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Geology of the Killik-Etivluk Rivers Region, Alaska

By ROBERT M. CHAPMAN, ROBERT L. DETTERMAN, and MARVIN D. MANGUS

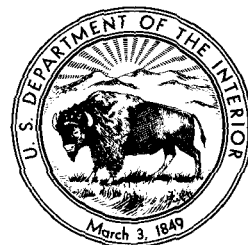
EXPLORATION OF NAVAL PETROLEUM RESERVE NO. 4
AND ADJACENT AREAS, NORTHERN ALASKA, 1944-53

PART 3, AREAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 303-F

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This report is based on fieldwork by Robert M. Chapman, Robert L. Detterman, Marvin D. Mangus, Robert S. Bickel, G. Donald Eberlein, Charles A. Kirschner, Arthur H. Lachenbruch, Milton C. Lachenbruch, Charles D. Reynolds, Karl Stefansson, Robert F. Thurrell, Lawrence A. Warner, and James Zumberge



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CONTENTS

	Page		Page
Abstract.....	325	Stratigraphy—Continued	
Introduction.....	325	Quaternary system.....	382
Location and size of area.....	325	Glacial deposits.....	382
Previous work.....	325	Anaktuvuk glaciation.....	383
Early exploration.....	325	Itkillik glaciation.....	384
Geological investigations.....	325	Echhooka glaciation.....	385
Recent investigations.....	326	Fluviatile deposits.....	385
Acknowledgments.....	328	High-level terrace deposits.....	385
Geography.....	328	Alluvium.....	386
Relief and drainage.....	328	Lacustrine deposits.....	386
Accessibility.....	331	Eolian deposits.....	387
Climate.....	332	Igneous rocks.....	388
Place names.....	332	Occurrence and distribution.....	388
Animals and plants.....	333	Petrology.....	389
Population and archeology.....	333	Structure.....	389
Permafrost.....	334	Brooks Range province.....	389
Stratigraphy.....	334	Southern foothills section.....	390
Devonian system.....	334	Northern foothills section.....	391
Upper Devonian limestone.....	334	Oolamnagavik River structural high.....	391
Hunt Fork shale.....	336	Kurupa anticline.....	392
Kanayut conglomerate.....	337	Aupuk and Killik Bend anticlines.....	392
Mississippian system.....	340	Geologic history.....	393
Kayak shale.....	340	Economic geology.....	394
Lisburne group.....	341	Petroleum possibilities.....	394
Wachsmuth limestone.....	345	Paleozoic rocks.....	395
Alapah limestone.....	346	Triassic and Lower Cretaceous rocks.....	395
Carboniferous and Permian systems.....	347	Lower and Upper Cretaceous rocks.....	396
Siksikpuk formation.....	347	Nanushuk group.....	396
Unnamed Carboniferous and Permian unit.....	348	Colville group.....	397
Triassic system.....	348	Structure.....	398
Shublik formation.....	348	Gas seeps.....	399
Jurassic system.....	350	Coal.....	399
Tiglukpuk formation.....	350	Colville River.....	400
Cretaceous system.....	352	Kurupa River.....	401
Okpikruak formation.....	352	Oolamnagavik River.....	401
Fortress Mountain formation.....	353	Killik River.....	401
Torok formation.....	357	Phosphate-bearing rocks.....	401
Nanushuk group.....	360	Selected Bibliography.....	403
Tuktu formation.....	361	Index.....	405
Chandler formation.....	369		
Killik tongue.....	370		
Niakogon tongue.....	378		
Ninuluk formation.....	381		
Colville group.....	382		

ILLUSTRATIONS

[Plates are in separate volume]

PLATE	43. Geologic map.	
	44. Columnar sections of the Paleozoic formations.	
	45. Columnar section of the early Mesozoic formations.	
	46. Columnar sections of the Fortress Mountain formation.	
	47. Columnar sections of the Torok formation.	
	48. Correlated columnar sections of the Nanushuk group.	
	49. Glacial map.	
FIGURE	54. Index map of the Killik-Etiviluk Rivers region.....	326
	55. Index map showing areas studied.....	327
	56. View of Killik River pass.....	329
	57. View of Howard Pass.....	330
	58. Vertical and horizontal views of drained lake.....	335
	59. View of overturned fold in Lisburne group.....	343
	60. View of Lisburne Ridge.....	344
	61. View of Smith Mountain.....	354
	62. Diagrammatic sections of the Nanushuk and Colville groups.....	362
	63. View of glacial lake deposit on Killik River.....	386
	64. View of sand dunes on Killik River.....	387
	65. Geographic occurrence of coal and phosphate.....	400

TABLES

TABLE	1. Gradients of some streams in Killik-Etiviluk Rivers region.....	331
	2. Weather data for Killik-Etiviluk Rivers region for period May 15 to September 1, 1946, 1949, 1950, and 1953.....	333
	3. Fossils of Kayak shale.....	342
	4. Fossils of Lisburne group.....	346
	5. Microfossil check list for Paleozoic and early Mesozoic formations.....	349
	6. Fossils of Shublik formation.....	350
	7. Fossils of Torok formation.....	360
	8. Fossils of Tuktu formation.....	367
	9. Microfossil chart for the Nanushuk group.....	368
	10. Plant fossils from Killik tongue.....	378
	11. Porosity-permeability of selected samples.....	397
	12. Analyses of gas from Aupuk and North Colville seeps.....	399
	13. Analysis of samples of coal from the Killik-Etiviluk Rivers region.....	402
	14. Yields of carbonization products by Fischer low-temperature carbonization assay at 500°C, as received coal basis.....	402
	15. Chemical and physical properties of gas by Fischer low-temperature carbonization assay at 500°C.....	403
	16. Analysis of field samples showing percent P ₂ O ₅ and equivalent uranium.....	403

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

GEOLOGY OF THE KILLIK-ETIVLUK RIVERS REGION, ALASKA

By ROBERT M. CHAPMAN, ROBERT L. DETTERMAN, and MARVIN D. MANGUS

ABSTRACT

The Killik-Etivluk Rivers region is an area of about 5,800 square miles in the central part of the Brooks Range and Arctic foothills provinces of northern Alaska. About 1,500 square miles along the western side of the region is in Naval Petroleum Reserve No. 4.

Bedded sedimentary rocks at least 36,000 feet thick are exposed in the region. The rocks are dominantly of marine origin and range in age from early Late Devonian to early Late Cretaceous; they have been divided into 17 formations. Paleozoic sedimentary rocks, exposed only in the Brooks Range and the southern foothills section of the Arctic foothills province, consist of slate, shale, quartzite, quartzitic conglomerate, chert, and limestone. The source area for the Paleozoic rocks was apparently to the north; deposition was continuous from Late Devonian to Late Mississippian. Rocks of Pennsylvanian age are absent and Permian rocks overlie the Mississippian. A southerly source area is indicated for the Mesozoic sedimentary rocks in the foothills; these rocks are primarily shale, siltstone, sandstone, and conglomerate. Deposition of the Mesozoic sedimentary rocks was not continuous. The oldest Mesozoic rocks are early Middle Triassic and the youngest are early Late Cretaceous. Sedimentary rocks of Tertiary age are not present in the Killik-Etivluk Rivers region.

The bedded rocks are deformed by a system of west-striking folds and faults. Large overturned folds, thrust faults, and reverse faults are characteristic of the Brooks Range. Folds in the southern foothills section of the Arctic foothills province are small, tight, and steeply plunging; numerous small high-angle faults cut the bedded rocks in the southern foothills section. Large open folds are characteristic of the northern foothills section, with only minor faults present.

Mafic intrusive rocks in the form of small sills and plugs are present in the Brooks Range and southern foothills section. These mafic rocks are primarily dolerite and gabbro that may be intruded along thrust faults.

Surficial deposits of glacio-fluvatile, lacustrine, and eolian origin cover about 30 percent of the region. Part of the region was glaciated at least three times by alpine valley gaciers that are tentatively assigned a pre-Wisconsin to Wisconsin age. A glacial lake about 25 miles long was formed in the Killik River valley; the drained lakebed is now a sand dune area.

Two small gas seeps in the Colville River valley near the mouth of Aupuk Creek are the only surface indication of possible petroleum and gas accumulation in the northern foothills. Some oil shale occurs in rocks of Triassic age near the Oolamnagavik River and Imnaithiak Creek in the southern foothills section of the Arctic foothills province.

Subbituminous to bituminous coal in beds a few inches to 3 feet thick are common in the northern part of the region in

rocks of the Chandler formation of late Early Cretaceous to early Late Cretaceous age.

Phosphate-bearing rocks occur in the Lisburne group of Mississippian age and the Shublik formation of Triassic age in the Brooks Range and the southern foothills. The shale generally contains less than 5 percent P_2O_5 .

INTRODUCTION

LOCATION AND SIZE OF AREA

The Killik-Etivluk Rivers region is in the southern central part of northern Alaska. It lies north of the crest of the Brooks Range, south of the Colville River, and between the Killik River and the western limit of the Etivluk River drainage (fig. 54). This area covers about 5,800 square miles; about 1,500 square miles along its western side is in Naval Petroleum Reserve No. 4.

PREVIOUS WORK

EARLY EXPLORATION

The only recorded exploration in this area previous to 1924 was that of Ensign W. L. Howard, U.S. Navy, in 1886 (Stoney, 1900, p. 66-71). Howard, accompanied by Eskimos, traveled by dogsled from the Brooks Range pass which now bears his name, down the Etivluk River to the Colville River and thence northward to Barrow. Schrader (1904, p. 31) reported that a party of prospectors in the summer of 1903 crossed through a pass in the Brooks Range at the head of the Killik River, traversed this river to its confluence with the Colville River, and went about 50 miles up the Colville from the mouth of the Killik. Apparently members of this party provided Schrader with a sketch map of the Colville River and tributaries, which he incorporated in his published maps (Schrader, 1904, pls. 2, 3). Both exploratory journeys provided valuable geographic information but only a few geological observations.

GEOLOGICAL INVESTIGATIONS

In 1924 the first systematic geological studies of this region were made by Smith and Mertie (1930). From a camp in the Brooks Range near the head of

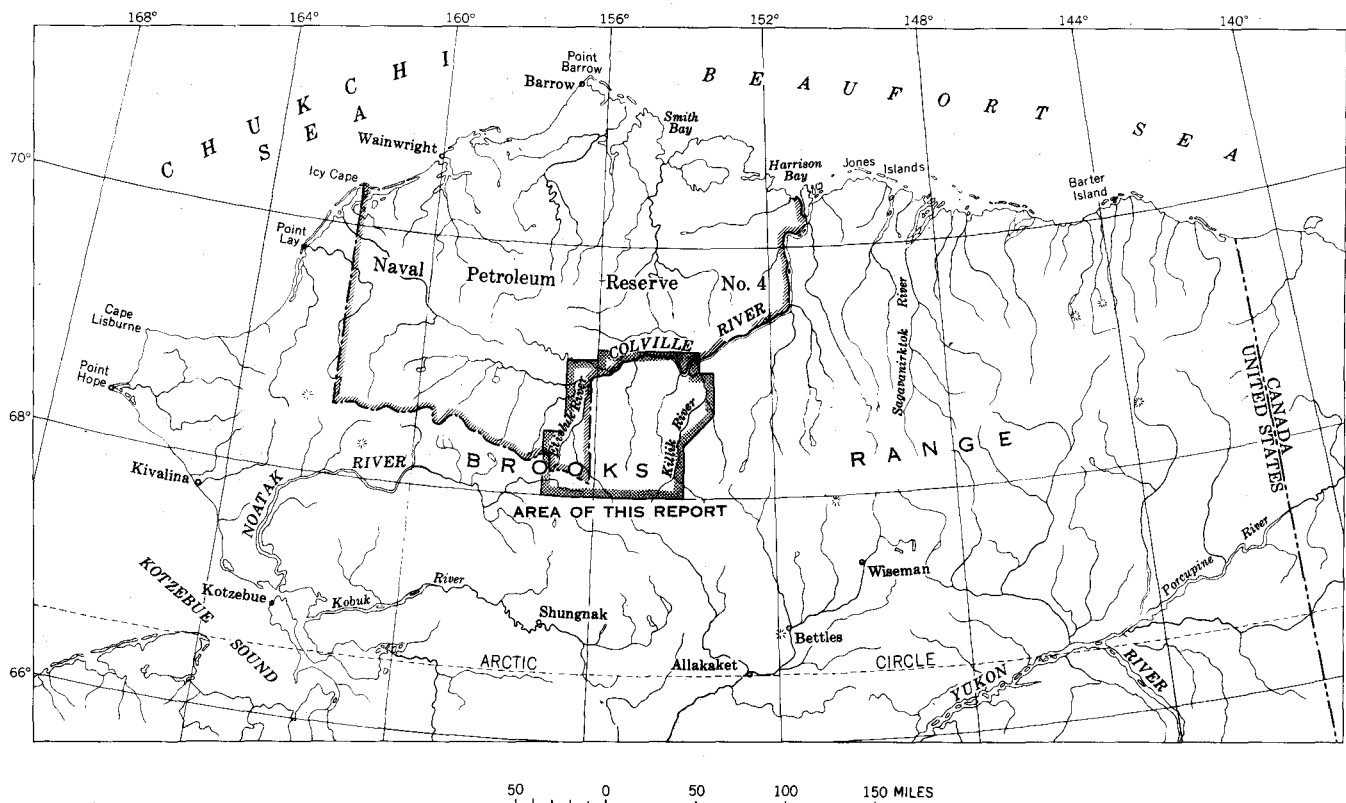


FIGURE 54.—Index map showing location of the Killik-Etiviluk Rivers region, Alaska, in relation to Naval Petroleum Reserve No. 4.

the Killik River, Smith descended the Killik, went up the Colville River to the Etiviluk River and ascended this river 20 miles before turning back to continue northward on the Awuna River. Mertie, starting from the same camp, spent more time on the Killik and tributaries and then went downstream on the Colville River.

In 1925 Gerald FitzGerald, topographic engineer, and W. R. Smith, geologist, went down the Colville River to the Etiviluk River and up the Etiviluk to its head; they crossed the Brooks Range through Howard Pass (Smith and Mertie, 1930, p. 19-21).

Both expeditions were made as part of the investigations by the Geological Survey of petroleum possibilities in Naval Petroleum Reserve No. 4, which was established by executive order in February 1923.

RECENT INVESTIGATIONS

No recorded geological work was done in the Killik-Etiviluk Rivers region between 1925 and 1945. In the spring of 1945, the Geological Survey, in cooperation with the Navy Department's petroleum investigations in Naval Petroleum Reserve No. 4 and adjacent areas, began a program of geologic mapping in northern Alaska that included nearly all the Killik-Etiviluk Rivers region (fig. 55). A Navy geological party, in

charge of Lt. W. H. Phillippi, traversed the Colville River between the Oolamnagavik River and Aupuk Creek in 1945. In the same year Warner and Kirschner traveled by boat from lat 68°23' N. to the Colville River and mapped the geology along the Killik River. In the 1946 field season, Chapman and Thurrell made geological traverses along the Oolamnagavik River from about lat 68°30' N. to the mouth, along the Kurupa River from lat 68°38' N. to its mouth, and along the Colville River between the Kurupa and Killik Rivers. This party also traveled by boat.

The geology along the Colville River between the Etiviluk and Kurupa Rivers was mapped in August 1947 by Thurrell. In the later part of August 1948 Stefansson, Detterman, Mangus, and W. W. Patton, Jr., made a brief examination of the geology in the vicinity of Kurupa Lake. The fieldwork ended with the onset of snowy weather.

In 1949 a party including Mangus, Detterman, M. C. Lachenbruch, and A. H. Lachenbruch made a geological traverse along the Etiviluk River from the headwaters at Howard Pass to the mouth; the party traveled most of this distance by boat. This traverse also included the lower 20 miles of the Nigu River; it was extended about 10 miles south of Howard Pass to include Flora Creek and other headwater tributaries

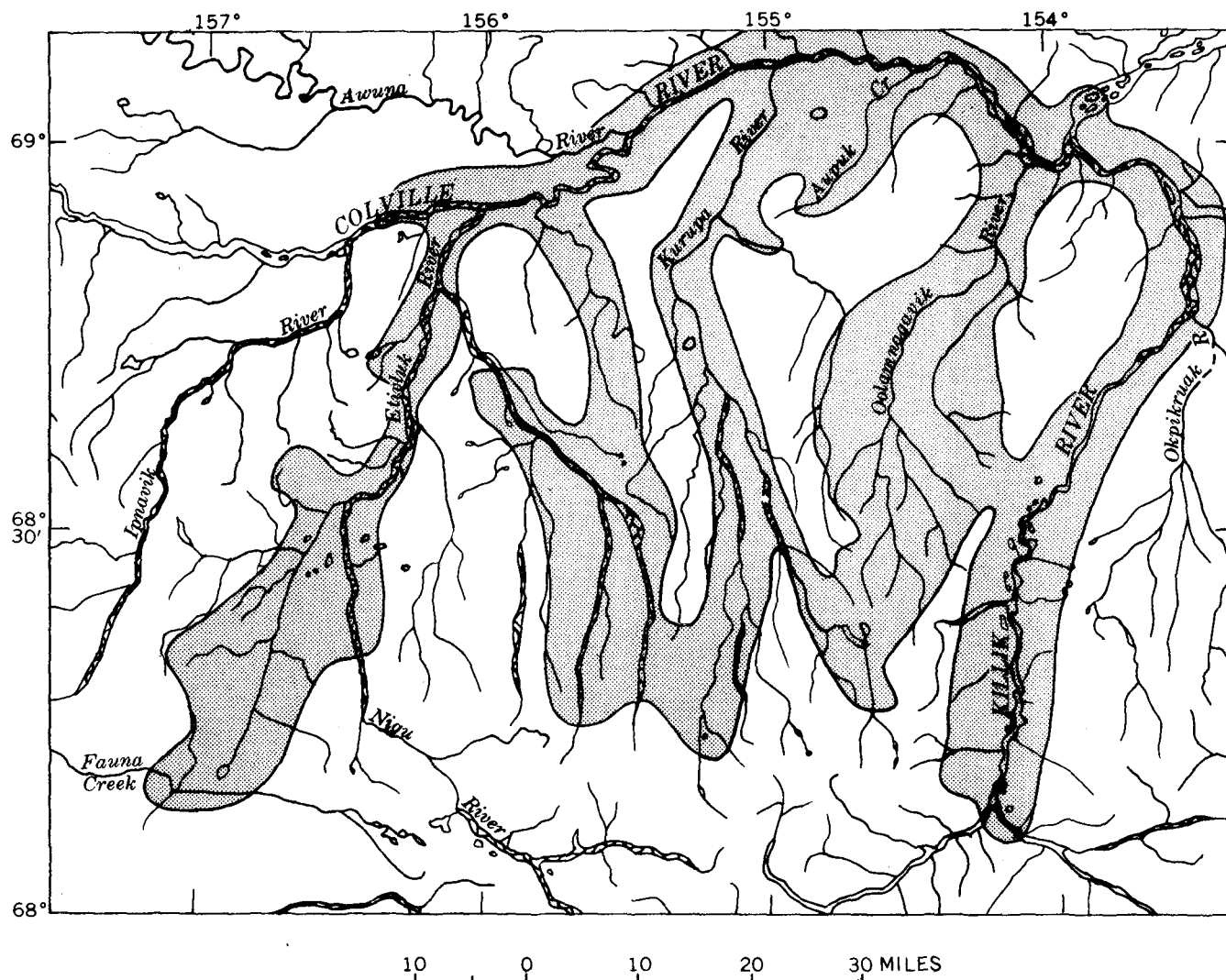


FIGURE 55.—Index map showing relation of field mapping (shaded) to photogeologic mapping in the Killik-Etiviluk Rivers region, Alaska.

east of the Aniuk River. Later in the season the party studied the geology of the area adjacent to the upper Killik River between the mouth of Easter Creek and lat 68°23' N.

In 1950 Chapman, Eberlein, and Reynolds mapped the geology in the area of the upper Oolamnagavik and the Kurupa Rivers and the East Fork of the Etiviluk River, and continued a traverse northward along Kucher Creek to the Colville River. During August 1950, Eberlein and Reynolds restudied and mapped the Aupuk anticline along the Colville River between Kucher Creek and the Oolamnagavik River; this party traveled overland by weasels (small tracked cargo-carrying vehicles designed for military use in World War II).

During the 1953 field season Detterman and Bickel traveling by boat, made detailed reexaminations along the Killik River between lat 68°27' N. and the mouth

of the river, along the Colville River between Aupuk Creek and the Killik River, and also along the lower 4 miles of the Oolamnagavik River. Bickel reexamined the area adjacent to the Etiviluk River between the mouth of the East Fork of the Etiviluk River and the Colville River. With the exception of this 1953 work and the study of the Aupuk anticline in 1950, the fieldwork can best be classed as "detailed reconnaissance." In many parts of this area, detailed mapping was impractical, owing to lack of outcrops and (or) lack of time, although detailed data were collected in places where exposures were especially good. The work of parties traveling by boat was in general limited to the area that could be reached in a day's round trip on foot from camps established on the rivers.

Since completion of the fieldwork, the compilation of field data has been supplemented by study and interpretation of the excellent vertical aerial photographs

taken by the U.S. Navy, which give complete coverage of the mapped area.

ACKNOWLEDGMENTS

A project of the magnitude and duration of this study, in such a remote and uninhabited area, could not have been completed without the assistance and cooperation of many people. The authors wish particularly to acknowledge the geologic work of L. A. Warner and C. E. Kirschner and that done in 1950 by G. D. Eberlein and C. D. Reynolds; their work has been incorporated in this paper.

It is a pleasure to commend the unfailing cooperation, ability, and congenial companionship, even under occasional extremely adverse physical conditions, of the following personnel who assisted the geologists of the various parties:

- 1945, Ome Daiber, camphand; Elder Lebert, cook.
- 1946, Edward G. Sable and Arthur H. Lachenbruch, geologic field assistants; Delmar L. Isaacson, cook.
- 1947, James H. Zumberge, geologic field assistant.
- 1948-1949, Elder Lebert, cook.
- 1950, W. Douglas Carter and William L. D'Olier, Jr., geologic field assistants; Richard D. Olson, cook; Max H. Davis, Arctic Contractors' weasel mechanic.

Much of this area would have been inaccessible without the air transportation handled, often under hazardous conditions, by the pilots of Wien Alaska Airlines, Alaska Airlines, and Transocean Airlines. Naval and Arctic Contractors' personnel provided invaluable assistance many times during the work.

The work of three of the field parties were facilitated by caches of food, weasel fuel, aircraft gasoline, and some equipment that were placed at predetermined localities along their route of travel before the work began. Edward J. Webber in 1946, M. D. Mangus in 1949, and A. Samuel Keller and Irvin L. Tailleux in 1950, all ably supported by "bush" pilots, successfully completed these hazardous airborne operations.

