the map area. The formation crops out in much the same fashion as in the northern belt, except that outcrops in the southern belt are less conspicuous than those of the northern belt. This is partly because the grayish-weathering colors of the southern belt rocks are generally darker than those to the north, and partly because the Utukok Formation makes up most of the prominent mountains along the southern belt west of the Utukok River. East of the Utukok River, the Utukok Formation is not as conspicuous and the Kogruk Formation composes many of the more prominent ridges. The Kogruk is well exposed in cutbanks along the Utukok River from about 1.5 to 2.6 miles above the mouth of Kogruk Creek.

In addition to these well-defined belts of exposure, rocks mapped as Kogruk Formation are exposed north of and adjacent to the Utukok exposures at Chertchip Creek, and occur at many localities along two complex structural belts. The first strikes west from the Chertchip Creek exposures at least as far as Elbow Creek; farther north, a second belt stretches from the eastern limits of the area, at about lat. 68°47' N., southwest at least as far as Driftwood Creek. Most of these localities consist of rubble patches and bands containing sparse outcrops of fossiliferous and unfossiliferous carbonate rocks resembling those of the Kogruk. They are discontinuous, irregularly spaced, and range from a few feet to several hundred feet in width. Not all of them are shown on the geologic map.

Character and thickness. -- The Kogruk Formation consists almost entirely of interbedded limestone and chert. Limestone, about 85 percent of the formation, ranges in color from dark gray and brownish gray to nearly white, weathers medium to light gray and grayish orange, and is finely to coarsely crystalline and silty to granular. Most of the limestone is well indurated and is in part siliceous although some bioclastic varieties are friable and soft. Much of the limestone emits a bituminous odor from freshly fractured surfaces. Beds range from about 1 to 5 feet in thickness, although some are as much as 20 feet thick; and fracture in blocky, massive, and platy fragments. The strata are locally fossiliferous, containing abundant crinoidal debris which constitutes as much as 75 percent of some beds. Horn corals, colonial corals, brachiopods, and bryozoans, in part silicified, are also common. The thickest beds, and those of lighter color, are generally composed of coarsely crystalline limestone. In many exposures, limestone beds are highly fractured and siliceous recementation of fractures occurs in several localities.

Chert occurs with the limestone as lenses, irregular nodules and interbeds averaging about 3 inches in thickness; occasionally they are as much as 1 foot thick. The chert is mostly dark gray to

black; some is light bluish gray and white in color. Some of the black cherts emit a fetid odor when freshly broken. In most exposures, the chert is not concentrated at persistent stratigraphic horizons but is randomly distributed throughout the formation; however, in some sections the percentage of chert is higher in the uppermost part of the formation. Some of the chert contains silicified fossils similar to those found in the limestone.

Thin beds of limy shale are interbedded with limestone in some sections, but constitute a minor part of the formation. Medium-gray dolomitic limestone in beds less than 1 foot thick also occurs in some sections but does not seem abundant or widely distributed in the Kukpowruk-Nuka Rivers region.

Section 4. Kogruk Formation, type section. Measured by E. G. Sable, August, 1950.

Unit	Thickness in feet
Tupik Formation	
Fault?	
1. Limestone and chert interbedded. Limestone, dark gray to medium light gray, platy to massive, dense, silty; crinoidal debris common. Siliceous limestone in upper 25 feet of unit contains silicified spiriferoid brachiopods and horn corals. Chert, dark gray to medium gray, in irregular beds and lenses, comprises about 30 percent of lower half of unit, and about	

20 percent in upper half. Resistant unit . . . . 130±

2. Limestone with few interbedded irregular chert nodules. Limestone includes medium-gray bioclastic types, in massive beds as much as 8 feet thick, interbedded with dark-gray, thin-bedded, platy to fissile, very finely crystalline and silty limestone. Contains crinoidal debris and scattered spiriferoid and productid brachiopods . . . . 220±

3. Rubble of limestone and chert similar to that in unit 1, but less resistant. Some thin-bedded, platy, argillaceous limestone . . . . 150±

4. Limestone and chert interbedded. Limestone, medium dark to dark gray, weathers medium light gray and grayish orange; fine to medium crystalline, soft, in beds averaging about 4 inches thick, with fetid odor on fresh fracture surfaces. Contains abundant crinoidal debris and horn corals, and less common spiriferoid brachiopods, productid brachiopods, and colonial corals. Chert, dark gray to black, not abundant, poorly exposed unit . . . . 20±

Total measured thickness . . . . 520±

Utukok Formation. Contact believed to be gradational.

Section 5. Kogruk Formation, mountain exposures at lat. 68°34'45" N., long. 160°50' N., measured and described by J. T. Dutro, Jr., on July 10, 1951.

Unit	Thickness in feet
Top of section, overlain by Okpikruak Formation.	
1. Chert, dark gray, granular, iron stained on upper surface	0.3
2. Silicified limestone, light brownish gray	2.7
3. Limestone, light brownish gray, coarse grained, contains silicified crinoidal debris and shell fragments; about 5 percent black chert nodules in lower 10 feet	37±
4. Limestone as in unit 3, with lensatic concentrations and silicified crinoidal debris	5
5. Limestone, brownish black, fine to medium grained, weathers medium gray, contains 40 percent black chert nodules and 10 to 20 percent fine bioclastic material	20
6. Partly covered. Limestone, dark brownish gray to brownish black, weathers medium gray, with 10 percent granule-size bioclastic material	8
7. Limestone as in unit 6, beds 0.1 foot thick	3
8. Limestone as in unit 6, but beds 1 to 3 feet thick with thinner interbeds 0.1 to 0.2 foot thick	9

9.	Limestone as in unit 6; contains <u>Syringopora</u> colony 1 foot in diameter and 1 foot thick at top of unit	2
10.	Limestone, light brownish gray, fine grained, with 60 to 75 percent very coarse crinoidal debris and other fossil fragments in lenses as much as 0.3 foot thick	4
11.	Limestone, brownish gray, subaphanitic, mostly in massive beds 5 to 8 feet thick, contains about 25 percent small pebble-size crinoidal debris. Thinner limestone beds 0.1 to 0.3 foot thick 6 to 8 feet below top of unit, contain black chert nodules	25
12.	Limestone and chert interbedded. Limestone medium dark gray, coarse grained, weathers light bluish gray, in beds 1 to 2 feet thick. Black chert, about 10 percent of unit, in beds 0.3 to 0.5 foot thick and nodules about 0.3 foot long and 0.1 foot thick, elongated parallel to bedding	23
13.	Limestone as in unit 12, but medium grained, in beds 0.2 to 0.6 foot thick	29.5
	Thickness measured	168.5±
	Utukok Formation?	
14.	Covered	645±
15.	Limestone, interbedded, medium dark gray, fine grained, sandy with 40 to 50 percent crinoidal granule-size fragments and limestone, brownish gray, fine grained sandy, weathers medium gray, with lamellar fluted surfaces. Crinoidal beds, about 70 percent in lower 20 feet, disappear upward	60
16.	Talus covered	75±
	Measured thickness	780±
	Fault	

Two thin sections of limestones from the Kogruk Formation were examined under the petrographic microscope. In hand specimen, sample 50ASa195 is very light gray to yellowish gray, coarse grained, crinoidal, and massive to blocky. In thin section the rock can be termed a very coarse grained fossiliferous calcarenite (Pettijohn, 1957). The rock has a granular structure, with no preferred orientation of grains. Carbonate cement, probably entirely calcite, makes up about 50 percent of the section. Poorly sorted detrital grains consist mostly of crinoid debris and shell fragments and subround, angular, or irregularly shaped carbonate, as much as 1.5 mm in diameter with a modal size of about 0.5 mm. A few crinoid columnals have been replaced by cryptocrystalline quartz. Smaller carbonate fragments may also be comminuted shell and crinoid debris. A few tiny circular black opaque grains, possibly carbonaceous material, are also present.

Sample 50ASa238 from the Kogruk Formation in hand specimen is a medium-dark to olive-gray medium-grained limestone. In thin section it is similar to 50ASa195 except that it is finer grained with constituents less than 0.75 mm in diameter and grains are about 30 percent of the section. Hematite, limonite, and a moderate yellow opaque mineral are present as coatings on some carbonate grains, along irregular fractures, and finely disseminated in the matrix. A few small euhedral carbonate crystals, possibly dolomite, are present. A small amount of black opaque material is present in some fractures. Pore space is less than 5 percent. The rock is a medium- to coarse-grained fossiliferous calcarenite.

Measurements believed to represent the total thickness of the Kogruk Formation were obtained at a few localities. These sequences, however, may be cut by faults which were not recognized during field studies; they lie in structurally complex belts and show considerable variation in thickness within relatively short distances. The thickest section of Kogruk, measured by M. D. Mangus 5 miles west of the type section, is about 1,500 feet thick. Seven miles to the southwest, a section was estimated by E. G. Sable to be 1,400 feet thick. The type section, however, and a section measured by Sable 3 miles east-northeast of the type section are about 520 and 590 feet thick, respectively. These two sections are overlain by the Tupik Formation and underlain by the Utukok Formation. East of these sections, in a sequence measured by Mangus along Kogruk Creek, the Kogruk Formation

is at least 1,100 feet thick. In the most southeasterly exposures, east of Kogruk Creek, a much thinner Kogruk overlies the Utukok Formation and is overlain by Cretaceous rocks. There the thickness of Kogruk Formation is variable and ranges from 50 to 100 feet.

In the northern belt exposures, no reliable total thicknesses of the Kogruk were obtained. In the western part of the belt along the upper part of Spike Creek, Kogruk sections underlying the Tupik Formation are as much as 1,500 feet thick; but the sections may be repeated by faulting and maximum reliable stratigraphic thicknesses are not more than 800 feet. Farther east, in the headwaters of Iligluruk Creek, the Kogruk overlies the Utukok, and is overlain by Cretaceous rocks. There, thicknesses of the Kogruk Formation are not more than 600 feet. From upper Iligluruk Creek to the Utukok River, thicknesses of Kogruk overlying the Utukok Formation thin progressively eastward to about 50 feet at the Utukok River. One mile east of the Utukok River, however, a partial section thickness of 1,200 to 1,400 feet is estimated. Several sections of Kogruk Formation, overlying the Utukok Formation east of this section, show progressive eastward thinning and are overlain by rocks of Cretaceous age.

Stratigraphic relationships.-- The lower contact of the Kogruk Formation with the Utukok Formation seems gradational. The upper contact with the Tupik Formation appears to be conformable, although the lithologic change is abrupt. The base of the Tupik Formation may represent an erosional or non-depositional hiatus or fault which would account for some of the thickness changes in the Kogruk Formation; however, variable thicknesses of units or unrecognized breaks within the Kogruk Formation itself may be present. The likelihood of the latter possibility is suggested by the rock character in the sections examined along the northern belt of exposures. In the thickest sections, the middle and upper parts of the formation contain thick, resistant limestone beds, whereas the lower part is poorly exposed and appears to be composed of relatively nonresistant strata. Thinner sequences of Kogruk, which overlie the Utukok Formation and are unconformably overlain by the Okpikruak Formation of Cretaceous age, contain massive resistant rock types similar to those in the middle and upper parts of the thicker sections. The thinner sequences possibly represent only the middle or upper parts of the formation which rest directly on the Utukok Formation with the lower part of the Kogruk absent.

Tupik Formation

The Tupik Formation is named after the Tupik Creek, the east-flowing major headwater tributary of the Utukok River. The type section of the formation is exposed on the south side of Tupik Moun-tian, adjacent to and south of the Kogruk Formation type section.

Distribution and outcrop.-- Rocks of the Tupik Formation are typically exposed in the western DeLong Mountains west of the Utukok River, mostly along the south sides of the same belts of outcrop as the Kogruk Formation. Exposures of the Tupik Formation are more restricted than those of the Kogruk in lateral extent. The local

absence of Tupik in these belts can be attributed in part to erosion before deposition of Cretaceous sediments and in part to faulting. In the northern belt of outcrops, the Tupik Formation is exposed west of long. 161°38' W., mostly in rubble-covered ridges and hills lower than the prominent mountains held up by the Kogruk Formation. In the southern belt of outcrops, the Tupik was mapped from the Utukok River westward to about long. 161°32' W. where it crops out in largely rubble-covered hogback ridges on the south sides of the high mountains made up of Kogruk and Utukok Formations. The Tupik also crops out in a small area on the northern front of the belt 5 miles west of the Utukok River where it caps several ridges composed mainly of the Kogruk and Utukok Formations.

Rocks of the Tupik Formation, not as resistant as those of the Kogruk, are generally not well exposed in the Kukpowruk-Nuka region. The largely rubble-covered ridges underlain by the Tupik are dark gray in color, locally accentuated to grayish black by the presence of abundant black lichens which seem to prefer these and other dark siliceous rocks for their habitat. Rubble patches covered with platy limestone and chert fragments of the Tupik produce a pleasant musical tinkling sound when walked upon. Outcrops of Tupik Formation have a distinctive banded appearance due to the weathering of alternating chert and limestone beds. On aerial photographs the Tupik can generally be distinguished from the Kogruk and Utukok Formations by this banded appearance and its darker color tone, but it cannot be distinguished from other cherty sequences of Paleozoic and Mesozoic ages by these criteria.

Rocks which resemble those of the Tupik Formation, mapped as the dark-colored facies of the Lisburne Group, and are known from fossils to be in part equivalent to the Tupik, are exposed both west and east of the Utukok River in belts north and south of the outcrop belts discussed above. The northernmost belt of these rocks, exposed in discontinuous _en echelon_ ridges, extends eastward from beyond the headwaters of the Kukpowruk River, subparallel to the northern belt of Kogruk and Utukok Formations, nearly to the Utukok River. It strikes toward the complex structural belts east of the Utukok River which contain similar rocks in several belts of outcrop and it extends beyond the Nuka River east of the map area. The southernmost belt of rocks resembling the Tupik Formation is composed of mountain exposures in the Utukok and Kugururok Rivers headwaters, but their areal extent is not known. The belt probably extends southeastward in the DeLong Mountains beyond the mapped area.

Character and thickness.-- The Tupik Formation consists mostly of 50 to 70 percent thin-bedded platy limestone with thin interbeds of chert. Limestone is mostly dark/to grayish black, weathers light olive gray to light grayish brown, and is aphanitic, finely crystalline, or silty. The limestone is well indurated, dense, in part siliceous, and commonly emits a fetid odor from freshly fractured surfaces. Beds average about 2 inches in thickness, but some are as much as 2 feet thick. Grayish-black chert occurs as irregular beds, lenses, and

nodules commonly less than 2 inches in thickness but as much as 1 foot thick. Locally, both the limestone and chert contain scattered fossil remains which consist mostly of rhynchonelloid, orbiculoid, and linguloid brachiopods, and crinoid fragments.

Section 6. Tupik Formation, type section. Measured by E. G. Sable, August, 1950.

Unit	Thickness in feet
Incomplete. Top is Holocene erosion surface.	
1. Limestone and chert, interbedded. Limestone, medium dark gray to grayish black, silty to aphanitic, dense, weathers light olive-gray, mostly in platy beds averaging less than 6 inches in thickness but with some massive beds as much as 1.5 feet thick. Chert, grayish black, in irregular beds and lenses as much as 6 inches thick, occurs mostly with thicker limestone beds. Chert and limestone in upper 65 feet of unit form resistant sets of beds as much as 10 feet thick separated by beds of platy limestone. Silicified brachiopods and small amount of crinoidal debris in limestone and chert in upper 65 feet of unit. Platy limestone about 50 percent of unit, massive limestone, 30 percent, chert, 20 percent	135±
Disconformity or Fault?	
Kogruk Formation	

One thin section of limestone from the Tupik Formation, sample 50ASa242 was examined under the petrographic microscope. In hand specimen the rock is a dark gray to grayish black, dense, and silty. In thin section, the rock is silty calcilutite (Pettijohn). In thin section, a yellowish gray in color is imparted by undetermined submicroscopic material in the carbonate cement which makes up about 70 percent of the section. Well-sorted grains of carbonate and quartz with average size of 0.02 mm are imbedded in the carbonate matrix. Boundaries of quartz grains are irregular, and some of the quartz has been extensively replaced by carbonate. A few crinoidal and shelly fragments as much as 0.7 mm long and 0.2 mm wide, some of which are partially replaced by quartz, are imbedded in the cement. Small grains of hematite, limonite, and a black opaque substance, probably organic matter, make up less than 2 percent of the section. Several straight carbonate-filled fractures intersect the bedding nearly at right angles. A black opaque substance extends along bedding for short distances away from some of the fractures, and probably was introduced from the fractures before they were filled. Isolated pore spaces make up about 5 percent of the section.

The total thickness of the Tupik Formation is not known with certainty. In most sequences the upper part of the formation is not well exposed; in other sections the formation is missing because of pre-Cretaceous erosion or faulting. The thickest sequence of the Tupik, computed from field data and measurements on aerial photo-

graphs, lies in the headwaters of Kugururok River at about lat. 68° 32'30" N., long. 161°23' W. and is about 700 feet thick. There the Tupik is overlain with apparent conformity by rocks of probable late Paleozoic and Triassic age. Elsewhere, measured sections of the Tupik Formation are less than 300 feet thick.

Carboniferous-Permian Systems

Cherty and Shaly Rocks

There is considerable uncertainty regarding the classification of cherty and shaly rocks which are older than the Triassic Shublik Formation and, in part, equivalent to and younger than the Mississippian Lisburne Group. These sparsely fossiliferous rocks are complexly folded with and faulted against various other rock units and are themselves highly deformed. They contain rock types similar to those of the Shublik, Siksikpuk and Tupik Formations. In some parts of the area they are dominantly bedded black chert. Fossils collected from these beds suggest that they range in age from Early Mississippian to Permian.

In some localities, three generally different units are recognized. Elsewhere, only one unit is exposed along an outcrop belt. Some outcrop belts are structurally too complex to allow differentiation of these individual units on the geologic map. Consequently, while they have been mapped separately in some parts of the area, in other places they are mapped as one undivided unit. These Carboniferous and Permian rocks, lying in overthrust plates, are of great importance in the understanding of the regional structure because the recognition of their proper position in the stratigraphic column would aid greatly in interpreting the magnitude of thrust faulting. Future work should place emphasis on their differentiation and possible correlation with Paleozoic rocks of different lithologic character, principally the formations of the Lisburne Group and the Nuka Formation.

Distribution and outcrop

The Carboniferous-Permian cherty and shaly rocks are confined almost entirely to the belts of thrust faulting in the southern part of the Southern Foothills and the DeLong Mountains. They are widely distributed and crop out either in narrow linear belts which can be traced for as much as 20 miles, or in irregularly shaped areas as much as 8 miles wide. The resistant cherty rocks form either high hogback ridges, commonly with several hundred feet of relief, or mountainous masses more than 1,500 feet high. These cherty rocks are highly fractured and their rubble covers most of the slopes. Outcrops occur along crests of ridges and in cutbanks where resistant beds protrude through rubble cover. Shaly rocks are poorly exposed except in widely scattered stream cuts. Gray and black lichens commonly accentuate the dark colors of the rock rubble to produce black ridges and hills which contrast with the lighter weathering colors of the other rock units. These rocks are also associated with mafic igneous rocks in many areas.

Character and thickness

Several distinctive rock types constitute the Carboniferous-Permian rocks in the Kukpowruk-Nuka region.

The stratigraphic position of some of these rocks has been determined with a fair degree of certainty; that of others is not well known.

Three general lithologic units, both consisting dominantly of chert with lesser amounts of claystone or shale, limestone, dolomitic siltstone, and siliceous siltstone occur above Mississippian Lisburne Group or below the Triassic Shublik Formation rocks at several localities. No complete sequence is known anywhere in the area, however, and the relationships of the partial sections allow only a general stratigraphic interpretation. The three units are distinguished on the basis of color, thickness of individual chert beds, relative abundance of dark-colored limestone, character and abundance of sparse fossil assemblages, and differences in the proportion of shale. They are referred to as the dark-colored facies of the Lisburne Group, the dark-colored cherty unit, and the light-colored cherty unit. The dark-colored units are probably in part at least time equivalent; the light-colored unit is younger than these.

The dark-colored facies of the Lisburne Group closely resembles the Tupik Formation in many exposures but in some outcrops it contains more abundant shale, thicker beds of chert, and more rarely, sandstone. Rocks in sections 9 and 10 are representative of the unit.

The dark-colored cherty unit is 50 to 90 percent black and dark gray vitreous to dull chert with interbeds of black shale and minor dark limestone, dolomite, and siltstone. The chert is mostly even bedded; beds average 4 to 6 inches thick, although some are as much as

12 inches thick and a few reach 3 feet in thickness. Weathering colors are light gray or, in the case of rocks called "Halloween cherts" by field parties, bright hues of orange and yellow. Sections composed mostly of chert form highly resistant and structurally competent units. Interbedded shale is fissile, sooty, soft to siliceous, and occurs commonly in thin units, although some are as much as 60 feet thick. The shale contains pyrite nodules and weathers yellowish orange at some localities. In some other sections, black chert and interbedded medium-dark-gray siliceous dolomite form a distinctive massive unit which ranges from 35 to 120 feet thick. This unit overlies dark-gray shale containing lenses of dark-gray limestone and siltstone which weather yellowish orange. It probably lies near the base of the sequence. Grayish-green and medium-gray chert and argillite and bluish-gray chert constitute minor parts of the dark-colored cherty unit, but are more common in the upper unit. A minor proportion of dark-gray siltstone is also interbedded with black chert and shale in some sections.

The total thickness of the dark-colored rocks is unknown because their lower contact commonly lies along faults. More than 1,700 feet of dark-colored facies of the Lisburne Group was measured in the headwaters of the Kukpowruk River. In the vicinity of Tupik and Iligluruk Creeks, unfaulted sections of dark-colored units 310 feet and 240 feet thick, respectively, were measured. The base of the sequence was not exposed at either locality. East of the Utukok River, these rocks are

extensively exposed but/cut by many faults. (are) In the headwaters of Seagull Creek, barring possible faulting, the dark-colored cherty unit is more than 600 feet thick, and where it comprises most of the high mountainous mass in the headwaters of Chertchip Creek, this unit is estimated to be as much as 1,000 feet thick.

The light-colored cherty unit of the Carboniferous-Permian cherty and shaly rocks is characterized by interbedded chert, argillite, and shale of diverse colors: medium gray, greenish gray, olive-gray, grayish green, bluish gray, and grayish red. Black chert and shale form minor amounts of the sequence. Chert beds average 1 to 3 inches thick and rarely are as much as 2 feet thick. They are uniformly bedded to nodular. Cherts are vitreous to dull, in part silty, commonly weather greenish to olive-gray, and include both uniformly colored beds and beds characterized by streaky color banding. Sections composed almost entirely of chert are as much as 220 feet thick. In other sections dark-gray shale containing thin siltstone and sandstone lenses is as much as 100 feet thick. Medium-gray, massive, banded argillite comprises 140 feet of a 340-foot-thick section on upper Seagull Creek.

A distinctive association of rock types consisting of grayish-red and grayish-green chert, siliceous shale, and argillite with minor amounts of reddish and greenish siltstone occurs at one or more levels in the upper unit at some localities. The chert and argillite occur as irregular lenticular beds less than 4 inches thick; the shale is fissile to blocky. In some outcrops, the coloration corresponds to bedding; in others it crosses bedding in an irregular fashion. In most measured sections where this facies is exposed, it is less than 25 feet thick. At one isolated locality in the headwaters of Chertchip Creek, however, more than 125 feet is exposed. The reddish and greenish colors may not be primary sedimentary features. Reddish chert and limestone have been observed in exposures which are indisputably Triassic Shublik Formation. At these places the colors are clearly post-depositional. The irregular color distribution in some of the Carboniferous-Permian upper unit rocks suggests that at least some of the colors are post-depositional.

The total thickness of the light-colored cherty unit is not known because of faulting and pre-Cretaceous erosion. From a comparison of partial sections, the average thickness of the unit is estimated to be about 500 feet.

The following partial sections of Carboniferous-Permian cherty and shaly rocks are representative of these units in the Kukpowruk-Nuka region:

Section 7. Carboniferous-Permian cherty rocks, exposed in hills 1 mile north of Tupik Creek, lat. 68°33'30" N., long. 161°07' W. Measured by E. G. Sable, August 12, 1950.

Unit	Thickness in feet
Top of section. Overlain by Okpikruak Formation.	
A. Light-colored cherty unit.	
1. Mostly covered. Scattered rubble of chert and siliceous shale, grayish green, olive-gray, bluish gray, medium to dark gray	200
2. Silceous shale and chert; grayish red and grayish green, nodular to fissile, irregular beds; a few thin grayish-red siltstone lenses	10
3. Chert and siliceous shale; medium gray, dull; nodular chert in beds less than 4 inches thick	15
4. Chert, with minor thin shaly interbeds; chert mostly medium gray and bluish gray with some interbedded black and greenish-gray beds; uniform to undulating bedding surfaces; unit contains thin bed of sedimentary breccia composed of angular chert fragments, less than half an inch in diameter, in a gray chert groundmass	40
B. Dark-colored cherty unit.	
5. Mostly covered. Rubble of black chert and shale	100±
6. Chert, black; massive beds from 1/2 inch to 2 feet thick; thin interbeds of black shale; bright iron-stained weathering on fracture surfaces. .	35

7. Chert and siliceous dolomite, interbedded; chert about 50 percent of unit in upper part, increases to 70 percent in lower part; black to dark gray, vitreous to dull, in part silty, in irregular beds as much as 1½ feet thick and lenses as much as 2 inches thick and 2 feet long; dolomite medium dark gray, weathers grayish brown, olive-gray, and moderate yellowish brown; silty, in part laminated, irregular beds as much as 5 inches thick; contains a few orbiculoid brachiopods (50ASa219f); resistant unit 120

8. Shale, dark gray; with thin lenses and beds of olive-gray to dark-gray siltstone and limestone weathering bright yellowish orange . . . . 35±

Base of section. Fault

Total thickness . . . . 555±

Triassic rocks are exposed near the above section, but their contact with the Carboniferous-Permian units is believed to lie along a fault. Farther west, in the headwaters of Spike Creek, a somewhat different sequence of Carboniferous-Permian rocks is overlain by Triassic rocks. The upper part of this sequence may include rocks of the Shublik Formation.

Section 8. Composite section of Carboniferous-Permian-Triassic? rocks exposed along Spike Creek and tributary, lat. 68°35'30" N., long. 161°45' W. Measured by E. G. Sable, July, 1950.

Unit	Thickness in feet
Top of section. Overlain by Shublik Formation.	
A. Light-colored cherty unit.	
1. Largely rubble covered. Chert and shale; chert grayish green, black, gray; shale mostly dark gray; minor thin limestone beds in upper part	200±
2. Chert, grayish green, uniformly bedded; beds less than 6 inches thick, average 2 to 3 inches; thin interbeds of shale; 1-foot bed of light gray siliceous limestone at top of unit	65
3. Argillite, dark greenish gray, blocky; beds less than 1 foot thick; gradational to thin beds of chert and shale	60±
4. Chert, greenish gray and medium gray, interbedded; thin shale interbeds	25
5. Covered. Fault?	20
B. Dark-colored cherty unit or dark-colored facies of Lisburne Group.	
6. Interbedded chert, limestone, and shale. Chert and limestone 70 percent of unit, black to grayish black, irregular lensing beds as	

much as 3 feet thick; limestone weathers yellowish gray, fine to coarsely crystalline, in part laminated, with bituminous odor; contains orbiculoid, leiorhynchid, productid, and chonetid brachiopods in one 3-foot bed; black shale, 30 percent of unit, not well exposed 60

Base of section. Anticlinal axis or fault.

Total thickness. . . . . 430±

The thickest well-exposed section of these rocks, in the headwaters of the Kukpowruk River, consists mostly of the lower "black facies."

Section 9. Carboniferous-Permian cherty rocks exposed in headwater tributaries of Kukpowruk River, lat. 68°24'30" N., long. 162°42' W. Measured by R. M. Chapman and E. G. Sable, June, 1949.

Top of section

Unit	Thickness in feet
A. Light-colored cherty unit (Permian?)	
1. Chert, mostly medium dark gray, grayish red, greenish, yellowish gray, uniform to banded; uniformly bedded, beds 1 to 5 inches thick; minor amounts of interbedded black chert and silty shale	90±
2. Covered. Probably mostly shale	100±

B. Dark-colored facies of Lisburne Group.	
3. Chert, black, massive, beds 3 to 12 inches thick; interbedded with lesser amounts of dark-gray limestone and minor amounts of black clay and silty shale; abundant calcite veinlets	75
4. Covered	100±
5. Limestone, interbedded chert and shale. Limestone dark gray to black, sublithographic, fetid odor; chert black, in uniform beds and lenses; silty shale black, about 20 percent of unit	150
(Note: All limestones in this section emit a fetid odor from freshly fractured surfaces)	
6. Mostly clay and silty shale, black, fissile; minor amounts of interbedded chert and limestone as in unit 5	100
7. Limestone, black, weathers yellowish gray and light gray, dense; interbedded black chert beds and lenses as much as 1 foot thick; some black siliceous shale	70
8. Limestone, chert, and shale as in units 5 and 6; shale and chert predominant in upper 100 feet; quartz-filled veinlets and vuggy cavities common	200
9. Limestone, medium gray to black, silty, weathers light gray, laminated; minor amounts of interbedded black chert and shale	40

10. Shale, limestone, and chert interbedded. Limestone as in unit 9, 20 percent of unit; black shale 60 percent; 2- to 8-inch-thick chert beds, 20 percent 150

11. Limestone, medium dark gray, sublithographic to silty, weathers yellowish gray and light gray . . . 10

12. Shale, black, fissile; contains beds and lenses of soft black limy siltstone less than 1 inch thick . . . 45±

(Note: Section below this exposed 1 mile northeast in mountain gulley. Exact correlation between upper and lower sections uncertain.)

13. Limestone and shale interbedded. Limestone predominant, dark gray to black, silty to finely crystalline, contains thin layers of dwarfed fauna including brachiopods, crinoidal debris, and bryozoans 25

14. Limestone, dark to medium gray, oolitic texture; in part fossiliferous 9

15. Chert, black, evenly bedded, 2- to 6-inch beds; thin interbeds of black shale 18

16. Limestone, shale, and chert interbedded. Limestone predominant, as in unit 13; black chert as thin lenses in limestone 15

17. Chert, black, with thin interbeds of black shale in upper 5 feet; tiny organic remains in chert 15

18. Limestone, dark gray to black, massive, finely crystalline 5

19. Interbedded chert and very fine grained black dolomite(?); calcite veinlets common 20

20. Limestone, medium gray, weathers light gray, massive 3

21. Chert, black, massive to blocky, in part finely banded; with thin interbeds of black shale 40

22. Talus of black chert with small amount of siliceous limestone breccia. Fault? 35

23. Limestone and shale interbedded, black to dark gray; dwarfed fauna including brachiopods in lower part of unit 18

24. Limestone and shale interbedded, as above; few small chert nodules in limestone contain tiny indeterminate fossile remains 29

25. Limestone, black, finely crystalline, massive; 4-foot bed of black shale in middle of unit 17

26. Limestone talus; includes 1-foot bed of black shale at top of unit 8

27. Limestone, dark gray to black, thinly bedded; minor amounts of interbedded black shale near top of unit . 12

28. Talus, limestone and shale 60

29. Interbedded black chert, shale, and limestone; beds less than 6 inches thick 6

30. Talus, shale, limestone, and chert as above . . . . . 50+

Base of section. Fault.

Total thickness . . . . 1515±

Along the mountain front between the Utukok River and Spike Creek, the dark-colored facies of the Lisburne Group is in part of Early Mississippian age and overlies Devonian rocks. Basal sandstone and shale may be Kayak Shale (Bowsher and Dutro, 1957) equivalents.

Section 10. Dark-colored facies of the Lisburne Group exposed in cutbanks on west side of Iligluruk Creek tributary, lat. 68^{o} 36' N., long. $161^{o}16'$ W. Measured by E. G. Sable, August 9, 1950.

Unit	Thickness in feet
Top of section. Fault, dipping 55^{o} south.	
1. Chert and shale interbedded, black; with a few dark-gray limestone nodules	8
2. Chert, limestone, and shale interbedded; black to dark gray; chert 70 percent of unit; limestone finely crystalline to silty, in beds as much as 2 feet thick and as irregular nodules in chert	15
3. Limestone, medium dark gray, weathers medium gray, silty to finely crystalline, dense, massive, irregular to nodular beddings; organic odor from freshly fractured surfaces	5
4. Chert, limestone, and shale interbedded, dark gray to black; limestone, in part, in thin platy beds; in part fossiliferous (*Leiorhynchus* sp. and other brachiopods. . .	5
5. Limestone, as in unit 3	8
6. Chert, black, beds as much as 4 inches thick; inter-bedded with minor amounts of black shale	3
7. Limestone, as in unit 3, but with thin interbeds of black shale	9
8. Chert and shale interbedded, black, weathers yellowish gray, in beds as much as 4 inches thick; upper part of unit dominantly chert with nodules of medium-gray lime-stone; lower part dominantly shale with nodules of chert . .	16
9. Silty and clay shale, black, weathers to "sulfur yellow" color; contains nodules of limy quartzitic siltstone, weathering yellowish orange; nodules of olive-gray arilla-ceous limestone, as much as 1 foot thick, near base of unit	62
10. Rubble covered, black shale and siltstone; black limy spherical concretions at top of unit associated with shale; goniatite, *Muensteroceras* sp. found in concretion.	50±
11. Sandstone, dark gray to black, weathers yellowish orange and light brown, dense; beds as much as 1 foot thick; some sand grains are iron stained.	15

12.	Covered	4
13.	Shale, black and medium dark gray, with thin interbeds of siltstone similar to sandstone as in unit 11	9
14.	Sandstone, as in unit 11	20

Base of section. Underlain by Devonian rocks of section 2.

Total thickness . . . . 239±

Four samples of siliceous rocks form the Carboniferous-Permian sequence were examined under the petrographic microscope. The first two samples are from the lower unit.

In hand specimen, sample 51ASa129 is black chert containing lenses of dark-gray, silty-appearing siliceous material. In thin section, the siliceous material is composed of about 30 percent dolomite rhombs in a finely crystalline quartz groundmass. No sharp contact between the dolomitic portion and that composed entirely of quartz can be seen. Tiny black opaque grains, probably carbonaceous matter, are scattered through the section.

Sample 51ASa52 in hand specimen is a dark-gray, silty- to waxy-appearing chert in which gradations in grain size can be seen with a hand lens. In thin section, angular grains of quartz, plagioclase feldspar, opaque minerals, and spheroidal grains of an isotropic substance surrounded by brownish aureoles occur in a groundmass of almost isotropic, very finely crystalline quartz.

Stratigraphic relationships

In the headwaters of Spike and Iliglurik Creeks, Carboniferous-Permian cherty and shaly units overlie the Tupik Formation at several localities, and along the belts of Lisburne carbonate rock exposures the cherty units are interpreted to lie between the Lisburne Group and Triassic rocks. North and east of the main Lisburne Group exposures, however, the base of the dark-colored facies of the Lisburne Group is interpreted to normally overlie Devonian rocks at two localities at the DeLong Mountain front. These exposures are in cutbanks on Iligluruk Creek (Section 10), and a tributary of Spike Creek. At the former locality, a Muensteroceras of Early Mississippian age was found in a sequence of black shale and siltstone overlying brownish shale and limestone of Devonian age. Less than 100 feet of well-exposed section separates the Muensteroceras beds from fossiliferous Devonian limestone. Black chert and limestone 100 feet above the Muensteroceras occurrence contains leiorhynchid brachiopods of probable Late Mississippian age.

At the Spike Creek locality relationships are not as clear. Here, 60 feet of black chert, shale, and limestone contains a few orbiculoid brachiopods and lies within 20 feet of Devonian limestone.

These relationships suggest that the dark-colored rocks of the Carboniferous-Permian cherty rocks include time equivalents of all of the Mississippian Lisburne Group rocks exposed farther south and that the entire Mississippian sequence here may be largely chert and shale. If this interpretation is correct, then the Utukok, Kogruk, and Tupik Formations have probably been superposed onto the cherty units by large-scale overthrusting.

Within the Carboniferous-Permian cherty sequence no major structural or erosional breaks were recognized. The significance of the thin sedimentary breccia beds or reddish zones is not known.

Triassic rocks overlie the cherty unit in several widely scattered localities but, where examined, the contact between the two sequences is obscured by unfossiliferous shale and chert rubble which is similar to rock types in both sequences.

The upper cherty unit contains some rock types like those of the Siksikpuk Formation exposed in areas farther east (Patton, 1958) but the scarcity of diagnostic fossils in these units in the Kukpowruk-Nuka region makes specific correlation difficult. General stratigraphic position and rare fossils, however, suggest that they are equivalents of the Siksikpuk Formation and/or the Nuka Formation. Because the Siksikpuk Formation is also exposed to the west at Cape Lisburne (Campbell, 1967), it is likely that its equivalents would be present in the Kukpowruk-Nuka region.

Fossils and age

Megafossils found at scattered localities in the Carboniferous-Permian cherty rocks are almost entirely confined to the dark-colored units and occur mostly in sections containing carbonate rocks. Except for a few localities, it has not been possible to satisfactorily correlate these sections because of the complex structure and lack of stratigraphic detail. All of the fossils from

the lower unit and from rocks which are lithologically similar to it point to a late Paleozoic age, and most collections are Early to Late Mississippian in age. Rhynchonelloid, orbiculoid, chonetid, and linguloid brachiopods are the more common types often associated with scattered crinoidal debris. Some of the collections resemble those from the Tupik Formation.

No fossils of definite Pennsylvanian age have been recognized in rocks of the Kukpowruk-Nuka region.

The upper unit of the Carboniferous-Permian sequence is unfossiliferous except for a few gastropod and brachiopod shells, and undiagnostic shell fragments which may represent leiorhynchid brachiopods or pectenoid pelecypods. From its general stratigraphic position, and, in part, lithologic similarity to the Siksikpuk Formation of eastern area, the unit may be Early Permian in age. It is also possibly equivalent, in part, to the Nuka Formation. Finally, the uppermost part of the sequence may include rocks of Triassic age at a few localities.

Nuka Formation

Rocks of Permian and probable Permian age include cherty and argillaceous sequences described in the foregoing section of this report. Some of these are lithologically similar to the Siksikpuk Formation (Patton, 1958), and are mapped with Carboniferous-Permian cherty and shaly rocks in the Kukpowruk-Nuka region. Other Permian rocks, in large part lithologically different from the Siksikpuk Formation, are assigned to the Nuka Formation (Tailleur and Sable, 1963).

This formation has been directly traced into the Kukpowruk-Nuka region from adjoining areas farther east where the type section is exposed. Rocks of the mapped unit as described here correspond to the original definition of the Nuka Formation (Tailleur and Sable, 1963) and not to the restricted usage of Tailleur, Mamet, and Dutro (1972).

Distribution and occurrence

The main outcrops of the Nuka Formation lie in the southeastern part of the Kukpowruk-Nuka region, mostly between lats. 68°40' N. and 68°43' N. Resistant units of the formation are exposed in high north-facing hills and in linear, mostly rubble-covered ridges. Lowlands between the hills and ridges are tundra covered. West of these exposures, the formation is present at many localities in several complex structural belts as far west as the headwaters of Elbow Creek. These exposures consist of linear ridges and rubble-covered patches not connected with the larger main exposures. The westernmost known exposures lie near southern boundary of the area, near Cairn Creek, a tributary of the Kugururok River. The northernmost known exposures consist of a few isolated and mostly rubble-covered patches in the vicinity of Storm Creek at about lat. 68°44' N.

Weathered exposures of the Nuka Formation are mostly pale to moderate yellowish brown and light to medium gray. From a distance, some of the outcrops resemble the Utukok Formation in weathering color. Resistant units of the Nuka form ledges and cliffs and talus of these units is composed of dominantly boulder-size blocks. On aerial photographs, the outcrops and rubble are light gray to white in tone and

resemble those of the Kogruk Formation.

Character and thickness

The Nuka Formation, as exposed in the Kukpowruk-Nuka region, consists largely of arkosic sandstone and conglomeratic sandstone, platy limestone, shale, and siltstone. Chert, sandy dolomite, and conglomerate make up minor parts of the formation. The coarser clastic rocks are unlike other clastic rocks in the area; they are relatively clean and well sorted, consist almost entirely of well-rounded to subangular quartz and feldspar grains, and include some glauconitic sandstones. Sandstones and conglomerates, which comprise about 50 percent of the sections examined, are mostly fine to very coarse grained, very light to medium gray and yellowish gray in color, and weather gray to moderate yellow-brown. They are quartzitic to friable and contain scattered granules and small pebbles of clear to frosted quartz, feldspar, and black chert. Fossils include scattered crinoid columnals and shell fragments and, more rarely, whole shells, mostly of productid brachiopods. Some of the coarse clastic rocks are medium dark gray, probably due to organic matter, and others are a distinctive gray-green color due to the presence of glauconite and chlorite. The sandstones and conglomerates occur in blocky to massive beds averaging about 2 feet thick, but as much as 10 feet thick, and form resistant units as much as 100 feet in thickness. They are massively crossbedded (foreset beds inclined as much as 20° from topset beds), laminated, and uniform in appearance, and beds are commonly lenticular.

Limestone and limy siltstone are mutually interbedded and are interbedded with sandstone units. The limestones are mostly dark gray and silty, although some light-gray and olive-gray limestones and finely crystalline to sublithographic cherty limestones are present. Grayish-green, glauconitic limestone is interbedded with sandstone and other types of limestone in some exposures of the formation. Some limestone beds contain scattered granules of quartz and black chert. Fossiliferous limestone contains brachiopods (mainly productid types), bryozoans, horn corals and crinoidal debris, in part silicified. The limestone beds are commonly less than 1 inch thick, but may reach as much as 1 foot in thickness. They are commonly laminated, with laminations an eighth of an inch to a quarter of an inch thick. Much of the thin platy limestone resembles that of the Tupik Formation, but associated chert is more common in the Tupik. In the Nuka Formation, chert interbedded with the limestones is medium dark gray, uniformly bedded, and in beds as much as 6 inches thick. Rubble exposures of bluish-gray, greenish-gray, and grayish-red chert, commonly associated with the clastic facies of the formation, are mapped with the Nuka.

Unfossiliferous shale and siltstone, associated with and appearing to both overlie and underlie some of the resistant sandstone and limestone sequences described above, are also mapped as Nuka Formation. Dark-gray, fissile to hackly, silty shale comprises 70 to 80 percent of these rocks. It is interbedded with thin lenses and beds of dark-gray and medium-dark-gray siltstone which weathers bright yellowish brown and yellowish orange. Both the shale and siltstone are laminated

to finely crosbedded and are, in part, calcareous.

Four thin sections of Nuka Formation clastic rocks were examined under the petrographic microscope. Two sections are of granule conglomerate. Sample 51ASa62, in hand specimen is medium light gray and light olive-gray, massive, quartzitic, with iron-stained weathering surfaces. Subround, frosted grains of quartz and feldspar are as much as 5 mm in diameter. In thin section, the rock is intermediate between a quartzitic feldspathic sandstone and a quartzitic arkose. Detrital grains, estimated to comprise 90 percent of the section, are poorly sorted and tightly packed. They range to as much as 4.4 mm in diameter with modal size of 0.25 mm. They consist largely of quartz, about 80 percent, mostly in single grains but with some composite grains, which may be vein quartz or chert. Microcline (10 percent) and plagioclase (about 5 percent) (Albite, Ab_{90}-Ab_{10} and Oligoclase, An_{75}-An_{25}), and a few grains, possibly orthoclase, comprise the remainder. Cement, about 20 percent of section, is cryptocrystalline quartz with minor carbonate. A yellowish-gray earthy mineral (limonite?) is conspicuous in the cement and along intergrain contacts. Sample 51ASa231 in hand specimen is similar to 51ASa62, but is medium dark gray in color. In thin section, the rock is also similar to 51ASa62, except that mineral grains range from subround to angular, quartz grains (about 70 percent) exhibit irregular etched edges, feldspars (30 percent) are in part sericitized or replaced by carbonate and include larger proportaion of plagioclase than 51ASa62. Cement (about 20 percent of section) includes minor amounts of carbonate. A dark-brownish-black substance, probably organic matter, is common along intergrain contacts and in the cement and gives the rock its dark color.

Two very fine grained sandstones from the Nuka Formation were also examined under the microscope. Sample 51ASa124 (Section 11, unit 12) in hand specimen is grayish green and well indurated. In thin section the rock is a calcareous feldspathic sandstone. Moderately well-sorted, subangular to angular grains of quartz, plagioclase, and microcline in relative order of abundance are the major grain constituents. Some feldspars are in part sericitized and replaced by carbonate, others are clean in appearance. Glauconite(?), tourmaline(?), opaque minerals, and bryozoan(?) fragments replaced by carbonate are minor elements. Modal size of grains is .06 mm. Cement comprises about 25 percent of the section and is dominantly calcite with some green chlorite and limonite.

Sample 51ASa315 in hand specimen is yellowish gray and well indurated. In thin section it resembles 51ASa124, but grains are more closely packed, tiny scattered grains of hematite are present, and the chlorite is dominantly brown in color.

No single complete sequence of the Nuka Formation is known to be exposed in the area. The formation has been overthrust onto rocks as young as Early Cretaceous and is commonly overlain unconformably by Early Cretaceous rocks. In the southeastern part of the area, the maximum exposed thickness of the formation is probably more than 1200 feet. In the complex structural belts west and north of these

exposures, sequences composed dominantly of the resistant coarse clastics and limestones range from a few tens of feet to about 450 feet thick.

Section 11. Nuka Formation, headwaters of Kidney Creek.

Measured by E. G. Sable on July 4, 1951.

Unit	Thickness in feet
Top of section. Overlain by rubble	
1. Silty shale and siltstone interbedded. Shale dark gray, fissile, hard, about 70 percent of unit. Siltstone dark gray and medium gray, weathers bright yellowish brown, argillaceous, finely laminated and crossbedded, in lenticular beds ½ inch to 1 inch thick . . .	200±
2. Covered	50±
3. Rubble. Limestone, quartzitic siltstone, and quartzitic sandstone. Limestone medium gray, weathers pale yellow-brown, platy, contains scattered subround to subangular black chert pebbles as much as a quarter of an inch in diameter and few brachiopods. Siltstone medium dark gray, calcareous. Sandstone very light gray, fine to coarse grained, well-rounded grains appear to be clear to frosted white quartz	25±
4. Rubble. Limestone, medium dark gray, sandy, silty, and argillaceous, platy to blocky	10±
5. Limestone as in unit 4, beds 3 inches to 1 foot thick,	

contains brachiopods, bryozoans, and crinoid debris. Interbedded with small amount of medium crystalline fossiliferous limestone. One 6-inch bed of medium-dark-gray chert 25 feet above base	30
6. Siltstone, olive-gray, platy, calcareous, contains poorly preserved brachiopods and chrinoid debris	5
7. Mostly covered. Limestone, dark gray, sandy, platy, with interbedded siltstone as in unit 6	17
8. Sandstone and quartzite, very light gray, weathers yellowish brown to white, clean, calcareous, in lenticular massive beds 1 to 4 feet thick; in part massively crossbedded. Unit thins eastward to 25 feet thick within 2,000 feet distance	40
9. Talus covered, Sandstone, quartzite, and limestone as in units 8 and 9	15
10. Sandstone, grayish green, very fine to coarse grained, contains white quartz grains, massive to platy, calcareous, slightly micaceous, friable to well indurated	5
11. Talus covered. Sandstone, quartzite, and limestone as in units 8 and 10	30
12. Interbedded sandstone, conglomeratic sandstone, and quartzite. Grayish-green sandstone as in unit 8, in beds 1 to 5 feet thick, 60 percent of unit. Sandstone, medium dark gray, very fine grained, calcareous, with	

coarser lenses containing granules and small subround pebbles of quartz and black chert; about 35 percent of unit. Limestone, dark gray, platy, finely crystalline, about 5 percent of unit, contains poorly preserved brachiopods and crinoid debris. Small amount of dark-gray bedded chert in talus	20
13. Sandy limestone and limy siltstone, light to dark gray, weathers moderate yellowish brown, contains scattered quartz grains, blocky to platy	5
14. Talus covered	25±
Fault	
Measured thickness	477±

The descriptions of Nuka Formation rocks apply to the northern belts of outcrop of the formation. Farther south, exposures of shale, siltstone, sparsely fossiliferous platy limestone, limestone conglomerate, and chert, are present in the headwaters of Kidney Creek and in a belt extending at least from the headwaters of Trail Creek as far west as the mountains in the vicinity of Cairn Creek. The shale, siltstone, and limestone strongly resemble the less-resistant rock types described above. Quartzose sandstone rubble similar to that described above is exposed along part of the latter belt and, if not faulted, overlies or is interbedded with a dominantly shale-siltstone sequence. The sequence appears to be underlain by black chert and limestone of probable Mississippian age; it is intruded by mafic igneous rock and is in fault contact or unconformably overlain by rocks of Jurassic or Cretaceous age. A description of one section of this sequence, which is mapped as the questionable Nuka Formation, is given below.

Section 12. Nuka Formation(?) exposed along mountain side on west side of Trail Creek. Measured by E. G. Sable, July 13, 1951.

Unit	Thickness in feet
Overlain by Okpikruak Formation.	
1. Rubble, gray and black chert	?
2. Chert, grayish green, bedded	10±
Fault?	
3. Chert and argillite, grayish green, uniformly bedded, beds 1 to 4 inches thick, Minor amount of grayish-red weathering chert	45
4. Covered	20
5. Microgabbro sill, grayish green, medium crystalline. . . .	50
6. Marble, light gray, very finely crystalline.	4
7. Microgabbro sill, similiar to unit 5	5
8. Chert, black, silty, weathers yellowish orange, beds 2 to 6 inches thick. Recrystallized zone of granular chert 4 inches thick at top.	13
9. Limestone and chert interbedded; limestone dark gray, sublithographic platy to blocky, weathers light olive-gray and brownish gray; 70 percent of unit; contains few rhynchonelloid brachiopods. Chert, black, as irregular nodules and beds. Unit has banded appearance . . .	20
10. Limy, silty shale and limy, argillaceous siltstone, interbedded; medium to medium dark gray, weathers yellowish gray and yellowish brown, fissile to platy, laminated, contains scattered pebbles to boulders of limestone, and lenses and irregular beds of light- to medium-gray crinoidal limestone; scattered crinoid debris in shale.	45±
11. Limestone conglomerate. Matrix dark-gray, very finely crystalline soft limestone; as much as 70 percent. Subround pebbles to 5-foot boulders of several limestone types including medium-to dark-gray, medium-grained limestone and white friable limestone, and pebbles of black chert. Massive unit.	40
12. Limestone, dark gray, platy, sublithographic, weathers light gray; massive unit	15
Measured thickness.	277±

Unfossiliferous shaly sequences, similar to shales in the sections discussed above, are exposed in the headwaters of the Nuka River, Kidney Creek, Trail Creek, and Cairn Creek. There is as much as several hundred feet of dominantly silty shale with interbedded yellowish-orange and yellowish-brown weathering siltstone and limestone.

Exact relationships with the other shaly sequences are not known but, on a lithologic basis, and because in part they lie along the same belts of outcrop, the shaly units are believed to be generally correlative. Most outcrops of the unfossiliferous shaly units underlie grayish-green and grayish-red chert, siliceous shale, and argillite of possible Permian age. Along a tributary of Cairn Creek, they overlie black chert and limestone of probable Mississipian age.

A section representative of this sequence, including overlying Permian(?) chert, siliceous shale, and argillite, is described below:

Section 13. Nuka Formation(?) exposed along south side of Trail Creek. Measured by E. G. Sable, July 12, 1951.

Unit	Thickness in feet
Okpikruak Formation; fault or angular unconformity.	
1. Poorly exposed. Chert, medium gray, glassy to granular, beds 1/2 inch to 3 inches thick, weathers moderate yellowish green	35
2. Chert, bluish gray, glassy, beds 1 to 3 inches thick . . .	8
3. Chert, grayish red, grayish green, and bluish gray; grayish-red chert about 60 percent of unit in beds 1/2 inch to 3 inches thick; reddish coloration also crosses bedding of greenish and bluish cherts.	35±
4. Chert, medium dark gray, granular to subvitreous, weathers light gray, 80 percent of unit. Greenish-gray and bluish-gray chert, 20 percent of unit	20±
5. Rubble covered. Siliceous shale, dark gray, weathers pale yellowish gray	10
6. Chert and argillite interbedded. Chert, bluish gray and greenish gray, interbanded and uniformly colored beds 1 to 3 inches thick, 70 percent of unit. Argillite, greenish gray, beds 1/8 inch to 2 inches thick	20
7. Mostly rubble covered. Interbedded silty shale, limy shale, and siltstone. Shale dark gray, micaceous, laminated to finely crossbedded, weathers moderate yellowish brown and yellowish orange, organic odor from freshly fractured surfaces; about 90 percent of unit. Siltstone, medium dark gray, weathers moderate yellowish brown, argillaceous, in part calcareous, in lensing beds as much as 3 feet thick.	65
8. Siltstone and silty shale interbedded as in unit 7, but siltstone dominant in large lenses as much as 20 feet thick	38
9. Rubble covered. Silty shale and siltstone as in unit 7 . .	10
10. Siltstone similar to that in unit 7, laminated.	15
11. Silty shale, limy shale and siltstone interbedded as in unit 7; shale dominant	?
12. Rubble covered. Silty shale, limy shale, and siltstone as in unit 7; shale dominant.	12
13. Limy shale, limy siltstone, and silty shale interbedded	

similar to unit 7; shale dominant 35

Measured thickness . . . . 303±

Section 14. Composite section of Nuka Formation(?), exposed on mountain slopes and tributaries of Cairn Creek, Kugururok River. Measured by E. G. Sable, August, 1950.

Unit	Thickness in fe[et]
Top section. Overlain by mafic igneous rock.	
1. Clay shale and silty shale, dark gray, weathers yellowish orange and reddish orange, fissile. Contains scattered concretions and lenses of reddish-weathering clay ironstone and bright yellowish-orange-weathering siltstone	75±
2. Siltstone, medium gray, weathers yellowish brown, laminated, probably a lense.	10±
3. Shale with lenses of siltstone as in unit 1	65
4. Shale, black, silty, contains scattered nodules of clay ironstone	60
5. Sandstone rubble; light gray, clean, friable, quartzose (position of this unit uncertain)	20?
6. Break in section. Covered.	20?
7. Chert, black, massive beds as much as 1 foot thick. Scattered crinoidal debris.	30
8. Limestone, medium gray, weathers yellowish brown to olive-gray, very finely crystalline to silty, thin bedded, finely laminated and crossbedded. Contains orbiculoid and linguloid brachiopods	65
9. Siltstone and shale, poorly exposed	10
10. Limestone, medium gray, finely crystalline, massive	2
Base of section	
Total thickness	357+

Stratigraphic relationships and mode of deposition

No significant depositional or erosional breaks were observed in exposure[s] Nuka Formation in Kukpowruk-Nuka region, but relationships of units within the formation are not well understood. This is a marine deposit, in which the clastic constituents have been relatively well sorted and reworked. Frosted grains, high-angle and tangential crossbedding, and the clean character and lenticular nature of the sandstone beds suggest an aeolian origin, in part, with reworking in a relatively shallow, clear sea. Interbedded limestones represent intervals of relative quiescence of shallow marine waters during which abundant brachiopods and crinoid assemblages existed. The nearly unfossiliferous shale and argillaceous siltstone sequences represent deposition from turbid water with sluggish current activity.

Interpretation of lateral facies differences is difficult because of the present structural positions of units referred to the Nuka

Formation. The main exposures of the formation are interpreted to lie in an overthrust block. Their original position prior to faulting is not known except that it is interpreted to have lain south of the present outcrop localities. The more southern, dominantly shale, sequences are interpreted to belong to the formation, and suggest relatively quiet, deeper water deposition. They may represent either an overthrust block which originated south of the more northern exposures, or a relatively autochthonous block over which more northerly rocks moved.

If this assumption is correct, the source area lay to the north. Clastic constituents indicate that the source area was rich in felsic rocks, and that only the stable lighter and more resistant minerals survived transportation and deposition.

Triassic System

Shublik Formation

The name Shublik Formation was first applied by Leffingwell (1919, p. 115-118) to a sequence of dominantly dark shale, limestone, and sandstone of Late Triassic age in northeastern Alaska. Triassic rocks in the Kukpowruk-Nuka region, first reported by Smith and Mertie (1930, p. 188-189) at the heads of the Utukok and Colville Rivers and in the Kukpowruk River valley, include chert, sandstone, shale, and limestone. Smith and Mertie recognized that these rocks differed lithologically from those in the type Shublik Formation. More recent investigations have shown that many of the outcrops mapped as Triassic

by Smith and Mertie are now interpreted to be Carboniferous, Permian, Triassic in age. The strata here referred to as the Shublik Formation are rocks which in part are similar to those in the exposures of the type Shublik, but they also include some considerably different rock types.

Distribution and outcrop

Although the Shublik Formation is widely distributed in the Kukpowruk-Nuka region, most of its exposures are of small areal extent. The main belts of Triassic outcrop extend along the front of the DeLong Mountains from the eastern limit of the area at about lat. 68°47' N. southwestward beyond the Kukpowruk River. These belts are composed of several discontinuous bands expressed as linear or curving ridges of moderate relief. Farther north and west, similar Triassic outcrops are scattered. These also trend generally southwest and are associated with rocks of several ages. South of the main belts of Triassic exposures, and west and north of the Nuka River, fossiliferous Triassic rocks were seen only at a few localities. In the headwaters of the Utukok River and west, however, Triassic outcrops, although discontinuous, are more abundant. They lie for the most part between the main northern and southern belts of Lisburne Group and south of the Lisburne Group southern belt
The southernmost locality of Triassic rocks in the region lies on the north side of Mount Bastille. Triassic rocks have been reported south of the Kukpowruk-Nuka region along the Nimiuktuk and Kugururok Rivers (J. T. Dutro , Jr., 1951, written commun.), as far west as the vicinity of Cape Lisburne (Smith and Mertie, 1930, p. 187), and at many

other localities throughout northern Alaska (Payne and others, 1951).

The Shublik Formation is generally not well exposed. Hills and ridges underlain by the formation are largely rubble covered, and beds in most cutbank exposures are extremely contorted, broken by faulting, and largely covered by talus. Many outcrops can be easily recognized, from a distance, because of the distinctive grayish-orange and pale-yellowish-orange- ("buff"-) weathering colors of fossiliferous, cherty limestone that is associated with dark chert and shale. On aerial photographs, the light-weathering limestone traces contrast sharply with the dark cherts and distinguish many exposures of the Shublik from adjacent rocks. Traces are commonly sinuous or, where broken by faulting, are discontinuous and lie at angles to the regional strike of the

Character and thickness

Chert, shale, siliceous shale, and limestone, in approximate order of abundance, comprise the dominant rocks of the Shublik Formation in the Kukpowruk-Nuka region. Chert is variable in abundance, comprises 50 to 90 percent of the sections examined, and is mostly evenly bedded. Beds average less than 3 inches thick, but may be as much as 6 inches thick; locally they contain fossils on bedding surfaces. In addition, chert occurs as nodules and lenses in shale and as irregular lenses interbedded with limestone. The cherts are commonly bluish-gray, olive-gray, medium light gray, and black. Grayish-red, grayish-green, and grayish-olive chert is less common. Weathering colors, commonly various shades of grayish yellow, yellowish orange, grayish green, and light gray, extend as much as a quarter of an inch/ below

the weathered surfaces. Large masses of red jasperoid quartz-veined chert, as much as 50 feet thick, in which bedding is not discernible, are associated and are mapped with the Shublik Formation rocks at a few localities.