The assistance, helpful comments, and contributory fieldwork in adjacent areas by personnel of the Geological Survey, including paleontologists, H. R. Bergquist, A. L. Bowsher, J. T. Dutro, Jr., B. H. Kummel and R. W. Imlay, whose fossil identifications added much in the age determinations of the mapped units, are gratefully acknowledged.

This report was compiled jointly by the three authors, with each author responsible for individual sections. The introduction was written by Robert M. Chapman, with the following exception: Climate by Robert L. Detterman. The section on permafrost was written by Marvin D. Mangus. The stratigraphy of the Pale-

ozoic and early Mesozoic sedimentary rocks was written by Mangus and Chapman and that of the Cretaceous and Quarternary by Detterman. The igneous rocks are discussed by Mangus. The sections on structure were written by Mangus, Chapman, and Detterman following the same general divisions that are used in the discussion of the stratigraphy. Economic geology was written by Chapman, with the following exceptions: coal by Detterman; phosphate by Mangus and Chapman.

GEOGRAPHY

RELIEF AND DRAINAGE

The Killik-Etiviluk Rivers region includes parts of two well-defined physiographic provinces, the Brooks Range and the Arctic foothills (Payne, 1951), the latter being subdivided into southern and northern sections. The Brooks Range province, which includes approximately the southern one-third of this region, includes also the western part of the rugged Endicott Mountains that reach a maximum altitude of 7,400 feet near the Killik River, and the Howard Hills at the head of the Etiviluk River, which have a maximum altitude of about 4,900 feet. The average relief in the part between the Killik and Kurupa Rivers is approximately 3,400 feet; between the Kurupa and Etiviluk Rivers it is about 2,200 feet. Although the topography is quite rugged, there are very few prominent landmarks in the mapped region.

The southern foothills section of the Arctic foothills province includes prominent west-trending ridges, groups of hills, isolated hills of various sizes, and some broad featureless tundra-covered areas. The maximum altitude within this section is along the southern boundary where several hills rise to between 3,500 and 4,000 feet. In the northern part of this section, Smith Mountain near the Etiviluk River and a group of hills between the Oolamnavik and Killik Rivers are approximately 3,200 feet in altitude and are outstanding landmarks. The average relief within this section is approximately 900 feet.

Several excellent passes through the Brooks Range in the Killik-Etiviluk Rivers region are broad and open, and are less than 3,400 feet in altitude; foot and weasel travel is entirely feasible. The valleys are so free from obstacles such as steep grades, incised valleys, and morainal boulders that one can use tracked vehicles very easily in an east-west direction between the Noatak-Etiviluk Rivers area and the Killik-John Rivers divide, a distance of over 100 airline miles. Besides facilitating movement from one drainage system to another on the ground, the passes also provide excellent routes for single-engine aircraft in traveling through the mountains in overcast weather.

In the Killik River drainage, Easter Creek affords several tundra-covered passes into the south-flowing drainage system of the John River-Hunt Fork and the Alatna-Kutuk Rivers drainage. At the headwaters of April Creek, several excellent passes into the Alatna drainage are present. The one at the head of the east fork was used by the Geological Survey expedition of 1924 (Smith and Mertie, 1930, p. 10-15). The valley of the upper Killik River where it bends 90° and changes course from northwest to northeast is open to the Alatna and Nigu Rivers drainages (fig. 56). Along the course of the Nigu River and its tributaries, passes can be found almost anywhere from the Nigu and Etivluk Rivers into the Noatak River. The upper courses of these rivers flow in broad, open glaciated valleys.

The Etivluk River affords the lowest and easiest pass through the Brooks Range in the mapped area (fig. 57). This pass was used by the Geological Survey expedition of 1925 (Smith and Mertie, 1930, p. 19-21) and by Ensign Howard in 1886 (Stoney, 1900).

Approximately the north one-fourth of the mapped area lies within the northern foothills section of the Arctic foothills province. It includes a generally featureless belt along the southern boundary of this section, succeeded northward by a gentle escarpment and then by broad, relatively low, rolling ridges that trend west. There are no outstanding topographic landmarks, and the maximum altitude does not exceed 2,000 feet. The average relief is approximately 300 feet.



FIGURE 56.—Oblique view of the Killik River pass through the Brooks Range. Photograph by U.S. Navy.

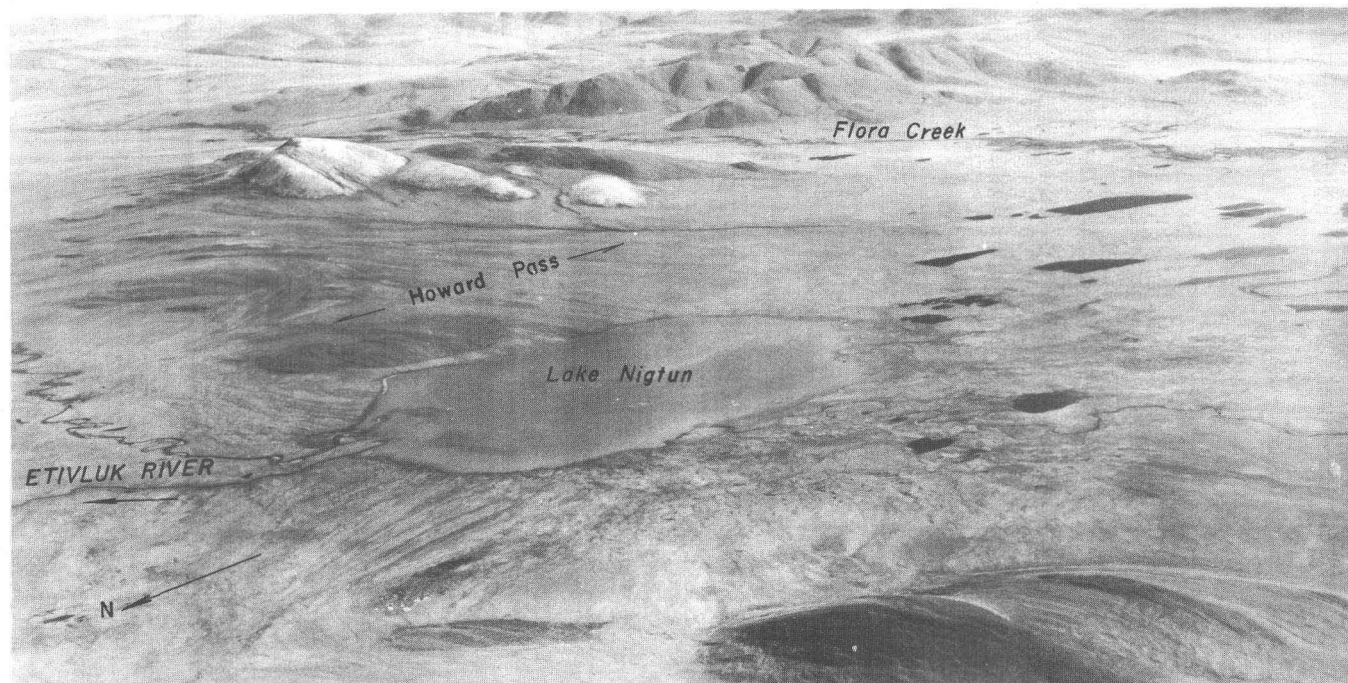


FIGURE 57.—Oblique view of the Howard Pass area showing route through the Brooks Range. Photograph by U.S. Navy.

The Killik, Oolamnagavik, Kurupa, and Etivluk Rivers and their tributaries, all north-flowing rivers that head in the Endicott Mountains and in the highest foothills, carry nearly all the drainage from this area into the east-flowing Colville River, which is the largest river in northern Alaska. The only independent smaller streams of consequence are Kucher and Aupuk Creeks, and they head in the foothills and flow into the Colville River. In the extreme southwestern part of the mapped region, the drainage is southwesterly into the Aniuk River on the south side of the Brooks Range. The only other drainages that differ markedly from the northerly pattern are the upper valleys of the Nigu and Killik Rivers, which trend west and east respectively, and of Easter and April Creeks, which trend west.

The larger valleys within the Brooks Range province have been sculptured by valley glaciers, and some, notably the Killik, Kurupa, and Nigu, have a typical broad-floored, U-shaped cross section. Glacial and alluvial debris, composed of material ranging from silt to boulders, is abundant. The courses of the main streams are braided and generally shallow with low to moderate gradients, except in the extreme headwaters where they issue from steep narrow mountain valleys. The interstream areas are well drained, many of them are rocky and precipitous, and they are usually dry once the melt water has drained off.

In the southern foothills section most of the rivers, except the Killik and Nigu, have braided channels in at least part of their courses, although in most places

one main meandering channel is developed. The average depth of water is probably about 3 feet; the channels and valley floors are laden with glacio-fluvial and reworked glacial material that has been carried northward by the present streams. Most of the tributary streams are small, not braided, and some are intermittent. The Killik River is not braided, and in the northern 20 miles of its course within this section, has a moderately steep gradient in a boulder-laden channel that cuts through glacial debris and moraines to form a series of "whitewater" rapids that are somewhat hazardous to navigate. The current in these rapids probably flows at 9 to 12 miles per hour. The Nigu River in the southern foothills section is similar to this stretch of the Killik River. In general the interstream areas are well drained, and the ground is wet but not swampy; however, some parts are swampy enough to seriously hamper cross-country foot travel.

In the northern foothills section only the Etivluk and Killik Rivers are conspicuously braided, although all the main streams have formed wide gravel-laden valley floors in which their present meandering channel and a few distributaries are slightly incised. The Colville River is primarily confined to one channel that is 300 to 800 feet wide and is estimated to average 10 feet in depth. Most of the interstream areas are well drained, although some of the low and featureless areas remain swampy throughout the summer.

The flow of water and the breakup of ice in the streams usually begins between May 14 and 25. Ice disappears from the lakes between June 1 and July 15, depending

upon the altitude, run-in of melt water, exposure to direct sun, and depths of the lakes. The volume of water in all the streams fluctuates considerably during the summer season. Usually the highest water stage for the rivers occurs within 3 to 7 days after the breakup starts, and many small tributary gullies and washes carry water only at this time. Normal and low-water stages following the complete melting of the snow cover are changed appreciably only by periods of late snowfall in the uplands followed by rain, or by two or more days of persistent rainfall; heavy downpours or cloudbursts are extremely rare. The tundra has a vast capacity to hold rainfall and release it slowly. The occasional high-water stages during the summer occur abruptly and with great force when once started, and they subside usually within 2 days unless more rain falls. In August 1946 the Colville River near the Kurupa River rose 2 to 3 feet within 10 hours, as a result of rains in the Brooks Range and southernmost foothills. A number of torrential flood-stages were observed in the course of fieldwork, but none quite equaled the maximum stage during spring breakup.

The gradients of the streams in the Killik-Etiviluk Rivers region were established from altitudes measured by altimeter. These altitudes are only approximate, but the control probably was sufficient to establish relative gradients (table 1).

TABLE 1.—Gradients of some streams in Killik-Etiviluk Rivers region

Stream	Approximate length (miles)	Average gradient (ft per mile)	Average gradient to morainal front (ft per mile)
Killik River	126	23	-----
Upper Killik River (divide to Easter Creek)	44	44	44
Easter Creek	36	34	34
Killik River sand dune area	34	6	6
Oolamnagavik River	72	39	68
Kurupa River	72	36	100
Nogak Creek	40	35	90
Ivotuk Creek	32	30	49
Nigu River	76	23	31
Etiviluk River	68	18	17
Colville River	72	4	-----

Aufeis fields, also known as "river glaciers," "ice fields," and "flood ice," and generally called "glaciers" by the natives, build up throughout the winter season on many of the rivers and their larger tributaries. At least 12 significant accumulations of aufeis have been observed on the Killik, Oolamnagavik, Kurupa, Etiviluk, and East Fork of the Etiviluk Rivers. They form in, and probably tend to enlarge, wide low-gradient parts of the flood plains, and they seem to recur annually in the same locations. These ice deposits are formed by overflow water, which runs all winter. After the first ice freezes over the river, it is broken by hydro-

static pressure from beneath, and heaves and cracks enough to allow the water to come to the surface and overflow. The overflowing water freezes quickly, and the action is soon repeated. During this procedure the ice deposit builds up in thickness from several feet to as much as 15 feet, and also enlarges laterally and lineally. Some of the fields have an area of several square miles. On a cold (-20° to -40°F) clear day, a large cloud of ice fog, caused by the difference in temperature between the running water and the air, hovers over the ice.

The aufeis fields in this region are seasonal, and the size depends upon the amount of water overflow and the winter temperature. Most of the fields disappear by late June, but some last well into August.

Lakes of several types are present, but not abundant, within this area. Most of the lakes within the Brooks Range province and in the southern part of the southern foothills section are the result of glacial scouring and (or) damming by glacial debris. A few small lakes are present on gravel terraces and in upland interstream areas. Numerous small lakes and several large ones occur in the valley bottoms along the Killik, Nigu, and Etiviluk Rivers in the mountains and southern foothills, but there are only a few small lakes along the smaller streams. Many of the lakes are shallow, probably not exceeding 10 to 12 feet in depth. Notable exceptions, both in size and in depth, are Kurupa and Cascade Lakes, which probably are at least 50 feet deep.

Some thermokarst lakes are present in the silt overlying the gravel terraces in the northern foothills part of this region. Some lakes, formed in abandoned channels and other valley bottom depressions, occur along the Colville River and several of the other larger streams.

ACCESSIBILITY

The Killik-Etiviluk Rivers region can best be entered by air, although it can be reached by arduous overland travel, as was done in the early days, through mountain passes at the heads of the Killik and Etiviluk Rivers. There are no settlements, camps, roads, or airfields in the area. Umiat, the only established camp and airfield in this part of Alaska, is on the Colville River about 60 airline miles northeast of the mouth of the Killik River. Barrow is about 175 miles north-northwest.

In the winter season it is possible to land small, ski-equipped aircraft within easy reach of most of the area. Large lakes provide safe landing areas for twin-engine ski-wheel-equipped aircraft. In the summer, lakes and numerous stretches of the larger rivers will accommodate pontoon-equipped aircraft, and, except during floodwater stages, gravel bars suitable for wheel landings can be found along the largest rivers.

In connection with the work in this area, wheel landings by large single-engine aircraft were made on smooth gravel bars on the south side of the Colville River just downstream from the mouth of the Kurupa River, immediately upstream from the mouth of the Oolamnagavik River, and at the mouths of the Killik and Etivluk Rivers. Pontoon and ski landings were made on the large lakes along the Killik River at lat 68°30' N., on Kurupa Lake, the lakes immediately north of Smith Mountain, Howard Pass Lakes, Lake Betty, and Etivluk Lake. Several miles southwest of the mouth of the Etivluk River an airstrip large enough to accommodate twin-engine aircraft was constructed in 1952, but it has not been maintained.

Gravel-bar landing strips, which were used successfully by small aircraft, were cleared and leveled by the field party in 1950 at lat 68°30' N. and lat 68°40' N. along the Oolamnagavik River. With little work and equipment, landing strips could be made at many places within this area except in the extremely mountainous terrain. Due allowance must be made for altitude, performance of various types of aircraft, and especially the skill of the pilot, in evaluating the usability of many of the natural landing areas. The area, while not easy to traverse, presents no problems not found in other parts of northern Alaska. Shallow-draft, 18-foot folding canvas boats have been used successfully on the Killik River below Easter Creek, on the Oolamnagavik River north of lat 68°30' N., on the Kurupa River north of lat 68°40' N., on the East Fork of the Etivluk River north of lat 68°40' N., on the Nigu River north of lat 68°12' N., and on the Etivluk River north of lat 68°20' N. Larger boats can be used on the Colville River. Weasels are very useful for cross-country travel, and all but the most mountainous terrain can be negotiated easily by them. In both weasel and boat travel, the skill and experience of the operator determine the limits of safe use.

CLIMATE

Meteorological records were kept by the authors during the 1946, 1949, 1950, and 1953 field seasons. Table 2 summarizes the weather conditions during the field season from May through August; the table was compiled from observations taken at 3-hour intervals from 9 a.m. to 9 p.m. in 1949 and 1953. The observations for the years 1946 and 1950 were taken at irregular intervals and were not used in determining the monthly mean values or the 2-year mean values. A total of 1,268 observations was used. The temperature was read from an unprotected thermometer, and both the wind velocity and precipitation were estimated; however, the values given are probably low rather than high.

The Killik-Etivluk Rivers region includes at least two distinct meteorological provinces; the Brooks Range and the adjacent foothills is one province, and the northern part of the southern foothills and the northern foothills section is another. In May and June there are more clear warm days in and near the mountains than farther north; conversely, there are more storms during July and August. Table 2 does not take into consideration the meteorological provinces, but is an average of the records for the entire region. The weather observations were taken at the various camp locations and the camps were moved frequently; thus it was impractical to compute records for a specific province.

A brief analysis of table 2 will give a general idea of the conditions under which the geologic investigations were made. The sky was clear only 5 percent of the time and overcast 54 percent of the time. The mean temperature was 49°, with a maximum of 88° and a minimum of 15°. Precipitation, generally in the form of rain or drizzle, occurred on an average of 41 days out of every field season; although some snow fell in every month, it was more common in May and August. An average of one thunderstorm occurred each year, generally accompanied by severe squalls and hail. Storms usually move in from the southwest, not uncommonly with a rising barometric trend. Precipitation generally does not fall in large quantities, although as is common in semiarid regions, the amount may vary considerably within a short period of time. The prevailing wind directions are north to northeast with a shift to south and southwest during June and July.

PLACE NAMES

The names used in this study for physiographic features and geologic structural features in the region have been derived from three sources: from names the early explorers gave to a few of the more conspicuous features, from names both the early and the recent geologists who worked in the region gave to unnamed features, and, insofar as known and practical, from native names that have been used by Eskimos who were familiar with the region. In addition to names established by the explorers and geologists, many of the Eskimo names were obtained and some corrections were made by the personnel of the Topographic Division of the Geological Survey in 1956 during the course of their fieldwork in this region. Most of the names, with authority for their usage and for some their meaning are on file with the Board of Geographic Names of the Geological Survey; names not in this file can be documented in the older publications listed in the bibliography of this paper.

TABLE 2.—Weather data for Killik-Etiviluk Rivers region for period May 15 to September 1, 1946, 1949, 1950, and 1953

[No records for May 1950; no wind velocity records for 1946 and 1950. Figures shown for maximum wind velocity are single highest observed for month, except for monthly and 2-year means]

Month and year	Sky condition (percent of time)					Weather and Obstruction to visibility (percent of time)				Precipitation			Wind										Temperature (° F)			
													Direction (percent of time)								Velocity (mph)					
	Clear	Scattered	Broken	Overcast	Unlimited ceiling	Snow	Rain, drizzle	Fog, haze, smoke	Unlimited visibility	Amount (inches)	Occurrence (days)		Thunderstorms	Calm	North	Northeast	East	Southeast	South	Southwest	West	Northwest	Mean	Maximum	Mean	Maximum
May 1946.....	0	28	50	22	20	22	0	40	45	0.1	3	0	0	60	30	0	0	0	0	0	10	---	---	28	39	17
May 1949.....	8	6	20	66	16	28	6	0	60	.6	8	0	4	40	24	4	2	16	0	0	10	10	35	38	76	15
May 1953.....	0	0	10	90	0	30	1	12	43	.3	7	0	10	1	66	0	0	0	14	3	6	7	25	34	51	25
Mean.....	4	3	15	78	8	29	3	6	52	.45	8	0	7	21	45	2	1	8	7	1	8	8	30	36	---	---
June 1946.....	10	20	55	15	40	0	50	4	70	.5	15	1	15	24	0	2	2	15	12	16	14	---	---	49	80	21
June 1949.....	3	10	40	47	13	17	15	9	70	1.0	15	1	2	29	8	2	3	16	20	2	18	11	60	45	83	24
June 1950.....	9	14	30	47	30	0	28	5	80	.4	19	0	43	6	6	3	8	4	8	16	6	---	---	44	67	27
June 1953.....	4	25	24	47	35	1	18	9	83	1.2	15	1	8	15	30	1	1	6	8	17	14	9	40	51	70	35
Mean.....	4	17	32	47	24	9	16	9	76	1.1	15	1	5	22	19	1	2	11	14	10	16	10	50	48	---	---
July 1946.....	8	42	30	20	44	0	37	13	60	.4	11	3	9	30	21	3	3	3	5	5	21	---	---	54	80	31
July 1949.....	19	30	33	18	59	0	4	1	98	.1	5	0	4	24	17	12	2	23	13	1	4	11	40	57	88	31
July 1950.....	20	24	16	40	53	0	43	47	80	.2	16	1	40	15	4	2	2	6	3	12	14	---	---	48	78	30
July 1953.....	2	23	25	50	35	3	22	13	79	.8	10	0	8	16	22	6	2	7	14	13	12	9	45	53	79	37
Mean.....	11	26	29	34	47	1	13	7	88	.45	8	0	6	20	20	9	2	15	13	7	8	10	41	55	---	---
August 1946.....	0	29	18	53	25	20	65	7	57	.8	19	0	11	7	4	7	0	4	25	35	7	---	---	45	73	29
August 1949.....	2	14	31	53	20	1	20	2	97	.4	13	0	10	18	1	0	5	42	24	0	0	8	40	61	80	31
August 1950.....	11	21	24	44	32	0	35	27	80	.4	11	0	50	0	9	7	8	2	7	17	0	---	---	47	72	29
August 1953.....	0	4	33	63	13	0	25	20	76	.4	7	0	15	10	35	0	1	6	26	7	0	6	25	54	72	30
Mean.....	1	9	32	58	16	1	23	11	86	.4	10	---	12	14	18	0	3	24	25	4	0	7	32	58	---	---
2-year mean.....	5	14	27	54	24	10	28	16	75	2.4	41	1	8	19	26	3	2	14	15	5	8	9	60	49	---	---

ANIMALS AND PLANTS

The animal and plant life within this area is similar to that in most other parts of northern Alaska. Caribou are abundant, moose and grizzly bear are common, and mountain sheep are common but confine themselves to rugged mountainous terrain. Foxes, wolves, weasels, ground squirrels, marmots, and wolverines are common. Ducks, geese, and small birds are abundant. Grayling can be found in most streams and lakes, whitefish and lake trout are common in Kurupa and Etiviluk lakes, and pike were found in valley-floor lakes along the Killik River. The density of mosquito population certainly equals, if not exceeds, that of any other area in Alaska. Gnats are also numerous, and were especially abundant in 1949 and 1950.

Many species of small plants are ubiquitous, and the plants rarely exceed 12 inches in height, except adjacent to streams. Some small alders are present on slopes at low altitudes, and willows ranging from 2 to 15 feet in height are common on the gravel bars along the larger streams. A few poplar trees, not more than 2 to 3 feet in height, were noted in sheltered gullies along the Etiviluk and Oolamnagavik Rivers at about lat 68°30' N., and some as much as 15 feet high occur along the Killik River at lat 68°40' N.

POPULATION AND ARCHEOLOGY

As previously stated there are no settlements within the Killik-Etiviluk Rivers region. Umiat, a camplike base of no established permanency, and Barrow are the closest points from which supply and transportation into this area could be effected. A seminomadic group of Eskimos now reside at Anaktuvuk Pass in the Brooks Range about 63 miles east of the southeast corner of this area. Apparently this group, the only remaining inland Eskimos in Alaska, has made hunting trips into the area in recent years. Evidence of old camp sites, of caribou, mountain sheep, and moose skulls, and of rifle cartridges shows that the area has been traversed by Eskimo hunting parties at various times in the past.

Flint chippings were found at a number of sites on prominent hilltops and bluffs along the upper Oolamnagavik River. Apparently Eskimos used these places as lookout points during caribou hunts, and passed their time by making flint implements while awaiting wandering bands of caribou. Similar flint chips are not uncommon in the sand dunes along the Killik River between the mountain front and the group of large lakes. The age of the flint chips is undetermined. Old camp or village sites, also of unknown age, were

discovered at Nigu Lake and in the vicinity of Howard Pass. These sites were found in the normal course of geologic fieldwork, and probably many more could be located if an intensive search were made by archeologists.

In 1886, Howard (Stoney, 1900, p. 66-71) found a group of Eskimos camped at a place called Etivolopar, believed to have been at the mouth of the East Fork of the Etivluk River. It is not clear whether this was a temporary camp or an established village. In 1950, W. P. Brosgé and H. N. Reiser found several old village sites at Etivluk Lake. It is possible that this was the village Howard (Stoney, 1900, pl. 1) called Issheyak, which was on the divide between the Noatak and Colville River drainages. A small group of Eskimos, who had lived with the Anaktuvuk Pass group since 1949, were living along the Killik River near the lakes at the mountain front in 1945. Apparently they had resided in this vicinity for several years, but probably were not there in 1924, as Smith and Mertie (1930) made no mention of them.

PERMAFROST

Perennially frozen ground, or permafrost, underlies the entire mapped region. In the tundra- or vegetation-covered areas the ground below the top 6 to 12 inches remains frozen during the entire year, but in the more porous and permeable gravel bars and ancient gravel deposits, the ground thaws to a depth of several feet by late August. In the upper Killik valley, in several inactive dune sand deposits, the sand was thawed to a depth of 16 inches in 1949.

Excellent examples of a drained lakebed, of ice wedges, and of polygonal ground were examined in 1946 in the area just south of camp C-July 21-46 on the Kurupa River. The bed of a lake, drained so recently that little to no vegetation had taken root in it or on its alluvial outwash fan, is about 5 miles south of this camp and on a gravel terrace (40 to 50 ft higher than the river level) on the west side of the Kurupa River (fig. 58). The drainage channel apparently developed along an ice wedge, which on melting formed a small gully; the channel was subsequently enlarged by headward erosion, and it ultimately provided a path for rapid outlet of the lake water. Older drained lakebeds that are overgrown with vegetation are also shown in figure 58.

A circular topographic feature, approximately 400 feet in outside diameter, is located on the east side of Etivluk Lake. It consists of two concentric ridges, each about 50 feet wide and 6 feet high, that are separated by a trough 50 feet wide. The soil is sand and fine gravel of glacial origin. This "ring" structure was interpreted as a permafrost phenomena by Brosgé and

Reiser, who examined it, but, owing to lack of time and bad weather conditions, could not make a detailed investigation.

STRATIGRAPHY

The rocks exposed in and underlying the Killik-Etivluk Rivers region are, with the exception of a few mafic intrusive bodies, predominantly sedimentary and include a few metasedimentary units (pl. 43). The sedimentary rocks range in age from early Late Devonian through Quaternary, and probably all ages except Pennsylvanian and Tertiary are represented. The section has been divided into 17 formations, which constitute a thickness of at least 36,000 feet. Shale, sandstone, and siltstone are the most abundant rock types; conglomerate, limestone, quartzite, and slate are much less common; and coal, ironstone, gravel, sand, and clay form a small percentage of the total section.

Many of the formations cannot be exactly delimited in either vertical or lateral extent, owing to the similarity of lithology, to many gradational contacts, to the general scarcity of fossil remains, and to the lack of exposures in many large sections of the region. The structural complexity, especially in the southern foothills section, increases the problems of stratigraphic correlation.

DEVONIAN SYSTEM

Devonian rocks, the oldest known in the mapped area, are believed to have been deposited in a marine environment. They have been divided into three distinct mappable rock units: the Upper Devonian limestone, the Hunt Fork shale, and the Kanayut conglomerate.

UPPER DEVONIAN LIMESTONE

Between the Nigu and Etivluk Rivers and approximately 4,000 feet due east of camp M-June 11-49, an Upper Devonian limestone crops out in an isolated exposure consisting of three small mounds and several associated rubble traces. The actual size of this outcrop has been exaggerated on plate 43 in order to show it as a cartographic unit.

The rock in this exposure is a thick-bedded fine to coarse crystalline limestone that is very light yellowish gray to light olive gray and well fractured. It weathers light gray to white, with a rough tripolitic surface. This outcrop of limestone is probably part of a fault block.

The age of this unit, as determined by J. T. Dutro, Jr., (written communication) from a collection of invertebrate fossils, is late Middle or early Late Devonian. Dutro stated:

The fauna consists of: rugose coral, undet.; *Atrypa* sp.; *Spinatrypa* sp.; *Scutellum* cf. *S. tullium* (Hall); and ostracodes (pos-

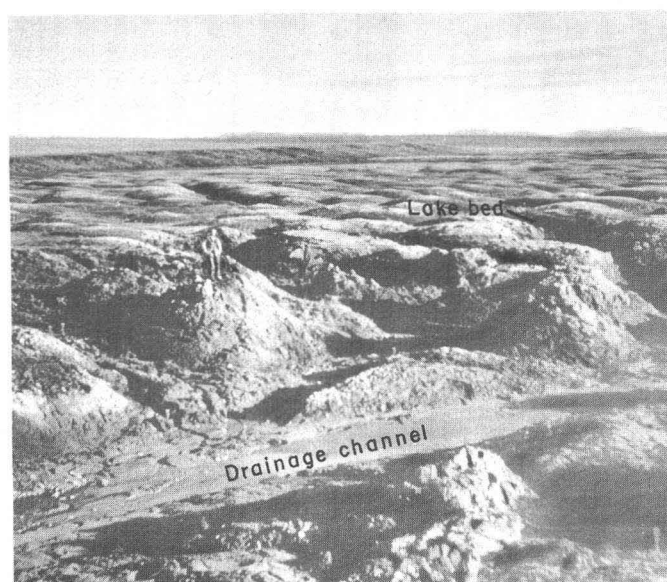


FIGURE 58.—Vertical view (above) of drained lake on the high-level terrace on the west bank of the Kurupa River; photograph by U.S. Navy. Horizontal view (below) of drained lake on west bank of Kurupa River, showing floor of lakebed; photograph by R. M. Chapman.

sibly *Bairdia*). This assemblage is either late Middle Devonian (upper Givetian) or early Upper Devonian (Frasnian) in age. The *Scutellum* is similar to the Tully form and would seem to indicate a late Middle Devonian age. Similar species, however, have been reported from the Frasnian of Germany and Australia, and the genus ranges through Chemung time. The fauna is probably the same age as that reported from the Kiligwa and Nimiuktuk River valleys farther west where about the same time interval is represented by brachiopod and coral assemblages.

These rocks probably are equivalent in age to a part of the thick sequence of limestone and dolomite that is exposed in the Kugururok valley approximately 120 miles to the west (J.T. Dutro, Jr., oral communication). This sequence of carbonate rocks is well exposed on Mount Bastille, which is in the Kugururok valley at approximately lat 68°28' N., and long 160°55' W.

HUNT FORK SHALE

A thick sequence of shale, locally metamorphosed to slate, that lies beneath the Kanayut conglomerate and above Middle Devonian metasediments of the central Brooks Range, is here named the Hunt Fork shale. The rocks were originally described as Devonian (Smith and Mertie, 1930, p. 139-151).

The Hunt Fork shale is very thick and forms a well-defined stratigraphic unit in the central Brooks Range; it has been mapped as a continuous belt from the south end of Chandler Lake to the Aniuk River. Over this distance of about 120 miles, the unit ranges in width from 5 to 20 miles. The belt of outcrop is typically a relatively low, conspicuously trenchlike valley between the more rugged and resistant rocks to the north and south. The formation commonly forms prominent low hogback ridges in these east-trending valleys.

The Hunt Fork shale is not entirely exposed at any one locality; the greatest thickness was measured in June 1951 by Patton, at the type locality 25 miles east of the Killik River at lat 68°18' N. and long 153°20' W., along Fire Creek, an east-flowing tributary of the Okokmilaga River.

At the type locality the rocks dip 6° to 15° S., and approximately 3,200 feet of shale, slate, siltstone, and sandstone was measured; the lower contact was not seen, but the upper part is gradational into the overlying Kanayut conglomerate.

The Hunt Fork is predominantly shale, locally metamorphosed to slate, with minor amounts of interbedded hard sandstone and siltstone. The shale is gray brown to dark gray and weathers a mottled dark yellow red. In general where slate is present, the cleavage is well developed and original bedding has been obliterated; some dark bands which are thought to be old bedding planes cross cleavage and can be followed short distances. The slate is dark gray green to black and weathers dark yellow red. The siltstone

beds are dark gray green and have a conchoidal fracture. They are more abundant near the top of the section and grade upward into sandstone and quartzite.

Type section of Hunt Fork shale

[Measured by W. W. Patton, Jr., June 1951]

Kanayut conglomerate.

Hunt Fork shale:

	Feet
Clay shale, silty shale, and siltstone. Shale is dark gray to black, with interbeds of yellow-red-weathering siltstone; grades upward into interbedded shale and light-gray fine- to medium-grained medium- to massive-bedded sandstone.	1,000
Clay shale and siltstone. Shale gray; weathers dark yellow red. Unit makes nonresistant zone of bright-red soil. Siltstone thin bedded, dark gray green; weathers dark yellow red.	245
Slate and siltstone. Slate dark gray to black; weathers black. Clay slate at top becomes silty slate near bottom. Minor interbedded siltstone is greenish gray, thin bedded, hard; weathers dark yellow red.	690
Silty shale and siltstone. Shale silty, gray to greenish gray, with a few dark-gray silty concretions as much as 4 in. in diameter; weathers dark yellow red. Locally the cleavage is stronger than the bedding. Minor interbeds of dark-gray yellow-weathering siltstone.	450
Silty shale, siltstone, and sandstone. Shale and siltstone are dark gray and weather dark yellow red. In upper part of interval minor amounts of interbedded gray-green thin-bedded, very fine grained sandstone that weathers dark yellow red. Cleavage well developed locally in the shale.	800+
Total	3,185+
Section ends in gravel and tundra.	

Occurrence.—The Hunt Fork shale in the mapped area is very similar to that of the type locality and is well exposed in the southern part of the mapped area; the best exposures are along the upper Killik River at its confluence with Easter Creek. This southern outcrop belt is approximately 16 miles wide and forms a conspicuous system of east-trending valleys. Aerial photographs indicate that the belt narrows considerably to the west and ends 8 miles east of Etivluk Lake.

Approximately 2 miles north of Etivluk Lake, the Hunt Fork shale crops out in a narrow belt of low relief about 1 mile wide. It is parallel to the upper Nigu valley for approximately 10 miles; then it strikes west to the Etivluk River where it is covered by Quaternary deposits; it is not exposed west of the Etivluk River.

Topographically the formation in the upper Killik Valley forms striking sharp hogback ridges with a relief of 1,000 to 1,500 feet. Where the shale and slate ridges are capped by a minor amount of the inter-

calated and more resistant siltstone and the overlying quartzite formations, the ridges have ragged serrate crests and form some of the highest peaks in the central Brooks Range.

Character and thickness.—In the upper Killik area the shale is gray brown to dark gray and weathers a mottled brown on the lower slopes of the mountains, but above 4,000 feet or near the crests it is dark gray to black. The slate is soft and foliated, with smooth shiny cleavage faces; at most localities the bedding has been obliterated. The intercalated siltstone is thin to medium bedded, dark gray, and very hard; it breaks with conchoidal fracture and weathers dark gray brown.

One striking feature of the shale and slate is the relative abundance of anastomosing quartz veins, and in many places the ridge slopes are white with milky quartz regolith. Pyrite and marcasite crystals are common in the quartz with small amounts of chlorite and galena. Small calcareous lenses are also associated with the shale.

Toward the top of the section the shale gives way to siltstone and fine-grained sandstone. The sandstone contains both invertebrate and vertebrate fossils.

The Hunt Fork shale that occurs in the upper Etivluk Valley 5 miles south of camp M—May 28–49 is hard and indurated, and erodes to form long low narrow well-rounded ridges; the more arenaceous and silty beds form prominent little mounds and small breaks in slope. The shale is greenish brown and nonfossiliferous, and weathers a gray bronze. Fucoidal markings are present along the bedding planes.

In the upper Killik Valley where the largest exposures of Hunt Fork shale occur, the rocks were not measured, but the formation is probably at least 3,500 to 5,000 feet thick. The upper contact between the Hunt Fork and younger beds is gradational.

Structurally the Hunt Fork formation is in a belt of complex folds and faults. Most of the incompetent shale and slate is tightly folded and crushed and has a regional south dip. The cleavage in general has a south dip; thus, both the south-dipping bedding and the cleavage form continuous dip slopes. Because of the uniformity of the formation, it is difficult to determine the magnitude of thrusting. Observations made along the upper Etivluk Valley indicate that the Hunt Fork shale forms the core of a west-plunging anticline.

Age and correlation.—A few marine brachiopods, pelecypods, gastropods, and fish teeth were found in the upper part of the formation. The age of these fossils was designated as Late Devonian by Dutro. Below are listed the fossils found.

USGS Paleozoic loc.	Area	Location	USGS quadrangle map	Fossil
14075.....	Killik River valley.	2 miles north of Easter Creek, east side of river.	Killik River 1:250,000; 1:63,360, A-2.	<i>Spirifer?</i> sp. <i>Palaeoneilo?</i> sp. <i>Eunemia?</i> cf. <i>E.?</i> <i>speciosum</i> Whiteaves.
14076.....	do.....	do.....	Killik River subquadrangle A-2.	<i>Camarotoechia</i> sp. <i>Punctospirifer?</i> sp. <i>Schizodus</i> sp. <i>Nuculana</i> sp. <i>Palaeoneilo?</i> sp. Gastropod, gen. and sp. indet. <i>Bradfordoceras?</i> sp.
14077.....	do.....	do.....	do.....	<i>Nuculana</i> sp. <i>Bradfordoceras?</i> sp. Pelecypod, gen. and sp. indet. Do.
14078.....	do.....	do.....	do.....	<i>Eunemia?</i> cf. <i>E.?</i> <i>speciosum</i> Whiteaves. Cephalopod, gen. indet.
14079.....	do.....	do.....	do.....	<i>Nuculana</i> sp.

KANAYUT CONGLOMERATE

Occurrence.—The Kanayut conglomerate crops out in the southern part of the mapped area within the Brooks Range province, in an east-trending belt about 19 miles wide. This belt is almost entirely Kanayut conglomerate, except in several localities where the continuity is broken by small outcrops of Hunt Fork shale. Topographically this formation consists of massive, high, rugged mountains that are the backbone of the Brooks Range in the Killik-Etivluk Rivers region. The general relief of these mountains is about 3,500 feet, and some peaks reach an altitude of 7,400 feet.

The type locality of the Kanayut conglomerate is about 80 miles east of the upper Killik River near Shainin Lake in the central Brooks Range (Bowsher and Dutro, 1957). The section in the Killik-Etivluk region is similar in lithology and thickness to the type section.

Character and thickness.—The Kanayut conglomerate is well exposed in the vicinity of camp M—Aug. 7–49. Here the lower part of the formation is about 1,200 to 1,500 feet thick and is composed of intercalated thin and crossbedded dark-green to black shale siltstone and platy sandstone that weather dark-red brown. The contact with the underlying Hunt Fork shale appears to be gradational. This lower zone grades upward into a coarser clastic section of medium-bedded to massive hard light-gray-green quartzite and sandstone with interbedded lenticular to massive-bedded quartzitic conglomerates 15 to 30 feet thick. Small limonitic specks, probably weathered pyrite crystals, are scattered throughout the sandstone and quartzite, and in places are abundant enough to cause the rock to weather a red brown. The coarser clastic section is approximately 3,400 to 3,700 feet thick, and is characterized by mountain faces marked by steplike ledges. The ledges are

formed by massive layers of quartzite and quartzite conglomerate, between which the interbedded slate, shale, or siltstone has been eroded.

The conglomerate beds are composed predominantly of colored chert pebbles, but in many places the pebbles are mostly black chert and white quartz. The pebbles are commonly subangular to round, and a few are angular. The general size range is from $\frac{1}{4}$ to 1 inch in diameter. Some of the conglomerate beds are maroon or olive green, and in these beds the pebbles and matrix are of the same material and color. Generally these conspicuously colored conglomerates are small localized lenses in the massive light-gray-green quartzitic conglomerates.

Intercalated beds of maroon and green micaceous hackly-fractured shale, mudstone, siltstone, and sandstone form a very small part of the section. They occur in beds ranging from 2 to 15 feet in thickness. Pyrite nodules $\frac{1}{4}$ inch to 3 inches in diameter are fairly common in the shale and siltstone.

Only nondiagnostic plant remains and coal were found in the Kanayut conglomerate, in thin- to medium-bedded clean light-gray crossbedded sandstone. The coal seams range from $\frac{1}{8}$ inch to 2 inches in thickness, and from 6 inches to 4 feet in length. This formation is predominantly of nonmarine origin.

Section of the Kanayut conglomerate measured in the mountains on the east side of Killik River near camp M—Aug. 5-49 (pl. 44, column 5)

Kanayut conglomerate (section incomplete):

	Feet
10. Sandstone, thin- to medium-bedded, light-gray, fine-grained; speckled with limonitic specks; grains well rounded; weathers red brown.....	220+
9. Quartzite, massive-bedded; medium-gray-green pebble conglomerate. Pebbles composed of colored chert and milky quartz; well rounded, $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter. Unit weathers red brown.....	80
8. Siltstone, thin- to medium-bedded, maroon and olive-green, hard, micaceous; interbedded with silty shale.....	40
7. Conglomerate, massive-bedded, gray-green; matrix a medium-grained quartzite; pebbles well rounded, $\frac{1}{4}$ to 1 in. in diameter, and composed of colored chert. In places the matrix is a maroon quartzite made of fine chert. Intercalated with the quartzite and conglomerate are thin beds of shale and siltstone. Approximately 70 percent conglomerate, 25 percent quartzite, 5 percent shale and siltstone.....	650

Kanayut conglomerate—Continued

	Feet
6. Quartzite and conglomerate, massive-bedded, medium-gray-green, medium-grained. Conglomerate pebbles are colored chert. In some lenses the matrix and pebbles are chert of the same color; these lenses are maroon and olive green. Chert pebbles are well rounded and $\frac{1}{4}$ to 1 in. in diameter. Quartzite has some limonitic specks scattered throughout.....	925
5. Quartzite, medium- to massive-bedded, light gray-green. Some small scattered lenses of conglomerate. Very clean subrounded grains, with limonitic staining.....	360
4. Conglomerate, massive-bedded, medium-gray-green. Conglomerate has quartzite matrix, with minor amounts of light-gray-green quartzite. Intercalated with the quartzite are indurated thin-bedded maroon shale, siltstone, and sandstone containing pyrite concretions.....	920
3. Quartzite and conglomerate, medium- to massive-bedded, light-gray-green. Some intercalated thin- to medium-bedded red sandstone and siltstone.....	400
2. Quartzite and sandstone, medium- to massive-bedded, light-gray to green, fine- to coarse-grained; very crossbedded.....	425
1. Quartzite and quartzitic conglomerate, medium- to massive-bedded, light-gray-green. Some intercalated thin-bedded micaceous red sandstone, siltstone, and shale. Conglomerate pebbles subround to round, made of colored chert, $\frac{1}{2}$ to 1 in. in diameter....	920

Total..... 4, 940+

Other good and accessible exposures of the Kanayut conglomerate were examined 5 miles south of Kurupa Lake, at Outwash Creek 6 miles south of camp E—July 11-50, and 5 miles south of camp E—July 16-50 on both sides of Ivotuk Creek. The Kanayut conglomerate at these localities is very similar in lithology to the rocks measured in the upper Killik valley, and includes siliceous sandstone, quartzite, highly colored chert-granule and grit conglomerate, pebble conglomerate, interbedded shale, and well-indurated siltstone. The sandstone is thin to medium bedded, light gray, with light-red phases, fine to very fine grained, and well indurated to quartzitic. The conglomerate is massive bedded, with light-gray-green matrix; the pebbles are red, green, gray, and black chert and milky quartz, subangular to subround, and are between $\frac{1}{8}$ and $\frac{3}{4}$ inch in diameter. The shale is medium gray, light to dark red, and green, sandy and micaceous in part, fissile, moderately to well indurated.

In the vicinity of Etivluk Lake the Kanayut conglomerate was examined by Brosgé and Reiser in 1950. At this location the Kanayut conglomerate is almost entirely sandstone, quartzite, and shale with very minor amounts of grit and pebble conglomerate. The rocks are mainly medium-bedded light-gray medium- to coarse-grained angular quartz sandstone, and quartzite. The sandstone contains some black chert grains and small lenses (1 to 6 in.) of dark-red medium-grained sandstone, and very sparse, scattered beds of typical conglomerate. The pebbles of the conglomerate are colored chert, milky quartz, and ironstone. Interbedded with the sandstone and quartzite are thin beds of black, green, and red shale. Plant fossils were found throughout the section but are nondiagnostic.

The Kanayut conglomerate in the vicinity of Etivluk Lake appears to be conformable and gradational with the underlying Hunt Fork shale. A thickness of 9,000 feet was estimated by using field dips, altitudes established by barometer, and horizontal distances computed from aerial photographs. This measurement may be in error by $1,000 \pm$ feet because of the gradation into the Hunt Fork shale.