Shale comprises 10 to 40 percent of the sections examined and is mostly black, grayish green, and olive-gray. Black sooty shale, interbedded with black limestone and chert, occurs in units as much as 15 feet thick. In some localities it contains spherical black cherty concretions as much as 6 inches in diameter. Some shales have a high organic content and can be ignited. One exposure of black limy shale on the Kukpowruk River yielded abundant pelecypods of the genus Halobia. The greenish and grayish shales are mostly siliceous and commonly occur in thin units interbedded with chert. Some shale units in the Shublik Formation contain conodonts.

Limestones of two distinctly different types occurs in the Shublik Formation. A distinctive easily recognizable zone, consisting of olive-gray- to medium-gray-, "buff"-weathering, dense, lithographic, cherty limestone interbedded with variegated chert, occurs in the upper part of the formation. It varies from a few feet to 35 feet in thickness. Limestone beds, commonly less than 2 inches thick, range to 4 inches in thickness. Some of the limestone is fossiliferous and coquinoid, bearing the pelecypod Monotis. The shells are silicified in many of the limestone beds and the zone contains a correspondingly greater amount of chert than where silicification is not present. In some sections, _Monotis_-bearing chert occupies the stratigraphic position of the limestone. These cherts are of secondary origin, the result of replacement of carbonate by silica.

The second type of limestone is dark gray to black and very fine grained to finely crystalline. It occurs in beds and lenses averaging less than 2 inches, but as much as 6 inches thick. The limestone is interbedded with black chert and black shale in one or more zones below the "buff"-weathering limestone and chert. Dark limestone beds are locally fossiliferous and contain shells of the pelecypods _Daonella_ and _Halobia_. These dark zones resemble rocks in some units of late Paleozoic age and, where unfossiliferous or with poorly preserved or fragmental fossils, the Paleozoic and Triassic rocks are difficult to distinguish. Shublik chert beds are not as thick as many of the Paleozoic cherts, however, and Shublik Formation dark limestone and chert units are thinner and less resistant than those in the Paleozoic sequences.

Minor rock varieties in some sequences of the Shublik Formation include light-gray, dense, black-veined cherty marble associated with the "buff"-weathering limestone and chert zone, and olive-gray, yellowish-orange-weathering, thin-bedded siltstone that is interbedded with chert and limestone.

The rock types of the Shublik, with the exception of the "buff"-weathering _Monotis_-bearing limestone beds, are in themselves not distinctive of this formation. Carboniferous and Permian units contain similar appearing cherts, shales, and dark limestones. Unless

the rocks are fossiliferous or exposed in sections where associations with other rock types are recognized, great uncertainty exists as to whether they represent the Shublik Formation or rocks of late Paleozoic age. Even the criterion of association breaks down at some localities where these rock types are unfossiliferous and are in fault contact with other units. Some of the cherty sequences which are mapped as Shublik Formation may locally include units of late Paleozoic age.

An absolute range of thickness for the Shublik Formation in the mapped area is not known. Lack of well-exposed sections in which structural repetition of beds can be ruled out, post-Triassic erosion, and uncertainty about the lower contact make thickness measurements difficult. The thickest, well-exposed section bounded by fossiliferous beds is 86 feet. In other more poorly exposed sections Triassic fossils are present through as much as 100 section-feet. Thicknesses seem highly variable, and in many parts of the area the Shublik has been completely eroded prior to deposition of younger Mesozoic beds. Preserved sequences of the formation are believed to be at least 260 feet, and perhaps as great as 400 feet thick.

The following section is representative of the formation in the mapped area:

Section 15. Shublik Formation, exposed in cutbank on west side of a tributary of Thunder Creek, lat. 68°45' N., long. 160°19' W. Measured by J. T. Dutro, Jr., July 25, 1951.

Unit	Thickness in feet
Top of section.	
1. Fossiliferous limestone, medium gray and light olive-gray, weathers "buff" color, dense, very finely crystalline to lithographic, thin-bedded 0.1-0.2 foot; contains irregular nodules of bluish-gray chert; in part fossiliferous and coquinoid; with _Monotis_ _subcircularis_ (Gabb) (USGS loc. 24104)	13+
2. Chert, medium bluish gray, olive-gray, and dark gray, uniform to banded, glassy to dull, conchoidal fracture, thin bedded; contains few pyrite grains; interbedded black shale less than 5 percent of unit	22
3. Interbedded chert and limestone, dark gray to grayish black, beds 0.1-0.2 foot thick	10
4. Rubble covered. Black shale	15
5. Chert, olive-gray with black streaks, beds as much as 0.2 foot thick; interbedded with dark-gray clay shale and olive-gray silty shale	10
6. Interbedded limy siltstone and chert; siltstone, light olive-gray, weathers grayish orange; chert, medium gray to medium dark gray	1

Unit	Thickness in feet
7. Interbedded chert, limestone, and shale; chert, black, in 0.1-0.2-foot-thick beds, 70 percent of unit; sandy limestone, very fine grained, dark gray to brownish gray, 20 percent of unit; black shale 10 percent of unit; scattered pyritic nodules	7.5
8. Chert and limestone, black; one massive bed; large shells of _Daonella_ cf. _D._ _dubia_ Gabb and _Daonella_ cf. _D._ _moussoni_ Merian (USGS loc. 24103)	0.6
9. Chert, limestone and shale, as in unit 7	8
Fault	
10. Chert and shale; chert, medium gray, olive-gray, and blue-gray, glossy to dull, beds 0.05-0.1 foot thick; shale olive-gray, silty about 5 to 10 percent of unit	15
Total thickness measured	103+
Base of section. Fault.	

A sequence somewhat unlike the above described exposures was examined in the southern part of the area a quarter of a mile north of the Mount Bastille Devonian Kugururok Formation-type section. Chert and limestone are the dominant rock types but the section also contains granule conglomerate and sandstone. Fragmental shells identified as _Monotis_ _subcircularis_ (Gabb) by Bernhard Kummel occur within the conglomerates.

Section 16. Shublik Formation(?) exposed along tributary creek of Kugururok River, approximately lat. 68°29' N., long. 160°51' W. Measured by J. T. Dutro, Jr., and E. G. Sable, July 15, 1951.

Unit	Thickness in feet
Top of section. Overlain by unfossiliferous dark-gray and black shale containing gray calcareous siltstone lenses.	
1. Poorly exposed. Chert, medium gray, greenish gray, grayish red, dull to glassy	20
2. Chert and limestone interbedded; minor amounts of granule conglomerate and sandstone. Chert and limestone, grayish green, medium to dark gray, and grayish red; interbanded colors within beds; glassy to dull; beds uniform, 1 to 6 inches thick, averaging 4 inches. Two conglomerate beds 35 and 50 feet above base of unit, medium gray to grayish red and less than 4 inches thick, contain elongate subround granules and small pebbles of black, gray, and greenish chert; gradational upwards into cherty sandstone and siltstone. Gradational bedding common in cherty sandstone and siltstone. Few 1/8-inch beds of light-grayish-green, very fine grained sandstone. Shell fragments of <u>Monotis subcircularis</u> (Gabb) in conglomerate beds	85
3. Mostly rubble. Upper part, chert and limestone as in unit 2. Lower part, chert, bluish gray, medium gray, and greenish gray	35±
4. Chert and limestone interbedded. Chert as in lower part of unit 3, beds 1 to 5 inches thick, dull to glassy, about 70 percent of section. Limestone, medium gray, cherty, uniform, gradational into chert	60
Measured thickness	200±

Base of section

(Section overlies 75 feet fissile black shale, underlain by 250 feet gray, greenish, bluish and black chert, underlain by more than 500 feet interbedded black chert and limestone. These units are mapped as undivided Carboniferous-Permian rocks.)

The presence of <u>Monotis</u> <u>subcircularis</u> (Gabb) dates the above sequence as Late Triassic in age, and the rocks are mapped as Shublik Formation.

Two thin sections of chert from rocks mapped as Shublik Formation were examined under the petrographic microscope. Sample 51ASa16, in hand specimen, is medium dark gray to black, and contains scattered spherical grains. In thin section the rock is composed of crypto-crystalline quartz with about 10 percent black, fragmental and whole, oölitic grains which range from 0.06 to 0.12 mm in diameter and are partially or wholly composed of quartz. A spherulitic structure is present in some of the grains. Some grains have roughly circular centers of quartz aggregate; centers of others are of an opaque material. The rock also contains about 10 percent reddish-brown, in part, spheroidal grains. A brownish opaque substance coats these grains. Fractures cutting the rock are filled with carbonate or quartz.

Sample 51ASa157a, in hand specimen, is a light olive-gray, milky-appearing, dense chert. Thin black veins cut the rock. In thin section the chert is composed wholly of cryptocrystalline quartz showing weak orientation. Grains of limonite(?) are scattered throughout the section but are not abundant. Fractures are filled with carbonate and limonite(?).

One thin section from the upper limestone unit (51ASa21) was examined under the petrographic microscope. In hand specimen the rock is chert and cherty limestone, in part coquinoid, light to medium dark gray, weathers grayish orange and light brown, dense, and contains veins of calcite. In thin section, the rock consists of carbonate (about 60 percent) and finely cryptocrystalline quartz (about 40 percent) occurring together throughout the rock. Shell fragments have been almost entirely replaced by microcrystalline quartz and are separated by layers composed dominantly of carbonate. Other smaller, whole shells enclosed in dominantly microcrystalline quartz are also replaced by quartz and are outlined by nearly euhedral crystals or crystal aggregates of carbonate, probably dolomite. Euhedral carbonate crystals and carbonate aggregates are also scattered through the groundmass. A yellowish-gray opaque mineral is present as small grains and is finely distributed in the carbonate. Some small carbonate-filled veins are present. It appears that a carbonate rock has been partially replaced by silica which, in turn, has been partially replaced by the euhedral carbonate.

Stratigraphic relationships

No depositional or erosional breaks are known within the Shublik Formation in the mapped area. The formation overlies cherty beds of Late Paleozoic age in some localities, and clastic sequences in others, but the latter relationship may be due to faulting. The base of the Shublik has not been definitely recognized in the area. Along Spike Creek and in the Utukok River headwaters, the unit appears to grade downward into cherty and shaly rocks which overlie rocks of Mississippian age. These cherty rocks are, in part, similar to rocks of known Permian age in the central Brooks Range (Patton, 1958). The Shublik Formation is overlain, unconformably, by one of several formations of Early Cretaceous age. In many parts of the area, the Shublik Formation is absent as a result of pre-Cretaceous and Cretaceous(?) erosion.

Fossils and age

By far the most common fossil in the Shublik Formation is *Monotis subcircularis* (Gabb) of Late Triassic (Norian) age. This pelecypod is found in the "buff"-weathering limestone-chert zone in the upper part of the formation and in chert beds correlated with this zone. Other fossils associated with *Monotis subcircularis* (Gabb) and *Monotis* sp. include a gastropod, *Naticopsis*? sp., *Pecten* sp., and a questionable ammonite fragment.

Halobia cordillerana Smith and *Halobia* sp., of Late Triassic (Karnian) age have been found in dark limestones and black cherts below the "buff" weathering zone. In one outcrop near Driftwood Creek fossil fragments identified as *Halobia* sp. and *Monotis*? sp. occurred together in rubble of dark and light limestone. In that place they are either within 10 section-feet of each other or are contemporaneous. On the Kukpowruk River, Halobia cf. H. ornatissima Smith was found in black limy shale below the "buff"-weathering limestone.

Precise locations of Triassic fossil collections made by P. S. Smith in 1926 in the upper Kukpowruk and Kokolik River drainages (Smith and Mertie, 1930, p. 193) are not known. All of these were reported to contain Pseudomonotis subcircularis (Gabb) (Smith and Mertie, 1930, p. 193). The name of this pelecypod has since been changed to Monotis subcircularis (Gabb) (Muller, 1938).

Pelecypods identified by Bernhard Kummel as Daonella cf. D. dubia Gabb and Daonella cf. D. moussoni Merian were collected from a black limestone and chert bed of Section 15, about 65 feet below limestone beds bearing Monotis subcircularis (Gabb). According to Kummel, the genus Daonella is generally a good marker for the Middle Triassic.

All Triassic megafossils in the Kukpowruk-Nuka region therefore point to a Late and Middle Triassic age for the Shublik Formation. However, as far as can be determined, all of these fossils are from the upper or, possibly, middle part of the formation. It may be that unfossiliferous rocks directly below these beds are of Early Triassic age.

Microfossils were recovered from four of eight samples. Two samples, collected from beds between the Monotis-bearing "buff" limestones and the Daonella beds (see Section 15), yielded foraminifera

and conodonts. Nodosaria shublikensis Tappan and other long-ranging foraminifera were reported from 51ADu145 and 148, according to H. R. Bergquist (written commun., 1952). The same samples contained the conodont Gondolella, in addition to unidentified bladelike and bar-like conodonts, according to W. H. Hass (written commun., 1957). Another sample, from about 10 feet below the Daonella beds, contained fragments of Gondolella and bladelike and barlike conodonts, according to Hass. Of five samples whose stratigraphic position is uncertain, four were barren and the fifth contained the conodonts Gondolella, Hindeoella and bladelike, barlike, and platelike conodonts.

Nodosaria shublikensis Tappan was described from the type Shublik Formation (Tappan, 195 , p. 11) where it is known to be of Late Triassic age, but it may range into older Triassic beds.

Hass reports that Gondolella ranges from Middle Pennsynvanian through Middle Triassic and perhaps into the Upper Cretaceous.

Mode of deposition

Shallow, quiescent seas probably covered the entire Kukpowruk-Nuka region during Middle and Late Triassic time. The dark limestone, chert, and shale in the lower and middle parts of the Shublik may represent deposition in relatively deep water or where current action was weak. The light limestones and cherts in the upper part of the formation represent shallow shelf, probably lagoonal or bay deposits in clear seas, during which time the pelecypod Monotis flourished. The origin of the bedded chert is a problem yet unsolved, although much of the chert appears to be postdepositional. The locations of source areas for the fine clastic rocks in the Shublik are also not known, but they may have lain to the south, as inferred from the presence of granule-size sedimentary breccia and conglomerate in the southernmost part of the area near Mount Bastille.

Jurassic(?) and/or Cretaceous Systems

Several thick units of terrigenously derived clastic rocks in the Kukpowruk-Nuka region are assigned to the Cretaceous systems. These rocks are of drastically different aspect from those of Paleozoic and earlier Mesozoic ages, and indicate a radical change in sedimentation processes, tectonic framework, and depositional environments from those represented by the older rocks.

No Jurassic rocks were recognized in the Kukpowruk-Nuka region during early investigations (Smith and Mertie, 1930, p. 195). Studies since then have shown that, in parts of the area, sparsely fossiliferous beds, largely wacke and mudstone, underlie rocks of known Early Cretaceous (Neocomian) age and overlie Triassic, Permian, and probably Mississippian rocks. These strata may include rocks of Jurassic age, although no diagnostic fossils were found in them. The rocks are in structurally complex interrelationships and relationships with adjoining rocks of various ages, and are associated with cherty and shaly rock types which are similar to Triassic and some upper Paleozoic rocks. Some of these units resemble the fossiliferous Okpikruak Formation of Cretaceous age described below, and it is possible that all of them are units of Early Cretaceous age. The units are the wacke with cannonball concretions

unit and two wacke, sandstone, mudstone, and conglomerate units.

Sedimentary rocks that are now known or regarded to be of Early Cretaceous age in the Kukpowruk-Nuka region were considered by Smith and Mertie (1930, pl. 1, p. 196-232) to belong to both the Lower Cretaceous and Upper Cretaceous Series. Their division was based upon differences in lithology and fossil content between the clastic rocks exposed in the northern part of the area as compared to those in the southern part, and upon the interpretation that the less-deformed northern sequence overlies the structurally complex southern facies with pronounced angular unconformity. As a result of more recent studies, five Cretaceous rock units in the Kukpowruk-Nuka region can be correlated with named units defined elsewhere in northern Alaska. These units are the Okpikruak Formation, argillaceous unit, and Fortress Mountain, Torok, Kukpowruk, and Corwin Formations. All of these units, with the possible exception of part of the Corwin Formation are of Early Cretaceous (Neocomian and Albian) age.

The ages and correlations of other unnamed units described below are uncertain; they occur in different belts of exposure most or all of which probably occur in different allochthonous thrust sheets. Informally named units considered to be Late Jurassic or earliest Cretaceous in age are herein called the wacke with cannonball concretions unit, the argillaceous unit, two wacke, sandstone, mudstone, and conglomerate units, and the micaceous sandstone unit.

Wacke with Cannonball Concretions

Distribution and outcrop

The wacke with cannonball concretions unit is exposed in several structural belts in the Southern Foothills and DeLong Mountains from the eastern limit of the Kukpowruk-Nuka region, at about lat. 68°43' N., westward and southwestward to the headwaters of Elbow Creek and Kogruk Creek. The northernmost exposures of the formation lie east of the Nuka River at about lat. 68°47' N., and the southernmost exposures lie about 1.5 miles south of Kogruk Creek at long. 160°48' W.

Rocks of the unit are not well exposed and, except for conglomeratic and cherty strata, and associated mafic rocks, they are poorly resistant, and are topographically expressed as low, mostly rubble-covered hills and discontinuous ridges or tundra-covered lowlands. Cutbank exposures are common along the upper part of the Nuka River and its north-flowing tributaries and along Driftwood Creek west of Thunder Mountain. These are also largely rubble covered, however, and beds are highly folded and cut by numerous faults. As seen on aerial photographs, the surface expression of the formation is not distinctive, and exposures resemble other poorly resistant rocks of Cretaceous age.

Character and thickness

Interbedded mudstone, siltstone, graywacke, and conglomerate comprise about 70 percent of the wacke with cannonball concretions unit exposures in the Kukpowruk-Nuka region. Bedded chert, conglomeratic mudstone, and siliceous shale are interbedded or associated with these clastic rocks. Variegated shale and

siltstone are also present in some localities, but their stratigraphic relationships to the above rocks are not known. Extrusive and intrusive mafic igneous rocks are associated with exposures of the formation, particularly along the Nuka River and Driftwood Creek. At some localities they intrude or are interbedded with shale, graywacke, and chert units. Although many of the clastic rocks in the unit are similar in composition to those in the Okpikruak Formation of Early Cretaceous age, the wacke with cannonball concretions unit generally lacks the more uniform and rhythmic bedding that characterizes many exposures of the Okpikruak. The unit also contains bedded chert and mafic rocks, neither of which has been recognized in the Okpikruak Formation.

Mudstone, which comprises 40 to 60 percent of the exposures, is mostly dark gray but also may be medium gray, greenish gray, and black. Strata are platy to hackly, and occur in units as much as 400 feet thick. Some mudstone units weather to a "gun-metal"-blue color. Locally they contain a wide variety of nodules, concretions, and lenses, which include dark-gray, grayish-olive, and grayish-green, dull chert occurring mostly as nodules and lenses; greenish-gray to grayish-black silty and sandy spheroidal "cannonball" concretions, some of which have concentric structure, which average 4 inches but may be as much as 2 feet in diameter; dark-gray silty limestone lenses, some with cone-and-cone structure; and argillaceous lenses and nodules which commonly weather reddish brown.

Poorly stratified conglomeratic mudstone, in units as much as 40 feet thick, contains scattered subround to subangular granules, pebbles, and cobbles made up largely of black and gray-green chert, with lesser amounts of argillite, sandstone, limestone, mudstone, and mafic igneous rock. Angular to subangular boulders as much as 8 feet in width also occur in these shale units, and consist mostly of chert, chert breccia, and limestone breccia. Some of these boulders may be fault blocks which do not represent deposition contemporaneous with that of the shale. Others, however, are completely enclosed in mudstone, and there is little doubt that they and the shale were deposited contemporaneously. These exotic conglomeratic mudstones resemble the "wildflysch" deposits and almost certainly represent sedimentation attendant to orogeny.

Graywacke, ranging from silt to coarse sand size and locally conglomeratic, constitutes about 20 to 30 percent of the exposures. It is greenish gray and medium dark gray, weathers dark reddish brown, moderate brown, and olive-gray, and is poorly stratified. The graywacke commonly occurs in lenticular beds, mostly less than 5 feet but in places as much as 25 feet thick, interbedded with shale and siltstone in units as thick as 200 feet. Beds are massive to blocky and highly fractured. The rock is well indurated, generally dense, locally quartzitic, and in part calcareous. Some beds contain common to abundant spheroidal "cannonball" concretions which average about 6 inches in diameter but may be as much as 5 feet across. The concretions are sandy or silty, more calcareous than the enclosing rock, dense, generally resemble the graywacke matrix, and are like those found in the shale.

Graywacke conglomerate, conglomeratic sandstone, and scattered boulders in fine-grained, clastic rocks are interbedded with or occur in the graywacke, siltstone, and shale sequence. Conglomerates are variable in thickness and composition within single outcrops. They are poorly sorted and contain as much as 70 percent granule- to boulder-size constituents enclosed in clay to coarse sand-size matrix. Some of the conglomerate beds, believed to lie at or near the base of the formation, are composed almost entirely of black and greenish chert and argillite. Other beds, believed to lie higher in the sequence, also contain sandstone, limestone, shale, conglomerate, silty "cannon-ball" concretions, and a few mafic and felsic rocks. Granule- to pebble-size fragments are commonly subround to subangular although some of the conglomerates are composed dominantly of angular chert fragments. Cobble- and boulder-size fragments are commonly angular to subangular, mostly less than 3 feet in diameter, but as much as 20 feet long and 8 feet wide. In general, the coarsest conglomerates lie in the southern part of the area in the upper parts of the Nuka River and Driftwood Creek drainage. Those conglomerates exposed farther north are composed of cobble-size or finer material.

Chert, interbedded with shale, graywacke, and siltstone, probably makes up less than 10 percent of the formation, and occurs in lenticular masses averaging less than 15 feet, but in places as much as 40 feet thick. The chert consists mostly of grayish-green, grayish-olive, and dark-gray interbanded and uniform varieties, but bluish-gray and gray chert is also present. Irregular and lenticular beds are commonly less than 3 inches thick, weather light gray, grayish green, or yellowish gray, and are commonly iron stained. Thin units of siliceous shale and argillite are interbedded with the chert. Unless associated with the clastic rocks described above, cherty units of the wacke with "cannonball" concretions unit are difficult, or sometimes impossible, to distinguish from other cherty units of Triassic and Late Paleozoic ages.

Sections in which there is no repetition of beds by faulting or folding are rare. These range from a few feet to about 400 feet thick. Because of the lack of known key horizons, discontinuous exposures, complex structural relationships, and rapid lateral facies variation, it has not been possible to correlate many of these sections. A reliable total thickness for the unit in the mapped area has not been obtained. As inferred from the diverse rock types which make up scattered sections along Nuka River tributaries, the unit is believed to be more than 1,000 feet thick; it is possibly as much as 1,500 feet thick in some places, and is absent in other places due to erosion prior to deposition of Early Cretaceous rocks.

A representative sample of graywacke from the wacke with "cannonball" concretions unit (51ASa250) in hand specimen is greenish gray, weathers moderate brown, is fine to medium grained, dense, blocky, and slightly calcareous. In thin section, the rock contains about 40 percent chlorite and carbonate cement, in part sericitic, with some microcrystalline quartz. Grains are predominantly angular to subangular,

poorly sorted, as much as 0.8 mm in mean diameter with a modal size of about 0.4 mm. They consist of quartz (about 60 percent) in single crystal grains and composite grains grading downward in fineness to chert, plagioclase (20 percent), rock fragments (15 percent) and black, brown, and yellowish-gray opaque minerals (less than 5 percent). Grains of mica, carbonate, and tourmaline(?) are relatively rare. Some grains of plagioclase are clear; others are extensively sericitized and replaced by calcite. Most quartz-grain boundaries are sharp, but some boundaries with the chlorite and calcite are irregular and etched.

One thin section of a "cannonball" concretion (51ADu29) was examined under the petrographic microscope. In hand specimen the spheroidal concretion is 2 inches in diameter, with concentric structure, medium dark gray to dark greenish gray, and weathers grayish orange. In thin section, the rock is similar to the section of graywacke described above, but the cement is about 50 percent of the rock and the percentage of carbonate in the cement increases toward the center of the concretion. Grains are as much as 0.6 mm in width with modal size of about 0.1 to 0.2 mm. A few subround grains of greenish mineral, perhaps glauconite, are also present.

Stratigraphic relationships and mode of deposition:

Interrelationships of rocks that compose the wacke with cannonball concretions unit and relationships of this formation with other map units are poorly known. The unit overlies rocks ranging from Triassic to probably Mississippian age, and it is associated with Devonian rocks in the upper part of the Nuka River. However, the nature of the lower contact was nowhere defined with certainty. It is likely that many of the relationships with older rocks may be due to faulting. Nevertheless, it seems that the unit lies unconformably on older rocks, and that several different facies represent its basal beds. Some beds interpreted to be basal consist of chert conglomerate and sandstone; others are shale, and still others are graywacke and shale containing the distinctive sandy "cannonball" concretions. These may be contemporaneous local facies or they may represent different times of deposition interrupted by periods of erosion. It is possible that these strata were deposited on an erosional surface of considerable relief or a terrain composed of complexly folded and faulted older rocks. Because the unit has been involved in the thrust faulting which characterizes much of the regional structural pattern, the different basal facies may represent different overthrust plates, each far removed from its original depositional position.

The wacke with "cannonball" concretions unit underlies the Okpikruak Formation in almost certain unconformable angular relationship along the Nuka River and its tributaries. The Okpikruak rests on several different facies of the unit along this outcrop belt, but most commonly overlies the "cannonball" concretion-bearing graywacke and shale.

The diverse rock types which comprise the unit suggest rapidly changing sedimentary conditions, and the dominant clastic rocks are orogenic types which represent the initial stages of northward depo-

sition into the Colville geosyncline (Payne and others/ 1951). Pronounced lateral facies changes, poorly stratified, lenticular clastic beds, graywacke conglomerate containing a large proportion of angular fragments and, locally, boulder-size constituents, and sandy "cannonball" concretions, suggest rapid, chaotic deposition.

Although the presence of coarse wacke-type clastic rocks suggests a nearby source area, it is not certain that these rocks are actually close to their original positions of deposition. Some or all of them are in overthrust blocks which have moved north from their original source. In part, rocks of the unit are interpreted to have been overridden by other overthrust plates. Although evidence that the source areas for these sediments lay south of the Kukpowruk-Nuka region is fairly certain, the actual positions of these areas are not known.

Volcanic activity during deposition of these beds is indicated by the presence of mafic extrusive rocks within the sequence. Other mafic igneous rocks, which almost certainly are sill-like intrusive bodies, have been intruded subsequent to at least part of deposition but preceding deposition of Okpikruak Formation rocks.

The mode of origin of the bedded cherts is not known. They may be all or in part silicified tuff beds associated with the volcanic activity. Examination of chert samples under the petrographic microscope has neither substantiated nor disproved this hypothesis. The origin of these and other cherty rocks poses an interesting problem which remains to be solved.

Wacke, Sandstone, Mudstone, and Conglomerate Units

Unfossiliferous clastic rocks, exposed in several structural belts in the southern foothills and DeLong Mountains south of the belt of the micaceous sandstone unit and north of fossiliferous Okpikruak Formation rocks, are mapped as two units of wacke, sandstone, mudstone, and conglomerate. Lithic types are not particularly distinctive. The strata overlie rocks ranging from Devonian(?) to Triassic age, and underlie the Okpikruak Formation in some places. Bedding relationships with Triassic and Paleozoic rocks range from conformable to as much as 45° discordance. The clastic rocks may represent equivalents of the Okpikruak or, in part, Fortress Mountain Formations; they contain rock types which are found in these formations.

The clastic rocks are poorly exposed and mostly rubble covered in the mapped area. They consist of interbedded sandstone, wacke, siltstone, and shale, with minor amounts of conglomeratic sandstone and conglomerate. Mudstone and claystone comprise about 60 percent of these rocks and is dark gray to grayish black, hard, and micaceous, in units averaging about 5 feet in thickness. The sandstone and siltstone are medium gray, medium dark gray and greenish gray, weather light to moderate brown and olive-gray, thin to medium bedded, generally well indurated, highly micaceous, slightly to highly calcareous, and in part crossbedded. Shale and sandstone-siltstone units are repeated in roughly rhythmic pattern. Clear, well-formed quartz crystals, mostly less than 1 inch but as much as 3 inches in diameter and exhibiting

skeletal structure, are associated with these rocks in rubble. Conglomerate consists of granule- to pebble-sized angular chert fragments embedded in a very fine to medium-grained sandy micaceous matrix.

One thin section of the conglomerate was examined under the petrographic microscope. The rock is a graywacke. Poorly sorted angular and subangular chert fragments 1 to 6 mm in width comprise about 50 percent of the section. These are surrounded by closely packed, angular to subround grains, with modal size of about 0.3 mm, consisting mostly of clear quartz in single crystal grains, chert, and mica, with lesser amounts of plagioclase, carbonate, and rock fragments. Cement consists of carbonate, chlorite, and sericitic material. The carbonate appears to have wholly or partially replaced some feldspar grains, and some quartz grains have irregular outlines against the cement.

Along the front of the DeLong Mountains, between the Kokolik River and Storm Creek, these strata in part appear to represent a coarser facies of the micaceous sandstone unit. Included in these highly deformed rocks are sedimentary breccias in which angular fragments consist almost entirely of chert and argillite. In addition, there are medium-to dark-gray, brownish-weathering graywacke and subgraywacke sandstone, siltstone, mudstone, and conglomerate containing sedimentary and igneous rock fragments.

Pebble to boulder conglomerate of two types are mapped with these units; one type is characterized by contained clasts of chert, sandstone, and mafic igneous rocks; the other by a high proportion of mafic and felsic igneous rocks. A section including the latter type of conglomerate is described below.

Section 17. Exposed along north front and top of Thunder Mountain.

Measured by J. T. Dutro, Jr., June 23, 1951.

Unit	Thickness in feet
Top of section. Overlain by Okpikruak Formation, rhythmically interbedded wacke and mudstone facies containing coarsely ribbed Buchia shells.	
1. Graywacke-type sandstone, medium gray to greenish gray, weathers moderate brown, fine to coarse grained, in beds 0.2 to 0.4 foot thick, flaggy, slightly undulating bedding surfaces, but generally evenly bedded	525±
2. Conglomerate, matrix of dark gray to dark grayish green, fine to medium grained, dense sandstone, about 20 percent of rock; mostly subrounded to rounded pebbles and cobbles as much as 3 inches in diameter, about 90 percent of which are of mafic and felsic igneous rocks, which from hand specimen are greenish-gray diorite, dark-green diabase, medium-dark-green coarsely crystalline gabbro, light-gray and pink granite and granophyre, and gray quartz diorite. Smaller pebbles of the above types are mostly subangular. Conglomerate contains less than 10 percent subangular pebbles of fine-grained sandstone and angular fragments of black shale.	250±

Measured thickness	775±

Fault? Section overlies highly folded rocks of wacke with "cannonball" concretions unit.

Total thickness of these units are unknown but are estimated to exceed 2000 feet. Two units are differentiated mainly on the basis of association with different suites of older rock types and apparently more abundant and coarser grained conglomerates in the eastern unit which extends from the eastern borders of the region to the Utukok River.

Of the 43 shale samples collected from these units for microfossil content, all but four were barren. The four samples contained foraminifera considered by H. R. Bergquist to be nondiagnostic for precise age determinations.

Micaceous Sandstone Unit

The micaceous sandstone unit sequence consists largely of dark-gray to grayish-black siltstone and shale, and lesser amounts of sandstone. It overlies Triassic rocks and underlies the wacke and conglomerate member of the Fortress Mountian Formation in the Kukpowruk-Nuka region. The age of the unit and its exact relationships to other rocks in the area are not known.

Distribution and outcrop

Rocks of the micaceous sandstone unit are exposed in the southern foothills, in a southwest-trending belt about 1/8 mile to 8 miles wide, from at least the Nuka River at lat. 68° 46' N. to west of Spike Creek. The belt adjoins the main belt of the conglomerate member of the Fortress Mountain Formation on the north, and on the south, adjoins a belt of high hills composed of rocks of various ages which are mostly faulted against the micaceous sandstone unit.

Rocks of the unit weather to linear ridges and hills which are generally lower than those of the adjacent belts. Rubble traces of siltstone and sandstone give a finely striped or banded appearance to many of the hills. The less resistant shale weathers to mud, and flowage of the mud and rock rubble produces a finely streaked appearance to hillsides. In general, the appearance of these hills is similar to those underlain by the sandstone member of the Fortress Mountain Formation. Cutbank exposures of the unit are best exposed along Driftwood Creek and its tributaries and along the Utukok River.

Character and thickness

Silty shale and clay shale, siltstone, and very fine grained sandstone, in decreasing order of abundance, constitute the major rock types of the micaceous sandstone unit. These are typically medium to dark gray and grayish black, well stratified and rhythmically interbedded. Beds are mostly hard to quartzitic and moderately to highly micaceous. They contain pyritic and dense ferruginous claystone nodules and, rarely, carbonaceous fragments.

The shale, mostly grayish black but containing some greenish-gray and grayish - red beds in the lower part, is fissile, in part paper thin, hackly, and nodular, and generally resembles other dark shales in the area. Some beds are iron stained and show "gunmetal" blue-stained surfaces.

Siltstone and sandstone are mostly medium dark gray to medium gray, weather light olive-gray to brownish hues, and are in part iron stained or with "gunmetal" blue stain. Beds are mostly less than 1 foot, but may be as much as 5 feet thick, platy to massive, and commonly exhibit fine crossbedding and graded bedding. A granule-size chert conglomerate layer, less than 1 inch thick, occurs at the base of some sandstone beds. In addition, common features are small irregular ripple marks, casts of worm trails, borings, indeterminate organic markings and small-scale scour markings.

In some localities, fractures in sandstone and siltstone are filled with calcite or drusy quartz. Some greenish-gray, reddish-brown weathering sandstone is interbedded with the above rocks, probably in the upper part of the formation. Sandstone beds also appear to be more abundant in the upper part of the unit.

Section 18. Section of micaceous sandstone unit. East bank of Driftwood Creek, lat. 68°43' N., long. 160°30' W. Measured by P. H. Shannon, September 2, 1950.

Unit	Thickness in feet
Top of section, fault contact with Jurassic(?) rocks.	
1. Siltstone and interbedded shale. Siltstone, dark gray, hard; shale, grayish black	4
2. Siltstone, dark gray, very hard	1
3. Siltstone, with thin interbeds of soft grayish-black silty shale; siltstone, medium dark gray	

to dark gray, weathers medium gray, highly micaceous, soft, in beds 1 to 4 inches thick, 60 percent of unit 50

4. Claystone and clay shale, interbedded; claystone, medium dark to dark gray, weathers reddish brown, very soft, in 2-inch beds; clay shale, grayish black, soft, in 1-inch beds 6

5. Siltstone and silty shale, as in unit 3, but all beds about 1 inch thick 20

6. Siltstone, medium dark gray, very hard, weathers light olive-gray with greenish hue. 1

7. Siltstone and silty shale, as in unit 3, siltstone 50 percent of unit; alternating beds as much as 4 inches thick in lower 36 feet of unit, gradually decreases to 1-inch beds in upper 12 feet. 48

8. Clay shale, grayish black, nodular. 3

9. Siltstone, medium dark gray, weathers brownish gray, highly micaceous, contains "swirly" crossbedding. 2

10. Clay shale, as in unit 8. 5

11. Siltstone, medium gray, hard; almost a claystone 2

12. Siltstone and silty shale interbedded in equal amounts, all beds about 4 inches thick. 14

13. Siltstone, as in unit 9 1

14. Silty shale, grayish black, iron stained. 5

15. Siltstone, as in unit 9 1

16. Siltstone and silty shale, interbedded, as in unit 3, beds less than 3 inches thick 12

17. Siltstone, as in unit 9 2

18. Siltstone and silty shale, as in unit 3, beds as much as 6 inches thick 21

19. Siltstone, olive-gray, hard, weathers light olive-gray. 2

20. Clay shale, nodular 1

21. Siltstone and silty shale, interbedded in equal amounts, beds as much as 5 inches thick 13

22. Clay shale, grayish black, very hard. 10

23. Silty shale and siltstone, interbedded. 4

24. Clay shale. 4

25. Siltstone and silty shale, interbedded in equal amounts, beds as much as 6 inches thick 6

26. Clay shale. 2

27. Siltstone, as in unit 9, with thin interbeds of silty shale. 1

28. Clay shale and siltstone, interbedded; shale 50 percent of unit in upper 6 feet with 3-inch siltstone beds, 90 percent in lower 9 feet with 4-inch siltstone beds. 15

29. Clay shale. 3

30. Silty shale, grayish black, with very thin ¼-inch to 1/2-inch interbeds of dark-gray siltstone. 16

31. Siltstone, as in unit 9 1

32. Silty shale, grayish black, grades downward into unit 33 3

33. Siltstone, medium gray, hard, clean, uniform beds. 4

34. Silty shale and siltstone, as in unit 30. 6

35. Silty shale 8

36. Siltstone, medium dark gray, weathers light olive-gray, finely laminated. 5

37. Clay shale, grayish black, in nodular beds as much as 2 inches thick; grades downward into unit 38. 6

38. Siltstone, as in unit 9 2

39. Siltstone, as in unit 11. 5

40. Silty shale and siltstone, as in unit 30. 11

41. Silty shale 2

42. Siltstone, as in unit 11. 4

43. Silty shale 5

44. Siltstone, as in unit 9 1

45. Silty shale, dark gray; grades downward into unit 46 6

46. Siltstone, dark gray, finely laminated. 1

47. Siltstone, as in unit 11. 4

48. Silty shale, 70 percent of unit, interbedded with siltstone; some contortion of beds 12

49. Covered; possible fault? 6

50. Silty shale, clay shale, and siltstone, interbedded, beds less than 3 inches thick 36

51. Clay shale, as in unit 37, lower 2 feet crushed appearing, grades downward into unit 52 13

52. Siltstone, as in unit 19. 5

53. Clay shale, as in unit 37 8

54. Siltstone, as in unit 19. 4

55. Siltstone and silty shale, in gradational interbeds less than 4 inches thick. 3

56. Siltstone 1

57. Siltstone and silty shale, as in unit 55. 2

58. Clay shale, as in unit 37 4

59. Siltstone and silty shale, as in unit 55. 3

60. Siltstone, as in unit 19. 1

61. Clay shale, crushed 5

62. Siltstone and silty shale, as in unit 55, but heavily iron stained. 3

63. Siltstone, medium gray, weathers brownish gray, quartzitic, dense 1

64.	Silty shale	1
65.	Siltstone, as in unit 63.	1
66.	Siltstone and silty shale, as in unit 55.	3
67.	Clay shale, as in unit 37	6
68.	Siltstone, as in unit 63.	2
69.	Clay shale, as in unit 37	2
70.	Siltstone, as in unit 19.	1
71.	Siltstone and interbedded silty shale, as in unit 55	10
72.	Clay shale, dark gray to grayish black, paper-thin beds	5
73.	Siltstone and silty shale, as in unit 55.	2
74.	Siltstone, medium dark gray, weathers olive-gray, hard, clean appearing, in beds as much as 1 foot thick; thin silty shale interbeds	5
75.	Silty shale, dark gray, paper-thin beds, soft	6
76.	Siltstone, as in unit 19.	0.5
77.	Silty shale, as in unit 75.	2
78.	Siltstone, as in unit 19.	1
79.	Silty shale, dark gray to black, sandy, soft, contains elongate claystone(?) nodules as much as 6 inches long	3
80.	Siltstone, as in unit 19.	1

81.	Shale, as in unit 79	9
82.	Siltstone, as in unit 74, but weathers light gray, blocky, cut by calcite veins; poorly exposed.	10±
83.	Silty shale, with interbedded siltstone beds as much as 2 inches thick.	18
84.	Siltstone, as in unit 74	2
85.	Silty shale, as in unit 79	15
86.	Silty sandstone, medium dark to dark gray, weathers light olive-gray, micaceous, hard; contains mud markings, abundant shale fragments, and fine crossbedding	12
87.	Siltstone and shale, interbedded, in beds 1-2 feet thick	6
88.	Clay shale	8
89.	Shale, upper 6 inches appear crushed	1.5
90.	Siltstone	6
91.	Silty shale.	2
92.	Siltstone, 60 percent of unit, shale 40 percent, beds 4 to 6 inches thick.	21
93.	Siltstone and shale, interbedded, beds mostly less than 4 inches thick, with few siltstone beds as much as 1 foot thick; shale about 60 percent of unit	77

94. Siltstone, medium dark gray, micaceous, hard, in 2-inch beds; about 10 percent of thinly bedded shale 7

95. Siltstone and silty shale, intergradational. 2

96. Silty shale. 2

97. Siltstone, medium gray, weathers light olive-gray, hard; calcite-filled fractures 1

98. Siltstone and silty shale, intergradational. 6

99. Siltstone, as in unit 97 1

100. Siltstone and silty shale, intergradational. 2

101. Siltstone, as in unit 97 1

102. Siltstone and shale, intergradational, fissile, grades downward into unit 103 8

103. Shaly siltstone, medium gray 1

104. Clay shale, medium dark gray; lower 1 foot sheared. 10

105. Siltstone, medium dark gray, weathers olive-gray, poorly indurated, dusky-blue stain 1

106. Clay shale, greenish gray. 0.3

107. Silty shale, dark gray, grayish black, and dusky blue; in part, sheared. . . . . 46±

108. Clay shale, greenish gray, fissile 5

109. Clay shale and silty shale, grayish red, fissile 16

Measured thickness. . . . . 800±

Bottom of section, anticlinal axis

Note:

(In units not described, siltstones are medium dark gray to dark gray, weather light olive-gray, are hard and slightly to moderately micaceous; the lower contacts of many siltstone units are abrupt and the beds contain mud markings and indeterminate organic(?) markings on their lower surfaces; shale is dark gray to grayish black.)

Two thin sections of sandstone and siltstone from the micaceous sandstone member were examined under the petrographic microscope. In hand specimen, sample 50ASa166 is a fine-grained platy-micaceous sandstone that weathers olive-gray. The grains appear well sorted. In thin section, the rock is intermediate between a quartzitic subgraywacke and a quartzitic calcarenite. Cement and matrix comprises about 30 percent of the section. The cement consists of: microcrystalline quartz containing small euhedral carbonate crystals; black opaque metallic minerals; crystal aggregates of pyrite, black nonmetallic material and limonite; and sericitic paste containing carbonate and chlorite. Grains are mostly subangular, but range to angular and subround and are fairly well sorted; modal size is about 0.15 mm but may reach 0.3 mm in diameter. Grains consist of: clear quartz (estimated at 40 percent) partly sericitized and replaced by carbonate;

carbonate (30 percent) as subround grains and euhedral crystals; chert (20 percent); muscovite; plagioclase (Andesine, $Ab_{60}An_{40}$); rock fragments; and, mostly, limonitic opaque minerals.

The siltstone sample (50ASa318) in hand specimen resembles the sandstone but is more micaceous and weathers pale olive to light brown. In thin section too, it is similar to the sandstone. The modal grain size is 0.05 mm, cement contains minor amounts of metallic minerals but more carbonate than the sandstone and the rock contains about 20 percent muscovite.

In the two partial stratigraphic sections measured thicknesses of the unit were 900 feet along the Utukok River and 800 in the type section on Driftwood Creek. An estimated total thickness, based in part upon structural reconstruction across the belt of exposures, is between 1,000 and 1,500 feet.

No well-exposed contacts between the micaceous sandstone unit and the wacke and conglomerate member of the Fortress Mountain Formation were seen during field studies. Along the west bank of the Utukok River, the unit overlies the wacke and conglomerate member, but the contact is interpreted to lie along a high-angle reverse fault with the micaceous sandstone unit in the upthrown block. Elsewhere, rocks of both units are highly folded near their contact. Along Elbow Creek, Driftwood Creek and near Storm Creek, the wacke and conglomerate member dips dominantly north, away from the belt of Driftwood Formation exposures. Within a few hundred feet of the contact, beds in the two units appear conformable at several localities

along Kidney Creek, Driftwood Creek, and tributaries of Storm Creek.

Age and distribution

No identifiable megafossils were found in the micaceous sandstone member. Worm trails, borings, some carbonaceous fragments and indeterminate organic(?) markings are present in some beds. One fossil collection containing the fine-ribbed pelecypod *Buchia* (USGS loc. no. 23566) was found in limy nodules interbedded with wacke and mudstone at the south edge of the micaceous sandstone unit belt of exposures, along a tributary of Storm Creek. This exposure, mapped as Okpikruak Formation, overlies Triassic rocks and appears to underlie beds of the Driftwood Formation exposed scarcely 50 feet to the north. Contacts are obscured by rubble. If the Okpikruak rocks normally underlie the micaceous sandstone unit at this locality, the unit is younger than, or equivalent to, rocks of the Okpikruak Formation exposed farther south. The micaceous sandstone unit is tentatively assigned an Early Cretaceous age.

Of 21 shale samples collected from the micaceous sandstone unit for microfossil content, all but five were barren. The five samples contained foraminifera which are considered by H. R. Bergquist to be either too poorly preserved or nondiagnostic for age determination.

Cretaceous System

Argillaceous Unit

Fossiliferous rocks of Lower Cretaceous (Neocomian) age which lie along structural belts north of Okpikruak Formation exposures are mapped as the argillaceous unit. These include exposures in the

Kukpowruk River valley 8 miles southwest of Igloo Mountain; discontinuous exposures between the Utukok River and Thunder Creek, best exposed along Driftwood Creek at lat. 68°46'40" N., long. 160°42' W.; and strata in the vicinity of Storm Creek, 10 miles southwest of Lake Noluk.

Rocks mapped as the argillaceous unit in the Kukpowruk River valley are poorly exposed in a cutbank on the south side of the river and across the river in several cutbanks along an abandoned channel. The exposures are interpreted to lie in a structurally complex anticlinal fold and are overlain by rocks of the Fortress Mountain Formation sandstone member. Rocks of the argillaceous unit at this locality are not more than a few hundred feet thick and consist of mostly interbedded soft black and dark-gray claystone, medium-gray, fine-grained sandstone, brownish to black coquinoid claystone with finely ribbed Buchia (Valanginian), and unusual rock types such as gray clay, septarian and marcasite concretions, limestone breccia, pebble conglomerate, limy spherical claystone "cannonball" concretions, limestone with cone-in-cone structure, ferruginous siltstone, and claystone concretions with coarsely ribbed Buchia and coquinoid limestone with finely ribbed Buchia.

The exposures of argillaceous unit along Driftwood Creek are of small areal extent and consist predominantly of shale with interbedded coquinoid limestone beds and lenses, and cherty nodules near the assumed base of the section.

Section 19. Argillaceous unit, Driftwood Creek, measured by E. G. Sable and J. T. Dutro, Jr., June 3, 1951.

Unit	Thickness in feet
Top? of section. Possible synclinal axis.	
1. Mostly covered, probably underlain by shale; rubble of coquinoid limestone, greenish gray to light gray, weathers grayish red to pale brown, locally contains well-rounded chert granules, and closely packed shells of Buchia sp.	25±
2. Clay shale, greenish gray, hard, poorly exposed	17±
3. Coquinoid limestone, as in unit 1, a single bed, with finely ribbed Buchia	8
4. Clay shale, dark gray, fissile, with shiny surfaces, contains two 6-inch lenses of coquinoid limestone	6
5. Coquinoid limestone, as in unit 1; one lenticular bed, with finely ribbed Buchia.	5
6. Clay shale, as in unit 4, contains several lenses of medium-dark-gray silty limestone, as much as 2½ feet long	11
7. Rubble of dark-gray and greenish-gray shale with medium- to dark-gray chert nodules.	7
8. Clay shale, black and greenish gray, iron stained, hard, contains carbonaceous wood fragments and medium-to	

dark-gray chert lenses and beds less than 1 inch thick. . .	7
Fault?	
Measured thickness.	86±

This sequence is interpreted to lie on the north limb of a synclinal fold along a fault, and is flanked by conglomeratic sandstone and shale of the Fortress Mountain Formation. The south limb of the syncline contains a sequence nearly identical to that described above, and fossils collected from coquinoid limestone beds on these include finely ribbed Buchia and a belemnite, Cylindroteuthis sp.

Okpikruak Formation

The Okpikruak Formation of Neocomian age, named by Patton (*in* Gryc and others, 1951, p. 159-160) at its type section about 160 miles east of the Kukpowruk-Nuka region, consists of interbedded graywacke sandstone and shale. It is characterized by a rhythmic alternation of beds, conglomerate beds locally near the base, and early Lower Cretaceous Buchia pelecypods. In the Kukpowruk-Nuka region, a rock sequence of Neocomian age which rests on Mississippian to Jurassic(?) rocks, is mapped as Okpikruak Formation. Two distinctly different facies of Neocomian rocks, occupying different outcrop belts, have been recognized. The southern facies is similar to that described by Patton. It is named the wacke member of the Okpikruak Formation in the Kukpowruk-Nuka region. The northern facies consists of relatively clean quartzite, sandstone, coquinoid siltstone, and shale and is here called the quartzite

member of the Okpikruak.

Wacke Member

Distribution and outcrop.-- Rocks of this member are widely distributed in the southern foothills and DeLong Mountains. They are exposed in fairly continuous belts, as much as 2½ miles wide, in the southern part of the area west of the Utukok River. The outcrop belts strike southwest beyond the southern limits of the area, probably at least to the Kivalina River (Smith and Mertie, 1930, p. 200). They are also present east of the Utukok River in several discontinuous outcrop belts, as much as 3 miles wide, which strike generally east and northeast beyond the limits of the map area.

The wacke member is commonly expressed in high, rounded to moderately rugged hills and mountains. Most of them, when seen from a distance, are a dark-reddish-brown color. This weathering color is particularly distinctive in outcrop belts in the DeLong Mountains south of the northernmost main exposures of Kogruk Formation, and in outcrops along and south of the Nuka River. Farther north, similar rocks questionably referred to the Okpikruak Formation weather to lighter hues of reddish brown and light brown. Well-exposed but structurally complex sections of the member are present in cutbanks in the headwaters of Spike Creek and along the Nuka River; structurally simple sections of similar, but unfossiliferous strata, are exposed in mountain-side exposures along Trail and Seagull Creeks.

On aerial photographs, the general appearance of Okpikruak exposures south of the northernmost Kogruk Formation exposures contrasts sharply with that of adjoining rocks. The hills and mountains composed of Okpikruak Formation are medium gray in tone, even textured, and are cut by well-incised streams in subdendritic drainage patterns. North and east of these belts, the appearance of wacke member is similar where the belts of exposure are wide, but in narrow outcrop belts the member is difficult to distinguish from other clastic rocks.

Character and thickness.-- In general, three rock facies represent the wacke member in the Kukpowruk-Nuka region. These include: 1) a local conglomerate facies consisting of graywacke conglomerate and conglomeratic mudstone (of shale, siltstone, and sandstone); 2) a more or less rhythmically bedded facies consisting of shale, siltstone, and graywacke; and 3) a wacke facies consisting of graywacke, conglomeratic graywacke, siltstone and shale. The wacke member in the DeLong Mountains has a higher percentage of coarser grained rocks than exposures in the northern part of the area where more shale is present. The conglomerate facies is locally present in the basal or near-basal beds of the formation; the rhythmically bedded facies and the graywacke facies probably intertongue. Neither appears to maintain a constant position in the member throughout the area. However, along the Nuka River and in the belt that extends from Trail Creek across Seagull Creek, the rhythmically bedded facies consistently underlies the coarser wacke facies. In those localities it represents the lower part of the formation. On the other hand, west of the Utukok River in the headwaters of Spike Creek, the lower part of the formation is represented by rocks of the wacke

facies overlain by finer grained unfossiliferous rocks resembling the rhythmically bedded facies. In other exposures west of the Utukok River, rhythmic bedding is not conspicuous in the lower part of the formation; instead, a relatively greater proportion of fine clastics with lenticular beds of graywacke is present.

Conglomeratic facies.--Conglomeratic mudstone, siltstone, and graywacke ranging from less than a foot to at least 30 feet in thickness locally represent the basal beds of the wacke member. These are best exposed in the headwaters of the Utukok River, but are also present in many localities from Spike Creek east to the Nuka River. The conglomeratic mudstone is dark gray, silty, commonly limy, with poorly developed bedding. It locally contains minor amounts of grayish-green sandstone in lenses as much as 1 foot by 5 feet in dimensions. It contains randomly scattered, subround to angular, granule- to cobble-sized fragments of bluish, grayish, greenish, and black chert, gray limestone, cherty limestone, and mafic igneous rocks. Reworked Mississippian crinoidal debris and horn corals are present in some exposures. The shale locally contains Early Cretaceous Buchia pelecypods. Small pyrite crystals and aggregates are present in some exposures of the mudstone. Medium-dark-gray to dark-grayish-green conglomeratic siltstone and conglomeratic graywacke represent lateral coarsening of the mudstone beds in some exposures. At some localities where conglomeratic beds of the Okpikruak Formation rest on, or are within several thousand lateral feet of, Mississippian limestone exposures (for example, in the hills north of Kogruk Creek at approximate lat. 68°34'N., long. 160°50'W.), the conglomeratic beds contain angular pebbles and cobbles of limestone and black chert identical to the Mississippian beds. In some places these rocks contain as much as 20 percent crinoidal debris. These conglomerate beds were doubtless locally derived and were deposited within short distances of the source rocks. Some may represent but slightly reworked residual deposits.

Conglomerate units composed of granule- to boulder-size material are well exposed in the Brooks Range province at the headwaters of Iligluruk Creek and the Utukok River. A conglomerate unit, estimated to be as much as 500 feet thick along Tupik Creek, is believed to represent a local facies of the basal part of the Okpikruak Formation. The massive conglomerate overlies cherts of late Paleozoic age and crops out as huge pinnacles and spires along the creek. The matrix, composed of dark-greenish-gray and dark-gray sandy, silty, and clay material, is 20 to 30 percent of the rock. Granule- to boulder-sized fragments as much as 4 feet in diameter, with average size of about 6 inches, are angular to well rounded, poorly sorted, and lie in chaotic to roughly bedded positions. Coarse constituents are: black and grayish chert and fossiliferous Triassic limestone (estimated at 45 percent of the contituents) in subangular to well-rounded granules, pebbles, and cobbles; subround to round pebbles and cobbles of mafic and felsic igneous rock (20 percent); Mississippian limestone and chert, in part fossiliferous, in angular to subangular cobbles and boulders up to 4 feet in diameter (20 percent); quartzite and sandy limestone (possibly Utukok Formation) in angular and subangular pebbles, cobbles,

and boulders as much as 2 feet in diameter (5 percent); grayish-green sandstone cobbles, subround to round, as much as 6 inches in diameter (less than 5 percent); white quartz cobbles, subround to round, as much as 4 inches in diameter (less than 5 percent); and subround schistose quartzite and black slaty argillite cobbles (less than 5 percent). No fossils were found in this exposure, but along the west side of the Utukok River, 1¼ miles north, a conglomerate exposure like that described above, except that the maximum clast sizes are slightly smaller, contains abundant shell fragments and shells of *Buchia* sp. preserved in the matrix.

Other similar exposures in the headwaters of Iligluruk Creek and Kugururok River drainages with boulders as much as 15 feet in diameter are mapped as Okpikruak Formation. The matrix of some of these conglomerates contains shell fragments of *Buchia* sp.; others are apparently unfossiliferous. The conglomerates are not persistent units but appear to grade laterally into either interbedded graywacke sandstone and shale or units composed dominantly of shale. East and northeast of the headwaters of the Utukok River, many isolated exposures of conglomerate, as much as several hundred but commonly less than 30 feet thick, are present in the southern foothills and mountains. No fossils were found in these conglomerates, however. These conglomerates of uncertain correlation are mapped in the wacke, sandstone, mudstone, and conglomerate units discussed elsewhere in this report.

Rhythmically bedded facies.-- The rhythmically bedded facies of the Okpikruak Formation is dominantly of silty and clay shale, with interbedded graywacke and subgraywacke sandstone and siltstone, ferruginous limestone, and a few thin conglomerate lenses. Rocks typical of this unit are exposed in several cutbanks along the Nuka River, 2 to 6 miles southwest of 1951 camp 9. Here, it consists of 60 to 80 percent medium-dark-gray to grayish-black shale in units commonly less than 3 feet, but as much as 15 feet, thick. The shale is platy, hackly, and nodular, and some beds contain well-rounded siltstone pebbles and shells of the pelecypod Buchia. Beds of fine-grained sandstone and siltstone average less than 1 foot, but are as much as 3 feet thick and are mostly even bedded. The sandstone and siltstone are commonly dark gray, greenish gray, and olive-gray, contain claystone clasts and carbonaceous fragments, and are laminated to finely crossbedded. Graded bedding is a common feature and the lower surface of many sandstone beds contains sole markings, which, however, are not as common or prominent as those in rocks of the Fortress Mountain Formation. Some thin sandstone and siltstone beds are coquinoid types, locally composed of 10 to 30 percent Buchia shells. Ferruginous limestone lenses and elongate nodules comprise 5 to 10 percent of the exposures, are silty, dense, medium to dark gray, and commonly weather dark reddish brown and light brown. Many of these nodules are fossiliferous.

Rocks of the rhythmically bedded facies exposed on the south side of Thunder Mountain are at least 410 feet thick. They represent the lower part of the formation and contain as much as 70 to 80 percent

shale in units as much as 35 feet thick. The unit is 250 to 400 feet thick along the Nuka River.

In some exposures, such as those along Trail and Seagull Creeks, unfossiliferous sequences about 500 feet thick contain rocks nearly identical to those described above and are mapped as questionable Okpikruak Formation. These contain small amounts of interbedded greenish-gray shale. In these localities, and in some exposures of fossiliferous Okpikruak Formation like those immediately north of the Nuka River, the rocks have been metamorphosed to quartzites, argillites with "pencil" fracture, and siliceous limestone.

Wacke facies.-- The wacke facies is well exposed in the headwaters of Spike Creek, in the headwaters of the Utukok River, and north of the Nuka River. It consists of variable amounts of interbedded graywacke sandstone, siltstone, shale, conglomeratic graywacke sandstone, and graywacke conglomerate. The coarser grained rock types comprise from 50 to 80 percent of the sections examined. They are mostly dark grayish green, greenish gray, and medium dark to dark gray, commonly weather dark reddish brown, light brown, and dark yellowish orange, and are very fine to coarse grained. The rocks are moderately indurated to hard, calcareous to quartzitic, micaceous, and massive to platy. Although they commonly are present as lenticular and massively crossbedded units 2 to 5 feet in thinner, well-stratified, laminated or finely crossbedded units. Graded bedding is a common feature and claystone clasts and carbonaceous fragments are present in some beds. Shell fragments and shells of several species of the pelecypod Buchia are scattered throughout the coarse clastic rocks of some sections. Lenticular conglomerate and conglomeratic sandstone beds, interbedded with the sandstone, contain granules and pebbles mostly of chert and cherty argillite with a few igneous and limestone fragments. Silty shale and, less commonly, clay shale are interbedded with the coarser rocks as units generally less than 2 feet thick. The shale is dark gray to grayish black, fissile, nodular, and blocky and in some sections weathers a gun-metal blue color. Locally fossiliferous, ferruginous limestone lenses and nodules are interbedded with the shale and coarser clastics. They are similar to those in the rhythmically bedded member, but are less abundant in the wacke member.