Section of Kanayut conglomerate in the mountains west of Etivluk Lake at camp B—Aug. 10–50

(Estimated by W. P. Brosgé and H. N. Reiser)

	Feet
Quartzite and quartz sandstone, thick-bedded, light-gray (80 percent); thin-bedded platy sandstone (10 percent); and black clay shale (10 percent)	4,400
Sandstone, thick-bedded, light-gray, fine- to medium-grained (40 percent); thin-bedded light-gray platy medium-grained sandstone (40 percent); black to red clay shale (20 percent). Some scattered lenticular beds of quartzitic grit to pebble conglomerate	4,600

Other good exposures of the Kanayut conglomerate are present from 2 miles south of camp M—May 28–49, along the Etivluk River, to several miles north of camp M—July 24–49 in Howard Pass (pl. 44, column 1). Here the formation consists of considerably less conglomerate than in the Killik and Kurupa River valleys. The typical lithology is massive-bedded coarse- to medium-grained light-gray-green quartzite and quartzitic conglomerate. The conglomerate pebbles range in size from $\frac{1}{4}$ to 1 inch in diameter, and are composed of subangular to subround quartz and colored chert, the majority being black chert and milky quartz.

Interbedded with the massive quartzite and conglomerate are thin-bedded light-gray rusty-weathering platy medium- to coarse-grained sandstone, and maroon and olive-green micaceous shale, mudstone, siltstone, and sandstone. The thickness of the Kanayut south of camp M—May 28–49 was estimated to be more than 5,000 feet.

Section of Kanayut conglomerate (pl. 44, column 1)

	Feet
Kanayut conglomerate (section incomplete):	
12. Sandstone, thin-bedded, light-gray; rusty-weathering. Very clean sandstone with limonitic specks throughout; some plant fossils and ripple marks	125+
11. Sandstone, thin- to medium-bedded, white to light-gray, very hard; weathers red brown and has limonitic specks throughout; limonitic specks appear to be weathered pyrite cubes; intercalated with dark-gray hard shale	240
10. Conglomerate, massive-bedded, light-gray-green, lenticular, with quartzitic matrix; well-rounded colored chert and milky quartz pebbles $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter	80
9. Quartzite, medium-bedded, light-gray-green, medium-grained; weathers red brown; a few intercalated pebble-conglomerate lenses. Pebbles are well rounded, gray, black, and white quartz, $\frac{1}{4}$ to $\frac{1}{2}$ in. in diameter. Intercalated with the quartzite are maroon siltstone and shale	250
8. Conglomerate, massive-bedded, light-gray-green; weathers red brown. Pebbles are well rounded, black, gray, and white quartz, $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter. The matrix is medium- to coarse-grained gray-green quartzite	120
7. Quartzite, medium- to massive-bedded, light-gray-green; weathers whitish gray. Quartzite is sparsely specked with limonite and is intercalated with maroon siltstone and sandstone; 95 percent quartzite, 5 percent siltstone and sandstone	720
6. Siltstone, thin- to medium-bedded, maroon and olive-green; intercalated with red and green micaceous shale. Some pyritic concretions in the siltstone. 60 percent siltstone, 40 percent shale	120
5. Quartzitic conglomerate, medium-bedded, light gray-green; weathers red brown. Quartzite is very clean and has limonitic specks on fresh fractured surfaces. The conglomerate occurs as lenses in the quartzite; the pebbles are well rounded, gray, black, and white chert, and are $\frac{1}{4}$ to 1 in. in diameter	600
4. Quartzite, thin- to medium-bedded, light-gray-green; weathers dark red brown; medium grained; crossbedded with ripple marks; intercalated with hard silty micaceous maroon and olive-green shale and siltstone	240
3. Quartzite, medium-bedded, light-gray-green, dark-red-brown weathering. Pebble conglomerate occurs as lenses in the quartzite. Conglomerate pebbles are well rounded, white, gray, and black chert. $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter. Between the beds of quartzite are thin beds of hard indurated shale	450
2. Sandstone, thin-bedded, light-gray; weathers light red brown; very crossbedded, with limonitic specks throughout the mass. Intercalated with the sandstone is medium-gray-brown shale	160

Kanayut conglomerate—Continued

	Feet
1. Quartzite, medium-bedded to massive, light-gray-green; weathers dark red brown; medium grained. Conglomerate occurs as small lenses in the quartzite. The pebbles are white, gray, and black chert ($\frac{1}{4}$ to 1 in. in diameter), and are well rounded. The quartzite beds are intercalated with thin beds of gray-brown hard shale.....	560
Total.....	3,665

Field studies indicate that the Kanayut conglomerate in the southern part of the mapped area is less conglomeratic than to the north. This southward transition from conglomerate to sandstone and quartzite indicates a northerly source area for the Kanayut conglomerate.

The Kanayut conglomerate, although more competent than the underlying rocks, forms a series of overturned and appressed folds with a regional south dip. Field evidence indicates that the entire northern front of the Kanayut conglomerate belt is a broken overturned anticline whose south limb has been thrust northward over the younger rocks. Associated with the thrusting are high-angle reverse, block, normal, and transverse faults.

Age and correlation.—The Kanayut conglomerate in the Killik-Etiviluk Rivers region lacks any diagnostic fossil evidence that would establish its age. The lower gradational contact with the Hunt Fork shale of Late Devonian age and the similarities between the section in this area and the Kanayut conglomerate in the Shainin Lake area as described by Bowsher and Dutro (1957) indicate that this formation is Late Devonian in age.

MISSISSIPPIAN SYSTEM

In the Killik-Etiviluk Rivers region, the Mississippian system is represented by the marine Kayak shale and the Lisburne group, the later being made up of the Wachsmuth and Alapah limestones (Bowsher and Dutro, 1957). The aggregate thickness of these formations in this region is approximately 2,800 to 3,500 feet. The exposures of Kayak shale are confined to the Brooks Range province, and the Lisburne group is exposed in the Brooks Range and in isolated mountains and ridges in the southern foothills section.

KAYAK SHALE

The type locality of the Kayak shale is about 90 miles east of the Killik River in the central Brooks Range at the confluence of Alapah and Kayak Creeks, 4 miles south of Shainin Lake (Bowsher and Dutro, 1957). The Kayak shale in the Killik-Etiviluk region is a readily identifiable formation, owing to its topographic expression and to the contrast in lithology between it

and the overlying and underlying formations. It probably ranges in thickness from 850 to 1,020 feet in the mapped region.

Occurrence.—The Kayak shale crops out in two mappable belts in this region. The smaller belt, which is approximately 18 miles long and 0.5 to 2 miles wide, is in the southwest corner of the mapped area in the vicinity of Howard Pass. The larger northern belt lies in the northern part of the Brooks Range, trends westward across the entire Killik-Etiviluk region, and ranges from 0.25 to 3 miles in width. Topographically the Kayak shale is characterized by saddles and by breaks in slope between the shale and the more resistant underlying and overlying formations. The Kayak shale is a relatively incompetent unit, and has been greatly deformed and sheared by folding and faulting. Overturned and recumbent folds caused by thrusting from the south are common.

Character and thickness.—The Kayak shale at Howard Pass near camp M—July 24–49 is very similar to the type locality. In the Howard Pass area the rocks consist of clay shale, arenaceous fossiliferous limestone, and platy sandstone. Most of the sandstone is near the base of the section, and it grades upward into black clay shale. Near the top of the section, the clay shale is calcareous and grades into thin-bedded highly fossiliferous, arenaceous rusty weathering fine to coarsely crystalline limestone.

Section of Kayak shale at Howard Pass (pl. 44, column 1)

	Feet
Kayak shale (section incomplete):	
6. Shale, black, clayey; weathers rusty. Near top of section is thin platy arenaceous limestone....	60
5. Covered; probably shale; thickness estimated....	480
4. Sandstone, massive, light-gray-brown; weathers red brown; hard, fine-grained.....	50
3. Shale, thin-bedded, black; weathers black. Interbedded with sandstone and siltstone which are thin bedded, gray brown, hard, siliceous, and crossbedded.....	125
2. Shale, fissile, black; weathers brown; very hard; contains $\frac{1}{2}$ - to 1-in. ironstone concretions.....	75
1. Sandstone, thin-bedded, medium-gray-brown; weathers dark red brown; crossbedded, hard; breaks into flat plates; contains a few invertebrate fossils.....	70
Total.....	860+

In the Killik valley near camp M—Aug. 23–49, good exposures of the Kayak shale occur in the northern belt. Here the rocks are very similar to those of the type locality, and a complete section was measured. The contact with the older rocks is a thrust fault, and the contact with the overlying rocks appears to be conformable.

Section of Kayak shale in the Killik valley (pl. 44, column 5)
Wachsmuth limestone.

Kayak shale:

- | | <i>Feet</i> |
|---|--------------|
| 5. Limestone, thin-bedded, medium-gray, rusty-weathering, very arenaceous, medium- to coarse-crystalline, very fossiliferous (USGS Paleozoic loc. 14087). This limestone may be the top of the Kayak formation or it may be basal Wachsmuth limestone formation..... | 30 |
| 4. Shale, thin-bedded, black, dark-gray-black weathering; soft with some small ironstone concretions ½ to 1 in. in diameter. Soft clay-ball concretions and thin-bedded limestone are sparsely scattered through the shale..... | 65 |
| 3. Limestone, thin-bedded, medium-gray; weathers bright red brown; medium crystalline, arenaceous, fossiliferous, and platy..... | 75 |
| 2. Shale, thin-bedded, black, rusty-weathering, fissile; with flat fossiliferous limestone nodules, 1 to 8 in. in length, which weather a light buff gray. Shale is intercalated with thin-bedded dark-gray fine-grained sandstone and siltstone (95 percent shale, 5 percent sandstone and siltstone)..... | 700 |
| 1. Sandstone, thin-bedded, medium-gray-brown, fine-grained. Intercalated with the sandstone is hard black red-weathering fissile shale..... | 150 |
| Total..... | 1,020 |

Kanayut conglomerate.

The Kayak shale was examined in detail at five localities between Kurupa Lake and Outuk Creek. At all localities it is similar to the Kayak shale of the type locality. It is predominantly silty shale, dark-gray to black, highly micaceous in part, well indurated, platy to fissile, with interbedded thin siltstone and sandy layers and ironstone concretions; 14 samples of shale were barren of microfossils. The remainder of the section contains minor amounts of dark-gray to black unfossiliferous clay shale, very fine grained sandstone, and reddish-brown coquina and hydroclastic limestone. A reddish-brown weathering is conspicuous in parts of the section.

Section from Outuk Creek about 3 miles southwest of camp E-July 16-50 (pl. 44, column 3)

Kayak shale, (section incomplete):

- | | <i>Feet</i> |
|---|-------------|
| 2. Clay shale, thin-bedded, black, hackly-fracturing, noncalcareous; with minor amounts of intercalated thin-bedded medium gray-brown hard siliceous siltstone..... | 750 |
| 1. Sandstone, thin-bedded, light gray-brown; weathers red brown; with intercalated siltstone, which is thin bedded, very hard, and siliceous.. | 100 |
| Total..... | 850 |

Good exposures of the Kayak shale were found in the northern belt on the Etivluk River, along Fay Creek, and several miles east of camp M-May 28-49. These

exposures are lithologically similar to the Kayak sections previously discussed.

Age and correlation.—The Kayak shale is Early Mississippian in age (Bowsher and Dutro, 1957). In this region, as in the type locality near Shainin Lake, the upper part of the formation contains fossils in abundance. Megafauna collections, including corals, bryozoans, crinoid debris, brachipods, pelecypods, and ostracodes, are given in table 3. These collections, indicative of Early Mississippian age, were identified by Dutro.

LISBURNE GROUP

The type locality of the Lisburne limestone is at the head of the Anaktuvuk River, near Anaktuvuk Pass, in the central Brooks Range (Schrader, 1904, p. 71-72). Bowsher and Dutro (1957) raised this formation to the Lisburne group, which is divided into two formations, the Wachsmuth limestone (Early Mississippian) and Alapah limestone (Late Mississippian). The type localities of the Wachsmuth and the Alapah limestones are in the Shainin Lake area, central Brooks Range, Alaska.

The Lisburne group was mapped as one unit at most localities in the Killik-Etivluk Rivers region in the fieldwork done prior to 1951. Since then much faunal and stratigraphic work has been done on the Lisburne group, and, as a result, it has been possible to rework the earlier field data and separate the Lisburne group into two formations at some localities (pl. 43). There was not sufficient faunal or lithologic data to differentiate the formations at other localities shown as Lisburne group undifferentiated (pl. 43), or else these localities were not examined in the field and mapping was done from aerial photographs.

The Lisburne group crops out in five main west-trending belts and in several scattered outliers along fault zones in the Killik-Etivluk Rivers region. These belts of outcrop are discussed in order from south to north.

The southernmost belt is in the vicinity of Howard Pass and camp M-July 24-49, and north of Flora Creek. It comprises a group of low well-rounded ridges on the south flank of the belt of mountains that begins about 7 miles east of camp M-July 24-49 and extends west-northwest across Howard Pass and thence beyond the western limit of this region to form part of the Howard Hills. This belt is approximately 1 mile wide, and has a discontinuous length of about 15 miles in the mapped area.

The second, or next northerly, belt, which is approximately along lat 68°21' N., and parallel to the front of the Brooks Range, is made up of sharp rugged ridges with relief ranging from 1,000 to 2,600 feet. These resistant ridges, which are cut by the Killik River

TABLE 3.—Fossils of Kayak shale

[Identified by J. T. Dutro, Jr. Field samples 50 ARe 128, 158, Kurupa Lake; 50 ARe 196, 207, Kutchiakruak Creek; 50 ARe 224, 232, Itovuk Creek; 49 AMg 89, 49 ADt 108, 114, 116, Howard Pass; 49 ALa 156, 49 ADt 19, Fay Creek; 49 AMg 104, 118, Killik River]

Fossil	Field sample (USGS Paleozoic locality)															
	50 A Re 128e (12322)	50 A Re 128h (12323)	50 A Re 158 (12324)	50 A Re 196 (12326)	50 A Re 207 (12327)	50 A Re 224a (12329)	50 A Re 224c (12330)	50 A Re 232 (12331)	49 A Mg 89 (14080)	49 A Dt 108 (14081)	49 A Dt 114 (14082)	49 A La 156 (14083)	49 A Mg 104 (14084)	49 A Dt 19 (14085)	49 A Dt 116 (14086)	49 A Mg 118 (14087)
Crinoid debris.....	x	x	xx		x	x	x		x		x	x				
Platyerinid columnals.....							x									
Rugose coral, undet.....							x								x	
Caninoid coral, undet.....	x															
Fenestrate bryozoan, undet.....					x						x				x	
Bryozoan, undet.....																
Schuchertella sp.....												x		x		xx
Leptaena cf. <i>L. analoga</i> (Phillips).....												x				
Chonetes sp.....		x									x	x				
Productella sp.....					?											
Avonia? sp.....											x					
Productus sp.....		x														
Camartothecia aff. <i>C. chouteauensis</i> Weller.....									x				x			
sp.....		x	x	?	x		x	x			x	x		x		
Spirifer aff. <i>S. tornacensis</i> de Koninck.....	x	x	x	x		x	x									
cf. <i>S. striatiformis</i> Meek.....						x	x									
cf. <i>S. platynotus</i> Weller.....															x	
aff. <i>S. minnewankensis</i> Shimer.....															x	x
sp.....		x								x	x			x	x	x
Cleiothyrodina sp.....																
Torynifer? sp.....																x
Punctospirifer sp.....									x		?	x				x
Syringothyris sp.....																
Solemya? sp.....		x											x			
Mytilarca sp.....													x			
Schizodus sp.....																
Pelecypod, undet.....		x							x				x	x		x
Platyceras sp.....			x		x								x	x		x
Ostracodes, undet.....									x	x				x		x
Fish teeth, undet.....		x								x						

(fig. 59), Imnaitchiak Creek, and the upper Kurupa River and tributaries, form a nearly continuous outcrop belt extending from Kaishak Hill on the east side of the Killik River to a point about 34 miles west at the head of Nogak Creek. At the head of Nogak Creek the Lisburne group is faulted out and is overlain by the older Kayak shale and Kanayut conglomerate.

The Lisburne group apparently is not exposed along the trend of this belt between the head of Nogak Creek and the Nigu River. The area between Ivtovuk Creek and the Nigu River has been examined only on aerial photographs; so it is possible that some small isolated fault blocks of the Lisburne group are present in the area but have not been recognized. On the east side of the Nigu River valley, the Lisburne group reappears in small well-rounded scattered hills and isolated stream cutbanks, and from this point the Lisburne extends westward along lat 68°21' N., across the Etivluk River near Fay Creek. The width of this outcrop belt is 1.5 to 3 miles near the Killik River; farther west it is generally narrow but varies in width from narrow rubble traces to as much as 1 mile.

The third belt of the Lisburne group is rather indistinct and is composed of three small thrust blocks approximately along lat 68°27' N. Between Iteriak and Outwash Creeks the two large fault blocks form prominent sharp hogbacks that have outcrop areas

of about 0.75 and 2.25 square miles. The third and smallest fault block crops out 3 miles southwest of camp M-June 11-49 and about 2.5 miles west of the Etivluk River.

The fourth belt of Lisburne group rocks forms a west-trending, discontinuous series of prominent rugged limestone ridges, approximately along lat 68°30' to 68°35' N., that coincide with a major west-trending fault or fault zone. The belt extends from the East Fork of the Etivluk River to the western boundary of the mapped region. Between the East Fork of the Etivluk River and the western side of the Iteriak Creek valley, a distance of about 13 miles, these ridges are approximately 0.5 to 0.75 mile wide, and their strike is askew to the general trend of the belt. The Lisburne group does not crop out near Outwash Creek, but the probable western extension of this belt is in a series of outcrops that form low, well-rounded ridges which begin 2.5 miles west of Outwash Creek and trend northwestward across the Etivluk River (near camp M-June 14-49) to form Puvakrat Ridge.

The fifth and farthest north belt in which the Lisburne group is exposed lies approximately along lat 68°36' N. The major outcrops are on Lisburne Ridge, a narrow northwest-trending hogback, rounded in part, that coincides with a major fault. This ridge, which has a relief of 600 to 1,000 feet, begins about 2 miles

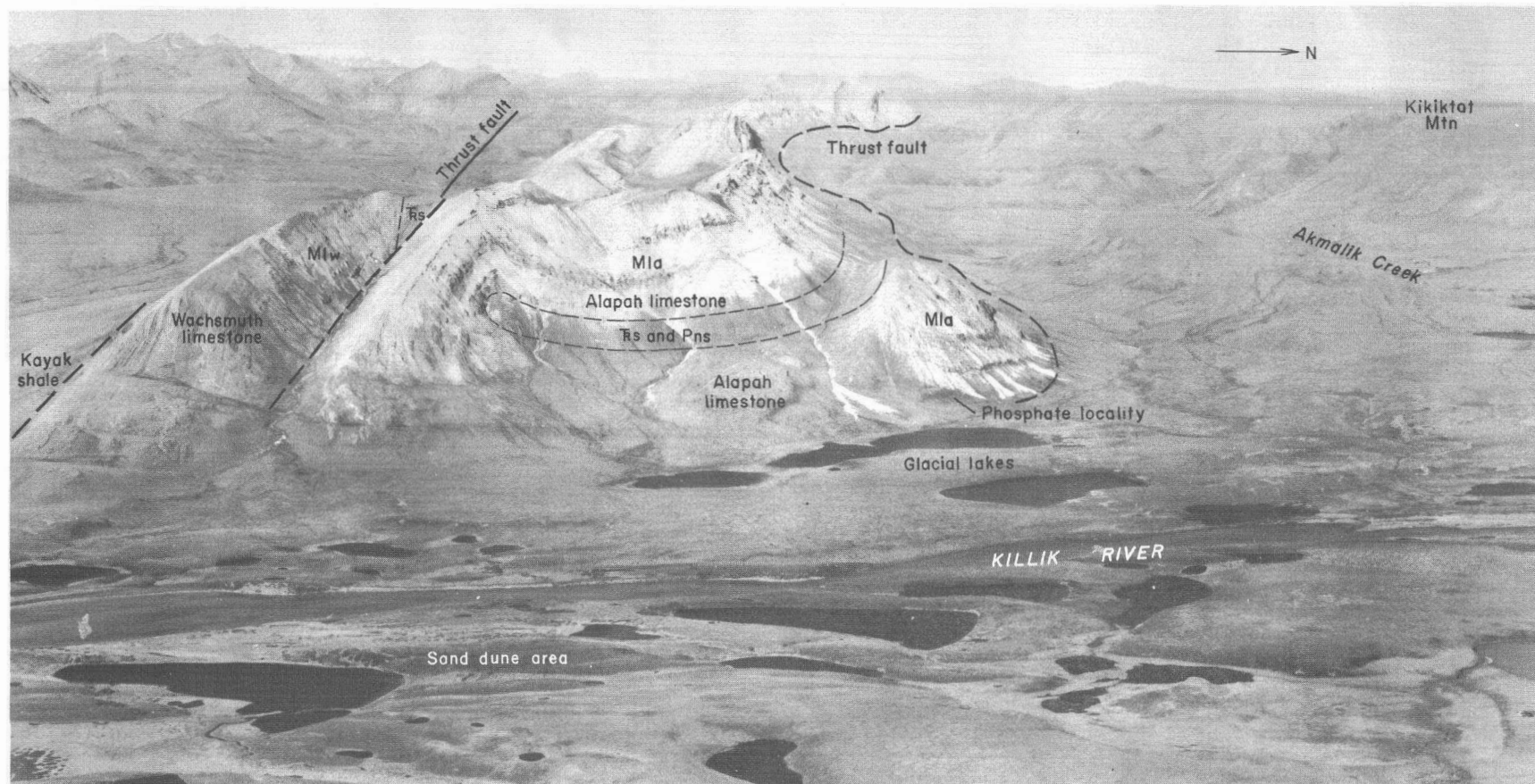


FIGURE 59.—Oblique view of overturned fold in the limestone of the Lisburne group, showing phosphate locality in the Alapah limestone. (Rs) Triassic Shublik formation; (Pns) Permian unnamed unit in Nuka-Ridge area and the Siksikpuk formation; (Mla) Mississippian Lisburne group, Alapah limestone; (Mlw) Wachsmuth limestone. Photograph by U.S. Navy.