One thin section of coquinoid graywacke (51ASa258), from the upper part of the member along the Nuka River, was examined under the petrographic microscope. In hand specimen the rock is dark greenish gray, weathers light brown, and contains very fine to granule-size fragments and shells of Buchia sp. In thin section, cement (about 50 percent) consists of cryptocrystalline quartz, calcite, chlorite, and clay material. Angular to subround, mostly elongate grains are scattered and poorly sorted together with granules as much as 1 by 4 mm in size. Grains consist of: rock fragments (estimated at 40 percent); quartz and chert (30 percent); carbonate (10 percent); fresh-appearing biotite (5 percent); plagioclase (5 percent) including andesine

($Ab_{60}An_{40}$), albite or oligoclase ($Ab_{90}An_{10}$), and possible bytownite or anorthite ($Ab_{10}An_{90}$); and carbonaceous matter, ore minerals, chlorite, and collophane(?). Buchia shells (less than 10 percent) are deformed and are composed mostly of carbonate which has been partially replaced by quartz.

All sections of the wacke facies, with the possible exception of that examined in the headwaters of Spike Creek, are incomplete as a result of faulting or recent erosion. The Spike Creek section, more than 1,600 feet and possibly 2,100 feet thick, overlies rocks of Jurassic or Triassic age. It is gradational upwards into at least 500 feet of unfossiliferous beds consisting mostly of thinly bedded shale and siltstone with interbeds of gray- and greenish-gray graywacke sandstone as much as 25 feet thick. Similar unfossiliferous sections which, in part, resemble the rhythmically bedded and wacke members are mapped as questionable Okpikruak Formation. Other unfossiliferous sections resembling the wacke member, all of which gradationally overlie strata resembling the rhythmically bedded member, include a measured thickness of 1,640 feet along Trail Creek (section 20), a measured and computed section of 750 feet along Seagull Creek, and an estimated thickness of 500 feet north of the Nuka River.

Stratigraphic relationships and mode of deposition. -- There is no doubt that an erosional hiatus of considerable magnitude preceded deposition of Okpikruak sediments and, from fossil evidence, the break probably represents . Jurassic time. The wacke member of the Okpikruak

Formation overlies a wide variety of rock units ranging from Triassic to Mississippian in age. In general, in the southernmost exposures the formation overlies older rocks such as the Lisburne Group of Mississippian age. Farther north, the Okpikruak more commonly overlies rocks of late Paleozoic, Triassic, and Jurassic ages. Because single beds of conglomerate in the Okpikruak contain fossiliferous angular rock fragments of older formations these older rocks apparently were exposed to erosional agents at about the same time.

The unconformity at the base of the Okpikruak represents a tectonic break as well as an erosional interval. In most localities where relationships of the Okpikruak with older rocks can be observed, the Okpikruak is conformable or nearly conformable with the older rocks; but in some places, for example, along the upper part of Driftwood Creek the formation rests on older rocks with angular discordance of as much as 35°. In addition, the map pattern in several parts of the area suggests angular relationships with the older rocks. In the upper parts of the Nuka River, Elbow Creek, and the Utukok River the formation overlies several older rock units along the same belts of outcrop.

In a few localities, the lower contact of the Okpikruak Formation is well exposed. North of Kogruk Creek, at lat. 68°35' N., long. 160° 49' W. the Okpikruak disconformably overlies the Kogruk Formation. Here the erosional surface is undulating, with local relief of about 5 feet within a few hundred feet along strike. Along this contact, the maximum thickness of the Kogruk Formation is about 170 feet (section 5), but 1½ miles east of this section, the Kogruk is locally

absent and the base of Okpikruak Formation is even more irregular; in several places gulleylike indentations as much as 10 feet deep in the Kogruk are filled with Okpikruak rocks, and the maximum thickness of the Kogruk, about 250 feet, thins to 10 feet within 1,000 feet along strike. In these exposures, and at many other localities where the Okpikruak overlies the Kogruk Formation, the Mississippian limestones are almost completely silicified within 1 to 3 feet of the contact.

The wacke member represents continued filling of the Colville geosyncline (Payne, 1951), following an orogenic interval in late Jurassic time. Source areas lay to the south and the orogenic belt of the Brooks Range geanticline may have shifted northward from its position during ate Jurassic time. Depositional conditions probably varied considerably in different parts of the Kukpowruk-Nuka region but, in general, deposition of the most coarsely clastic rocks is believed to have occurred in the southern part.

Local basal and near-basal conglomerate facies represent rapid and chaotic dumping from nearby source areas. Interbedded graywacke and shale beds represent typical flysch sedimentation, but massive crossbedding in many of the graywackes suggests that they were deposited in relatively shallow water with subsequent rapid sinking of the sea bottom. The rhythmically bedded facies suggests turbidite deposition; coquinoid bed and fine crossbedding indicate relatively shallow-water conditions during which currents were relatively weak and sediment supply was limited.

Quartzite Member

Distribution and outcrop. -- The quartzite member of the Okpikruak Formation is exposed in the Southern Foothills province along two outcrop belts which strike southwest from Adventure Creek to beyond the Kukpowruk River. The northern belt, typified by prominent north-facing, discontinuous ridges, extends southwest from Adventure Creek at lat. 68°44' N. across Iligluruk Creek. The southern belt, en echelon to the northern belt, is exposed in discontinuous high hills and ridges from west of Spike Creek at lat. 68°37' N. to beyond the Kukpowruk River. Several small mountainous masses composed chiefly of the quartzite member and surrounded by lower hills, lie along this belt. Among these is Tingmerkpuk Mountain.

Although rocks of the quartzite member are resistant, they are poorly exposed in cutbanks along Iligluruk Creek. Most of the ridges and hills are largely rubble covered, except at their crests and at a few localities along their north sides. The topographic expression and general appearance of these ridges and hills contrasts sharply with lower hills composed of clastic rocks of the Fortress Mountain Formation. From a distance, hills of the quartzite member are black, orange, and yellowish in color, and to some extent resemble the exposures of Paleozoic cherty rocks exposed farther south. Rock rubble is commonly covered by black lichens. On aerial photographs, exposures of the quartzite member are much darker in tone than those in the surrounding hills, and some have a roughly banded appearance.

Character and thickness.-- The quartzite member of the Okpikruak is typified by highly siliceous clastic rocks. Most prominent is very fine grained to silty quartzite, with interbedded siliceous siltstone, hard shale and, locally, coquinoid or limy siltstone. Quartzite comprises about 70 percent of the exposures examined. It is light gray, light olive-gray to dark gray, and grayish-green, and occurs in well-stratified massive to platy beds mostly less than 2 feet but as much as 20 feet thick. It commonly weathers light brown, moderate yellowish brown, and yellowish orange, or appears bleached with light-gray tones on weathering surfaces. Some beds exhibit a "gun-metal"-blue surface stain which extends as much as an eighth of an inch into the rock. Most of the quartzites appear uniformly bedded, but some beds are "gnarled" and irregular and contain worm trails, mud lumps, hexagonal impressions, and carbonaceous fragments on bedding surfaces. Thin-bedded, dark-gray, grayish-green and grayish-red shale and dark-gray to grayish-green siliceous siltstone, together with a few thin beds of friable gray sandstone, are interbedded with the quartzite. The sandstones are locally ripple marked, laminated to finely crossbedded, and some beds contain small silty concretions. At least three beds of medium-to dark-gray limy coquinoid siltstone, from about ½ foot to 2 feet thick, are interbedded with the shale and siltstone. They contain finely ribbed Buchia pelecypods.

These descriptions apply to the rocks exposed in the hills east of Iligluruk Creek and west of Spike Creek. The exposures near the

Kukpowruk River consist almost entirely of massive blocks of quartzite rubble. Little quartzite bedrock is exposed and no fossils were found at these localities.

One thin section of quartzite from the quartzite member (sample 50AMg63) was examined under the petrographic microscope. In hand specimen the rock is light olive-gray and dark gray, very fine grained, with gun-metal-blue weathering which extends as much as an eighth of an inch below the surface. In thin section, the cement (about 10 percent of the section) is composed of microcrystalline quartz, some chlorite, brownish ferruginous(?) films along grain boundaries, and bluish-black metallic material. Closely packed, roughly equidimensional subangular to subround grains, from about 0.02 to 0.2 mm in diameter with modal size of 0.1 mm, consist of quartz and lesser amounts of chert (estimated 80 percent of grains), black opaque minerals (15 percent), chlorite, muscovite, zircon, and limonitic grains. The rock is classified as a protoquartzite (Pettijohn). This may represent a reworked graywacke and, as such, probably was a winnowed shallow-water deposit.

At least 225 feet of the quartzite member is exposed in ridges east of Iligluruk Creek but this measurement probably does not represent the total thickness. West of Spike Creek no field measurements were obtained but there the member appears to be thicker and rough measurements from aerial photographs give a minimum thickness of 500 feet.

Stratigraphic relationships and mode of deposition.-- Rocks of the quartzite member are associated with the Triassic Shublik Formation at

two localities east of Iligluruk Creek. Contacts between the Shublik and Okpikruak are rubble covered. The fossiliferous Triassic beds at the eastern locality are interpreted as a complex anticlinal structure flanked by rubble of gray and reddish-gray shale and limy coquinoid siltstone of the quartzite member. If this interpretation is correct, the Okpikruak lies directly on the Shublik at this locality. East of Iligluruk Creek, the quartzite member appears to be overlain by rocks of the sandstone member of the Fortress Mountain Formation. Two interpretations of the relationships between the quartzite member and the Fortress Mountain Formation are considered equally plausible. The simplest interpretation is that the rocks of the quartzite member are in the axial zone of a tightly folded anticline in which the south limb locally has overridden the north limb. Some structural observations along this outcrop belt confirm the presence of anticlinal axes exposing Triassic rocks. According to this interpretation, the quartzite member normally underlies the Fortress Mountain Formation. Some evidence, however, points to a second interpretation that the quartzite member and associated Triassic rocks represent remnants of overthrust fault blocks which now are resting on rocks of the Fortress Mountain Formation. The evidence includes the discontinuous and scattered character of the quartzite member belts of exposure; small isolated exposures of Triassic rocks along these belts, all surrounded by rubble of Fortress Mountain Formation; the fact that most of the exposures of quartzite member represent the highest topographic features along this outcrop belt; a topographic, benchlike break, along both the north and south sides of some ridges composed of the quartzite member, which, if projected under the ridges does not exceed an apparent slope of 10^{o} south; and the local divergence of strike between the ridges composed of quartzite member and traces of the Fortress Mountain Formation, which in some localities appear to strike under both the north and south sides of the quartzite ridges. Available information on the regional structural features along these belts does not conclusively favor either interpretation. Along Adventure Creek the belt appears to lie in a general anticlinal zone, but along Iligluruk Creek the zone may be synclinal. In many isolated exposures, older rocks associated with outcrop belts of the Fortress Mountain Formation may be in high-angle-fault relationship with the younger rocks. On the other hand, they may represent large-scale overthrusting. Solution of this problem is of great import in deciphering the regional structural and stratigraphic relationships but it has not been satisfactorily resolved.

Beds of the quartzite member, composed of sand and silt-sized material, are relatively clean and well sorted. This is in sharp contrast to the graywackes exposed farther south. However, some of the features commonly found in the rhythmically bedded facies, including fine crossbedding and lamination, are found also in the quartzite member. The sandy sediments were probably deposited in relatively shallow water with current action sufficient to allow winnowing of the sand. The interbedded shale and Buchia-bearing siltstone probably

do not reflect much change in environmental conditions except, perhaps, that current action was weaker. The interbedded reddish and greenish shales may represent intervals of slow deposition and contemporaneous oxidation.

The linear but discontinuous outcrop pattern, clean and well-sorted character of the sands, geographic position of these rocks, and absence of Jurassic rocks suggest that they may have been local offshore bar deposits along a topographic high within the basin of Okpikruak deposition.

Fossils and age. -- R. W. Imlay (1961), after examining fossil collections from many areas in northern Alaska including those from the Kukpowruk-Nuka region, concluded that the coarsely ribbed Buchia pelecypods probably represent earliest Cretaceous (Berriasian) age, and that the finely ribbed Buchia are probably Valanginian. Field relationships in most localities tend to bear out Imlay's conclusion in that beds containing finely ribbed Buchia generally occupy a higher stratigraphic position than beds with coarsely ribbed Buchia. In some sections, however, finely ribbed Buchia occurs near the base of the wacke member of Okpikruak.

The absence of fossils along some belts of Okpikruak(?), such as the one south of Trail Creek, may reflect factors such as increased depth, severe current agitation, or unfavorable bottom conditions. The probable telescoping of lithologically similar fossiliferous and unfossiliferous rock facies by thrust faulting probably explains this [illegible] absence of fossils.

Three collections of pelecypods were made from coquinoid siltstone beds in the quartzite member of the Okpikruak Formation (fig. 12 and table 4). All three contain finely ribbed Buchia of Early Cretaceous age, according to R. W. Imlay. Therefore, they would appear to be equivalent to some part of the wacke member of the Okpikruak. Two of these collections (USGS Mes. Loc. 22481 and 22497) are from beds estimated to lie within 200 stratigraphic feet of Triassic rocks.

A total of 35 shale samples were collected for microfossil content from the Okpikruak Formation in the Kukpowruk-Nuka region. Only nine of these contain microfossils which, according to H. R. Bergquist, are foraminifera representing nondiagnostic forms. The foraminiferal assemblages have a Cretaceous aspect, but are not diagnostic for precise age determination.

Fortress Mountain Formation

The name Fortress Mountain Formation (Patton, in Gryc and others, 1956, p. 219-221) is applied to a thick sequence of nearly unfossiliferous clastic rocks consisting of several facies which outcrop in the central northern parts of the Kukpowruk-Nuka region. These rocks in part underlie and may be in part equivalent to the lower part of the Torok Formation; locally they overlie the Shublik and Okpikruak Formations

and other Mesozoic clastic units. The Fortress Mountain Formation is here divided into three informal members, the wacke and conglomerate, sandstone, and shale members, which outcrop respectively in separate south to north linear belts. The stratigraphic relationships of the members is uncertain, but the conglomerate and sandstone members are believed to be in part equivalent and appear to be overlain by the shale member. The sandstone member is also overlain by the Torok Formation farther north. All of these rocks were previously mapped in the Lower Cretaceous series by Smith and Mertie (1930).

Wacke and conglomerate member

Distribution and outcrop.-- The wacke and conglomerate member of the Fortress Mountain Formation is expressed in the southern foothills as a linear belt, 1/2 mile to 5 miles wide, which extends southwestward from the Nuka River at about lat. 68°45' N., to west of Spike Creek at lat. 68°38' N. The conglomerate member was not seen in the vicinity of the Kukpowruk River. The belt narrows both eastward and westward and attains its maximum width between Storm Creek and Driftwood Creek. The narrowing of the belt near the Nuka River is interpreted to be due in part to structure, and in part to stratigraphic thinning of the member. The narrowing of the belt at Spike Creek is believed to be due mostly to stratigraphic thinning.

Graywacke conglomerate and sandstone, the coarse clastic rocks of the member, are topographically expressed as narrow hogbacks and linear ridges which have relief of as much as 1,000 feet near Driftwood Creek.

Finer grained mudstone and siltstone, intercalated with the coarser clastics, are less resistant and are expressed in linear belts of low relief between the ridges and hills. The northern boundary of the wacke and conglomerate member is expressed as an abrupt topographic break, in sharp contrast to the nearly exposureless lowlands to the north. The southern boundary merges into lower hills underlain by Mesozoic clastic rocks and chert. Cutbank outcrops of the member are best exposed along the Nuka River, Thunder Creek, Driftwood Creek, and the Utukok River.

Character and thickness.-- The wacke and conglomerate member consists of about 40 to 60 percent graywacke and subgraywacke sandstone, conglomeratic sandstone, and conglomerate, with intercalated units of interbedded siltstone and mudstone almost identical to those in the wacke facies of the Okpikruak Formation. The recognizable differences are that the Fortress Mountain Formation does not contain the dark-grayish-green graywackes common in many exposures of the Okpikruak, has less vivid weathering colors, and contains very few fossils.

Massive, interlensing beds, lateral and upward vertical gradation to finer clastics, well-developed graded bedding, and crossbedding in the finer grained sandstones are typical of the coarse clastics of the wacke and conglomerate member. These rocks are dominantly greenish gray, but also range from light olive-gray to medium dark gray, weather light brown to light olive-gray, are moderately to well indurated, and occur in lenticular beds commonly less than 5, but as much as 30, feet

thick; they are interbedded and intergraded in resistant units as much as 75 feet thick. Strata are commonly micaceous and calcareous and, locally, contain clay pellets, carbonized wood and reed fragments, small pyrite nodules and, more rarely, sandy spherical concretions a few inches in diameter. Subround to subangular granule- to large-pebble-size rock fragments are locally abundant and form conglomeratic beds as much as 10 feet thick. The fragments consist mostly of chert and argillite, shale, and lesser amounts of white quartz, gray limestone, and mafic igneous rock. In a few localities, subround cobbles of combustible bituminous shale are found in conglomerate. In general, the coarsest phases and highest percentage of coarse clastic rocks in the conglomerate member occur between the Nuka River and Driftwood Creek, the widest part of the belt of exposures.

Very fine grained sandstone, siltstone and silty mudstone, with lesser amounts of claystone, are both mutually interbedded and interbedded with the coarser clastics. These finer rocks are nearly identical to those of the sandstone member as mapped farther north. Medium-dark-gray silty limestone lenses as much as 4 inches thick are interbedded with the fine clastics of the conglomerate member; in some exposures they represent the uppermost unit of graded bedding sequences. The limestone lenses weather light brown or "cream" colored, are predominantly laminated or finely crossbedded, and in some places contain carbonized wood fragments and scattered well-rounded chert and quartz granules.

Graded bedding is a common feature in rocks of both the wacke and conglomerate and sandstone members of the Fortress Mountain Formation. The lower contact of a typical graded sequence is abrupt and irregular; conglomerate or conglomeratic sandstone overlies claystone, and the bottom surface of the conglomeratic bed contains reverse impressions of the initial mud surface, abundant sole markings such as flute, groove, and striation casts, casts of lobate or elongate scour-fillings, mud flows, worm trails and borings, and elongate or circular fucoidal markings. Within the conglomeratic beds numerous clay pellets and carbonaceous fragments are randomly distributed. The conglomerate grades upward into successively finer sandstones of a more uniform texture which exhibit "curly" bedding in cross section. Succeeding sandstones and siltstones contain small-scale crossbedding and are overlain by laminated siltstone or silty limestone, silty mudstone and, finally, claystone. The claystone is again abruptly overlain by a conglomeratic bed. Sequences such as this are roughly rhythmic and range from a few inches to many feet in thickness. Although this ideal sequence is not present in all exposures, some graded bedding features are present in most outcrops and are reliable criteria for the determination of superposition in a succession of strata.

Section 20: Wacke conglomerate member of Fortress Mountain Formation. Cutbank, east side of Driftwood Creek; measured by E. G. Sable and J. T. Dutro, Jr., June 3, 1951.

Unit	Thickness in feet
Top of section. Probable fault contact with argillaceous unit of section 19.	
1. Sandstone, siltstone, and mudstone interbedded. Sandstone greenish gray, fine to medium grained, in lenticular beds.	13
2. Silty mudstone, sandstone, and siltstone interbedded. Mudstone 70 percent of section. Some medium-dark-gray silty limestone nodules in rubble	15
3. Sandstone and siltstone interbedded, grades upwards into medium-dark-gray silty mudstone. Sandstone very fine grained, greenish gray.	4
4. Interbedded graywacke-type granule conglomerate, sandstone, siltstone, and mudstone.	5
5. Mudstone, siltstone, and sandstone interbedded; similar rock types to those in unit 1 . . Shale 50 percent of unit.	8
6. Graywacke-type conglomerate, sandstone and siltstone interbedded; greenish gray, in beds as much as 3 feet thick, contains subround granules and pebbles of chert. Massive unit.	14
7. Silty mudstone, clay mudstone, conglomerate sandstone, and siltstone interbedded. Pebble conglomerate at base.	14

8. Similar to unit 6, but with 6-inch interbeds of mudstone. Massive unit 15

9. Similar to unit 6, but with lenses of mudstone as much as 6 inches thick and 15 feet long interbedded with coarser clastics. 10

10. Mudstone, grading downwards into sandstone and granule conglomerate. Abrupt contact with unit 11. 3

11. Similar to unit 10. Abrupt contact with unit 12. . . . . . 2.5

12. Siltstone, medium dark gray, micaceous, in 1/2-inch to 3-inch beds, contains carbonaceous plant fragments and angular claystone pebbles 7

13. Mudstone in upper 2 feet, grading downward into interbedded granule conglomerate, sandstone, and siltstone. Irregular bedding surfaces at base of conglomerate beds 10

14. Granule conglomerate, sandstone, siltstone and mudstone in rhythmically interbedded graded sequences 1 to 3 feet thick. 13

15. Mostly sandstone and granule conglomerate, greenish gray, in massive beds as much as 3 feet thick, contains well-rounded chert granules, carbonaceous fragments, and angular to subround mudstone pebbles, grades into mudstone in upper 2 feet of unit. Few 3- to 6-inch mudstone lenses interbedded 10

16. Mostly mudstone and siltstone interbedded, medium dark gray, platy, laminated, thin bedded. Few beds of greenish sandstone as much as 1 foot thick. 15

17. Interbedded granule conglomerate, sandstone, siltstone, and mudstone. Conglomerate and sandstone greenish gray to medium dark gray, 70 percent of unit, in massive beds as much as 1½ feet thick. Abrupt lower contact of conglomerate with unit 18, underside of conglomerate bed contains longitudinal rill-like markings striking north and northeast 19

18. Claystone and silty mudstone interbedded. Few thin sandstone beds in upper 2 feet of unit 10

19. Sandstone and mudstone interbedded in rough rhythmic fashion. Sandstone, medium gray, very fine grained, beds less than 6 inches thick, contain claystone pebbles; shale, medium dark gray, silty. 5

20. Mostly sandstone and granule conglomerate, with thin interbeds of siltstone and mudstone. Abrupt contact with unit 21. 4

21. Interbedded sandstone, granule conglomerate, siltstone, and mudstone. Sandstone and conglomerate of graywacke type, greenish gray and olive-gray, weather light olive-gray, slightly calcareous, generally fine grained, contain

granules of greenish, black, and brownish chert, and angular claystone pebbles as much as 2 inches in diameter. Mudstone, medium to dark gray, platy to blocky, about 40 percent of unit. Siltstone finely crossbedded.	10
22. Similar to unit 21, but mudstone about 10 percent of unit. Chert pebble conglomerate rubble at base of unit	28
End of exposure.	
Total thickness	234+

Descriptions of two graywacke sandstones, considered to be representative of the conglomerate member, are based on examination under the petrographic microscope. In hand specimen, sample 50AMg175, the rock is dark greenish gray, weathers light brown and olive-gray, and is very fine to coarse grained. Visible fragments are angular and roughly oriented along bedding. In thin section, the matrix, about 20 percent of the rock, consists of a very fine clay paste and chlorite. Angular to subround grains from about .05 to 1 mm in diameter are poorly sorted and consist of rock fragments, mostly chert and argillaceous rock (estimated at 70 percent), clear quartz (10 percent), and about (4 percent each) of plagioclase (albite or oligoclase and andesene), carbonate, biotite, muscovite, and opaque minerals. A small amount of chlorite occurs as grains.

Sample 51ASa3, in hand specimen, is a granule conglomerate, greenish gray to light olive-gray, with silty to coarse-grained matrix, is calcareous, and exhibits graded bedding. In thin section, carbonate cement comprises about 20 percent of the rock. Subround to angular, poorly sorted grains as much as 1.5 mm in diameter consist of rock fragments, mostly chert and argillaceous rock (estimated to be 85 percent of the grains), clear quartz (about 5 percent), black opaque minerals and unidentified minerals with whitish coating (5 percent) and lesser amounts of carbonate, plagioclase, and microcline.

The total thickness of the wacke and conglomerate member of the Fortress Mountain Formation in the Kukpowruk-Nuka region is not known. The major structural features in the belt of exposures consist of a narrow northward overturned synclinorium on the south edge of the belt and a larger normal anticlinorium to the north. These structures contain numerous tight folds with thrust faults of unknown displacement and are cut by many of transverse faults. No distinctive marker horizons are known in the member, and even thick resistant units cannot be traced for more than a few miles before they are cut by faults or lose their surface expression. Partial sections measured on limbs of minor structures include 1,300 feet along the Utukok River at 1950 camp 9, 1,700 feet on Thunder Creek, and sections several hundred feet thick along Driftwood Creek and the Nuka River. Some thickness estimates made from structural reconstructions across the belt of exposures, include possible thicknesses of 200 feet along Spike Creek, 2,000 feet along the Utukok River, 4,000 feet along Thunder Creek, and 1,000 feet along the Nuka River. From these estimates it seems that the wacke and conglomerate member thins both eastward and westward from the Thunder Creek vicinity.

South of the main outcrop belt of Fortress Mountain wacke and conglomerate member, a relatively narrow belt of small areal extent consisting of irregular hills and ridges is mapped as the conglomerate member from about 4 miles south to 7 miles southwest of Lake Noluk. The rocks in this belt consist of light-colored sandstone interbedded with graywacke conglomerate which locally overlies rocks of the Okpikruak Formation. The sandstone and conglomerate beds are gently dipping while the Okpikruak beds directly underlying these exposures are steeply dipping and isoclinally folded. A generalized section of these rocks, exposed at lat. 68°43' N., long. 160°12' W, is described below:

Section 21. Fortress Mountain Formation?. Examined by J. T. Dutro, Jr., July 19, 1951.

Unit	Thickness in feet (estimated)
Top of section, eroded.	
1. Sandstone, yellowish gray and light olive-gray, weathers moderate brown to light brown, fine to medium grained, thin bedded, flaggy	75

Unit	Thickness in feet (estimated)
2. Conglomerate, dark greenish gray, weathers light brown, graywacke type, contains subround pebbles and small cobbles of mafic and felsic igneous rocks, shale, chert, and sandstone	25
3. Sandstone, yellowish gray, pale olive, and light olive-gray, weathers grayish orange, light brown, and chalky greenish gray, mostly fine to medium grained, moderately indurated, fairly clean; in part exhibits laminated gradations in grain size, flaggy to blocky	150
4. Conglomerate similar to unit 2. Massive	75
5. Sandstone, similar to unit 3.	200
Total thickness	525+

One thin section of a sandstone from unit 5 of the above section (sample 51ADu128) was examined under the petrographic microscope. The rock in hand specimen is light olive-gray to yellowish gray, weathers pale to dark yellowish brown, medium to coarse grained, with numerous pore spaces. The cement, comprising about 50 percent of the rock, is mainly cryptocrystalline quartz with finely divided clay material, probably chlorite. Pore space is estimated to be about 15 percent, but pores are not interconnected. Subangular to subround, much fractured grains as much as .6 mm in diameter with modal size of .3 mm are largely quartz and chert (estimated 60 percent of grains), mostly siliceous and argillaceous rock fragments (20 percent), plagioclase (15 percent) consisting of andesene ($Ab_{60}An_{40}$) and albite or oligoclase ($Ab_{90}An_{10}$), and minor amounts of mica, probably muscovite. Plagioclase is fresh to sericitized. The rock is a quartzitic subgraywacke.

Stratigraphic relationships.— Although the wacke and conglomerate member locally overlies the micaceous sandstone unit with apparent conformity, as along Driftwood Creek, the base of the member may represent an unconformity of considerable magnitude. Between the Utukok and Nuka Rivers, the member appears to cross structural trends in the belt of exposures of the micaceous sandstone unit which narrows eastward. Along the Utukok River, the contact with the micaceous sandstone unit is interpreted to represent a reverse fault. Elsewhere, along the southern edge of the conglomerate member, contacts are not well exposed, and outcrops within a few hundred feet of the contact are highly folded.

Farther north, within and generally parallel to the belt of wacke and conglomerate member exposures, discontinuous exposures of Triassic rocks extend from south of Lake Noluk across the Utukok River. In some outcrops, the Triassic rocks appear to normally underlie the Fortress Mountain rocks in anticlinal relationship. In other exposures, however, the Triassic rocks are folded in synclines and, where exposed, contacts between the member and the Triassic rocks are interpreted to lie along faults. As with other

exposures of Triassic and associated rocks in belts of the Fortress Mountain Formation, it is uncertian whether these rocks everywhere underlie the Fortress Mountain, or whether they represent remnants of thrust blocks resting on the Fortress Mountain rocks. In the belt of wacke and conglomerate member exposures the Triassic rocks generally appear to lie along the crest of complex anticlinal structures and they are thus interpreted to normally underlie the rocks of the conglomerate member.

There are one or more stratigraphic breaks within the wacke and conglomerate member, but their significance and positions in the sequence are not known. Evidence for these breaks consists of discordant bedding relationships observed in several isolated outcrops where rock units are truncated by overlying beds with angular dip discordance of as much as 15°. At one locality, on the southwest limb of the small syncline exposed 3½ miles southeast of Lake Noluk, several hundred feet of section in the lower beds of the syncline are truncated by overlying beds with angular strike discordance of as much as 45°. These angular relationships probably do not represent large time intervals of uplift accompanied by subaerial erosion, but may be the result of slumping or shifting of local centers of deposition and subsequent scouring.