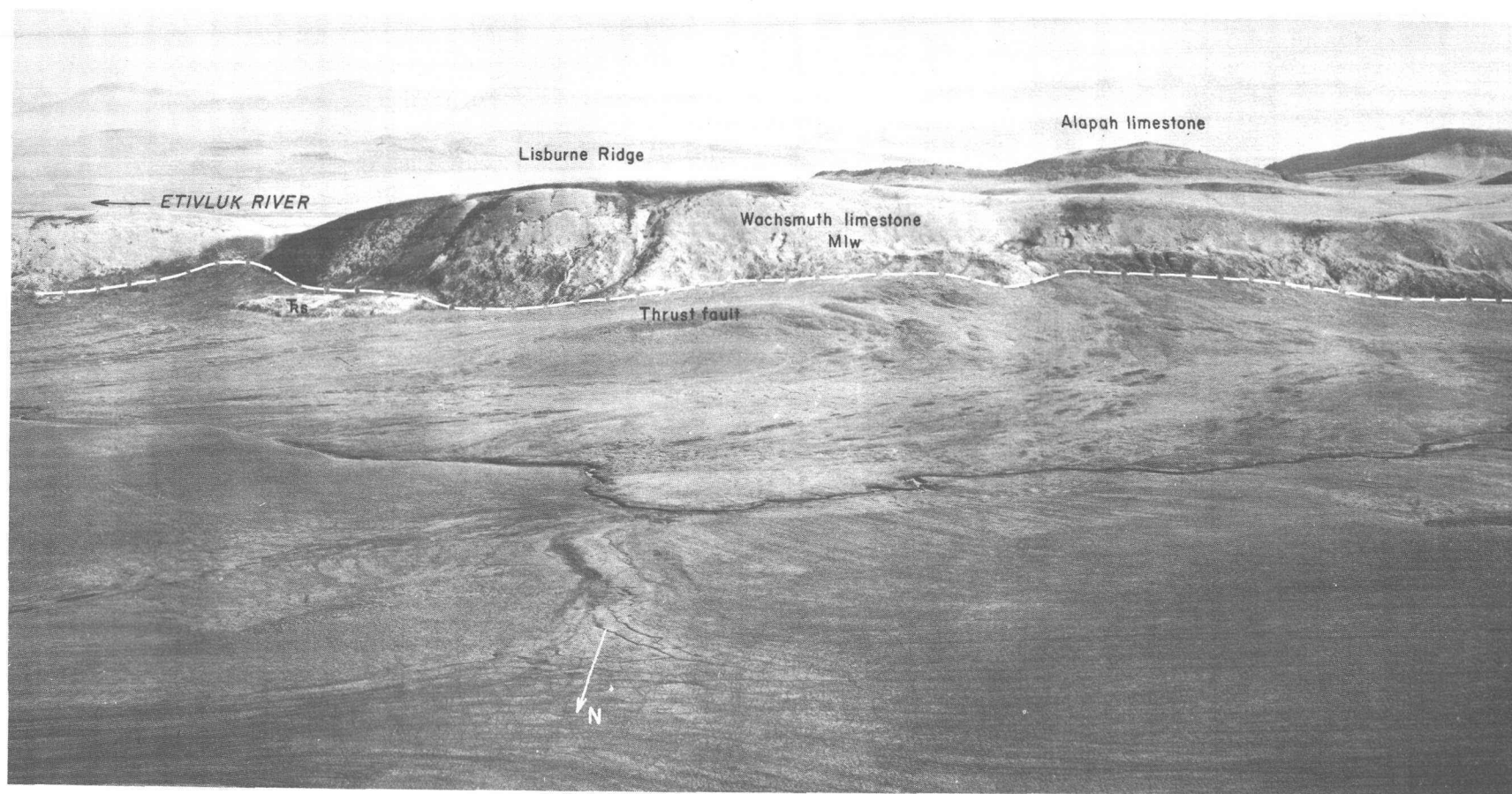


FIGURE 60.—Oblique view of Lisburne Ridge on west side of Etivluk River, showing (Rs) Triassic Shublik formation; (Mlw) Mississippian Lisburne group, Wachsmuth limestone; Alapah limestone. Photograph by U.S. Navy.

west of the Etivluk River and 4 miles north of camp M—June 14–49 and extends northwest into the Ipnarik River drainage. The width of the Lisburne group outcrop across the strike is approximately 0.5 mile. Four small and inconspicuous outcrops of the Lisburne group occur in this belt near the Oolamnagavik River and Pingaluligit Mountain, about 45 to 55 miles east of the Etivluk River. These exposures, with the exception of the one in a bluff on the Oolamnagavik River, are on knobs or low mounds that are largely covered with frost-heaved rubble and show very little rock in place.

WACHSMUTH LIMESTONE

The lower part of the Lisburne group, the Wachsmuth limestone, was examined at six localities in the Killik-Etivluk Rivers region: Killik River near camp M—Aug. 23–49, near the head of Imnaitchiak Creek, Kurupa Lake near camp E—July 1–50, Howard Pass near camp M—July 24–49, Fay Creek west of camp M—May 28–49, and on Lisburne Ridge.

Character and thickness.—The Wachsmuth limestone, in general, is thin to thick bedded, fine to coarsely crystalline, hydroclastic in part, arenaceous in part, dolomitic in part, dark gray on fresh surfaces, light to medium gray on weathered surfaces, tripolitic, and fossiliferous; it commonly has a fetid odor when freshly broken. Dark-gray to black nodular or thin irregularly bedded chert is common throughout the limestone, but forms a minor part of the section. A few thin units of dark-gray limy silty shale and dark-gray medium-grained calcareous sandstone are interbedded and are uncommon. The contact of the Wachsmuth limestone with the underlying Kayak shale appears to be conformable.

A complete section of the Wachsmuth limestone was not found at any of the six localities. Partial sections, ranging from 985 to 1,115 feet, were measured; the writers believe that the Wachsmuth is between 1,200 and 1,500 feet thick in this region.

Composite section of the Wachsmuth limestone near the Killik River, southwest of camp M—August 23–49 (pl. 44, column 5)

Wachsmuth limestone (section incomplete):	Feet
5. Limestone, massive-bedded, medium-gray; weathers light gray; hydroclastic and coarsely crystalline; upon fresh fracture gives off a strong fetid odor; contains no chert; some beds are dolomitic.	115
4. Limestone, massive-bedded, light-gray, weathers white gray; coarsely crystalline; upon fresh fracture gives off fetid odor; contains nodular dark-gray chert.	200
3. Limestone, medium- to massive-bedded, medium- to dark-gray, weathers light gray, coarsely crystalline; gives off strong fetid odor when fractured; fossiliferous; nodular dark-gray to black chert inclusions.	150
2. Limestone, medium- to massive-bedded, dark-gray; weathers light gray; fine grained; intercalated with ropey bedded dark-gray chert.	250

Wachsmuth limestone—Continued

1. Limestone, thin- to medium-bedded, dark-gray to black, weathers light gray, hydroclastic; has a strong fetid odor when fractured. Throughout the limestone are dark-gray to black chert nodules. Approximately 5 percent of unit is chert.

Total..... 1,115

Kayak shale.

The Wachsmuth limestone examined in the Howard Pass area is lithologically similar to the limestone on the Killik River. Here the basal part of the Wachsmuth is a thin-bedded platy arenaceous rusty-weathering, very fossiliferous limestone. The lower contact appears to be conformable with the Kayak shale. These particular limestones are lithologically similar to the lower formation (unnamed) of the Lisburne group mapped by E. G. Sable and Mangus on the Upper Utukok-Kokolik Rivers divide in 1950. The upper part is massive and marmorized by mafic intrusives in contact with the limestone.

Composite section of the Wachsmuth limestone at Howard Pass (pl. 44, column 1)

Wachsmuth limestone: (section incomplete):	Feet
5. Marble, medium-bedded to massive, light-gray; weathers white and very smooth; in contact with gabbro.	85
4. Limestone, medium-bedded to massive, medium-gray, weathers light gray; tripolitic and rough on weathered surfaces; some of the beds are dolomitic.	280
3. Limestone, thin- to medium-bedded, dark-gray to black; weathers light gray and very smooth on surface; very fine grained; has fetid odor.	160
2. Limestone, thin-bedded, medium-crystalline, medium-gray; weathers light gray and in flat platy slabs with rough surfaces; crinoidal. Near the middle of this unit is 50 feet of silty dark-gray limy shale.	200
1. Limestone, thin-bedded, medium-gray; weathers rusty red and in platy pieces; arenaceous, fossiliferous; intercalated thin-bedded medium-grained dark-gray rusty calcareous sandstone.	250
Total.....	975

Kayak shale.

West of camp M—May 28–49, on Fay Creek, only the lower part of the Wachsmuth limestone crops out. It consists of thin- to medium-bedded dark-gray ferruginous-weathering arenaceous fossiliferous fine- to medium-grained limestone.

The northernmost exposure of the Wachsmuth that was examined is on Lisburne Ridge. Here the limestone is medium bedded, finely crystalline and dolomitic, with numerous bands and nodules of chert. Because the rock is silicified, weathered surfaces are very sharp and rough. A strong fetid odor is given off when the rock is freshly fractured. The limestone is light medium gray and the associated chert is dark blue gray to black.

Age and correlation.—The Wachsmuth limestone in this region is similar in thickness, lithology, and fauna to that in the type locality near Shainin Lake (Bowsher

and Dutro, 1957). The fossil collections from this region consist mainly of corals, bryozoans, and brachiopods; they were identified as early Mississippian by Dutro (table 4).

TABLE 4.—Fossils of Lisburne group

[Identified by J. T. Dutro, Jr. Field samples 50 ACh 41F, 46 ATh 8, 46 ACh 10f, Imnaitchiak Creek; 49 AMg 115, 49 ADt 131, 49 ADt 132, Killik River; 50 ARe 170b, 50 AE 16, 12, 21, Kurupa Lake; 49 AMg 5, 1¼ miles east of Camp M—May 28-49; 49 AMg 11, ¾ mile northeast of Camp M—May 28-49; 49 ALa 10, 161, Fay Creek]

Alapah limestone							Wachsmuth limestone								
Fossil	Field sample (USGS Paleozoic locality)						Fossil	Field sample (USGS Paleozoic locality)							
	50 ACh 41F (12340)	46 ATh 8 (12346)	46 ACh 10f (12350)	49 AMg 115 (14093)	49 ADt 131 (14094)	49 ADt 132 (14095)		50 ARe 170b (12325)	50 AE 16 (12333)	50 AE 12 (12334)	50 AE 21 (12335)	49 AMg 5 (14089)	49 AMg 11 (14090)	49 ALa 10 (14091)	49 ALa 161 (14092)
Rugose corals, indet.			X	X	X		"Zaphrentis" konincki (s. l.) Milne Edwards and Haine. Rugose corals, undet.	X	X	X					
Lithostrotionid coral, undet.				X			Bryozoans, undet.				X				
Bryozoan, undet.			X				Dictyoclostus? sp.					X			
Chonetes sp.				X		X	Spirifer cf. S. subaequalis Hall.				X				
"Productus" sp.	X			X			aff. S. missouriensis Swallow.				X				
Buxtonia? sp.				X	X		aff. tenuicostatus Hall sp.		X		X		X	X	X
Onertonia? sp.			X		X		Athyris cf. A. lamellosa (Leveille)					X			
Krotovia? sp.			X				sp.							X	
Litoproductus aff. L. lyelli Verneuil					X	X	Punctospirifer aff. P. subtexta (White)					X			X
Morefieldella? sp.					X		sp.								
Rhynchonellid brachiopod, undet.					X		Syringothyris? sp.						X	X	
Spirifer aff. S. adonis Bell.	X	X		X	X		Platyceras sp.						X		
Brachythyris? sp.						X	Gastropod, undet.								
Athyris? sp.						X									
Eumetria sp.															
Dielasma sp.				X	X										
Gastropod, n. gen., n. sp.	X	X			X										
Ostracodes, undet.				X	X										
Fish teeth, undet.															

ALAPAH LIMESTONE

The upper part of the Lisburne group, the Alapah limestone, was examined and mapped at several localities in this region. Good exposures of Alapah limestone were examined along the Killik valley in the vicinity of camp M—Aug. 23-49, at Kurupa Lake in the area of camp E—July 1-50, and on the Etivluk River west of camp M—June 14-49. The most extensive exposures are along the northern front of the Brooks Range where the Alapah is in contact with the Wachsmuth limestone. Many small fault blocks, in exposures ranging in size from 30 square feet to several square miles, occur as far as 15 miles north of the main outcrop belt.

Character and thickness.—Near the Killik River the Alapah limestone is composed, in descending order, of dark-gray calcareous shale, medium-bedded dark-gray to black limestone, shaly limestone, and fine- to medium-grained black nodular cherty limestone. The contact with the Wachsmuth limestone is tentatively placed at the base of the black nodular cherty limestone.

The Alapah limestone at Kurupa Lake is predominantly light to medium gray massive fossiliferous limestone, cherty limestone commonly with hydroclastic and crinoidal facies, and medium-gray to black

bedded chert. A fetid odor is characteristic of most of the limestone. Dark-gray to black clay shale and limy shale make up a minor part of the section.

Section of the Alapah limestone just south of Kurupa Lake (pl. 44, column 4)

Alapah limestone (section incomplete):

	Feet
Fault.	
16. Limestone, medium- to massive-bedded, medium-gray, cherty; interbedded medium-gray recrystallized coarsely crystalline limestone.	50
15. Shale, dark-gray, calcareous, with abundant white mica; intercalated with dark-gray shaly limestone.	50
14. Limestone, medium-bedded, dark-gray, crinoidal.	7
13. Shale and limestone, interbedded; limestone is dark gray, crinoidal, coarsely crystalline; shale is black.	15
12. Limestone, medium-bedded, dark-gray, crinoidal.	15
11. Limestone, medium-bedded, black; interbedded with black sandy limestone and shale. Abundant bryozoa, crinoid columnals, and brachiopods.	15
10. Limestone, thin-bedded, medium-gray, blocky; weathers buff to light gray; crinoidal and bioclastic, becoming shaly upward.	135
9. Limestone, light-gray, coarsely crystalline; intercalated with medium-bedded medium-gray chert.	80

Alapah limestone—Continued

8. Chert, thin-bedded, black; interbedded with black siliceous shale and black fine-grained tripolitic limestone-----	50
7. Limestone, medium-bedded, medium-gray, blocky, cherty, grading into light-gray crystalline dolomitic limestone with interbedded chert. The limestone has black specks which are probably organic-----	25
6. Chert, thin-bedded, black; grades into light-gray coarsely crystalline limestone and dolomite....	100
5. Limestone, medium-bedded, dark-gray to black, with bands of black chert. Limestone has bituminous material in it-----	35
4. Limestone, medium- to massive-bedded, light-gray, medium-crystalline, crinoidal, bioclastic....	200
3. Shale, dark-gray, silty-----	15
2. Limestone, massive-bedded, medium-gray to gray-black, with dark-gray chert that has a ropey anastomosing structure. In places the chert is 3 feet thick-----	40
1. Limestone, massive-bedded, medium-gray, cherty, blocky, crystalline. Unit has pod-shaped chert nodules and is interbedded with medium-bedded black chert-----	25
Total-----	857

Rest of section covered.

The Alapah limestone exposed near the Etivluk River east of camp M—May 28–49 and northwest of camp M—June 14–49 is quite different in lithology from the rocks previously described. At these localities the Alapah consists predominantly of thin- to medium-bedded light- to dark-gray moderately fossiliferous chert; the chert is interbedded with thin-bedded light-gray medium-crystalline crinoidal limestone. The change in facies from predominantly limestone to predominantly chert appears to occur in the area between Iteriak Creek and the Etivluk River.

The true thickness of the Alapah limestone was not determined because of complex structure and the lack of time for detailed work. A minimum of 857 feet was measured, and the total thickness is estimated to be about 1,200 to 1,400 feet.

The maximum thickness for the entire Lisburne group in the mapped region is estimated to be 2,000 to 2,500 feet.

Age and correlation.—The Alapah limestone in this region, except in the two localities near the Etivluk River, is similar to that in the type section near Shainin Lake (Bowsher and Dutro, 1957). The fossil collections, including corals, brachiopods, and gastropods, from this region were identified as Late Mississippian by Dutro (table 4).

CARBONIFEROUS AND PERMIAN SYSTEMS

In the Killik-Etivluk Rivers region the Carboniferous and Permian systems are represented by the Siksikpuuk formation and an unnamed Carboniferous and Permian unit. These rocks are exposed at scat-

tered localities in the northernmost part of the Brooks Range and the southern part of the southern foothills section. The structure is complex and the exposures are not especially good in most of this part of the region. These factors, in addition to the lithologic similarity between these formations and the Triassic and Jurassic formations, make detailed differentiation of the Carboniferous and Permian rocks very difficult.

The type locality of the Siksikpuuk formation is in the southern foothills section along the headwaters of the Siksikpuuk River about 50 miles east of the Killik River (Patton, 1957). The type locality of the unnamed Permian and Carboniferous unit is in the area of Nuka Ridge along the headwaters of the Nuka River about 85 miles west of the Etivluk River (I. L. Tailleux, oral communication).

The Siksikpuuk formation and (or) the unnamed Carboniferous and Permian unit crop out in two general areas within the Killik-Etivluk Rivers region. One area is just east of Howard Pass where two west-trending belts of these formations have been mapped; one about 3 miles north of Flora Creek on the west side of Isikut Mountain, and the other about 4 miles south of Flora Creek and on the north side of Ikhkluk Mountain. The exposures in these belts are on small ridges and mounds, flanked by more prominent rugged ridges and hills formed by the more resistant rocks of the Lisburne group and the overlying Triassic Shublik formation. The second area of these formations is a west-trending irregular belt between lat 68°20' N. and 68°35' N. Within this belt many small isolated exposures, most of which are too small to show on plate 43, occur as mounds or rubble-covered hills surrounded by tundra. In this belt many larger areas are mapped as Carboniferous, Permian, Triassic, and Jurassic rocks undifferentiated; within these areas the rocks of these ages are generally poorly exposed and structurally complex, and are similar in lithology; it is difficult or impossible to delimit the formations accurately. The areas of undifferentiated rocks include small and large rounded hills, low sharp hogbacks, and small bluffs and creek-bank exposures of rock. In general this belt ranges from 1 to 10 miles in width.

SIKSIKPUK FORMATION

Character and thickness.—The Siksikpuuk formation consists mainly of thin-bedded red, green, yellow, and black chert, siliceous siltstone, and shale. Very fine grained limestone, calcilutite, and calcareous cannonball concretions are interbedded with the shale and chert. A partial section of the Siksikpuuk formation was measured along the east bank of the Nigu River, at Nigu Bluff, 4 miles south of the confluence of the Etivluk and Nigu Rivers (pl. 44, column 2). Here some of the section apparently is missing as a result of thrust

faulting. The rocks are typical interbedded red, green, yellow, and gray chert, siliceous siltstone, and shale. A detail description of the section at Nigu Bluff is given below.

Section of Siksikpuk formation at Nigu Bluff

Mafic igneous sill.	Feet
Siksikpuk formation (section incomplete):	
5. Chert, thin-bedded, yellow, maroon, and green, fine-grained, porcellainous; in contact with sill and heavily mineralized with pyrite cubes and pyrite concretions	60
4. Claystone, thin-bedded, yellow-ochre, appears to be bentonitic	2
3. Shale, thin-bedded, dark-gray to black, contains fine-grained dark-gray limestone, and cannon-ball concretions 1 to 8 in. in diameter. Thin-bedded light-gray hard calcilutite, having conchoidal fracture, is interbedded with the shale	200
2. Chert, thin-bedded, buff and green; has a jasperoid appearance; malachite-green coating covers weathered surfaces and bedding planes	100
1. Shale, thin-bedded, phyllitic, black and green; grades laterally into thin-bedded chert with carbonate veins. Minor amounts of maroon chert and shale	80
Total	442

Age and correlation. The megafauna described by Patton (1957) from the type section of the Siksikpuk formation was not found in the Killik-Etiviluk Rivers region. Of 17 samples from the colored shale that were processed for microfossils, seven were barren. A red-stained microfauna, including conodonts, radiolarians, and the arenaceous Foraminifera *Glomospirella* sp., *Ammobaculites?* sp., and *Involutina?* sp., was identified from these samples (table 5) by Bergquist, and on the basis of this fauna and the similarity of lithology between the rocks in this region and in the type section, the age of the Siksikpuk formation in this region has been established. The total thickness of the formation has not been determined, but it is probably at least 500 feet.

UNNAMED CARBONIFEROUS AND PERMIAN UNIT

Character and thickness.—The unnamed Carboniferous and Permian unit is lithologically similar to Permian rocks in the area of Nuka Ridge in the headwaters of the Nuka River, a north-flowing tributary of the Colville River, about 85 miles west of the Etiviluk River (I. L. Tailleux, oral communication). Inasmuch as the outcrops of this formation are poor and rare in the mapped region, little information could be obtained on the lithology, thickness, and fauna.

A small isolated outcrop of the unnamed Carboniferous and Permian unit was found 1.3 miles south of camp C-June 16-50 and 0.3 mile west of Innaitchiak Creek. The rocks are medium-bedded pale-yellow to light-gray clear-quartz granule to small pebble conglomerate, in part calcareous; fine- to medium-grained limy sandstone; and some finely crystalline limestone. An exposure of this formation immediately east of

camp E-July 16-50 on Ivtok Creek consists of sandstone made up of white and clear coarse subangular to subround quartz grains with calcareous cement.

Age and correlation.—No fossils were found in this formation in the mapped region. The age and correlation where established by analogy with the formation in the Nuka Ridge area.

TRIASSIC SYSTEM
SHUBLIK FORMATION

The Triassic system in the Killik-Etiviluk Rivers region is represented by the Shublik formation. The type locality of the Shublik formation is on Shublik Island in the Canning River, about 200 miles northeast of the Killik River (Leffingwell, 1919, p. 115-119). The Shublik formation at the type locality is described as Upper Triassic, but in the Killik-Etiviluk region this formation includes both Middle and Upper Triassic rocks.

Occurrence.—The Shublik formation is exposed many places in the southern foothills section and at several localities in the Brooks Range. In general, two areas of outcrops can be outlined: one in the vicinity of Howard Pass, and the other a west-trending belt in the southern part of the southern foothills section. In the Howard Pass area, there are two west-trending belts of outcrop: one along Rough Mountain Creek, 4 miles south of Flora Creek, and another about 2 miles north of Flora and Fauna Creeks. These belts are about 0.5 mile in width; the southern one is about 4 miles long and the northern one is approximately 13 miles in length. The west-trending belt of Shublik in the southern foothills is in the structurally complex area adjacent to the northern front of the Brooks Range, and is approximately 11 to 17 miles in width. Within this belt the Shublik formation is so complicated by faulting and folding that it is practically impossible to map all the exposures separately; thus, areas of outcrops in which rocks of Shublik and other formations are complexly intermixed have been mapped as undifferentiated Siksikpuk and Shublik, Shublik and Tiglukpuk, and Shublik, Tiglukpuk and Okpikruak formations.

Character and thickness.—The southernmost belt of Shublik formation at Howard Pass is metamorphosed to some extent by a large intrusive, but consists of dark clay shale, black, yellow, and green chert, and thin-bedded very fine grained light-gray buff-weathering *Monotis* sp.-bearing limestone. The northern belt of this formation in the Howard Pass area consists of unctuous claystone with pencil fracture, of calcilutite, and of thin-bedded cherty dark-gray limestones containing *Monotis* sp.

The Shublik formation within the large belt in the southern foothills is lithologically similar to that formation in the Howard Pass area. It consists of thin- to thick-bedded light-gray to light-tan sublithographic,

Table 5.—Microfossil check list for Paleozoic and early Mesozoic formations

[R indicates 1 to 12 specimens; C, 13 to 25 specimens; and A, over 25 specimens. Fossils listed stratigraphically but not to scale. Fossils identified by H. R. Bergquist and H. N. Tappan]

Fossil	Lower Cretaceous		Jurassic	Triassic	Permian
	Torok formation	Okpikruak formation	Tiglupuk formation	Shublik formation (unfossiliferous)	Siksikuk formation
	Fortress Mountain formation				
<i>Bathysiphon broegei</i> Tappan	R CR R	R			
<i>B. vitta</i> Nauss	R R	R			
<i>B. anomalocoelia</i> Tappan			R		
<i>Jaculella elliptica</i> (Deecke)			R		
<i>Involutina?</i> sp.					R A R A
<i>I. rotalaria</i> (Loeblich and Tappan)	R				
<i>Glomospirella</i> sp.			R		A R R
<i>Haplophragmoides topagorukensis</i> Tappan	R R				
<i>Ammobaculites?</i> sp.					A R
<i>Gaudryina kelleri</i> Tappan			R		
<i>G. tailleuri</i> Tappan	R				
<i>Trochammina eilete</i> Tappan	R R				
<i>Lenticulina</i> sp.		R			
<i>Marginulina gatesi</i> Tappan	R R	R			
<i>M. planiuscula</i> (Reuss)	R R	R			
<i>Nanushukella uniatensis</i> Tappan	R R R R				
<i>Gavelinella awunensis</i> Tappan	R R R				
<i>Eurycheilostoma robinsonae</i> Tappan	R				
<i>Pallatomorphina ruckerae</i> Tappan	R R R				
<i>Gyroldina loetterlei</i> Tappan	R R R				
<i>Dictyomitra</i> sp.		R			R
<i>Lithocampe</i> sp.	R R				R
Radiolaria unidentified					R C R R
Conodonts unidentified					R

partly silty fossiliferous limestone that sporadically contains small amounts of phosphate pebbles, medium-greenish-gray to black bedded chert, yellow to greenish chert, and medium-gray to black silty and clay shale that is in part fossiliferous. Float and pebbles of brownish to black oil shale are not uncommon, but oil shale has been found in place only near Imnaitchiak Creek about 1.5 miles south of camp C—May 28–46. The oil shale cannot be positively assigned to the Shublik formation, but the geologic relationship here and elsewhere strongly indicate this age. A few thin- to medium-bedded fine- to medium-grained micaceous graywacke sandstone beds possibly also should be included in the unit.

Several miles west of camp M—Aug. 23–49 on the

Killik River, the Shublik formation lies beneath the Alapah limestone in fault relationship, and the following incomplete composite section was measured (pl. 45, column 1).

Composite section of Shublik formation at Killik River
Alapah limestone.

Fault.	Feet
Shublik formation (section incomplete):	
6. Chert, thin-bedded, black, hackly.....	35
5. Limestone, thin-bedded, black, silty; has small phosphatic nodules ½ to 1 in. in diameter which weather with a bluish-white bloom. <i>Halobia</i> sp. and <i>Monotis</i> sp. present.....	25
4. Chert, thin-bedded, olive-green to black; weathers rusty. Near top a light-gray, buff- or cream-weathering extremely fossiliferous calcilutite contains <i>Monotis</i> sp.....	40

Tiglupuk formation rocks were not mapped separately because the similarity of lithology between them and the Shublik, Okpikruak, and Fortress Mountain formations, and the complexity of the folds and faults made identification uncertain. In the complex areas where isolated small outcrops of Tiglupuk formation have been identified or where some rocks of this formation are reasonably inferred to be present, the Jurassic is included in five undifferentiated mapped units (pl. 43).

The more resistant units of the Tiglupuk formation, in part, help to form large elongate whaleback ridges in the Imnaitchiak Creek-Kurupa Rivers area. The less resistant shale units weather readily and form poor outcrops and low rubble-covered slopes.

Character and thickness.—The Tiglupuk exposures mapped on plate 43 consist of: olive-green and greenish-gray graywacke-type sandstone of varying grain size; granule-pebble-cobble conglomerate and conglomeratic sandstone; siltstone; silty shale; medium-gray to greenish-gray clay shale; light- to medium-gray *Buchia* (*Aucella*) *concentrica* limestone coquina; and gray, greenish-gray, and bluish-gray chert. Shell detritus and cream-colored dull porcelaneous chert grains are common in the sandstone. The sandstone and conglomerate occur in massive beds 10 feet thick or more, and some form resistant rubble-covered ridges with poor outcrops. The pebbles and cobbles in the conglomerate include chiefly light- to medium-gray chert, milky and glassy quartz, and black chert, with minor amounts of unusually well rounded granite, basalt-gabbro, *Monotis* sp.-bearing light-gray limestone, greenish-gray Jurassic(?) sandstone (locally common), green chert, light-tan-gray mudstone, limestone from the Lisburne group with coral fragments, and altered mafic igneous rocks. In general the largest cobbles are 6 inches in diameter, but the average is 2 to 3 inches, and some boulders 3 feet in diameter were found. Most of the constituents are rounded to well rounded, and angular pebbles are not common. The clastic rocks weather yellow red to dark red brown. A limestone coquina, containing abundant fragmentary shell remains that could not be positively identified but that may be *Buchia* (*Aucella*) *concentrica*, of Jurassic age, was found in two isolated outcrops, one a mile and the other 2 miles north of camp C—June 16–50 on Imnaitchiak Creek.

A small exposure of 75 to 100 feet of fissile paper-thin soft noncalcareous clay or silty shale in beds 1 to 3 feet thick that includes concretions and fragments of steel-blue to gray siltstone and very fine grained sandstone and that probably is Tiglupuk formation, lies about 1.25 miles west of Camp C—June 22–50. The shale varies from dark yellowish red to greenish yellow and dark gray, and in part is weathered to steel blue and

purplish blue that suggests manganese staining. No mega- or microfossils were found in these rocks.

Although no fossils were found, the large hill about 1.5 miles southwest of camp C—June 16–50 on Imnaitchiak Creek is interpreted as being formed by the Tiglupuk formation. A section, composed of a 15-foot conglomerate unit overlain by an estimated 530 feet of sandstone and conglomeratic sandstone with both top and bottom covered, is present in this hill.

The 1,040-foot section that is exposed along the creek between Cascade and Kurupa Lakes (pl. 45, section 2) may be wholly or in part Tiglupuk formation. As exposed, 520 feet of chert overlies the clastic sequence, but field observations indicate that this entire section is overturned and thus the chert is older and could be part of the Shublik formation. No fossils were found in this section.

An exposure of possible Tiglupuk formation was examined on Puvakrat Ridge about a mile west of Camp M—June 14–49 on the Etivluk River. It is mapped as Tiglupuk, Okpikruak, and Fortress Mountain formations undifferentiated. The rock is a graywacke sandstone and conglomerate and may be 500 to 700 feet thick. The conglomerate is crossbedded, poorly cemented, and in part covered by a weathered mantle of pebbles and boulders on the ridge top and in the gullies. The pebbles and boulders range from ¼ inch to 28 inches in diameter and consist of mafic igneous rocks, limestone of the Lisburne group, limestone and chert from the Shublik formation, and colored chert, graywacke, and shale. Much of the formation is gray green and weathers rusty red brown.

No reliable thickness estimates can be given for the Tiglupuk formation in this region. Contacts with the under- and overlying formations were not seen, and nowhere was more than a partial section observed. It is likely that the thickness varies considerably, and in parts of the Killik-Etivluk Rivers region the formation may be absent. It is postulated that the Tiglupuk is 1,500 feet thick in the Killik-Oolamnagavik Rivers area.

Age and correlation.—The megafauna collections from the Tiglupuk formation in the mapped region are from the few exposures of a reddish-brown weathered limestone coquina. The preservation of the shells is so poor that none could be positively identified. According to J. B. Reeside, Jr., and R. W. Imlay (written communication, 1950) "the common form is guessed to be *Posidonia stella* Gabb." They suggested that this coquina may represent the *Buchia* (*Aucella*) *concentrica* zone that has been described by Patton (1956a). Lithologically the coquina is similar to that included in the Tiglupuk formation by Patton (1956a).

Thirteen microfossil samples were collected from beds of the Tiglupuk formation and Tiglupuk and Okpi-

kruak formations undifferentiated. One sample, 50 ARe 173, from 2.25 miles northwest of camp E-July 8-50, on the Kurupa River, contained the characteristic Jurassic microfossils *Bathysiphon anomelocoelia* Tappan, *Haplophragmoides topagorukensis* Tappan, *Glomospirella* sp., and *Gaudryina kelleri* Tappan. The other samples were either barren or contained long-ranging nondiagnostic Foraminifera (H. R. Bergquist, written communication).

The Tiglukpuk formation insofar as known in this region is similar to that in the region east of the Killik River described by Patton (1956a), and it is exposed in the same geologic and geographic belt. There is no apparent correlation in thickness, overall lithology, or fauna between the Tiglukpuk formation in this region, and in Topagoruk test well 1 (Collins, 1958). The Jurassic section in this well is about 2,000 feet thick, and a section thickness of 1,450 to 1,800 feet has been measured (Patton, 1956a) in outcrops in the region 50 to 75 miles east of the Killik River. Thus, little change in thickness but significant changes in lithology and fauna in a northward direction are indicated.

CRETACEOUS SYSTEM

The Lower Cretaceous rocks in the Killik-Etivluk Rivers region are represented by the Okpikruak, Torok, and Fortress Mountain formations and by part of the Nanushuk group. The rocks are chiefly shale, sandstone, siltstone, and conglomerate, and in aggregate have a section thickness of many thousand feet. Topographically prominent ridges and lowlands are formed by these formations.

OKPIKRUAK FORMATION

Occurrence.—The type locality of the Okpikruak formation is about 12 miles east of the Killik River on a small tributary of the Okpikruak River at approximately lat 68°34'30" N. and long 153°39' W. (Gryc, Patton, and Payne, 1951, p. 159-160). The Okpikruak formation in the Killik-Etivluk Rivers region crops out in the southern half of the southern foothills section, and in general is poorly exposed. The outcrops form three roughly defined and discontinuous west-trending belts. The southernmost belt includes a series of isolated synclines adjacent to the north front of the Brooks Range and between the Kurupa River and Tukuto Creek. The middle belt, which is 4 to 8 miles in width, lies approximately between lat 68°30' N. and 68°35' N., and includes a structurally complex zone in which these rocks, for the most part, are mapped as the Shublik, Tiglukpuk and Okpikruak formations, undifferentiated. The northernmost belt in which the Okpikruak occurs lies approximately between lat 68°34' N., and 68°41' N., and within this belt the rocks have been mapped as Tiglukpuk, Okpikruak and Fortress Mountain formations undifferentiated. In general,

the Okpikruak forms long high rubble-covered whale-back ridges that have 500 to 1,000 feet of relief.

Character and thickness.—The Okpikruak formation in the large syncline south of Lake Betty and between Kutchaarak Creek and the Etivluk River is composed of a sequence of alternating graywacke sandstone, pebble conglomerate, siltstone, and shale. The sandstone and conglomerate is dark olive green and weathers dark red brown. The pebbles in the conglomerate are subangular to subrounded and are mostly black, gray, yellow, and white chert, with some siltstone and sandstone pebbles. In places *Buchia* (*Aucella*) *crassicolis* Keyserling is abundant, and in other beds only shell fragments occur with interbedded black clay shale containing limy concretions $\frac{1}{2}$ to 2 inches in diameter.

Some half- to 5-inch well-rounded chunks of leathery black oil shale were found as float in some of the graywacke sandstone and conglomerate rubble along one of the ridges on the west side of the Etivluk River several miles west of camp M-June 6-49. The oil shale appeared to be pebbles and cobbles derived from the conglomerate by residual weathering.

In the vicinity of Kurupa River the Okpikruak formation is: medium-bedded medium- to fine-grained micaceous greenish-gray graywacke-type sandstone, with some calcareous beds, ironstone concretions, and a few carbonaceous plant remains, worm trails, and well-developed flow casts in the sandy beds; and medium-bedded dark gray-green, graywacke-type grit and pebble conglomerate. The pebbles are bluish-gray, black, green, and yellow chert, subangular to subround, and $\frac{1}{2}$ to $\frac{1}{4}$ inch in diameter. Some shell fragments occur in the conglomerate. Exposures of the formation in this area show a patterned repetition of these lithologic types that suggests cyclical deposition.

The contact between the Okpikruak formation and the underlying rocks was not seen in this region, and it can only be assumed that the Okpikruak overlies Jurassic rocks with little or no angular discordance. At some localities in northern Alaska, the Okpikruak overlies the Jurassic Tiglukpuk formation with angular discordance (Patton, 1956a, p. 218).

The thickness of the Okpikruak formation in the Killik-Etivluk Rivers region is estimated, on the basis of meager evidence, to be approximately 1,700 feet. At the type locality the formation is about 2,400 feet thick (Gryc, Patton, and Payne, 1951, p. 159).

Age and correlation.—The Okpikruak formation in the mapped region was correlated with the Okpikruak in other regions in northern Alaska on the basis of lithologic similarity and a few fossil collections. Megafossils are not common in the Okpikruak formation in the Killik-Etivluk Rivers region, and *Buchia* (*Aucella*) *crassicolis* Keyserling and a questionable *B.* (*Aucella*)

crassa Pavlow were identified by Reeside and Imlay from the few collections made. A meager microfauna was obtained from a few samples collected for this purpose (pl. 45).

FORTRESS MOUNTAIN FORMATION

Occurrence.—The type section of Fortress Mountain formation is a composite of sections exposed along the Kiruktagiak River and on Castle Mountain, approximately 30 miles east of the Killik River at lat 68°34' N. The name is taken from Fortress Mountain, which is about 6 miles west of the type section localities (Patton, 1956b, p. 219). The Fortress Mountain formation crops out in the mapped region only in a narrow west-trending belt between lat 68°40' N. and 68°45' N., in the northern half of the southern foothills section. This belt is characterized by low rounded mountains and ridges formed by coarse clastic rocks. Smith Mountain (fig. 61) lies at the western end and Pingaluligit Mountain at the eastern end of this area, which is a part of the major west-trending zone of Fortress Mountain rocks that extends across the greater part of northern Alaska; the ridges and peaks in this belt are in general the highest topographic features north of the Brooks Range.

A zone of low rounded hills mapped as Fortress Mountain and Torok formations undifferentiated lies immediately north of the topographically prominent Fortress Mountain belt, and gives way northward to a featureless lowland area underlain by the Torok formation. There are relatively few outcrops in the area of low hills, and the geology consequently is poorly known.

Just south of the area of Fortress Mountain formation is another west-trending zone of rocks that are mapped as Fortress Mountain, Okpikruak and Tiglukpuk formations undifferentiated. In general, this belt of undifferentiated rocks which ranges from 1 to 8 miles in width, is characterized by few and poor outcrops and by low rounded topography similar to that underlain by the Torok formation. Within this area a few higher ridges near Outwash, Nogak, and Iteriak Creeks are differentiated as Fortress Mountain formation.

A considerable part of the area included in the above-mentioned three zones is covered by tundra, terrace gravel deposits, and valley-fill alluvium. The ridges and outcrops are discontinuous, the lithology of the Fortress Mountain, Okpikruak, and Torok formations is in part similar, faunal remains are rare in all three formations, and apparently the structure is complex; therefore, it was not possible to delimit accurately, or in detail, the extent of the Fortress Mountain formation.

Character and thickness.—The Fortress Mountain formation is composed dominantly of thick units of dirty graywacke-type gray to green sandstone and

pebble-cobble conglomerate; thick units of clay shale and siltstone are interbedded with the sandstone and conglomerate. The overall ratio of these coarse clastics to shale is about 60 to 40 percent.

The formation as exposed in the Killik-Etivluk Rivers region is not exactly the same as that described from the type locality (Patton, 1956b); however, gross lithologic features are the same, and the rocks can be correlated with the Fortress Mountain formation. The stratigraphic sections (pl. 46) are divided into three units for the purpose of correlation: upper shale and siltstone, about 1,870 feet thick; conglomerate and sandstone, about 1,300 to 1,680 feet thick; and lower shale and siltstone unit about 2,800 feet thick. These three units are not a formal breakdown of the formation to be used in mapping, but are shown on plate 46 merely as an aid in correlating the incomplete sections exposed in the mapped region. These units are not differentiated on the geologic map (pl. 43).

The sandstone is generally fine to coarse grained, with many angular fragments of chert, medium bedded to massive, dark gray to green, crossbedded, and commonly calcareous. The conglomerate occurs in massive crossbedded units as much as 50 feet thick, as well as in thin lenticular podlike beds in the sandstone. The massive beds are characteristic of the upper part of the formation. Subordinate amounts of plant debris are found in the coarse clastic sequence. The dominant conglomerate constituents are colored chert, with minor amounts of white quartz, limestone, and mafic igneous rocks, and are generally angular to subround. The size of the constituents ranges from about 0.5 inch to as much as 24 inches, but the average size is about 1 inch to 7 inches. Although well sorted by size within individual beds, the fragments are larger in the upper part of the formation. Limestone and mafic igneous rock fragments are generally restricted to the upper part of the conglomerate and sandstone unit.

The shale is generally dark gray to black, fissile, soft, and commonly calcareous; it is dominantly clay shale, but silty shale and beds of siltstone are present. Locally the shale is well indurated and may have a hackly fracture; this is largely influenced by local deformation. Mudflow marks and swirl-bedding features are common in siltstone and sandstone that is interbedded with the shale; these sandstone beds may also show graded bedding. Ironstone and marcasite concretions are minor constituents of the shale sections.

The Fortress Mountain formation identified in the Killik-Etivluk Rivers region is apparently somewhat thinner than the 10,000-foot section that is exposed at the type locality (Patton, 1956b). A complete section of the formation was not found in the mapped area, but a composite of the measured sections indicates that

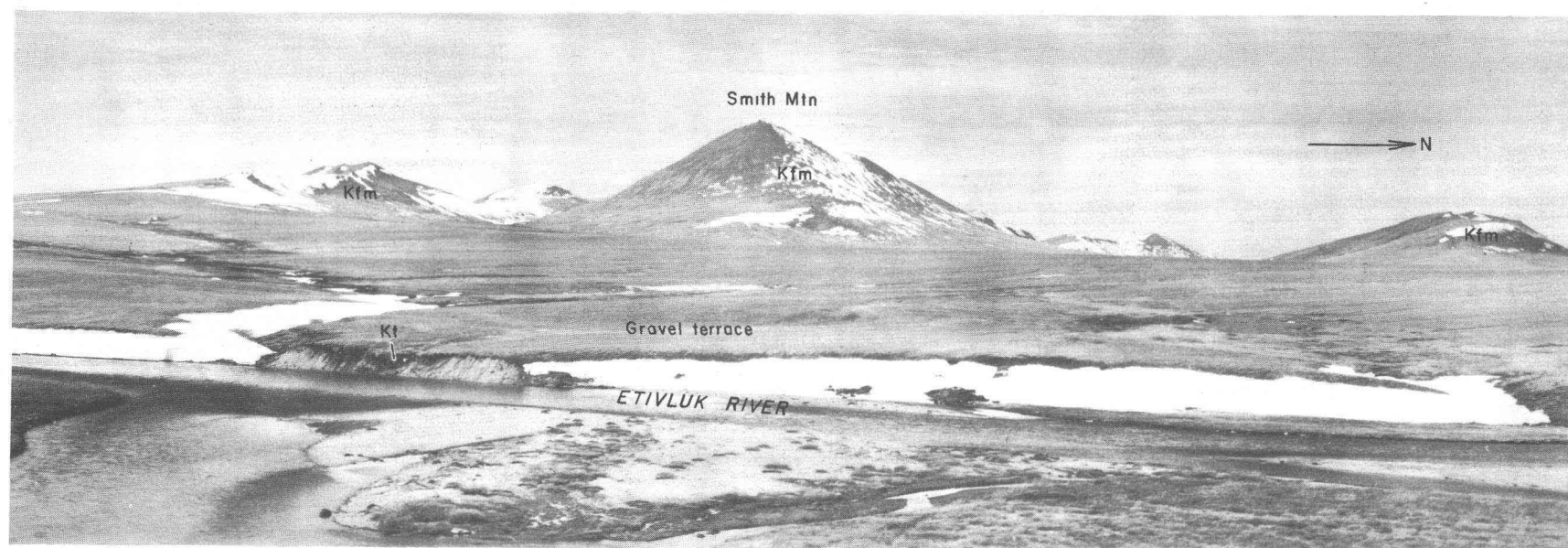


FIGURE 61.—Oblique view of Smith Mountain showing Fortress Mountain formation; (Kfm) Cretaceous Fortress Mountain formation; (Kt) Cretaceous Torok formation. Photograph by U.S. Navy.

about 6,000 feet of the formation is present. A section about 5,920 feet thick was computed from outcrops along the west bank of the East Fork of the Etivluk River near camp E—July 25–50. An unconformity was mapped at the base of a conglomeratic unit; it is believed that this unconformity is a local feature and that it does not greatly alter the thickness of the formation.

Columnar sections of the Fortress Mountain formation are shown on plate 46. The sections were measured in a number of discontinuous cutbank exposures along the major north-flowing streams, on Smith Mountain, and on the high ridges of Pingaluligit Mountain, between the Killik and Oolamnagavik Rivers. The sections are arranged in order from west to east. Where the field data are not complete enough to warrant detailed sections, generalized sections were compiled.

The Smith Mountain section (pl. 46, column 1) was measured during a traverse up the east side of the peak 5 miles N. 35° W. from camp M—June 17–49. The side of the peak is rubble covered and only the more resistant sandstone and conglomerate beds are well exposed as ledges; the section is generalized, but is of value because it is typical of the coarse clastic part of the formation in the western part of the mapped region. The total thickness may be in error by 10 to 15 percent.

Generalized section of Fortress Mountain formation on Smith Mountain

Fortress Mountain formation (section incomplete):

Conglomerate and sandstone unit:

- | | |
|---|------|
| | Feet |
| 4. Conglomerate, conglomeratic sandstone, sandstone, siltstone, and shale. Conglomerate and conglomeratic sandstone medium bedded to massive; pebbles and cobbles (½ to 7 in. in length) dominantly colored chert with few limestone and mafic igneous pebbles; abundantly crossbedded, poorly cemented green sandstone matrix. Sandstone thin to medium bedded, fine to medium grained, dark green. Siltstone and shale constitute about 20 percent of unit. In part rubble covered; computed thickness approximately----- | 640 |
| 3. Sandstone and shale. Sandstone thin to medium bedded, medium grained, dark green; contains angular rock fragments; poorly sorted----- | 210 |
| 2. Similar to unit 4; conglomeratic constituents dominantly of grit to pebble size; no limestone or igneous rock fragments; mostly rubble covered; computed thickness approximately----- | 830 |

Lower shale and siltstone unit:

1. Sandstone, siltstone, and shale; sandstone thin to medium bedded, fine to medium grained; dark-greenish brown; few angular chert pebbles and shale inclusions. Unit about 40 percent sandstone, 60 percent

Fortress Mountain formation—Continued

Lower shale and siltstone—Continued

1. Sandstone, etc.—Continued

shale and siltstone. Shale dark gray green, moderately indurated. Unit mostly rubble covered; computed thickness approximately-----

Feet

1,000

Total----- 2,680

Columnar section 2 from the East Fork of the Etivluk River was measured in a series of more or less continuous cutbanks along the west side of the river near camp E—July 25–50. The section is in south-dipping strata; the dip increases toward the north from 18° S. to 70° S. A local unconformity or possible fault is present at the base of the conglomeratic section. This section contains the most completely exposed sequence of known Fortress Mountain formation in the mapped region.