Precise relationships between the wacke and conglomerate member and the shale member of the Fortress Mountain Formation are not known. Beds near their contact belt of exposures are complexly folded, but the dominant dip is north and the wacke and conglomerate member appears to underlie the shale member. The boundary between the two members is mapped mostly on the basis of topographic expression between ridges composed of coarse clastic rocks to the south and the lowlands underlain by finer clastics to the north. The northern front of the wacke and conglomerate member is a relatively straight line and locally appears to truncate small-scale structures in rocks of this member; it may, in part, be the expression of one or more faults.

Rocks of the wacke and conglomerate member represent relatively rapid deposition of marine graywackes along the south edge of the Colville geosyncline, in a belt farther north than similar sediments in the Okpikruak Formation and other pre-Fortress Mountain clastic units. It is inferred that the mobile belt represented by the Brooks Range geanticline had moved farther north from its position in earliest Cretaceous time . Clastic rocks of earlier Cretaceous age, as well as Triassic and Paleozoic rocks, contributed material to the sediments of the conglomerate member. The lateral thinning of the member both to the east and west, and the absence of significant amounts of these rocks along the Kukpowruk River, suggests that deposition was restricted to a relatively local depocenter in which the thickest accumulation of the sediments and maximum subsidence of the basin floor occurred between Storm and Driftwood Creeks. East of the Kukpowruk-Nuka region, other belts of similar Fortress Mountain Formation conglomerate rocks in the southern foothills may also represent local

basins of deposition with deposition from point sources along the north front of the Brooks Range geanticline.

Fossils and age.-- The rocks of the wacke and conglomerate member are very sparsely fossiliferous. One ammonite fragment found in graywacke sandstone along the upper part of Adventure Creek (USGS Mes. loc. no. 22496) was identified by R. W. Imlay as Lytoceras? sp. One shell fragment of Buchia sp. was found in a limy nodule associated with rubble of sandstone and shale east of Driftwood Creek (USGS Mes. loc. no. 22494), but fossiliferous rocks of the Okpikruak Formation are exposed near this locality and the shell fragment may be from Okpikruak beds. Worm trails and fucoidal markings are common in some fine clastic beds and indeterminate carbonaceous wood and reed fragments are common in the coarser clastics.

Although its age is not known from direct fossil evidence, the wacke and conglomerate member is believed to be at least in part equivalent to the sandstone member of the Fortress Mountain Formation exposed farther north which contains some beds of Albian age. The wacke and conglomerate member may also be in part equivalent to the Okpikruak Formation and may, therefore, represent the entire interval between and including Valanginian to Albian time. No fossils representing Hauterivian, Barremian, or Aptian times have been found in northern Alaska, but fossiliferous Albian rocks have been recognized in many areas. On these bases, the wacke and conglomerate member of the Fortress Mountain Formation in the Kukpowruk-Nuka region is tentatively assigned to the late Lower Cretaceous (Albian), and is probably not younger than middle Albian.

Sandstone member

Distribution and outcrop.-- The sandstone member of the Fortress Mountain Formation is exposed in the southern foothills as linear belts which extend beyond the eastern and western limits of the area. Several poorly exposed belts strike roughly west between the Nuka and Colville Rivers, and a nearly continuous belt 2 to 8 miles wide extends from Driftwood Creek at lat. $68^{\circ}47'$ N. southwestward to the Koklik River. West of the Koklik River, the sandstone member is exposed in a wide belt which strikes southwest, crosses the Kukpowruk River, and extends beyond the limits of the mapped area. North of these relatively persistent belts, three isolated areas of the sandstone member exposures lie in the northern part of the Southern Foothills province.

Rocks of the sandstone member form rounded, mostly mud-, rubble-, and vegetation-covered hills and long, whaleback ridges which are about 700 to 1,000 feet high in the northern areas of exposures and range to about 1,500 feet of relief in the more southerly belts. As seen on aerial photographs, light-appearing ridge tops are commonly bare, with subdued rock traces, mud heavings, and fine linear features caused by flowage and creep of rock detritus. The appearance of these hills and ridges differs from those composed of Nanushuk Group rocks; there is an absence of cuesta- and mesa-like topography and a lack of sharply defined and persistent rock traces. As seen on aerial photographs, the rock traces exhibit rather chaotic, intensely folded and faulted patterns which resemble structures due to plastic flow.

Outcrops of the member are mainly limited to scattered stream cuts, although bedding traces and rock ledges are locally common on ridge tops. The weathering colors of rubble and traces, generally dull gray and olive hues, are not particularly distinctive. Cutbank exposures are more common along Iligluruk Creek drainages and the Colville and Nuka Rivers.

Character and thickness.-- Interbedded mudstone, claystone, siltstone, sandstone, and conglomerate in approximate decreasing order of abundance constitute the sandstone member of the Fortress Mountain Formation in the Kukpowruk-Nuka region. The relative amounts of these rock types are variable; shale and thinly bedded siltstone are estimated to comprise about 40 to 60 percent of the rocks, and are most abundant in the northernmost exposures. The sandstone member differs from the shale member of the Fortress Mountain Formation and the Torok Formation, both of which adjoin belts of the sandstone member, in its greater abundance of sandstone and the presence of thin conglomeratic beds, and differs from the wacke and conglomerate member of the Fortress Mountain in that it contains only minor amounts of conglomerate, the sandstones are generally cleaner and better sorted, and are gray and olive-gray rather than the greenish-gray colors common in the conglomerate member.

The more resistant clastic rocks of the sandstone member, sandstone, siltstone, and conglomerate, are scattered as individual units throughout the member. Where they are the dominant rock types, they form resistant units as much as several hundred feet thick. There are two such units in the Driftwood anticlines, one in the uppermost part and the other roughly 3,500 feet below the top. The sandstone beds increase in abundance southward, and many resistant units are present in the southern belts of exposure. The units are lenticular, however, and can not be traced for more than a few miles.

The sandstone is mostly medium gray and light olive-gray, but ranges from light to dark gray, olive-gray, and more rarely greenish gray; it weathers to dull shades of olive-gray, light brown, pale to moderate yellowish brown, and commonly contains chalk-white travertine-like carbonate deposits on weathered surfaces. Most of the sandstone is very fine to medium grained, moderately well sorted, uniform to gradationally laminated or with small-scale crossbedding and "curly" bedding restricted to layers less than a few inches thick. Coarse-grained sandstone commonly exhibits salt-and-pepper texture. The sandstone is commonly calcareous, argillaceous, and micaceous, and many beds contain rounded pellets and angular fragments of mudstone, a few chert granules and pebbles, sandy iron-stained nodules, and pyrite nodules and concretions. Abundant small carbonaceous fragments are locally concentrated along bedding surfaces, and the fragments are also scattered throughout many of the sandstone beds. Graded bedding is common, and the bottom surfaces of the beds contain abundant sole markings. Most of the sandstone is well indurated, but some beds are poorly indurated to friable, although of low porosity due to the pres-

ence of fine intergranular material. Irregular ripple marks were observed on some beds. Most of the sandstone beds are generally well stratified although some lenticular beds were observed; the beds are commonly less than 3 feet but range to more than 10 feet in thickness, and resistant units are as much as 110 feet thick. The sandstone weathers to platy, blocky, and massive fragments.

Lenses of graywacke conglomerate and conglomeratic sandstone, commonly only a few inches but as much as 3 feet thick, occur at the base of or within some sandstone beds. The conglomeratic rocks resemble those in the wacke and conglomerate member. The matrix of clay to coarse sand-size particles is greenish gray to olive-gray, and encloses scattered subround granules and small pebbles of chert, carbonaceous fragments, white quartz, greenish sandstone, igneous rocks, and gray limestone.

Rocks of the sandstone member seem to represent a similar but, in part, finer grained and cleaner facies of the graywackes exposed farther south. The rocks of the sandstone member are also more calcareous.

Interbedded silty mudstone and claystone are most commonly medium dark to dark gray and rarely yellowish gray, nodular blocky and fissile, soft to hard, and slightly to noncalcareous. They are well stratified, occur in beds less than 2 inches in thickness, and are commonly interbedded with thin siltstone beds in units as much as several hundred feet thick. Small mud cracks occur at a few localities, and small pyritic nodules are present in some beds. The mudstone and claystone weather to olive-gray and yellowish-gray mud associated with rubble of coarser grained rocks along ridges and hilltops. Some beds contain small carbonaceous fragments and, more rarely, larger fragments of coaly wood. In a small cutbank on Adventure Creek, about 9½ miles above the mouth, a 1/4-inch bed of clean vitreous coal, associated with highly iron-stained shale, occurs in a 50-foot section of claystone interbedded with thin siltstone beds; there is also one 4-inch layer of conglomeratic mudstone containing round to subround pebbles and irregularly shaped cobbles of dark-gray silty limestone.

The siltstone, interbedded and intergraded with finer and coarser clastic rocks, is mostly medium gray to dark gray, and light olive-gray, commonly calcareous, and in part iron stained. Beds range to about 2 feet in thickness and are commonly laminated or finely crossbedded. Thin beds and lenses of silty limestone are similar in appearance to the siltstone and constitute a minor part of the sequence.

Section 22. Sandstone member of the Fortress Mountain Formation, west side of the Spike Creek, measured by E. G. Sable, July 12, 1950.

Unit	Thickness in feet
Top of section, covered. Note: Although not described in all individual units, mudstone and claystone are commonly medium dark to dark gray, fissile to blocky, and micaceous. Sandstone and siltstone are	

dominantly medium gray, weather moderate yellowish brown, are commonly micaceous, and commonly contain fucoidal impressions and sole markings on bottoms of beds.

Unit	Thickness in feet
1. Sandstone, medium gray, weathers moderate yellowish brown, fine to coarse grained, poorly indurated to friable, 1/2- to 2-inch platy fracture, contains scattered carbonaceous wood fragments and chert-granule conglomerate as thin interbeds.	8
2. Claystone, dark gray, poorly exposed.	10
3. Sandstone, medium gray, weathers moderate yellowish brown, very fine grained, massive to platy, well indurated.	6
4. Mostly rubble covered. Few thin beds of claystone and medium-dark-gray siltstone.	35
5. Sandstone, similar to unit 3, but fine grained. Cut by calcite veins.	9
6. Rubble of claystone	7
7. Sandstone, similar to unit 3 but highly micaceous	4
8. Rubble of claystone	18±
9. Siltstone, medium dark gray, platy.	4
10. Rubble of claystone	4
11. Siltstone as in unit 9, finely crossbedded.	3
12. Mostly covered, some rubble of claystone.	35
13. Sandstone, medium gray, weathers moderate	

yellowish brown, thin bedded with beds 1/8 to
1 inch thick, poorly indurated. 3

14. Covered. Fault?. 20

15. Mostly covered, some rubble of claystone. 35

16. Sandstone, similar to unit 1, micaceous, platy
in lower part of unit, massive in upper part. 3

17. Sandstone, similar to unit 3, but medium
grained and laminated 6

18. Rubble of claystone 5

19. Sandstone, similar to unit 1, but fine grained. 6

20. Covered 45

21. Siltstone and sandstone interbedded. Lower 15 feet
of unit very fine grained, friable, with fissile
parting, upper 10 feet fine to medium grained,
blocky, iron stained, contains abundant carbonaceous
fragments on bedding surfaces 25

22. Claystone with interbedded thin siltstone
beds, poorly exposed. Claystone 95 percent
of unit 25

23. Sandstone, very fine grained, and siltstone,
"curly" bedding in lower 1 foot of unit 4

24. Claystone, poorly exposed . . . . 20±

25. Sandstone, very fine grained, lower 1 foot
fissile, upper 2 feet platy. Poorly indurated. 3

26. Claystone, poorly exposed 9

27. Siltstone, finely crossbedded 1

28. Claystone, silty shale, and siltstone interbedded.
Claystone 80 percent of unit. . . . . 25±

29. Sandstone, very fine grained, poorly indurated.
Abrupt contact with unit 30 2

30. Mostly covered. Claystone and silty mudstone rubble. . . . 25

31. Siltstone 1

32. Rubble of clay shale. 12

33. Sandstone, fine grained, platy to fissile,
poorly indurated. 3.5

34. Covered 60

35. Sandstone, similar to unit 33. Contains scattered
carbonaceous fragments, very micaceous. 3

36. Rubble of claystone . . . . 20±

37. Sandy siltstone, poorly indurated 2.5

38. Covered 12

39. Sandy siltstone as in unit 37 . . . . 2.5

40. Mostly covered. Rubble of claystone. . . . . 50±

41. Sandstone, medium light gray, very fine to
fine grained, hard to poorly indurated,
contains carbonaceous fragments 15

42. Mostly covered. Some rubble, dominantly clay-
stone, but also siltstone and silty shale . . . . 140±

43.	Sandstone, silty, poorly indurated.	2
44.	Mostly covered. Some rubble of claystone and silty mudstone.	50
45.	Silty mudstone.	2
46.	Rubble of claystone	15±
47.	Siltstone, blocky	5
48.	Siltstone and clay shale interbedded.	15±
49.	Mostly claystone with thin interbeds of siltstone	20±
	Fault?	
50.	Claystone with thin interbeds of siltstone.	35±
51.	Sandstone, very fine to fine grained, fissile to platy, moderately to poorly indurated. Cut by calcite veins.	8
52.	Claystone	20±
53.	Siltstone, dark gray, poorly indurated, lower 1 foot of unit massive.	5
54.	Shale and siltstone interbedded	18
55.	Claystone. Contorted bedding	20±
56.	Sandy siltstone, contains carbonaceous fragments and small pyrite nodules.	2.5
57.	Claystone, grades downward into	15

58.	Siltstone, grading downwards into sandstone, unit increasingly massive towards base.	30
	Bottom of section. Highly contorted beds. Fault?	
	Total thickness	990±

Two representative sandstone samples from the sandstone member of the Fortress Mountain Formation were examined under the petrographic microscope. Sample 50ASa3, from the East Driftwood Anticline, is light olive-gray, medium grained, uniform in appearance, and highly calcareous. Cement is composed of intergrowths of carbonate and crypto-crystalline quartz with some chlorite, and comprises about 10 percent of the rock. Grains are mostly subangular, moderately sorted and closely packed, and range from less than 0.2 to .4 mm with modal size of about .2 mm The grains consist of clear quartz (estimated to be 30 percent of the grains), rock fragments (25 percent) of mostly chert with some argillaceous rocks, carbonate (20 percent), black opaque minerals and unidentified minerals with yellowish opaque coating (10 percent), plagioclase including andesine (about 5 percent), hornblende(?) and biotite (about 5 percent), and muscovite (less than 5 percent). Some siderite may be present in a few small grains. The rock is a calcareous subgraywacke or intermediate between a quartz-itic subgraywacke and calcarenite.

The presence of fresh-appearing biotite in this sample combined with the abundant plastic mud associated with exposures in the Driftwood anticlines vicinity, are suggestive of volcanic activity. However, no tuffaceous or positively identified bentonitic material was recognized in the sandstone member.

Sample 50ASa49, collected in the southern part of the belt of exposures east of Iligluruk Creek, in hand specimen is medium light gray, weathers moderate yellowish brown, fine grained with salt-and-pepper texture, exhibits graded bedding, and is highly calcareous. Cement comprises about 30 percent of the rock and consists of fine-grained carbonate with a small amount of chlorite. Mostly subangular to angular fairly well sorted grains form less than .02 to .2 mm in diameter, with modal size of .08 mm consist of carbonate (estimated to be 35 percent of the grains), clear quartz (30 percent), chert (25 percent), muscovite (less than 10 percent), and rock fragments, opaque minerals, and plagioclase. The rock is intermediate between a subgraywacke and calcarenite.

No complete, unfaulted section of the sandstone member is known to be exposed in the Kukpowruk-Nuka region, and the total thickness of the member is not known. Partial thicknesses include about 4,400 feet in the axial zone of the East Driftwood anticline, based upon structural computations from scattered dip readings along the Utukok River, and about 3,100 feet along Spike and Iligluruk Creeks, where the rocks are better exposed. However, the thickness of the member is believed to vary considerably within the area; it is inferred to reach a maximum in the southern and western parts of the exposure belts and

may be as much as 5,000 feet thick between the Kokolik and Kukpowruk Rivers.

Stratigraphic relationships and mode of deposition.-- Within its southern belts of exposure, the sandstone member of the Fortress Mountain Formation is interpreted to locally overlie rocks of the Shublik Formation and the Cretaceous (Neocomian) rocks. Contacts between beds of the sandstone member and these rocks are obscured by rubble and some of the Shublik and Okpikruak rocks may actually overlie the sandstone member in thrust fault relationship. In the Kukpowruk Valley, 6 to 8 miles southwest of Igloo Mountain, the sandstone member overlies rocks of the argillaceous unit. Contacts are not exposed, but bedding traces of the sandstone member discordantly truncate traces of the older strata. The contact may either represent an angular unconformity or lie along a fault in this vicinity. West of the Nuka River, 3 miles west of the mouth of Pilly Fork, the sandstone member appears locally to overlie a complexly folded anticlinal structure containing graywacke sandstone, shale, and associated Shublik Formation rocks. Here, the general strike of the sandstone member beds is at considerable variance to those of the underlying rocks, and an angular unconformity is inferred. Along the south side of the southern belt of exposure, the sandstone member apparently underlies the shale member of the Fortress Mountain Formation. No clear relationships between the two were observed, however, and their relative positions are based on the structural interpretation that the shale member lies in a synclinal structure. Mapped contacts between the two members are drawn along obscure topographic breaks marked by hills containing the coarser and more resistant clastic rocks of the sandstone member. Along the north side of the southern belts of exposure of the sandstone member, the contact with rocks mapped as Torok Formation also lies for the most part along topographic breaks which are not everywhere well defined. Between Driftwood Creek and Tingmerkpuk River, this contact is a relatively straight line and may, in part, reflect one or more faults.

In the northern areas of exposures, the sandstone member occurs in what appear to be anticlinal structures flanked by rocks of the Torok Formation. Along the Driftwood anticlines the member directly underlies the Torok Formation and, although the actual contact is not exposed, the rocks appear to be conformable. The mapped contacts are drawn at the top of the uppermost resistant ridge-forming clastic unit of the sandstone member, along a break in slope. Similar relationships between the sandstone member and the Torok Formation are interpreted for those rocks in the other northern areas of exposures although the contacts in part lie along faults.

Evidence for relationships between the sandstone and wacke and conglomerate members of the Fortress Mountain Formation is indirect and consists of comparative lithologic character and features of rocks in the two units, their relative stratigraphic positions with regard to the shale member of the formation both appearing to underlie

that unit. The sandstone and wacke and conglomerate members are at least in part equivalent and the upper part and northernmost exposures of the sandstone member may be younger than any conglomerate member rocks.

Fortress Mountain Formation rocks probably represent a prograding, deltaic geosynclinal sequence. The strata indicate conditions of rapid deposition in which turbidity currents were important agents of transportation. Source areas lay to the south in the Brooks Range geanticline. Although the sandstone member is interpreted to be a northerly distal facies of the wacke and conglomerate member, it may in part be a younger progradational unit in which reworked sediments of the wacke and conglomerate member were incorporated as the geanticline axis migrated northward such as it did later in the Cretaceous (Payne and other 1951; Chapman and Sable, 1960). The more widespread character and apparent greater thickness of the sandstone member are features which seem to support this assumption. Following deposition of the sandstone member, the supply of coarse sediments diminished and the finer sediments making up the shale member were deposited.

Fossils and age.-- Megafossils in the sandstone member of the Fortress Mountain Formation are very rare. Surfaces of sandstone and siltstone beds locally contain worm trails, indeterminate circular and elongate markings, hexagonal impressions identified by R. W. Brown as _Retiphycus hexagonale_ Ulrich, possibly a plant form.

These structures, now called _Paleodictyon_, are interpreted as feeding trails by Seilacher (1954). An ammonite identified as _Colvillia crassicostata_ by R. W. Imlay, was collected from a sandstone bed along the Colville River (USGS loc. no. 23558). According to Imlay (1962), _Colvillia_ has been found also in the lower part of the Torok Formation from other areas in northern Alaska and probably represents late Early Cretaceous (Albian) time.

Shale member

Distribution and outcrop.-- The shale member of the Fortress Mountain Formation is exposed in the southern foothills in a persistent west- and southwest-trending belt about ½ mile to 4 miles wide which extends from east of the Nuka River to beyond Spike Creek.

Rocks of the nonresistant shale member are topographically expressed as relatively featureless swampy lowlands. Only a few rock traces are exposed and, except along the Nuka River and near the junction of Storm and Thunder Creeks, cutbank exposures are rare and scattered.

Character and thickness.-- Mudstone and claystone comprise about 60 to 80 percent of the rocks in the shale member. These, similar to that present in other units of the Fortress Mountain Formation, commonly are dark gray, fissile, blocky and nodular, and locally iron stained. A few beds exhibit small mud cracks. Claystone and mudstone occur in units commonly less than 1 foot but as much as 30 feet thick, interbedded with mostly thin siltstone and very fine to fine-grained sandstone beds. The siltstone and sandstone are similar to those in

the sandstone member but are generally very well indurated. Along Thunder Creek, and in some exposures further west, the surfaces of these beds are brightly iron stained. Fine-graded bedding and cross-bedding, mud markings, small pyrite concretions, and small ripple marks are characteristic of many of the sandstone and siltstone beds, which are commonly less than 4 inches thick, and rarely as much as 10 feet thick. Along the Nuka and Colville Rivers, the lower part of the formation contains a higher percentage of sandstone and siltstone and grades upward into predominantly argillaceous rocks (section 23). Along Spike Creek, exposures of the member are composed almost entirely of claystone and mudstone.

The total thickness of the shale member is not known, as no rocks known to be younger than the member were recognized along its belt of exposures. The thickest known section, about 3650 feet, is about 80 percent exposed in cutbanks along the Nuka River and Pilly Fork, and lies in the north limb of a major syncline. A few small drag folds were observed in the upper and lower parts of the section, but the section is not believed to be cut by major displacements.

Section 23. Shale member of Fortress Mountain Formation, west side of Nuka River and Pilly Fork; measured by R. H. Morris and E. G. Sable, August 22-23, 1951.

Unit	Thickness in feet
Top of section, eroded. Syncline axis.	
1. Silty shale, medium to dark gray, fissile to	

blocky, thin bedded, about 90 percent of unit.
Thin interbeds of siltstone, medium gray, weathers light gray, micaceous, calcareous, in beds less than 1 inch thick, finely cross bedded. Beds well stratified; unit contains few small drag folds. Unit about 80 percent exposed. . . . . 1,800±

2. Silty shale and siltstone interbedded as in unit 1, but shale about 70 percent of unit, platy, in part laminated. Few beds of very fine grained sandstone less than 1 inch thick. About 70 percent exposed . . . . 630±

3. Similar to unit 2, but includes soft sandy shale, platy, interbedded with 1-inch beds of very fine grained sandstone . . . . 700±

4. Sandstone, medium dark gray, weathers moderate yellowish brown to light olive-gray, micaceous, hard. . . . 2

5. Interbedded silty shale, clay shale, siltstone, and sandstone. Clay shale dark gray, fissile to nodular, in part laminated, small mud cracks seen on one bed. Sandstone mostly less than 1½ inches but as much as 4 inches thick. Shale about 60 to 70 percent of unit. . . . . 250±

6. Sandstone, medium gray, weathers light olive-gray, fine grained, micaceous, contains scattered carbonaceous fragments, massive to blocky, bedding partings 1 to 6 inches. . . . . 13±

7. Similar to unit 5. Sandstone, very fine to fine grained, in beds as much as 2 inches thick. Shale beds ½ inch to 4 inches thick with 1/8- to ½-inch partings. . . . 260±

Total thickness . . . . 3,650±

Stratigraphic relationships.-- The shale member is interpreted to lie in a synclinorial structure between complex anticlinoria of the sandstone and wacke and conglomerate members of the formation. The south limb of the synclinorium is highly folded and the member may be in fault contact with the wacke and conglomerate member. On the north side of the outcrop belt along the Nuka River, however, the north limb is relatively simple and the sequence appears to grade downward into the sandstone member. No other basal contacts of the shale member with older rocks were seen anywhere in the area.

The shale member may be a slightly coarser grained equivalent of the lower part of the Torok Formation exposed farther north where the Torok overlies the sandstone member of the Fortress Mountain Formation.

Fossils and age.-- No megafossils were found in the shale member. Thirty-six shale samples were collected for microfossil content and of these 30 samples were barren. The meager microfauna in the 11 fossiliferous samples of 105 total samples from all three members of the Fortress Mountain Formation identified by H. R. Bergquist include the three forms _Bathysiphon brosgei_ Tappan, _Haplophragmoides linki_

Nauss, and Conorbina?. These are also present in the lower part of the Torok Formation, but are not known from other rock units in the Kukpowruk-Nuka region.

Torok Formation

The Torok Formation, first described by Gryc, Patton, and Payne (1951), was redefined by Patton to include "the predominantly shale sequence that underlies the Nanushuk group in northern Alaska" (*in* Gryc and others, 1956, p. 222). At least the upper part of the formation can be traced westward from the type area for a distance of more than 200 miles and, in the northern part of the Kukpowruk-Nuka region the sequence underlies rocks of the Kukpowruk Formation and overlies the sandstone member of the Fortress Mountain Formation.

Torok Formation rocks exposed in the northernmost part of the mapped area and those farther north in the Utukok-Corwin area have been previously discussed by Chapman and Sable (1960). Other exposures of the Torok Formation in the Kukpowruk-Nuka region contain rocks which are similar to those described by Chapman and Sable, but rock sequences are not well exposed and the beds are tightly folded and faulted; little new stratigraphic or lithologic information is included in this report.

Rocks within the sequence mapped as Torok Formation had previously been considered to mark the dividing line between Lower and Upper Cretaceous Series by earlier investigators (Smith and Mertie, 1930, pl. 1) who interpreted the Late Cretaceous rocks to overlie the Early Cretaceous rocks with pronounced angular unconformity. More

recent studies show that the rocks of the Torok Formation are not younger than middle Albian age, but the sequence may contain one or more depositional breaks occupying the same general position as the one suggested by Smith and Mertie.

Distribution and outcrop

The Torok Formation underlies wide lowlands in the Southern and Northern Foothills provinces in the northern part of the Kukpowruk-Nuka region. Lowlands extend across the entire area and appear monotonously featureless in contrast to the hills and ridges underlain by rocks of the Fortress Mountain Formation and Nanushuk Group; however, they contain many small hills and ridges as high as 100 feet. There are a few mud- and rock-rubble traces on the hills and ridges, but for the most part the lowlands are covered by tundra and post-Cretaceous gravel deposits. Outcrops are mainly limited to small disconnected cutbank exposures that are most numerous along the Colville River, Driftwood and Adventure Creeks, and Tingmerkpuk River.

Character and thickness

Claystone, mudstone, and silty shale are the predominant rock types of the Torok Formation; interbedded siltstone, sandstone, limestone and varied nodules and concretions comprise less than 15 percent of the sequence. The shale and thin-bedded coarser rocks are uniformly bedded but thick beds of sandstone and siltstone, where well exposed, are mostly lenticular.

Claystone and mudstone are similar to those in the Fortress Mountain Formation. They are mostly medium to dark gray; some are olive-gray and yellowish gray, and rarely greenish gray; the shales weather grayish yellow, and some beds exhibit "gun-metal"-blue weathering surfaces. These fine-grained rocks occur in well stratified and, in part, laminated blocky, fissile, and nodular beds commonly less than 1 inch thick; units range from a few inches to more than 100 feet thick. The shale is in part calcareous and locally contains small ripple marks and mud cracks, mud markings, whitish or yellowish efflorescence along fractures, layered carbonaceous wood fragments associated with iron-stained shale, and ferruginous, limy, clayey, and pyritic nodules and concretions.

Siltstone and very fine to fine-grained sandstone, mutually interbedded and interbedded with shale in platy- to blocky-fracturing beds commonly less than 4 inches thick and in units mostly less than 2 feet thick, are light to dark gray and yellowish gray, weather yellowish brown, olive-gray and in part iron stained. They are hard, fairly clean, well sorted, locally calcareous, and some beds contain ripple marks, scour markings, ferruginous and pyritic nodules, scattered and layered carbonaceous plant fragments and mica flakes, clay pellets, burrows, trails, indeterminate organic markings and a few pelecypods.

Fine- to medium-grained sandstone also occurs in somewhat thicker, platy to massive lenticular beds and units commonly less than 5, but as much as 75 feet thick. Sandstone is commonly medium gray, weathers pale to moderate yellowish brown, with salt-and-pepper texture,

and otherwise resembles the more thinly bedded sandstone and siltstone. The thick-bedded sandstones more closely resemble similar rock types in the Nanushuk Group than those in the Fortress Mountain Formation; they are relatively clean, well sorted, contain relatively little visible mica, and commonly weather rusty and yellowish brown in contrast to the dull olive-gray and brownish colors characteristic of the Fortress Mountain sandstone beds. These Torok sandy units are scattered throughout the upper part of the formation, particularly in the upper 1,000 feet, but sandy units also occur in the middle part of the formation about 3,000 to 4,000 feet below the top. Sandy units, locally 75 feet thick, were recognized along the east-flowing part of the Colville River, on Plunge Creek, Adventure Creek, and Iligluruk Creek. These may represent a relatively persistent sandy horizon which extends throughout the belts of exposures; but because of the limited outcrops and uncertain structural relationships, the persistence of the sandstones as a marker horizon has not been demonstrated. Some sandstone beds also occur in the lower part of the Torok Formation; but where present, as along Adventure Creek, they are relatively thin and resemble strata of the sandstone member of the Fortress Mountain Formation.

A 550-foot sequence exposed along the north limb of the East Driftwood anticline, described by Chapman and Sable, represents the basal part of the formation at this locality and consists mostly of dark-gray clay shale which contains a small amount of dark-greenish-gray shale, lenses of yellowish-brown claystone, dark-gray silty limestone with cone-in-cone structure, and septarian concretions less than 2 inches in diameter. Part of this section was mapped as the argillaceous unit (p. 130-134). Ten miles east of this section, on the west side of the Colville River, similar rocks exposed in three cutbanks may represent the same horizon. In the southernmost cutbank at approximate lat. 68°51'30", rubble of light-yellowish-gray clay associated with greenish-gray and grayish-red shale overlies siltstone, sandstone, and shale of the sandstone member of the Fortress Mountain Formation on the north limb of a small anticline. One mile downstream, the following section is exposed on the south limb of an anticline.