Section of Fortress Mountain formation on the East Fork of the Etivluk River

Fortress Mountain formation (section incomplete):

Upper shale and siltstone unit:

12. Clay shale, dark-gray to black, fissile, soft; in beds 2 to 3 in. thick; nodular-weathered. Interbedded siltstone, silty shale, and sandstone; sandstone gray green, thin bedded (½ to 4 in.), very fine to fine grained, calcareous; contains mud-ball concretions locally and constitutes about 5 percent of the unit. In part rubble covered; computed thickness approximately-----

Feet

1,870

Conglomerate and sandstone unit:

11. Sandstone and clay shale with interbedded siltstone and silty shale; sandstone, in beds as much as 3 ft thick, dark greenish gray to light olive gray, very fine to fine grained, calcareous. Flow casts present on under side of beds; worm trails, fucoidal marks. Forty percent of unit is sandstone, 35 percent siltstone and silty shale, 25 percent clay shale. In part rubble covered; computed thickness approximately-----
10. Sandstone, pebble-cobble conglomeratic; dominantly cobbles at base and pebbles at top; pebbles subround to round. Consists of colored chert, few limestone and plutonic igneous cobbles near base; beds 5 to 10 ft thick, with light-green poorly cemented sandstone matrix; interbedded sandstone of same type, in beds 3 to 8 ft thick; some siltstone and shale-----
9. Covered; computed thickness approximately-----
8. Sandstone and silty shale. Sandstone, massive, medium-grained, light-green; composed of chert debris. Shale dark green, friable-----
7. Conglomerate and sandstone. Conglomerate in massive beds (20 to 30 ft thick), composed of colored chert, dominantly gray and green, few plutonic rock types; well rounded. Sandstone fine grained, light-green-----

420

320

100

60

106

Fortress Mountain formation—Continued

Conglomerate and sandstone unit—Continued		Feet
6. Sandstone and clay shale.....		100
5. Conglomerate; cobbles at base, pebbles at top; consists dominantly of light and dark gray, black, green, and red chert; few limestone and quartz cobbles; local ferruginous bands.....		160
4. Sandstone, massive, fine-grained, ferruginous.....		5
3. Conglomerate, similar to unit 5; contains local lenses of sandstone.....		25
2. Sandstone with few chert pebbles, coal fragments.....		4

Local unconformity.

Lower shale and siltstone unit:

1. Clay shale, black, fissile, soft, with interbedded sandstone; light gray, thin bedded to massive, fine grained; chert and quartz grains in silty matrix; unit about 80 percent shale and 20 percent sandstone.....	2,760
Total.....	5,930

The Kurupa River section (pl. 46 column 3) was measured on the east bank of a small tributary of the Kurupa River S. 45° E. from camp C—July 16-46. The column consists of strata that have been correlated with the conglomerate and sandstone unit and the lower shale and siltstone unit.

Section of Fortress Mountain formation on tributary of the Kurupa River

Fortress Mountain formation (section incomplete):

Conglomerate and sandstone unit:		Feet
16. Graywacke conglomerate, black chert pebbles, and fine-grained graywacke.....		15
15. Graywacke sandstone, greenish-yellow, and few black chert pebbles; very fine to fine grained; interbedded shale and siltstone in beds 6 to 10 in. thick. Unit mostly rubble covered, computed thickness approximately.....		130
14. Graywacke sandstone, pale-greenish-yellow, thin-bedded, very fine to fine grained.....		15
13. Interbedded graywacke sandstone, siltstone, and shale; rubble; computed thickness approximately.....		65
12. Conglomerate, pebble-granule; dominantly black chert. Irregularly bedded graywacke sandstone with some crossbedding; fine-grained, well-cemented; few clay pellets and plant fragments.....		25
Lower shale and siltstone unit:		
11. Sandstone, greenish-yellow, fine-grained, and shale; rubble; computed thickness approximately.....		170
10. Clay shale with interbedded siltstone and very fine grained graywacke sandstone; one 8-ft bed of fine-grained light-greenish-yellow graywacke near center of unit.....		225
9. Covered; computed thickness approximately.....		110
8. Clay shale and siltstone with 4-ft medium-gray thin-bedded medium-grained graywacke.....		30

Fortress Mountain formation—Continued

Conglomerate and sandstone unit—Continued		Feet
7. Clay shale and graywacke sandstone interbedded with siltstone; shale more abundant in upper part and graywacke in lower part. In part rubble covered; computed thickness approximately.....		670
6. Covered; computed thickness approximately.....		350
5. Graywacke sandstone thin- to medium-bedded, fine- to medium-grained; light-greenish-yellow; thin interbedded clay shale and siltstone.....		20
4. Clay shale and siltstone float in covered interval; computed thickness approximately.....		450
3. Clay shale and siltstone.....		140
2. Clay shale and siltstone float in covered interval; computed thickness approximately.....		510
1. Clay shale and siltstone in beds 4 to 12 in. thick.....		125
Total.....		3,050

The Heather Creek section (pl. 46, column 4) was measured in a series of discontinuous outcrops on the east bank of the creek between the anticlinal axis and the thrust fault at lat 68°40' N. to 68°41' N.; the strata dip 30° to 60° S. The exposed beds were measured and the stratigraphic thickness of the covered parts was computed; this may be in error by 15 percent.

Section of Fortress Mountain formation on Heather Creek

Fortress Mountain formation (section incomplete):

Upper shale and siltstone unit:		Feet
15. Clay shale, medium-dark-gray, fissile, soft noncalcareous; in beds 1 to 12 in. thick; interbedded with clay shale are silty shale, siltstone, and graywacke, all light yellow, poorly indurated, micaceous, carbonaceous, in beds 1 to 5 in. thick; some pyrite and chalcopyrite veinlets.....		100
Conglomerate and sandstone unit:		
14. Covered; computed thickness approximately.....		825
13. Graywacke, conglomeratic, beds 3- to 8-in. thick; fine to coarse grained; dull-greenish-yellow; granule-pebble conglomerate, dominantly subround black chert granules.....		40
12. Covered; computed thickness approximately.....		250
11. Sandstone, thin-bedded (4 to 5 in.), light-yellow-green, fine to very fine grained; contains a few chert pebbles and granules; carbonaceous; some interbedded calcareous siltstone. Unit partly rubble covered; computed thickness approximately.....		220
Lower shale and siltstone unit:		
10. Covered; computed thickness approximately.....		250
9. Siltstone, highly weathered.....		10
8. Covered; computed thickness approximately.....		310
7. Silty shale; weathers rust brown.....		45
6. Covered; computed thickness approximately.....		250
5. Graywacke, thin-bedded, medium-grained; light-greenish-yellow; some interbedded clay shale.....		20
4. Covered; computed thickness approximately.....		780

Fortress Mountain formation—Continued

Lower shale and siltstone unit—Continued		Feet
3. Graywacke, thin-bedded, very fine grained; medium-gray; interbedded siltstone and clay shale; undulatory bedding; nodular weathering.....		30
2. Covered; computed thickness approximately.....		175
1. Siltstone, sandy, greenish-gray, and silty shale.....		20
Total.....		3,325

The columnar section from the East Fork of the Oolamagavik River (pl. 46, column 5) was computed from rubble traces and outcrops on Pingaluligit Mountain 3 to 5 miles north of camp C—May 29–50. These prominent ridges are part of a complexly folded synclinal structure and the rocks are from high in the Fortress Mountain sequence.

Generalized section of Fortress Mountain formation on Pingaluligit Mountain

Fortress Mountain formation (section incomplete):		Feet
Conglomerate and sandstone unit: Dominantly graywacke sandstone with subordinate interbedded conglomerate, conglomeratic graywacke, silty shale, and siltstone. Graywacke light greenish yellow, thin-bedded (1 to 3 in.), fine grained; subangular black chert granules and pebbles. Conglomerate pebble-cobble (80 percent pebbles), 85 percent black chert, 10 percent colored chert, 5 percent graywacke. Siltstone and shale swirl-bedded with ropey mudflow marks and mud cracks. Unit mostly rubble; computed thickness approximately.....		1,000
Total.....		1,000

Age and correlation.—No megafossils were obtained from strata of the Fortress Mountain formation in the mapped region. The formation is locally fossiliferous in other parts of northern Alaska, and the age of the beds as determined by those megafossils is early Albian (late Early Cretaceous). Imlay (1961, p. 58) identified and described the fossils. The diagnostic species include the ammonites *Colvillia crasscostata* Imlay, *C. kenti* Imlay, *Beudanticeras* (*Grantziceras*) aff. (*Whiteaves*), and the pelecypods *Aucellina dowlingi* McLearn, *Thracia kissoumi* McLearn, *Pleuromya kelleri* Imlay, *Placunopsis nuka* Imlay, and *Inoceramus* cf. *I. altifluminus* McLearn. Part of the Fortress Mountain formation is correlated with the lower part of the Torok formation by means of the ammonites *Colvillia* and *Beudanticeras*, which are found in both formations.

A considerable part of the Fortress Mountain formation is shale; however, only 72 microfossil samples were collected and 46 of these were barren. The few fossils from these samples are shown in table 5; they were identified by Bergquist (written communication), who reported: “* * * the fossils have little value for identifying the sections from which they came as most are long ranging and nondiagnostic”. Some sections of Fortress Mountain formation in other parts of northern

Alaska were sampled more extensively for microfossils than were the sections from the mapped region; the microfauna from the other sections indicate that although some of the species are long ranging there are also some species restricted to the Fortress Mountain and Torok formations. *Gaudryina tailleuri*, which is found in the lower part of the Torok formation as well as in the Fortress Mountain, is particularly diagnostic and directly supports the correlation based on the ammonites *Colvillia* and *Beudanticeras*. The Fortress Mountain formation appears structurally to be in part equivalent to the Torok formation and perhaps in part to the Tuktu formation of the Nanushuk group.

TOROK FORMATION

Occurrence.—The Torok formation is exposed in a northwest-trending belt in the northern part of the southern foothills section of the Arctic foothills province. This belt is characterized by low, gently rolling topography with isolated ridges of sandstone and conglomerate rising above the lowlands underlain by shale; it is from 4 to 16 miles wide in the Killik-Etivluk Rivers region. The Tuktu escarpment rises abruptly from the lowland and generally forms the northern limit of exposures of the Torok formation, which is at lat 68°48' N., along the Killik River; in the Etivluk River area it is at lat 68°59' N. High ridges and mountains formed by the coarse clastics of the Fortress Mountain formation lie south of the lowlands; between the ridges of definite Fortress Mountain and the lowland of Torok is an area, 1 to 4 miles wide, of undifferentiated Torok and Fortress Mountain formations. The zone of undifferentiated strata has topographic and lithologic features common to both formations, but the rocks in the discontinuous outcrops cannot be correlated definitely with either formation.

Discontinuous outcrops of the formation are exposed along all the major north-flowing streams in the mapped area and on many of the smaller streams. The outcrops are generally confined to the stream banks that are being actively eroded; the soft, incompetent shale does not form good outcrops in the interstream areas. The outcrops are commonly overlain by terrace gravel that slumps down onto the bedrock and further complicates the measuring of a continuous stratigraphic sequence. The coarser beds of the formation can be traced into the interstream areas where they form low rubble-covered ridges.

The Torok formation is best exposed along the west bank of the Etivluk River and the east bank of Kucher Creek. The strata there are commonly folded into small, steeply plunging anticlines and synclines on the flanks of larger structures. The beds may be offset by small, high-angle faults, and drag folds are common; the beds dip steeply, generally about 25° to 50°.

A section of Torok formation about 45 feet thick is exposed in the center of the Kurupa anticline on the Kurupa River; this was not mapped on plate 43 because the outcrop is too small to show at the mapping scale.

Character and thickness.—A calcareous dark-gray to black clay shale is the dominant rock type of the Torok formation in the mapped region. Siltstone and silty shale in units 3 to 12 inches thick are commonly interbedded with the clay shale; the clay shale varies from soft and crumbly to well-indurated and hackly fractured, depending mainly on the amount of local deformation. Marcasite concretions, as much as 6 inches in diameter, are a common feature of the clay shale sections. Pyrite is found in the shale as crystals, but it rarely occurs as concretions.

The siltstone is generally thin bedded and may be laminated, dark gray with a greenish tinge to light gray, and calcareous. Many of the siltstone beds show mud-flow marks and swirl-bedding features that could have been formed by turbidity currents. Ironstone and marcasite concretions are present in the siltstone, as well as mud-ball concretions; plant fragments and megafossils are common locally in relatively narrow zones within the formation.

Graywacke sandstone and conglomeratic sandstone are important, although subordinate constituents of the formation; they probably form about 30 percent of the exposed rocks. The sandstone is generally shaly to thin bedded, very fine to fine grained, dark gray to green, and predominantly calcareous. In most outcrops the sandstone is in beds $\frac{3}{4}$ to 3 inches thick and is associated with siltstone; column 1 C (pl. 47) on the lower Etivluk River is an exception, about 90 percent of the exposed rock is graywacke sandstone. The conglomeratic constituents are mostly well-rounded black chert pebbles $\frac{1}{2}$ to 3 inches in diameter. A few intraformational shale and siltstone pebbles are present also.

A few thin lenticular beds of bony coal and calcareous siltstone concretions in the Kucher Creek section constitute the only other rock types in the Torok formation.

The exposed sections of the Torok formation can be correlated only on gross lithologic features; consequently, it is impossible to determine the total thickness of rocks present. The section at Kucher Creek is the most nearly complete; it is on the north flank of an anticline and the upper 3,100 feet, including the gradational contact with the Tuktu formation is exposed. The section as exposed is clay shale, silty shale, siltstone, and sandstone; it has considerably more sandstone, siltstone, and silty shale than does the type section of the Torok formation from the Chandler River about 32 miles east of the Killik River (Detterman, Bickel, and Gryc, 1963, p. 235). A covered interval

equivalent to 3,200 feet was computed by assuming that the strike and dip remain constant across the covered interval. Below the covered interval is 425 feet of calcareous siltstone, silty shale, and sandstone; thus, a computed thickness of 6,725 feet of Torok formation lies between the Tuktu formation contact and the axis of the first anticline south of the contact.

Three incomplete sections (A, B, and C) of the Torok formation were measured from exposures on the west bank of the Etivluk River; they cannot be correlated with each other nor with the Kucher Creek section. This fact may indicate that the Etivluk sections are additional lithologic units or merely that they represent a facies change. Section C is about 90 percent graywacke sandstone, with some black chert pebbles which is similar to the graywacke sandstone section at the type locality (Detterman, Bickel, Gryc, 1963, p. 235).

The Torok formation in the Killik-Etivluk Rivers region is probably on the order of 7,000 to 10,000 feet thick. The upper contact with the Tuktu formation is gradational, and some beds that are mapped as Tuktu formation in the Chandler River region may be mapped as Torok in the Killik-Etivluk Rivers region. In general, the beds are more complexly folded and more steeply dipping in the Torok formation than in the Tuktu formation, but there is no conclusive evidence of an unconformity between the two formations in the mapped region.

Sections of the Torok formation were measured along the Etivluk River and Kucher Creek. They cannot be definitely correlated, and probably do not represent the complete Torok sequence in the Killik-Etivluk Rivers region. The sections from the lower Etivluk River are shown (pl. 47) in order from south to north; the details within each column are in stratigraphic succession, but the overall stratigraphic relationship between the columns is not known.

The formation was insufficiently exposed elsewhere to measure sections.

Sections of Torok formation on the lower Etivluk River

Section A (incomplete), 1 mile upstream from junction with East Fork:		Feet
8. Silty shale, medium-gray; medium-green highly argillaceous siltstone; medium-green, very fine to fine-grained friable sandstone in 1- to 6-in. beds.		80
7. Clay shale, dark-gray, thin-bedded, with some interbedded silty shale.		120
6. Sandstone, thin-bedded, fine- to medium-grained, medium-green, highly argillaceous, slightly calcareous, with a few black chert pebbles $\frac{1}{2}$ to 3 in. in diameter; abundant wood fragments along bedding planes; few mud-ball concretions.		60
5. Siltstone, silty shale, and sandstone.		15
4. Sandstone, thin-bedded, medium-green, very fine grained.		20
3. Silty shale with interbedded siltstone.		40

Section A—Continued

	Feet
2. Sandstone, shaly to thin-bedded, medium-green, very fine grained, highly argillaceous.....	15
1. Clay shale, dark-gray, with some interbedded silty shale.....	230
Total.....	580

Section B (incomplete), 1½ miles north of section A:

5. Clay shale, dark-gray.....	200
4. Clay shale with interbedded silty shale, siltstone, and sandstone; shale in beds 1 to 6 in. thick; siltstone and sandstone beds 1 to 3 in. thick; sandstone, medium to light gray, very fine to fine grained; marcasite concretions as much as 6 in. in diameter associated with siltstone beds. Fossils from the unit include the ammonites <i>Cleoniceras tailleuri</i> Imlay and <i>Puzosia?</i> sp. and the pelecypod <i>Inoceramus</i> sp.....	200
3. Clay shale, silty shale, and siltstone; dominantly clays shale; marcasite concretions in siltstone beds; rubble; computed thickness approximately.....	420
2. Sandstone, thin-bedded, very fine to medium-grained, medium-gray to green, graywacke-type; some interbedded shale and siltstone; megafossils include the ammonite <i>Subarcthoplites bickeli</i> Imlay and pelecypod <i>Inoceramus</i> cf. <i>I. anglicus</i> Woods.....	80
1. Clay shale; units 10 in. thick interbedded with siltstone units 4 to 6 in. thick; a few thin beds of sandstone and silty shale.....	180
Total.....	1,080

Section C (incomplete), 3 miles north of section B:

8. Clay shale, dark-gray, with a few thin layers of siltstone and silty shale interbedded; rubble; computed thickness approximately.....	70
7. Sandstone, graywacke-type, thin-bedded (2 in. to 1 ft), laminated; swirl bedding common; very fine grained, medium-yellow-red, with some interbedded siltstone and shale.....	425
6. Covered; computed thickness approximately.....	120
5. Sandstone with silty shale interbedded; similar to unit 7.....	25
4. Covered; computed thickness approximately.....	390
3. Sandstone, with few black chert pebbles.....	8
2. Sandstone, thin-bedded, fine- to medium-grained, dark-green.....	77
1. Clay shale; rubble; computed thickness approximately.....	20
Total.....	1,135

Section of Torok formation on Kucher Creek

Tuktu formation.

Torok formation (incomplete):

	Feet
21. Sandstone, siltstone, and silty shale; sandstone massive, medium to dark gray, very fine to fine grained, calcareous; more abundant in upper part of unit.....	90
20. Covered; computed thickness approximately.....	40
19. Sandstone, siltstone, and silty shale; sandstone shaly to thin bedded (¾ to 3 in.); greenish gray, very fine grained, moderately calcareous, crosslaminated. Mudflow marks on siltstone.....	60
18. Covered; computed thickness approximately.....	80

Torok formation—Continued

	Feet
17. Silty shale, dark-gray, slightly calcareous, nodular, fractured; some interbedded calcareous thin-bedded sandstone and siltstone.....	370
16. Covered; computed thickness approximately.....	85
15. Silty shale with some interbedded sandstone ½ to 2 in. thick.....	210
14. Covered; computed thickness approximately.....	160
13. Siltstone with subordinate silty shale and sandstone; sandstone thin-bedded (¾ in.), dark-gray, very fine grained, calcareous.....	110
12. Silty clay shale, siltstone, and subordinate very fine grained yellow-brown sandstone; few lenticular beds of bony coal as much as 4 in. thick.....	240
11. Covered; computed thickness approximately.....	250
10. Siltstone, dirty, calcareous, with subordinate calcareous sandstone; abundant plant fragments.....	30
9. Covered; computed thickness approximately.....	30
8. Siltstone and silty shale; unit grayish black, weathered to dark gray, friable. Local sandstone units 5 to 6 ft thick, thin bedded, very fine grained, light olive gray, weathered to moderate yellow brown. Few small ironstone concretions. Sandstone more abundant in upper part. Fossil fragment from middle of unit.....	180
7. Siltstone, silty shale, and sandstone; rubble; computed thickness approximately.....	140
6. Covered; computed thickness approximately.....	595
5. Siltstone with subordinate amount of interbedded sandstone ½ to 2½ in. thick; very fine to fine grained; mudflow marks common.....	420
4. Covered; computed thickness approximately.....	3,200
3. Siltstone with some interbedded silty shale.....	65
2. Sandstone, thin-bedded (2 to 3 in.) very fine to fine-grained; medium-dark-gray, weathers to dark yellow brown.....	20
1. Silty shale, calcareous, with interbedded dark-gray calcareous siltstone; concretions of calcareous siltstone.....	340
Total.....	6,715

Age and correlation.—The age of the Torok formation has been determined from megafossils as early to middle Albian. The fossils were identified by Imlay (1961, p. 31). He divided the Torok formation into three parts: a lower part that is correlated with the lower part of the Fortress Mountain formation by means of the ammonites *Colvillia* and *Beudanticeras*; a middle part that contains *Subarcthoplites*, which occurs in Alberta in the Clearwater formation and in the upper third of the lower and middle Albian in Europe; an upper part that contains *Gastropylites* and *Cleoniceras*, which is found also in the Tuktu and Grandstand formations, and is correlated with the middle Albian in Europe.