Section 24. Torok Formation? West side of Colville River.

Examined by E. G. Sable, August 12, 1951.

Unit	Thickness in feet
Top of section, end of exposure	
1. Largely claystone, 80 percent of unit, dark gray to medium dark gray, nodular to platy, in sets of beds as much as 1 foot thick. Interbedded siltstone and small amount of fine-grained sandstone, medium light gray to light olive-gray, calcareous, finely cross-bedded, in beds less than 1 inch thick.	250
2. Sandstone, medium light gray, weathers dark yellowish orange, fine grained, calcareous.	1
3. Shale, siltstone, and sandstone interbedded as in unit 1, but sandstone beds as much as 6 inches thick; few 2-inch beds of limy claystone, light gray, weathers pale yellowish orange.	25±
4. Largely rubble. Shale 75 percent of unit, sandstone 15 percent, siltstone 10 percent. Few nodules of moderate red-weathering dense ferruginous claystone (ironstone), and fragments of claystone with cone-in-cone structure. . .	500±
Bottom of section. End of exposures	
Total thickness	776±

On the north limb of the same anticline, an isolated exposure includes 30 feet of dark-gray clay shale, the upper 15 feet of which contains irregular nodules of medium-gray, calcite-veined, silty limestone as much as 1 inch thick and 4 inches long. This shale overlies several hundred feet of interbedded siltstone, sandstone, and shale, in which the coarser grained rocks, typical of the sandstone member of the Fortress Mountain Formation, comprise 60 percent of the exposure. North of this exposure, scattered cutbanks consist predominantly of shale and the beds dip northward towards the axis of the Meat Mountain syncline.

The rocks interpreted to represent basal beds of the Torok Formation to some extent resemble strata of the argillaceous unit exposed in the Kukpowruk River Valley. However, no megafossils were found in the rocks along the East Driftwood anticline or on the Colville River. Microfossil samples from the Colville River exposures were barren, but one aggregate microfossil sample (Sample 51ASa306) from the Driftwood exposures contained a microfauna of possible Cretaceous age, according to H. R. Bergquist. Some of these rocks may represent argillaceous unit equivalents.

Thickness measurements of the Torok Formation are approximate; the formation is not completely exposed anywhere in the area, and, although the upper limits of the formation are fairly well defined in a few places where Nanushuk Group rocks are present, the lower limits are uncertain. Section measurements were calculated at localities where no major structural break is apparent. Measurements were made on vertical aerial photographs using field information from well-exposed but scattered outcrops. In each of these sections a few outcrops which lie near major anticlinal axes showed evidence of minor folding and faulting of unknown magnitude. The thicknesses were measured at three localities: along Adventure Creek south of the East Driftwood anticline; between Meat Mountain syncline and East Driftwood anticline; and north of the Colville River along long. $160^{\circ}10'$ W., on the south limb of Foggy syncline. The Meat Mountain 6,400-foot-thick section, is believed to represent the total thickness of the Torok Formation at that locality. The Adventure Creek section, about 5,200 feet thick measured from the bottom of the formation, and the Foggy syncline section, about 6,000 feet thick measured from the top of the formation, do not represent total thicknesses.

Stratigraphic relationships and mode of deposition

The Torok Formation overlies the sandstone member of the Fortress Mountain Formation along the East and West Driftwood anticlines and along the Colville

River with apparent conformity, although the actual contacts are not exposed. The Torok underlies the Kukpowruk Formation of the Nanushuk Group, and the contact is gradational and intertonguing. Because of this intertonguing, the upper part of the Torok Formation in the eastern part of the area is interpreted to be at least in part equivalent to several thousand feet of the Kukpowruk Formation in the western part (Chapman and Sable, 1960).

On the basis of rock types and stratigraphic position, at least the lower part of the Torok Formation may be equivalent to the shale member of the Fortress Mountain Formation, and some of the Torok beds may also represent a northern fine-grained facies of the coarser clastic rocks of the sandstone and conglomerate members of the Fortress Mountain. Microfossils from the lower part of the Torok and the sandstone member of the Fortress Mountain are generally similar but other fossil evidence is lacking. If these units are equivalent, the northward facies shift represents the normally expected decreased current competency in more distal areas of the geosyncline, and the vertical facies shift may represent both slower rate of uplift in the Brooks Range geanticline and a general southward marine transgression during Torok time.

Discordant bedding relationships within the Torok Formation were observed in a few isolated localities but they could not be traced beyond the exposures in which they occur. One example, along a tributary of the upper part of the Colville River, is discussed by

Chapman and Sable (1960, p. 76). These relationships may not be of major significance and are possibly the result of changes in current direction or subaqueous slumping down low initial slopes. Discordant bedding relationships reported by W. R. Smith along the Colville River near Reynard Creek were interpreted to represent an unconformity between Early and Late Cretaceous rocks (Smith and Mertie, 1930, p. 203). This exposure now mapped as Torok Formation, was revisited by E. J. Webber in 1948 who interpreted the angular relationships as an irregular low-angle fault.

Other angular relationships mapped within the Torok Formation which may denote one or more significant depositional breaks were recognized on aerial photographs at localities on the south limb of Meat Mountain syncline and between West Driftwood anticline and the major syncline west of Driftwood. The break in the Meat Mountain syncline lies roughly 2,000 feet below the top of the formation. These are mapped and have been described by Chapman and Sable (1960) as discordant truncation of bedding traces in the lower part of the formation by those in the upper part. An apparent discordant relationship within the Torok is also present in the northeastern part of the area, north of the Colville River. It is possible that these lines of discordance may be the surface expressions of faults, but the presence of a depositional and tectonic break within the Torok Formation is to some extent supported by microfossil evidence and observations of regional structure (Chapman and Sable, 1960). The relatively thick sandstone units, locally exposed

in the middle part of the formation, may be indicative of the suggested break between the lower and upper parts of the formation.

This thick sequence of dark shale which contains fairly large proportions of silt and some coarser clastic beds is a transported marine deposit believed to have been shed from the south into the downsinking Colville geosyncline. Bedding features such as the small mud cracks and local concentrations of iron-stained plant material indicate that some of the beds were deposited in shallow water. Fine laminations and evenly stratified units suggest that current activity was extremely weak during deposition of many beds, but coarser clastic beds represent periodic intervals of stronger current activity. The rarity of mega-fossils combined with the character of the sediments implies that muddy bottom conditions and turbid waters were unfavorable to bottom-dwelling organisms.

The thick lenticular units of sandstone and siltstone in the upper part of the formation, which in part underlie and in part are equivalent to the dominantly sandy sections of Kukpowruk Formation, represent depositional activity similar to, but generally less intense than, that of the Kukpowruk sediments. Conditions under which the upper part of the Torok was deposited are regarded, therefore, as approaching shelf-type deposition that characterizes the general northward regression of Cretaceous seas during deposition of the Nanushuk Group (Chapman and Sable, 1960).

Fossils and age

The few megafossils found in the Torok Formation in the Kukpowruk-Nuka region consist of pelecypods, the worm Ditrupa, and hexagonal markings. Three collections from sandstone beds in the Torok Formation or probable Torok Formation include one sample collected by P. S. Smith in 1926, previously identified by J. B. Reeside, Jr., and reexamined by R. W. Imlay in 1953, and two samples collected in 1950 and identified by Imlay.

13717 (26AS37) Igloo Mountain, near Kukpowruk River. Approximate lat. 68°46' N., long. 162°50' W. Torok Formation? Upper part?

Ditrupa n. sp.

pelecypods indet.

22480 (50ASa32) Plunge Creek, north of West Driftwood anticline, west of Utukok River. lat. 68°53'24" N. long. 161°21' W. Torok Formation, upper part?

Arctica? ap.

Panope? kissoumi (McLearn)

Inoceramus sp. juv.

Pleuromya sp.

50ASa18. West side of Adventure Creek, lat. 68°51' N., Torok Formation, middle part?

Paleodictyon hexagonale (Ulrich) (hexagonal markings)

With the exception of Paleodictyon and Inoceramus, the other fossils are also present in the overlying rocks of the Kukpowruk Formation in

the Utukok-Corwin region, farther north. In themselves, the fossils are not diagnostic of a specific age, but the stratigraphic position of the Torok Formation between the Fortress Mountain and Kukpowruk Formations, both considered to be of Albian age, indicates an Albian age for the Torok.

A more extensive microfaunal assemblage is recorded from the Torok Formation in the Kukpowruk-Nuka region than the combined assemblages of the other rock units. Although this may be partly due to the greater number of shale samples collected from the Torok, it is more probable that the Torok contains a greater abundnace of forms and variety of species.

A total of 146 shale samples were collected from the lower part, representing approximately the lower 4,500 feet. Of these, 40 samples were barren. Microfossils in the remaining samples include Dorothia chandlerensis Tappan, Haplophragmoides linki Nauss, Bathysiphon brosgei Tappan, and Trochammina eilete Tappan. Dorothia chandlerensis and Haplophragmoides linki are forms which are present in the lower part of the Torok Formation elsewhere in northern Alaska and are not certainly known to be present in the upper part of the formation (Bergquist, H. R., 1957, written commun.).

About 10 shale samples were obtained from the upper 1,000 feet of the Torok Formation in the Kukpowruk-Nuka region. These were either barren or contained long-ranging species of forminifera and cannot be adequately compared to those from the lower part of the Torok.

Microfossils from the upper part of the formation farther north in the Utukok-Corwin region (Chapman and Sable, 1960) lack Dorothia chandlerensis and Haplophragmoides linki and contain a somewhat different assemblage than those from the Kukpowruk-Nuka region, and more closely resemble assemblages in the overlying Nanushuk Group. Although a microfaunal break within the Torok Formation may be present, faunal data are too fragmentary to be more than suggestive. Other evidence for a possible nondepositional break within the formation has been discussed above, but the specific stratigraphic interval which may represent the break is not well exposed and has not been sampled.

Lower and Upper(?) Cretaceous Series

Nanushuk Group

Kukpowruk and Corwin Formations

The Nanushuk Group is a sequence of marine and nonmarine rocks in northern Alaska that directly overlies the Torok Formation and underlies the Colville Group (Gryc, Patton, and Payne, 1951, p. 162-164), and is of Early and early Late Cretaceous age (Detterman, *in* Gryc and others, 1956, p. 233). In the Utukok-Corwin region, north of and overlapping with the Kukpowruk-Nuka region, the group has been divided into two major rock units, a lower dominantly marine unit, the Kukpowruk Formation, and an upper dominantly nonmarine unit, the Corwin Formation (Sable, 1956). Rocks of these formations exposed in the Kukpowruk-Nuka region have already been described in detail by Chapman and Sable (1960), and discussion of these units in the present report

is of a general nature. Part of the geologic map of Chapman and Sable is here incorporated in the northernmost part of the Kukpowruk-Nuka region. Rocks of the Nanushuk Group had previously been included in the Upper Cretaceous Series by Smith and Mertie (1930).

Distribution and outcrop.-- Several large simple synclines composed of Nanushuk Group rocks, topographically expressed as mesas and cuestas, lie in the Northern Foothills province along the northern boundary of the Kukpowruk-Nuka map area. These include Foggy, Meat Mountain, Poko Mountain, and Igloo Mountain synclines, and synclines along the Kokolik and Kukpowruk Rivers. The mesas and cuestas rise to about 2000 feet above lowlands underlain by the Torok Formation. Their slopes contain relatively persistent rock ledges and rubble traces of resistant sandstone units which alternate with tundra- and rubble-covered bands representing less resistant rock types. Cutbank exposures are restricted to scattered outcrops along the major streams, the Kokolik and Kukpowruk Rivers.

Character and thickness.-- The Kukpowruk and Corwin Formations consist largely of sandstone, siltstone, and shale, parts of a northward prograding deltaic complex. The Kukpowruk Formation in the Kukpowruk-Nuka region contains about 35 percent subgraywacke to relatively clean sandstone, sandy siltstone, and thin lenses of conglomeratic sandstone and subround pebble conglomerate which are mostly gray, yellowish gray, and light olive-gray, and commonly weather yellowish brown. These occur in resistant units as much as 100 feet thick, which weather flaggy to massive and exhibit large-scale crossbedding, current and oscillation ripple marks, and graded bedding. Intercalated units of interbedded dark-gray shale, claystone, and thinly bedded siltstone resemble those in the Torok Formation. Carbonaceous shale, thin coaly beds, and nodules of clay and silty ironstone are present in minor amounts. Fossils, locally present in sandstone beds, consist mostly of pelecypods and worm casts or trails. Clay pellets and carbonaceous fragments are common throughout the formation.

Along the northern boundary of the Kukpowruk-Nuka region, the Kukpowruk Formation thins eastward from about 4,500 feet on the Kukpowruk River to about 2,750 feet on the Kokolik River. Partial sequences from which the top of the formation has been eroded include measured thicknesses of about 2,300 feet at Meat Mountain, 1,700 feet in Poko Mountain syncline and estimated thicknesses of 1,300 and 1,000 feet, respectively, at Igloo Mountain and Foggy synclines.

The dominantly nonmarine rocks of the Corwin Formation exposed in the synclines along the Kukpowruk River consist of rock types similar to those in the Kukpowruk Formation but include more abundant and thicker beds of coal, carbonaceous shale, conglomerate, and bentonite beds. The formation contains abundant carbonaceous fragments, carbonized wood remains, plant impressions, and ironstone nodules and lenses. The orange, reddish, and yellowish weathering colors of the Corwin, when seen from a distance, are distinguishing gross features, in contrast to the darker yellowish-brown-weathering hues of the Kukpowruk.

The Corwin becomes progressively more nonmarine upward in the sequence.

No complete sections of the Corwin Formation are exposed in the Kukpowruk-Nuka region; the upper part of the formation has everywhere been eroded. Partial thicknesses of the formation include about 3,500 feet on the south limb of the syncline along the Kukpowruk River (Coke basin in Chapman and Sable, 1960).

Stratigraphic relationships and mode of deposition.-- Because the Kukpowruk and Torok Formations are gradational and intertonguing, the two are in part equivalent. The basal contact of the Kukpowruk is placed at the base of the lowest persistent sandstone beds which form a break in slope above lowlands underlain by the Torok Formation. The Kukpowruk and the Corwin Formations are also gradational and intertonguing, and the position of their contact is not clearly defined. The base of the Corwin Formation is mapped in a transitional zone as much as several hundred feet thick, above which nonmarine rocks are dominant. Although local erosional breaks have been recognized within both the Kukpowruk and Corwin Formations (Chapman and Sable, 1960), these rocks are believed to represent an essentially continuous depositional sequence.

The Kukpowruk Formation is interpreted to represent an inshore delta plain and delta front facies deposited in a shallow sea with a widely fluctuating shoreline which, in general, regressed northward. The character and bedding features of the rocks indicate shelf-type deposition rather than true geosynclinal dumping, and the Kukpowruk probably represents the final filling stages of the Colville geosyncline. As the sea regressed northward beyond the limits of the map area, nonmarine delta plain and alluvial facies of the Corwin Formation were deposited.

Fossils and age.-- Megafossils and microfossils obtained from Nanushuk Group rocks in the Utukok-Corwin and Kukpowruk-Nuka regions have been reported by Chapman and Sable (1960). The megafossils in collections from the northern part of the Kukpowruk-Nuka region, identified by R. W. Imlay, include *Arctica* ? sp., *Panope*? *kissoumi* McLearn, "*Unio*", starfish undet., *Entolium* n. sp., and *Thracia* sp. According to Imlay (written commun., 1956), correlations of faunal assemblages from the Kukpowruk Formation with those from other areas in northern Alaska and Canada suggest that they are of Early Cretaceous age, not older than middle or upper? Albian.

The Corwin Formation is believed to be of late Early Cretaceous and Late Cretaceous ages on the basis of plant fossils (Chapman and Sable, 1960). This age, however, is questioned by Arnold, who believes, the flora to be of earliest Cretaceous age (Chester A. Arnold, written commun., 1958).

Microfossils from the Kukpowruk Formation are similar to those from the upper part of the Torok Formation and suggest an Albian age for the Kukpowruk according to H. R. Bergquist. Those from the Corwin Formation are rare and consist mostly of long-ranging forms, but are in general similar to the microfauna of the Kukpowruk Formation. The

microfauna from these formations has been discussed by Chapman and Sable (1960, p. 125).

Quaternary Deposits

Although geologic studies in the Kukpowruk-Nuka region have dealt primarily with bedrock geology, general observations were made on the Quaternary fluviatile deposits. These deposits, estimated to cover about 15 percent of the Foothills province, consist of sand, silt, and gravel in which constituents range to small boulder size. Subangular to subround pebbles and cobbles are the dominant constituents of the gravels and represent all bedrock that outcrops in the area; chert and well-indurated sandstone are the dominant types. No appreciable difference in mean fragment size was noted between gravels in the present alluvial flood plains and those in older gravel terraces, but detailed statistical comparisons were not made. A few ice-rafted angular boulders occur in the Holocene flood-plain deposits. Two general levels of unconsolidated alluvial deposits occur in the Kukpowruk-Nuka region.

Low-level terrace and flood-plain deposits

The lower and most recent level includes all deposits on the flood plains of present streams and stream-built gravel terraces generally less than 20 feet above stream level which lie along the flood plains. These deposits include several terrace levels along the major valleys in which most of the terraces lie within 10 feet of present stream level. The terraces range from 1 to 4 feet in height and have been deposited during recent periods of stream activity.

High-level terrace deposits

High-level gravel terraces include the deposits generally more than 20 feet above present stream levels; these lie roughly along the streams but their spatial arrangement is more irregular; in parts of the area they form a widespread gravel cover. Two general levels of high terraces are recongized. The lower general level about 20 to 50 feet above present streams is generally confined to lowland areas near confluences of major tributaries. Where examined, the terraces at this level consist of 5 to 10 feet of gravel and include:

1. Two terraces, 20 and 25 feet above the Nuka River east of Lake Nolik at approximately 1,950 feet altitude;

2. One terrace at roughly 2,100 feet altitude and less than 50 feet above Storm Creek, west of Lake Noluk;

3. One terrace between Driftwood Creek and the Utukok River at 1,550 feet altitude, 40 feet above the Utukok River;

4. One or more terraces between Iligluruk Creek and Tingmerkpuk River at about 1,150 feet altitude north of Kokolik Lake;

5. One or more terraces along Kukpowruk River drainages south of Igloo Mountain on which no data are avaliable.

The distribution of these deposits suggests that they were deposited by streams essentially following the same drainage patterns as those of today. The position relative to the low-level terrace deposits,

however, suggests a considerably older period of stream activity. The higher deposits may be Pleistocene in age, possibly correlative with the probable Pleistocene deposits exposed north of the area (Chapman and Sable, 1960, p. 128).

Gravel deposits at a considerably higher level than those listed above include the extensive gravel cover which extends northeastward from Driftwood Creek along the Colville River, and scattered deposits in small areas near the Nuka River, north of Iligluruk Creek, south of Poko Mountain, and at several localities 3 to 4 miles north of the mountain front between the Kokolik River and Driftwood Creek. Where examined, these gravels are less than 25 feet thick.

The Driftwood Creek-Colville River deposits constitute a single terrace which lies at about 2,000-foot altitude 450 feet above Driftwood Creek, and at about the same altitude 65 feet above the north-flowing portion of the Colville River. They probably represent deposits of the ancient Colville River, whose headwaters once extended farther west and have been captured by Utukok River drainages; their age is probably Pleistocene. Although the deposits consist dominantly of gravel-size constituents, poorly developed drainage on many of the terrace surfaces suggests that the gravels may in part be covered by a thin mantle of silt or loess.

The highest level terraces along the Nuka River have been mapped mostly fron aerial photographs. They appear to lie more than 100 feet above the Nuka River and are outlined by a distinct break in topographic slope.

North of Iligluruk Creek and south of Poko Mountain, scattered terrace remnants lie at about 1200- and 1400-foot altitudes 200 to 400 feet above the present streams. Two small terraces between the Utukok River and Elbow Creek lie at about 2500-feet altitude, 800 feet above the Utukok.

The relationship between the Driftwood Creek-Colville River terrace and the high terrace remnants exposed elsewhere in the area is not known. Detailed studies of these deposits may show that they all represent deposition by the ancient Colville River which formerly drained a much larger area; this explanation is favored by the authors. The deposits could also have been made by northwestward-flowing streams similar to those now in existence.

IGNEOUS ROCKS

Bodies of intrusive and extrusive mafic rocks, although individually of small size and areal extent, are locally abundant in the southeastern part of the Kukpowruk-Nuka region, and increase in abundance from southwest to northeast. Sills and sheetlike bodies, dikes, and small irregularly shaped intrusives, all of gabbroic to dioritic composition, were probably intruded at relatively shallow depths. Volcanic flows of basalt and microgabbro, some of which contain pillow structures, constitute the remainder of the igneous bedrock exposures.

Distribution and Outcrop

The exposures of igneous rocks are scattered along several structural belts in the DeLong Mountains and southern foothills from the headwaters of the Utukok and Kugururok

Rivers eastward and northeastward to beyond the limits of the map area. The igneous rocks lie entirely south of belts in which the Fortress Mountain Formation is exposed. Trends of individual igneous bodies are mostly parallel or subparallel to the structural belts in which they lie, but when the igneous rocks are considered together, their pattern of distribution crosses these structural belts from southwest to northeast; east of Storm Creek, the igneous rocks occur in belts adjacent to Fortress Mountain Formation exposures. Exposures of similar igneous rocks have been recognized in areas adjacent to the Kukpowruk-Nuka region, both to the east (Tailleur, Kent and Reiser, 1966) and south (J. T. Dutro, Jr., 1951, written commun.).

The largest igneous bodies in the mapped area lie in the headwaters of the Kugururok River, south of the Utukok River, at about lat. 68°30' N. Two dark jagged mountain masses with 2000 to 3000 feet relief are capped by sill-like bodies of mafic rock which probably represent one original igneous body more than 10 square miles in area. Outcrops occur as sharp pinnacles and sawtooth ridges and exhibit rough, highly fractured surfaces. Elsewhere in the mountains,sills outcrop as resistant ledges like those in the Nuka River headwaters, or as less conspicuous rubble traces and knobs. Within the foothills, isolated ridges and knobs of igneous rock are mostly less than 100 feet high, but where associated with resistant chert and limestone they locally form hills of impressive proportions. Some of the high ridges near the Nuka River south of Lake Noluk are of this type.

The igneous rocks weather brown or reddish brown. Where associated with Paleozoic sedimentary rocks, they can be distinguished by their weathering colors or by their darker hues on aerial photographs. In localities where they are associated with Mesozoic clastic rocks, however, igneous rocks cannot in most cases be distinguished from the coarser clastics except by field examination. In these localities, aerial photographs proved valueless in recognizing igneous rock exposures during preliminary interpretations of the area. Thunder Mountain was thought to be composed of mafic sills both from photograph study and when seen from a distance; not until foot traverses across these exposures were made was it determined that the mountain consisted of clastic sedimentary rocks.

Character and Size

The igneous rocks of the Kukpowruk-Nuka area are mostly tabular bodies of mafic composition. The rocks probably intruded at shallow depths include gabbroic and dioritic varieties in the form of sills, sheetlike bodies, and dikes. Igneous stacks, present in some localities in the foothills east of Storm Creek, may represent small domes or plugs; but evidence other than topographic expresssion is lacking. Basalt and microgabbro represent flows in some outcrops, as evidenced by pillow structures, planar flow structure, and incorporated rounded fragments of the same rock type interpreted to be partially assimilated flow breccia. Sills range from a few feet to 200 feet in thickness; the larger sheetlike bodies exposed in the headwaters of the Utukok and Kugururok Rivers

are estimated to be 500 feet or more thick; dikes, where recognized, are relatively thin, and may represent offshoots from sills; domes or plugs are as much as several hundred feet in diameter; and flows, mostly less than 20 feet thick, range to more than 100 feet in thickness.

Intrusive Rocks

Gabbro and rocks intermediate between gabbro and diorite are the most abundant intrusive rock types in the area. Diorite is less common and occurs in relatively thin bodies. No chronological sequence was recognized during studies of these rocks. Likewise, age relationships between the intrusive and volcanic rocks are not known, although at least some of them are probably contemporaneous.

Gabbro of the intrusive bodies is moderate to dark grayish green, medium to finely crystalline, and granitoid, ophitic, or porphyritic in texture. Microgabbro is sugary-textured, fine-to medium-grained gabbro commonly containing phenocrysts of pyroxene or feldspar less than half an inch in diameter. The less common coarse-grained and micropegmatitic varieties are composed predominantly of pyroxene and feldspar crystals as much as three-quarters of an inch in diameter. Very coarsely crystalline varieties, in which the crystals exceed 1 inch, occur within thick sill-like bodies of gabbro. Calcite-filled amygdules are present in some of the fine- to medium-grained gabbro, and are distributed haphazardly or concentrated along the upper parts of sills. Chlorite, epidote, and zeolites(?) also occur as amygdule fillings. Some of these rocks are slightly magnetic, and they are commonly altered to chlorite, carbonates, and serpentine.

Some igneous bodies interpreted to be intrusive because of their grain size and contact effects, contain xenoliths of limestone and chert. The xenoliths are mostly angular and range from a few inches to as much as 3 feet long and 2 feet wide. Most xenolith-igneous rock contacts show no visible alteration effects, but some fragments have rounded corners, are recrystallized and, more rarely, grade into the igneous rock. In some exposures, the xenolith fragments are obviously from the intruded strata but, in others, sills occur within rock types unlike those making up the xenoliths. At one place, 1 mile southeast of 1951 Camp 6, a sill of fine-grained diabase within interbedded shale and sandstone, contains limestone xenoliths of Paleozoic (Mississippian?) age. Exposures of this kind, coupled with the occurrence of some intrusives separating unlike age sequences along bedding plane faults and the presence of tectonic breccias along some of their borders, lead to the conclusion that many of the intrusives have either followed pre-existing thrust faults or were contemporaneous with some of the thrusting.

Many sills exhibit chilled borders and, more rarely, thin glassy selvage along their contacts; other show no evidence of endogene effects. However, most of the igneous bodies are extensively fractured with "stockwork" veining of calcite and chlorite; ferromagnesian minerals are largely altered to chlorite and feldspars are replaced

by calcite; and contacts are sheared. Thus, it is difficult to obtain fresh rock surfaces, and as a consequence, recognizable endogene effects have mostly been destroyed by these later alterations.

Contact effects along borders of the intrusive bodies include hardening and baking of shale and thin-bedded argillaceous limestone extending as much as 25 feet away from intrusives; alteration of shale and argillaceous limestone to dense hornfels, generally less than 1 foot but as much as 3 feet thick; silicification of sandstone and conglomerate; recrystallization of chert to a granular texture; introduction of pyrite; discoloration of dark chert to light greenish and grayish hues; and local marmorization of limestone.

Thin section examination of several rock types altered by intrusive bodies shows that pyrite as cubes, spherules, and irregular grains is apparently the only mineral directly related to contact mineralization. In general, the contact rocks seem little altered except for recrystallization of sedimentary carbonates, possible replacement of some grains by calcite, and silicification.

Factors that influence contact effects in intruded rocks include the shape and size of the intrusive body, the compositions of the intrusive and country rock, the depth of intrusion, and relative temperatures and fluid content of the invaded and igneous rocks. In the Kukpowruk-Nuka region, most of the intrusive rocks are sills and sheet-like bodies of generally similar composition. Although many of these which are more than 20 feet thick have produced contact effects extending several feet into the country rock, others of similar size intruding the same types of sediments show little or no effect. One gabbro sill 200 feet thick has only 1 inch of hornfels along its shale contacts with no visible effects beyond this. In contrast, another gabbro sill 150 feet thick has produced a baked and partly silicified zone more than 25 feet thick in shale. The larger sheet-like bodies in the Kugururok River headwaters show along their basal contact with shale only a thin discontinuous zone of grayish-red siliceous rock probably less than 1 foot thick. However, this may represent a mineralized shear zone, not related to the intrusion. Tentative conclusions drawn from these observations are that the igneous rocks were intruded under various environmental conditions. They may represent more than one stage of intrusion, or if contemporaneous, possibly differences in depth or accompanying differential degrees of tectonic deformation may have resulted in more intense contact metamorphism by some igneous bodies than others. Some sill-like bodies show well-developed contact effects along their lower contact, but little or no effects at their upper surface. Although these bodies may be flows, they lack definitive flow criteria.

An intrusive sill exhibiting wide variations in grain size with typical contact effects along its lower surface is exposed in a conical hill between Storm Creek and Nuka River at about lat. 68°39' N., long. 160°06' W. A tabular body more than 150 feet thick and ranging from microgabbro to gabbro intrudes Mesozoic(?) shale. At

the base of the igneous body a 25-foot zone of baked and hardened shale is present. The gabbro grades upward from a chilled zone into microgabbro containing scattered basic segregations in the lower 10 feet, and then into fine- to medium-crystalline gabbro. Seventy-five to 85 feet above the base the gabbro is very coarsely crystalline, with about equal amounts of plagioclase and pyroxene crystals as much as 1 inch across. The upper part of the intrusive is fine-grained gabbro, but the top is eroded. Although the variation in grain size in this body is probably due to differences in rate of cooling, other mafic bodies, including the large sheetlike bodies in the headwaters of the Kugururok River, show irregular variations in grain size, and may represent complex intrusions.

Petrographic microscope examinations of seven samples from intrusive bodies were made by R. H. Morris. Johannsen's system of classification was used. The following discussion is a summary of Morris' unpublished report.

"Samples were taken from different igneous bodies in various parts of the area east of the Utukok River. Microscopically, the rocks are much alike in their mineralogical composition and alteration features. With one exception, a diorite, the modal analyses percentages are similar, ranging from gabbro to meladiorite (3212H). Pyroxenes consist of pigeonite and diopside with partial to nearly complete replacement by chlorite, calcite, and bastite. Plagioclase feldspars consist of andesine ($Ab_{65}An_{35}$ to $Ab_{60}An_{40}$) or labradorite ($Ab_{55}An_{45}$); many feldspar laths exhibit zonal growth, are bent and sheared, and contain inclusions which are altered to chlorite. Calcite has partially or almost wholly replaced plagioclase, with possible liberation of silica which occurs as interstitial secondary quartz in some sections. Plagioclase is also altered to sericite and kaolinite. Ore minerals comprise 4 to 8 percent of the sections, and include magnetite, titaniferous magnetite, ilmenite, and pyrite. Accessories include a few grains of zircon and apatite. Serpentine, in some sections, is possibly an alteration product of olivine and pyroxenes. Calcite and quartz are present as veinlet fillings, and leucoxene, titanite, and limonite as alteration products of ore minerals."

Extrusive Rocks

Basalt and microgabbro in tabular bodies varying from a few feet to more than 100 feet thick outcrop sporadically along belts extending east-northeast from the headwaters of the Utukok River, and along the belts of the wacke with cannonball concretions unit exposures south of the Nuka River. The largest body of basalt at long. 160°, lat. 68°41' is about 2 miles long and half a mile wide at its widest point; it is at least 100 and possibly as much as several hundred feet thick. This is interpreted to be a fragment of an allochthonous thrust plate. Other smaller bodies, however, appear to be interbedded with Mesozoic(?) clastic rocks.

Most of the basalt and microgabbro is dark grayish green to dark gray, although some bluish gray basalt is present. Weathering colors

are reddish brown to light olive-gray. Individual bodies are fairly uniform in texture, massive, and some show planar flow structure from a few inches to 2 feet thick. Amygdules and vesicules are common in basalt and occur scattered or roughly concentrated in horizons within or at the tops of the bodies. Amygdule fillings are composed dominantly of calcite, and also include epidote, zoelites(?) and chlorite. Porphyritic basalts contain scattered phenocrysts of pyroxene as much as half an inch across, and in a few bodies alignment parallel to the sides is believed to represent planar flow structure. Pillows, commonly 2 feet wide and 1 foot thick, but as much as 3 feet by 2 feet, are fairly common but are often difficult to see in the highly fractured and sheared bodies. Where well developed in microgabbro and basalt, the pillows have chilled borders and radial fractures extending outward from their centers. Pillows and pillow layers are commonly separated by thin layers of shaly material. Sharply angular fragments of limestone, chert, siltstone, basalt, and microgabbro as much as 2 feet in diameter are present in some bodies, including those with pillow structure. The fragments appear to be haphazardly distributed and are rarely abundant enough to constitute a breccia. Perhaps they were of explosive origin and were dropped into submarine flows, or in part talus fragments and fractured bedrock incorporated in subaerial flows.

Thin sections from two pillow basalts were examined by R. H. Morris. In one sample, the fine-grained rock consists of a mass of labradorite ($Ab_{55}An_{45}$) laths and irregular chlorite and calcite patches which have completely replaced the ferromagnesian minerals. Some skeletons of ilmenite crystals have been partially or completely altered to leucoxene. The second sample is a porphyritic amygdaloidal basalt with phenocrysts of pyroxene (pigeonite to diopside) and occasional phenocrysts of plagioclase (andesine?) in a groundmass of fine, needlelike laths of plagioclase and interstitial glass. Larger plagioclase laths enclose abundant secondary chlorite. Some feldspar laths are oriented in a concentric pattern around amygdules which are filled by calcite and chlorite. Pyrite occurs as primary(?) grains and specks, and as secondary vein fillings associated with calcite.

Some of the basaltic and diabasic bodies may represent shallow intrusives. It is difficult to classify many of these rocks as volcanics or intrusives because they have been extensively fractured and sheared by later orogenic activity, and because their textural and structural features do not clearly reflect the mode of origin.

Mode of Occurrence and Age

Mafic rocks intrude sedimentary rocks of Mississippian to Early Cretaceous(?) age. The cherty and shaly rocks of Mississippian and Carboniferous-Permain(?) age, particularly the black chert and limestone facies, seem to be most commonly associated with sills and dikes. These sedimentary rocks are relatively even bedded and form structurally competent units which probably yielded by fracturing so that the magma gained easy entry along bedding planes and joints. The shaly rocks questionably referred to the Nuka Formation between the Utukok and Kugururok Rivers may have been intruded by large mafic sheetlike bodies.

but elsewhere, as south of the Nuka River, Nuka Formation clastic rocks appear to be free of igneous intrusion. The few contacts between intrusive rocks and the Nuka clastics may lie along faults. Triassic rocks, particularly those in the northeastern part of the area east of the Nuka River, are intruded as well as shale, graywacke, and conglomerate of Jurassic(?) or Early Cretaceous(?) age.

Basalt and microgabbro extrusives are interbedded or associated with shale, graywacke, and chert of the wacke with cannonball concretions unit, and are believed to be entirely restricted to this sequence. Basalt and microgabbro are also associated with Triassic and older rocks in a few localities, but it is not clear whether they actually represent extrusive activity or are shallow intrusive bodies. Most of the contacts with these older rocks are obscure and some probably lie along faults.

No igneous activity is recognized in rocks of known Cretaceous age. Some unfossiliferous clastic rocks associated with mafic rocks may be Cretaceous, and it has not been proved that such activity did not extend into at least earliest Cretaceous time. Nevertheless, wherever fossiliferous rocks of Cretaceous age are encountered in the area, they are free of igneous bodies. Furthermore, the Cretaceous rocks almost certainly overlie the wacke with cannonball concretions unit and its associated igneous rocks with angular unconformity in several parts of the area, and the Cretaceous clastic rocks contain a high percentage of relatively fresh igneous detritus mineralogically similar to the mafic intrusives.

If igneous rocks of Cretaceous age are present in the Kukpowruk-Nuka region, it is believed that they represent a waning stage of igneous activity, not repeated again until late Cretaceous time when volcanoes of unknown location contributed bentonite and tuff beds to sediments of the Nanushuk Group.

The evidence points to maximum igneous activity preceding the deposition of earliest Cretaceous age sediments. However, it is not known whether more than one stage of such activity occurred and the specific times of the activity are not clearly understood. Igneous clasts of mafic and acidic igneous rock in pre-Okpikruak Formation conglomerates point to igneous intrusion prior to Cretaceous time. However, the source areas of these pebbles are not known. If some of the mafic bodies intruding Paleozoic and Triassic rocks are pre-Jurassic, one would expect detrital feldspars in the Nuka Formation feldspathic sediments to indicate this; in reality they show no similarity to those in the mafic rocks. It seems unlikely that the Triassic sediments, of strikingly similar shelf facies throughout the area, accumulated during a period of extensive intrusion. The time of the mafic igneous activity within the area therefore appears restricted to late Jurassic, or earliest Cretaceous time.

STRUCTURAL GEOLOGY

Northward tangential stress has been the dominant factor in producing the structural features now exposed in the Kukpowruk-Nuka region. Although in general, progressively younger rocks are encountered

from south to north, the regional structural dip is south. High-angle thrust faults and folded overthrust plates are common in the DeLong Mountains and parts of the southern foothills. Nearly all fault planes dip south, as do the axial places of most folds in these provinces.

Regional strike is about N. 70 E. and parallels the trend of the mountain front. The entire map area lies on the west side of a major, northwardly convex structural salient which culminates east of the Nuka River. The convexity may reflect a major north-trending negative element which offered less resistance to overriding of thrust blocks from the south.

Except for the northern part of the area, the rocks are so highly folded, faulted, and contorted, that in places even the major structural relationships are not well understood. Stratigraphic sections in which repetition by faulting and isoclinal folding can be discounted are rarely more than a few hundred feet thick, and consistent relationships of many major rock units are limited to relatively local parts of the area. Chaotic melange-style structure in which rock unit relationships are unknown characterizes parts of the area east of the Utukok River; elsewhere, relatively simple structural features break down into structures with inexplicable relationships when followed along strike. Except for parts of the Lisburne Group and Shublik and Okpikruak Formations, major rock units are sparsely fossiliferous. In addition, recognition of overturned sections in cherty, shaly, and carbonate rock units is difficult because of lack of diagnostic bedding features.

The Kukpowruk-Nuka region is divided into three major structural belts. From north to south, the belts are the folded belt, the folded and faulted belt, and the overthrust belt.

Folded Belt

Restricted to the northern foothills and northern part of the southern foothills, the folded belt includes structures exposing rocks of the Nanushuk Group, Torok Formation, and sandstone member of the Fortress Mountain Formation. Okpikruak Formation equivalents are exposed in an anticlinal structure on the Kukpowruk River, and one known exposure of Shublik Formation occurs in the vicinity of the Kukpowruk River (I. L. Tailleur, oral commun, 1974).

Broad, gently dipping synclines containing Nanushuk Group rocks alternate with more complex anticlinal structures. These synclines at Igloo, Poko and Meat Mountains, along the Kukpowruk River, and north of the Colville River, strike east, and are characterized by relatively low dips. Some are slightly asymmetrical, the south limb being steeper. They are arranged in en echelon parallel to the general strike of the structural trends farther south. The anticlinal structures in which Torok Formation is exposed contain steeply dipping and closely folded beds near their axial areas and some may be surface expressions of thrust faults (Chapman and Sable, 1960). The thick shales of the Torok Formation are relatively incompetent and much of the close folding is probably the result of shale flowage.

A westward regional plunge is shown by the deeper folding of the Nanushuk Group in that direction; preserved sections of the Nanushuk

Group thickens from 2,300 feet at Meat Mountain syncline to more than 6,000 feet along the Kukpowruk River. As stated by Chapman and Sable (1960), this is good evidence of the existence of a major north-trending arch east of the Utukok River which has persisted from Nanushuk time to the present.

South of these structures, several complex anticlinal structures which expose rocks of the Fortress Mountain Formation in their axial areas are also distributed en echelon. These include Kukpowruk and Tingmerkpuk bulges, Iligluruk high, and the Driftwood anticlines, all of which strike generally east to northeast. In detail they contain steeply dipping rocks, minor folds, and faults of unknown displacement, most of which appear to be high-angle thrust faults with south side upthrown. The Kukpowruk and Tingmerkpuk bulges are structurally continuous with the wider folded and faulted belt to the south which contains similar structural fractures. The surface expressions of the Iligluruk and Driftwood structures, however, cannot be traced into the more southerly belts. Although much structural complexity lies in the intervening structures exposing Torok Formation, the folded belt is considered to be essentially structurally continuous with the folded and faulted belt.

The folded belt is interpreted essentially as a relatively autochthonous structural unit. Folding has resulted in some foreshortening and one or more thrust faults may be present along anticlinal structures in the Torok Formation as suggested by geophysical data here in areas farther north (Chapman and Sable, 1960).

The simple structure and east-striking pattern of individual folds in the Nanushuk Group and upper part of the Torok Formation contrast sharply with the structural complexity and dominant east-northeast trends farther south. This is in part due to the decreased intensity of orogenic effects northward. The structurally incompetent Torok Formation probably absorbed and dissipated much tectonic energy through shale flowage. In addition, a subsurface zone of flexure or faulting may lie along the northernmost exposures of the Fortress Mountain Formation, beyond which less stress was transmitted. Fortress Mountain rocks are in general more highly disturbed than the equally competent Nanushuk Group rocks; and interpretation of geophysical data shows that the subsurface structure of the Driftwood anticlines is highly complex as compared to the relatively simple structures 2 to 3 miles farther north.

Structures in the southwestern part of the folded belt do not indicate a westward deepening of a major basin during deposition of Fortress Mountain sediments.

It is speculated that structural conditions during deposition of the Fortress Mountain Formation were not the same as those during Nanushuk Group deposition. The presence of an erosional or nondepositional break within the Torok Formation has been suggested by Chapman and Sable (1960) from several lines of evidence. If such a break exists, it may reflect the time interval during which a major change in the broad structural features took place.

Folded and Faulted Belt

This structural element lies within the southern foothills, between the folded belt and the thrust belts of the DeLong Mountains, varies from 8 to 15 miles in width, and strikes about N. 70° E. It is believed to comprise an essentially relatively autochthonous unit which is generally continuous with the folded belt but whose southern boundaries are marked by major thrust and reverse faults.

In comparison to the folded belt, the folded and faulted belt is characterized by its linear pattern, dominant northeast trend, generally parallel linear belts of Lower Cretaceous clastic rocks, structures of greater complexity, and many narrow belts of older rocks such as the Triassic Shublik Formation.

Dominant structural features within the folded and faulted belt include highly folded and steeply dipping beds, high-angle reverse faults, and some thrust faults. The intensity of deformation increases southward, and in the southern part of the belt south dips are predominant. Somewhat broader structures are present in the southwestern part of the belt between the Kokolik and Kukpowruk Rivers, but eastward, the outcrop belts are more tightly compressed.

Described from north to south, the major structural features within the folded and faulted belt consist of:

1. Fortress Mountain sandstone member in a complex anticlinorium.
2. Fortress Mountain shale member in a narrow synclinorium.
3. Fortress Mountain conglomerate member in an anticlinorium along the northern part of its belt of exposures and a synclinorium along the southern part.
4. Shublik Formation and micaceous sandstone unit in a complex anticlinorium.

In addition, most of the isolated intermittent exposures of Shublik Formation along linear subparallel trends are interpreted to represent anticlinal structures, in part ruptured along their axes, with the south limbs thrust over the north limbs. Other Shublik Formation exposures appear to be associated with synclinal trends and their structural style is unknown. They may represent small remnants of overthrust faults or topographically high areas on which the overlying clastic rocks were deposited.

The Okpikruak Formation quartzite facies occurs in two *en echelon* belts of exposure within the folded and faulted belt. Relationships between this and adjoining rock units have been previously described, and the evidence for and against their occurrence as an overthrust remnant reviewed. The quartzite member is a highly competent unit,

one which could form the sole of an overriding thrust plate.

Structural relationships of the quartzite member as mapped are interpreted in the simplest manner, as anticlinal structures in part faulted against younger rock sequences.

Although the folded and faulted belt is considered to be an essentially autochthonous unit, high-angle thrust faults are common, and patterns of some faults suggest overthrusting within the belt. The fault patterns within the conglomerate unit west of the Utukok River are of this type. The essentially straight-line outcrop pattern along the north front of the belt, and the linear patterns of the major clastic rock units also suggest that faults may be present along the north side and along contacts of the major units within the belt. Faults are mapped along parts of these contacts and, where exposed, appear to be either high-angle reverse faults with south side upthrown or southward-dipping thrust faults in which the fault plane is at a high angle. Although the author recognizes the possibility that some major thrust faulting may be expressed by these relationships, field evidence points to generally normal relationships among the major clastic units; crustal foreshortening by faulting is interpreted to be of a limited nature. Despite the large amounts of sandstone and conglomerate in the clastic units, considerable interbedded shale is also present. The units therefore do not appear to be highly competent, and in themselves probably would not form major thrust plates. If their boundaries represented offshoots of a major sole fault at depth, then older rocks might be expected to occur along them, but none were seen. Most of the Triassic rocks within the clastic units can be most simply explained as occurring in normal or ruptured anticlines. Original fault planes, if present, have probably been modified by folding as in the structural belt farther south.

The proximity of rock units in the folded and faulted belt to the belts of intense deformation farther south is the major factor in producing the deformation of these rocks. The relative structural competency of the major rock units exposed in this belt is also a factor, particularly in determining the degree of deformation. The higher proportion of sandstone in the Fortress Mountain Formation west of the Utukok River, however, may be important in determining the somewhat broader folding of this unit west of the Kokolik River. The wacke and conglomerate member is perhaps somewhat more competent than the sandstone member, but it lies closer to the areas of maximum stress and is, therefore, more intensely deformed and cut by a larger number of thrust and reverse faults. The micaceous sandstone unit, south of the wacke and conglomerate member, is highly contorted, because of its shaly character, and nearness to the thrust belts farther south. In addition, it may have undergone more stages of deformation than the overlying conglomerate member. The Triassic rocks, particularly those in the southern part of the belt, are very severely deformed, and many exposures present a picture of bewildering structural complexity.

The quartzite member of the Okpikruak Formation is composed of

highly competent rocks. Although highly fractured and tightly folded in places, it has yielded mainly by faulting; between the Kokolik and Kukpowruk Rivers the faulting appears to be of the imbricate thrust type.

Another factor affecting deformation in this belt, other than the relative competency and thickness of rock units and nearness to the maximum stress points, is the northward extent of possible overthrusting plates onto this belt, which have since been eroded. Overriding thrust plates composed of competent rocks would impart a considerable degree of complexity to the structures in the underlying block.

Overthrust Belt

The overthrust belt lies mostly within the DeLong Mountains and extends south of the mapped area. It is here divided into two structural elements, the Kugururok-Kukpowruk block, and the Utukok-Nuka block, which have many similarities but which also contain unlike structural features.

Extreme structural complexity characterizes much of this belt. Intense deformation has resulted in numerous thrust faults including folded overthrusts, close folding and shearing of incompetent rock units, transverse faulting and, in parts of the area, chaotic melange-style structure and igneous intrusion .

The belt as a whole is largely an allochthonous cover of Paleozoic and Mesozoic rocks overlying highly contorted relatively autochthonous Paleozoic and Mesozoic beds. Direct evidence for this interpretation consists of:

1. Older rock units overlying younger rocks in fault relationship on a large areal scale. Some of these relationships extend as much as 30 miles along strike.

2. Presence of klippen consisting of Paleozoic rocks overlying Mesozoic rocks, and windows in which highly deformed rocks are exposed.

3. Isolated fault slivers of rocks considerably older than those they adjoin along the northern front of parts of the belt.

4. Imbricate thrusting of structurally competent rock units interpreted as attendant to major overthrusting.

Indirect evidence consists of:

1. Linear arcuate patterns along the front of and within the belt, and the truncation of structural trends by these patterns;

2. Superposition of considerably different lithologic types believed to be time equivalents;

3. Lack of orderly trends and stratigraphic relationships;

4. Chaotic structures;

5. Major structural features which seem difficult or impossible to explain by normal folding and small-scale faulting;

6. Presence of intrusive magmatic rocks in some overthrust plates and their absence in the overridden block in parts of the area.

Actual fault planes of low-angle overthrusts were not seen during fieldwork, but in areas of high relief, such relationships

are unmistakably present. Exposures in the vicinity of major structural breaks are characterized by intense contortion and shearing of underlying incompetent sequences, often combined with a series of thrusts in which fault planes commonly dip at angles of 30^{o} to 60^{o} S. These faults are characterized by shear zones in which gouge ranges from a few inches to more than a foot in width and contains minor amounts of breccia. Faults between competent units are expressed as silicified and brecciated zones. All thrust faults observed were parallel or at slight angles to bedding in the upper plate. The most consistent topographic expression of major faults is a break in slope on the north side of the south-dipping thrust sequence.

The exact locations of major frontal thrusts at the north front of the belt are interpretive; in the frontal portion it is represented by a zone of faulting in which many high-angle thrusts and highly folded rocks occur. Rocks belonging to the folded and faulted belt are probably infolded in the frontal portion, including Triassic rocks and younger rocks. Structural relationships are most complex in the eastern part of the belt near the northward bulge, and decrease in intensity towards the Kukpowruk River.

The maximum northward extent of the overthrust belt lies east of the Nuka River. Farther east, the front of the belt trends southeast, so that a northward bulge lies at the east limit of the Kukpowruk-Nuka region. If the belt is interpreted as a major overthrust block, the bulge represents either a concentration of northward tangential forces or a north-trending structural low. Dominant fold plunges in the Fortress Mountain Formation conglomerate member west of the bulge are eastward as are the plunges of synclinal folds within the thrust faulted belt. This points to the presence of a structural low east of the Nuka River over which the overriding fault block moved with relative ease. As discussed previously, however, the dominant structural plunge in the folded belt is west, suggesting the presence of a major north-trending Mesozoic-Cenozoic high, the Meade Arch, east of the Utukok River (Payne, 1955). Either the Meade Arch is not represented in the thrust faulted belt in the eastern part of the Kukpowruk-Nuka region, or the bulge east of the Nuka River is a minor structural feature on the west side of the Meade arch.

The relative degree of structural competency of the rock units involved in thrust faulting is an important factor in determining the expression of faulting in various parts of the belt and the relative amount of deformation within the different stratigraphic units. Highly competent rocks, relatively undeformed thick resistant units which form overthrust plates, include the Lisburne Group, Carboniferous-Permian cherty units, and the Kugururok and Nuka Formations. The igneous rocks are the most competent units in the area, but they occur mostly in thin bodies. Thicker sill-like units have been overthrust in the headwaters of the Nuka River and form parts of overthrust sheets in Kugururok River drainages. The combination of igneous sills and Carboniferous-Permian cherts results in extremely competent units,

common in the overthrust sheets in the eastern part of the area. The relatively thin but competent Shublik Formation has locally formed the sole of thrust plates but in general is not important in this respect. The Okpikruak Formation, where folded to excessive thickness, has locally acted as a thrust unit, but the wacke with cannonball concretions unit contains a high proportion of shale, and except for some thick conglomerate units assigned to this formation has rarely acted thus.

An unusual structural feature that is repeated in several places in the thrust faulted belt is folded low-angle thrust faults resulting in east-plunging <u>en echelon</u> synclinal structures resembling structures exposed north of the region but of greater complexity. The rocks comprising the upper plates of the faults vary in age and lithology. Some of the thrust plates appear to be relatively thin sheets less than 500 feet thick; others are much thicker. A striking small-scale example in the Kukpowruk-Kugururok block is the synclinal structure consisting of Triassic chert, limestone and shale which overlies and is overlain by rocks of the Okpikruak Formation, located 11 miles west of the Utukok River at lat. 68°34' N. The synclinal axis continues southwestward in the Okpikruak Formation, which contains lines of faulting similar to that described above, and is reflected in the synclinal structure of the Lisburne Group farther southwest. The folding in this instance is later than the overthrust faulting. Other structures which approximate this pattern are the imbricate unit fault structures in which cherty units and Okpikruak Formation are exposed 4 miles southwest of

Tupik Creek and, to a lesser degree, the overall structural pattern between Kogruk Creek and the Utukok River.

The east-plunging syncline-type structure is also well expressed farther east: just east of the Utukok River, in the smaller structures 10 miles east of the Utukok, and along the east-flowing part of the Nuka River. In these structures the relationships are not as clearly expressed as those in the western areas. Rather, the rock units are highly contorted and structure is difficult to decipher. However, they are interpreted in the same way as those described above; namely, as low-angle thrust plates which have been subsequently folded into complex synclines.

Interpretation and Age of Faulting

A useful approach to structural interpretation in the overthrust belt is one by Tailleur, Kent, and Reiser (1966) in the adjoining Nuka-Etivluk region. They recognize several lithologically different but time equivalent stratigraphic sequences which have been superimposed on/each other by sheetlike overthrusting and subsequently strongly deformed. In the Kukpowruk-Nuka region a similar interpretation provides a key to understanding the bewildering complexity of the structure and stratigraphy. In the overthrust and folded and faulted belts there seems to be six different lithologic associations, each believed to belong to a different overthrust plate. They are, from north to south:

1. Okpikruak Formation(?) wacke, sandstone, and conglomerate unit, mafic igneous sills, light- and dark-colored cherty rocks, and

dark-colored facies of thà Lisburne Group.

2. Wacke, sandstone, and mudstone unit, Shublik Formation light-colored and dark-colored cherty rocks, Devonian rocks.

3. Okpikruak Formation wacke member, wacke with cannonball concretions, Nuka Formation, mafic extrusive and intrusive rocks, cherty units.

4. Okpikruak Formation wacke member, Shublik Formation, cherty units, Tupik, Kogruk, and Utukok Formations of Lisburne Group.

5. Nuka Formation(?) shaly unit, mafic sheet-like bodies.

6. Kugururok Formation, mafic sheet-like bodies.

Number 1 above, exposed in the eastern and southeastern parts of the region seems to correspond to the Ipnavik sequence of Tailleur, Kent, and Reiser; numbers 4 and 6 to their Nuka Ridge sequence; and numbers 3 and 5 to their foothills sequence.

Interrelationships of these thrust plates are not everywhere clear because areas of melange-type clastic structure such as that between Elbow Creek and Driftwood Creek probably represent a mixture of highly disturbed relatively autochthonous lower plate rocks and embedded fragments of the upper plate, and because one or more episodes of post-thrusting tectonism have blurred evidence of specific limits of thrust plates.

Distances of overthrusting are unknown. Considering the variation in facies within the different plates, however, the hypothesis of total northward movement of 100 miles proposed by Tailleur, Kent, and Reiser (1966) does not seem unreasonable.

ECONOMIC GEOLOGY

Petroleum Possibilities

In general the Kukpowruk-Nuka region does not appear to offer attractive possibilities for petroleum in the rock units and structures that have been observed or can be reasonably inferred. Extensive faulting, tight folding, generally poor reservoir rocks, presence of igneous rocks, and the extent of early Mesozoic erosion in the area are all unfavorable factors. No evidence of surface accumulation of oil or gas was found during the explorations. On the basis of available data, however, the area cannot be dismissed as having no petroleum potential. Except for the seismic work covering a very small part of the area, no subsurface exploration has been undertaken. The character of subsurface structures which underlie the overthrust rocks in the southern part of the area, and the lithologic character of Paleozoic rocks which may underlie most of the foothills farther north are unknown; they may possess qualities which are favorable to petroleum accumulation.

The subsurface distribution and character of Devonian rocks in the area are unknown. The Kugururok Formation contains dolomite and limestone beds which may be favorable for oil accumulation. However,

one dolomite sample tested for porosity and permeability showed a porosity of only 0.7 percent and was impermeable. The small exposures of Devonian rocks farther north contain larger amounts of shale, and if they are representative of Devonian rocks in this part of the area, appear to have less favorable reservoir potential than those of the Kugururok Formation.

Mississippian rocks of the Lisburne Group in the DeLong Mountains, particularly the Kogruk and Utukok Formations, may also contain suitable reservoir units. Some sandy limestone and limy sandstone beds in the Utukok Formation appear to have visible porosity, but examination of thin sections showed that intergranular spaces between the well-sorted grains are mostly filled with carbonate. The thick Kogruk Formation limestones are somewhat more favorable as potential reservoir rocks. In the northernmost exposures of the formation, beds as much as 20 feet thick are composed almost wholly of crinoidal debris and these rocks are extrememly friable. These beds were not found in all sections of the Kogruk Formation, however, and they may be only local in occurrence. The larger part of the Kogruk Formation is composed of well-indurated limestone. Three representative samples showed an effective porosity of less than 1.7 percent, and were impermeable. The dense limestones and cherts of the Tupik Formation and other dark-colored rocks in the Lisburne Group are not considered to have good reservoir possibilities but could, under the proper structural conditions, afford a suitable cap rock overlying the Kogruk Formation. No reeflike structures were seen in the Lisburne Group.

The Carboniferous-Permian units consisting mostly of chert, shale, and dense limestone are also unfavorable reservoir rocks. The Nuka Formation contains clean, relatively well sorted sandstones of sufficient thickness to afford good reservoir beds. Some beds are friable; others are quartzitic. In thin sections of these rocks, a large proportion of the intergranular spaces is filled with quartz or calcite. Three samples of this formation tested showed porosities of 6.9, 6.3, and 2.5 percent, and permeabilities of 31, 5.7, and 0 millidarcys, respectively. The distribution and character of the formation can only be surmised. It is known to be present only in overthrust plates possibly far removed from its source and may not be present in the subsurface.

The cherty and shaly rocks of the Shublik Formation and the shale and dense siltstones of the Driftwood Formation show no promise of oil accumulation.

The clastic sequences such as the Okpikruak and Fortress Mountain Formations and units of similar lithologic composition are thick units, but the well-indurated graywacke and sandstones and conglomerates which characterize these formations appear to be poor reservoir rocks. The quartzite member of the Okpikruak Formation contains clastics which are well sorted, but these are dense and quartzitic. Four samples from the Fortress Mountain Formation conglomerate member showed a maximum porosity of 7.32 percent and less than 1

millidarcy permeability. The sandstone member of the Fortress Mountain Formation contains somewhat cleaner sandstones but these contain considerable interstitial calcite. Four samples collected along and west of the Utukok River in the main belt of sandstone member exposures yielded maximum porosity of 7.93 percent and 1.2 millidarcys permeability. A sample in the Driftwood anticlinal area showed porosity of 10.9 percent but the degree of permeability was not tested. The Torok Formation consists almost entirely of shale, and rocks of the Nanushuk Group do not occur in the subsurface of the Kukpowruk-Nuka region.

An additional indication of unfavorable reservoir conditions in the Mesozoic clastic rocks is the observation that these units become finer grained northward. Jurassic(?) and Okpikruak Formation rocks are probably represented by dominantly shale equivalents in the subsurface north of their surface exposures.

Although the degrees of porosity and permeability in the rocks are uniformly low, the structurally competent Paleozoic rock units are highly fractured. Such conditions, if present in the subsurface, might prove favorable for the migration and accumulation of petroleum. In several thin sections of the Tupik Formation and Carboniferous-Permian cherty rocks, a brown opaque residue, possibly a hydrocarbon, is present along the fractures. Many of the fractures have been subsequently filled with carbonate and quartz, however, and vein fillings by these minerals are relatively common in many exposures in the area.

Potential source rocks for petroleum in the Kukpowruk-Nuka region occur in many of the Paleozoic and Mesozoic sequences. Organic marine shales and limestones are abundant in the Tupik Formation and parts of the Carboniferous-Permian cherty units and the Shublik Formation. The Mesozoic clastic rocks also contain abundant dark shales.

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