Four collections of megafossils were obtained from rocks of the Torok formation in the Killik-Etiviluk Rivers region; they are listed in table 7. The two most important collections are from field samples 53 ABI

TABLE 7.—Fossils of the Torok formation

[Identifications by R. W. Imlay]

Field sample	USGS Mesozoic locality	Stratigraphic position	Column (pl. 47)	Area	Fossil								
					<i>Inoceramus</i> cf. <i>I. anglicus</i> Wood	<i>Inoceramus</i> sp. juv.	<i>Isognomon?</i> sp.	<i>Subarthrophites</i> <i>bickeli</i> Imlay	<i>Cleoniceras</i> <i>tailleuri</i> Imlay	<i>Puzosia?</i> sp. juv.	Worm boring	Elytrum of beetle	Fish skeleton
53 ABl 80.....	25811	Middle to upper.....	1	Etivluk River.....	X		X	X					
53 ABl 94.....	24639	do.....	1	do.....									
53 ABl 100.....	24640	do.....		do.....		X			X	X			
50 AE 107.....	23178	Unknown.....	2	Kucher Creek.....							X	X	X

94 and 53 ABl 100 (USGS Mesozoic locs. 24639 and 24640) (pl. 47, col. 1, sec. B). The ammonite *Cleoniceras tailleuri* Imlay was obtained from 24640, and *Subarthrophites bickeli* Imlay from 24639; a stratigraphic interval of at least 600 feet is indicated between the two fossil horizons. The stratigraphic interval between the occurrence of *Cleoniceras tailleuri* Imlay and the top of the Torok formation cannot be determined exactly, but is probably about 2,000 to 3,000 feet. Imlay (1961, p. 9) assigned the *Cleoniceras* in 24640 with the early Albian.

The *Subarthrophites* and *Cleoniceras* zones, which represent the middle and upper parts of the Torok formation, are present on the Etivluk River. Fossils representing the lower zone of Imlay have not been found.

The microfossils collected from the Torok formation do not give a clear indication of the age of the beds as most of the genera are long ranging and nondiagnostic. Fifty-eight samples were obtained, of which 32 were barren. The microfossils are shown in table 5; they were identified by Bergquist, who reported (written communication): "A few poorly preserved microfossils were found in samples from the Torok formation. These have little value for identifying the section from which they came, however, as most species are long ranging and nondiagnostic. One sample (47 AZ 600, Kurupa River) from the upper part of the Torok formation has identifiable material: abundant specimens of *Haplophragmoides topagorukensis* Tappan and two specimens of *Verneuilinoides borealis* Tappan; however, this meager fauna only indicates that the sample came from somewhere within the *Verneuilinoides borealis* faunal zone (Bergquist, 1958, p. 199). The presence of specimens of *Eurycheilostoma robinsonae* Tappan in sample 53 ABl 87 (Etivluk River) is unique if this sample is from the lower part of the Torok formation, because this is the only one in more than 400 samples in which the species occurred. I suggest that this may be the upper part of the Torok."

The nature of the contact between the Torok and Tuktuk formations cannot be precisely determined from exposures in the Killik-Etivluk Rivers region. Beds observed near the contact on the Kurupa River and Kucher Creek indicate that the contact is conformable and gradational; however, the northernmost exposure of the Torok formation on the Etivluk River dips 58° S. and the southernmost beds of the Tuktuk formation 4 miles north dip 5° N. In the Chandler River region (Detterman, Bickel, and Gryc, 1963) just east of the region under discussion, the contact is locally unconformable, with the degree of angularity ranging from 3° to 20°.

NANUSHUK GROUP

Sedimentary rocks of the Nanushuk group, as redefined by Detterman (1956, p. 233-244), are exposed in the northern part of the Killik-Etivluk Rivers region. The Tuktuk and Chandler formations are mapped, including the two named tongues of the Chandler formations, the Killik and Niakogon. The marine Ninuluk formation was not mapped west of the Killik River; however, the Niakogon tongue includes a few microfossil-bearing beds that may be interbedded thin layers of the Ninuluk formation.

The rocks of the Nanushuk group in the Killik-Etivluk Rivers region were mapped as two formations. The marine beds were mapped as Tuktuk formation and the nonmarine beds as Chandler formation. The Tuktuk is the lowest unit of the Nanushuk group, but in this region it differs from the type section on the Chandler River (Detterman, 1956, p. 233-235), in that marine tongues in the overlying Chandler formation are included in the Tuktuk. These marine tongues were mapped as Tuktuk because the lithologic character of the exposed rocks is more closely related to the Tuktuk than to the marine Grandstand formation of the Chandler River region (Detterman, 1956, p. 235-237). The lower contact of the Tuktuk formation has been placed at the base of the first massive sandstone unit in a dominantly marine clastic section. The contact with the dark-gray shale and siltstone of the underlying

Torok formation is gradational and probably transgresses time laterally. The upper contact with the overlying Chandler formation is at the base of the first nonmarine coal-bearing beds; this contact is marked also by a change in character of the sandstone from a dominantly gray green color to a yellow-red-weathering salt-and-pepper sandstone and conglomerate with a marked increase in white quartz as a constituent mineral. The contact between the Tuktu and Chandler is generally sharp and distinct, but it is not a time line; in fact, the contact undoubtedly transgresses time boundaries in a northward direction and perhaps to a lesser extent in a direction normal to the strike.

The southernmost exposures of the Nanushuk group are in the northwest-trending Tuktu escarpment, which, is a continuation of the escarpment that crosses the Chandler River region (Detterman, Bickel, Gryc, 1963, p. 237) and forms the southern boundary of the northern foothills section of the Arctic foothills province. The escarpment crosses the Killik River at lat 68°47' N., and is west-trending as far as Heather Creek; it crosses the Kurupa River at lat 68°50' N., and then swings abruptly toward the northwest to form the north bank of Kucher Creek and finally crosses to the north bank of the Colville River opposite the mouth of the Etivluk River, at lat 68°59' N. Rocks of the Nanushuk group are not present south of the escarpment, either because of erosion or nondeposition, mostly the latter as the group has not been identified south of the escarpment in any area. Rocks that differ in lithologic character but that may be in part time equivalents of the Nanushuk group are present south of the escarpment in the Torok and Fortress Mountain formations. In all, rocks covering about 900 square miles have been mapped as Nanushuk group.

The lithologic character of the group in the mapped region is very similar to that of the rocks at the type localities in the Chandler River region (Detterman, 1956, p. 233-244); individual beds can be traced from one region to the other, and, in general, there is close correlation between these regions. The rocks include subgraywacke sandstone, sandstone, conglomerate, siltstone, claystone, silty shale, and clay shale. Coal, limestone, ironstone (as concretions and beds), and bentonite (in the Niakogon tongue) are intercalated with clastic rocks.

The group is about 4,450 feet thick along the Killik River; it becomes thicker toward the northwest with a maximum of about 6,260 feet along the Colville River downstream from the mouth of the Etivluk River. The greatest thickening is between the Kurupa River and the western boundary of the mapped area. The relations of the stratigraphic units in the Killik-Etivluk Rivers region to those in the Utukok-Corwin area to

the west and the Chandler River region to the east are shown on figure 62.

TUKTU FORMATION

Occurrence.—The Tuktu formation is exposed in a narrow northwest-trending belt along the southern edge of the northern foothills section, and forms a prominent south-facing escarpment. This belt is about 70 miles long and 0.5 to 1 mile wide. The escarpment is not as outstanding in the Killik-Etivluk Rivers region as it is in the Chandler River region, but it is a readily identifiable topographic feature with relief of 500 to 1,000 feet. The beds that crop out in the escarpment dip north 5° to 20°.

A second belt of Tuktu formation is exposed along Kurupa anticline, particularly where the anticline is breached by the Killik, Oolamnagavik, Kurupa, and Colville Rivers. The beds in the anticline are folded more complexly than in the escarpment and are offset locally by axial thrust faults and small oblique slip faults. The faulting was most severe in the eastern part of the area between the Killik and Oolamnagavik Rivers. The best exposures of the formation in the Killik-Etivluk Rivers region are along this anticline.

The Tuktu intertongues with the overlying Killik tongue of the Chandler formation in the northwestern part of the area. This intertonguing relation was observed only on the north flank of Kurupa anticline from about 7 miles east of the Kurupa River to the western boundary of the mapped area. This unit was mapped as undifferentiated lower part of Killik tongue and Tuktu formation, because the tongues are generally too small to show at the scale used on plate 43. The same relation probably exists on the south flank of the anticline and in the exposures along the escarpment, but has not been positively established.

The upper part of the formation is exposed in the complexly folded and faulted area at Killik Bend, where the beds have been brought to the surface by a low-angle underthrust fault on the south flank of the overturned Killik Bend anticline.

Character and thickness.—The Tuktu formation in the Killik-Etivluk Rivers region is dominantly a marine clastic unit similar in gross aspect to the type section on the Chandler River (Detterman, 1956, p. 233-235), but it does contain some beds with littoral characteristics and in general has more coarse clastic material than the beds at the type locality.

The rocks are argillaceous dark-green to medium-gray shaly to massive, very fine to medium-grained sandstone, light-yellow-red conglomeratic sandstone, and gray-green siltstone and silty shale. Subordinate constituents include clay shale, ironstone and sandstone concretions, lenticular beds and concretions of limestone, and a few thin seams of coal.

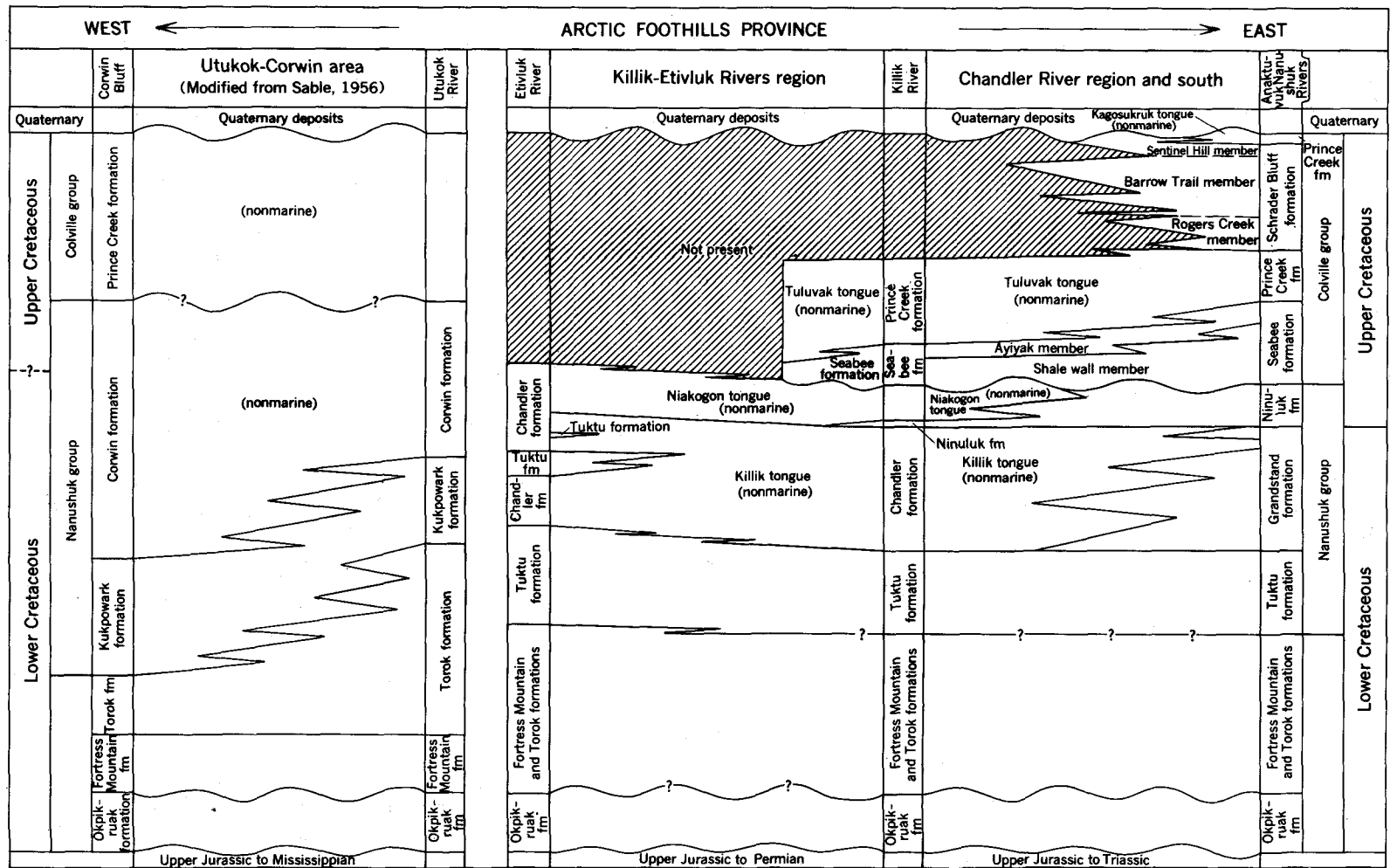


FIGURE 62.—Diagrammatic sections showing formation, member, and tongue relations of exposed Nanushuk and Colville group rocks in the central and western parts of the Arctic Foothills province, Killik-Etiviluk Rivers region, Alaska.

Conglomeratic sandstone is locally an important constituent of the stratigraphic sequence, whereas in the Chandler River region there is only a small amount of conglomerate in the Tuktu formation. The conglomeratic sandstone is most abundant along the Oolamnagavik River, and probably indicates that the area was structurally high at the time the rocks were deposited and was closer to the shore line. Colored chert is the primary constituent of the conglomerate; subordinate constituents include white quartz and intraformational sandstone and shale pebbles. The conglomerate in the Tuktu formation does not have the abundant white quartz that is characteristic of the nonmarine Chandler formation, nor does it have the iron-stained appearance of the conglomerate of the Chandler formation. Thus the conglomerate of the two formations can be readily differentiated.

The conglomeratic sandstone is commonly fossiliferous. The fossils may be derived from reworking of older beds; however, most of the fossils are casts, so it is impossible to tell whether they have been abraded by wave action. The conglomeratic sandstone is present in all outcrops in the escarpment area. The formation becomes more shaly toward the north and the conglomerate is missing. The littoral facies seemingly indicates that the escarpment occupies about the same position as the shore line did during the time the rocks were being deposited.

The sandstone is a subgraywacke and is predominantly very fine to fine grained, thin to shaly bedded, and medium gray to greenish yellow and green; it is commonly calcareous and contains much argillaceous material. Individual beds can be traced across the region in the escarpment, and they show considerable variations in lithologic characteristics, from a marginal-marine facies on the Oolamnagavik River to marine facies on Kucher Creek and the Colville River. Mud-ball concretions and clay galls are common features in the sandstone. Carbonaceous laminae are present in the marginal facies, and a few petrified logs occur in the Kurupa River section (pl. 48, column 2). Some of the sandstone is crossbedded but few ripple marks were noted. The crossbedding is confined primarily to the thin- to shaly-bedded sandstone and is most common in the area between the Kurupa and Colville Rivers. A 150-foot unit of fine-grained thin- to medium-bedded friable dark-green sandstone present in the Killik River section cannot be traced westward across the region as a single unit.

Clay shale and silty shale combined form less than 50 percent of the exposed rocks. In general, the shale sequence is not as thick as it is east of the Killik River (Detterman, Bickel, and Gryc, 1963). Silty shale is more abundant than clay shale and combined with

siltstone forms about 30 to 40 percent of the exposed rocks. Ironstone concretions as much as 3 inches in diameter are found commonly with the silty shale; surface weathering of the concretions has produced a ferruginous stain on the enclosing rocks.

The Tuktu formation is thicker in the western part of the Killik-Etivluk Rivers region than it is at the type locality (Detterman, 1956, p. 233-235). Two complete sections of the formation were measured; the Colville River section (pl. 48, column 1) is 2,269 feet thick and the Kurupa River section is 1,376 feet thick. The other sections are incomplete, owing to faulting or poor exposures.

The thicker section west of the Oolamnagavik River is due largely to a general thickening of the Nanushuk group in the northwestern part of the area. Some of the additional thickness may be a result of mapping beds at the base as Tuktu formation that were mapped as Torok formation farther east. The additional thickness of Tuktu may also represent in part a northwest facies change from nonmarine to marine strata.

The greater thickness of Tuktu in the western part of the Killik-Etivluk Rivers region and the gradual change in lithologic character from that of the type section seems to indicate that this stratigraphic sequence is approaching what Sable (1956, p. 2637-2641) defined as the Kukpowruk formation of the Nanushuk group in the western part of northern Alaska.

Following are the measured sections of the Tuktu formation. They are described in the same succession as on plate 48. The Colville River section (pl. 48, column 1) was measured along both banks of the river near the mouth of the Etivluk River. The Tuktu escarpment is on the north side of the Colville River opposite the mouth of the Etivluk River, and most of the section was measured at that locality. The section is on the south flank of the Oolamnagavik syncline and the strata dip 5° to 10° N.; this is the thickest section of the Tuktu formation measured in outcrops in northern Alaska. The exposed parts of the formation were taped and the stratigraphic thickness for the cover parts was computed; the total thickness is 2,269 feet.

Section of Tuktu formation along the Colville River, near the mouth of the Etivluk River

Upper part, Killik tongue.

	Feet
Tuktu formation:	
53. Sandstone, thin- to medium-bedded; medium grained at base and fine grained at top; green, ripple marked, fossiliferous (field sample 47 AZ 546-547).....	60
52. Silty shale.....	115
51. Sandstone, thin-bedded, medium-gray, fine-grained, carbonaceous; minor amount of interbedded siltstone; beds 6 in. thick.....	12
50. Silty shale.....	90

Tuktu formation—Continued		Tuktu formation—Continued	
	Feet		Feet
49. Sandstone, medium-bedded, gray, very fine grained, hard, with ironstone concretions 2 to 3 in. in diameter.....	1	23. Sandstone, thin to medium-bedded, light-green, fine to medium-grained; weathers light yellow red; rubble; computed thickness approximately.....	20
48. Silty shale.....	10	22. Covered; computed thickness approximately.....	25
47. Sandstone, thin-bedded to massive, medium-gray, fine-grained, carbonaceous; ironstone concretions 3 in. to 1 ft in diameter; some interbedded siltstone in upper part of unit....	25	21. Sandstone, thin-bedded, light-gray, fine-grained; rubble; computed thickness approximately....	10
46. Silty shale.....	100	20. Covered; computed thickness approximately.....	105
45. Sandstone, massive, dark-green, fine-grained; lenticular beds of pebble conglomerate; worm tracks and pelecypod casts (field sample 47 ATh 40F).....	5	19. Sandstone, thin-bedded, light-green to medium-gray, fine-grained; rubble; computed thickness approximately.....	30
44. Sandstone, thin-bedded, dark-green, fine-grained.	15	18. Covered; computed thickness approximately.....	110
43. Sandstone, massive, light-green, fine-grained; interbedded, swirl-bedded siltstone.....	10	17. Sandstone, thin-bedded to massive, very fine to fine-grained, light-green to medium-gray. A few thin layers of ¼-in. black chert pebbles and laminated siltstone pebbles in lower part of unit; very calcareous in upper 25 feet; mud-ball concretions common throughout. A few poorly preserved pelecypod casts and worm trails in lower part. In part rubble; computed thickness approximately.....	140
42. Sandstone, thin-bedded, dark-green, platy, fine-grained.....	10	16. Siltstone and silty shale; rubble; computed thickness approximately.....	30
41. Sandstone, massive, medium-gray, fine-grained, highly calcareous.....	10	15. Sandstone, thin-bedded to shaly-bedded, very fine grained; light-gray, few fossil worm casts present; rubble; computed thickness approximately.....	20
40. Silty shale, sandy, with limestone lenses 1 to 4 ft thick.....	25	14. Siltstone and silty shale rubble; computed thickness approximately.....	60
39. Sandstone, massive, medium-gray, very fine grained, with interbedded silty shale units 1 ft thick.....	15	13. Sandstone, thin bedded, very fine grained, light-gray, weathered to yellow gray; ledge forming; carbonaceous laminae, few fossil worm casts. In part rubble; computed thickness.....	20
38. Siltstone and silty shale, medium-dark-green; crossbedding in siltstone.....	25	12. Sandstone, siltstone, and silty shale rubble; computed thickness approximately.....	140
37. Limestone, lenticular, medium-gray.....	5	11. Sandstone, thin-bedded (1 to 3 in.), fine-grained.	3
36. Silty shale.....	25	10. Siltstone and silty clay shale.....	10
35. Sandstone, highly calcareous.....	5	9. Sandstone, massive, fine-grained, dull-green.....	2
34. Silty shale.....	10	8. Clay shale, dark-blue-gray.....	3
33. Sandstone, highly calcareous.....	3	7. Sandstone, thin-bedded to massive, fine-grained; dull-green, layered mudstone concretions as much as 1 in. in diameter; carbonaceous laminae.....	15
Lower part, Killik tongue (see page 372).		6. Siltstone, silty shale, and clay shale rubble; computed thickness approximately.....	40
Tuktu formation:		5. Sandstone, thin-bedded, fine-grained, with occasional blue chert pebbles as much as 2 in. in diameter, and ironstone concretions ½ to 3 in. in diameter; abundant carbonaceous laminae.....	20
32. Siltstone and silty shale rubble; computed thickness approximately.....	80	4. Silty shale and clay shale, dark-gray to black, with a few interbedded siltstone and very fine grained sandstone layers. Lenticular beds of dense hard medium-gray sandstone scattered throughout unit in addition to the layered sandstone.....	120
31. Sandstone, massive, light-yellow-red, fine-grained, with lenticular beds of pebble conglomerate 1 to 5 in. thick; poorly preserved pelecypods (field sample 47 ATh 39F).....	40	3. Covered interval containing rubble of sandstone, siltstone, silty shale, and clay shale. Computed thickness approximately.....	140
30. Sandstone, thin-bedded, green, fine-grained.....	40	2. Clay shale and silty shale.....	40
29. Silty shale, greenish-gray, with numerous small ironstone concretions.....	60		
Lower part, Killik tongue (see page 373).			
Tuktu formation:			
28. Siltstone and silty shale with numerous, small ironstone concretions.....	25		
27. Conglomeratic sandstone, medium-green-gray, thin to medium-bedded, fine to coarse-grained, with concretions of pebble conglomerate as much as 24 in. in diameter containing plant and pelecypod fossils (field samples 47 ATh 27f, 47 ATh 37f; USGS Mesozoic loc. 24638).....	25		
26. Siltstone rubble; computed thickness approximately.....	35		
25. Graywacke sandstone, thin-bedded, medium-gray, very fine grained, silty; rubble; computed thickness approximately.....	40		
Lower part, Killik tongue (see page 373).			
Tuktu formation:			
24. Covered; computed thickness approximately.....	120		

Tuktu formation—Continued

Feet

1. Sandstone, thin to medium bedded, fine grained; light-gray to buff, weathers orange brown; calcareous in part, ripple marks of oscillation type; worm trails common. In part rubble; computed thickness approximately----- 125

Total----- 2,269

Torok formation.

The Kurupa River section (pl. 48, column 2) was measured in a series of bluffs on the east bank of the Kurupa River just north of the mouth of Heather Creek; in strata on the north flank of Kurupa anticline, the dip decreases from 45° N. near the anticlinal axis to 22° N. at the contact with the Killik tongue of the Chandler formation. The section is moderately well exposed. This section of the formation is 5 miles north of the escarpment and may not be exactly an equivalent of the escarpment facies.

Section of Tuktu formation on the Kurupa River

Lower part, Killik tongue.

Tuktu formation:

Ft In

24. Graywacke sandstone, shaly-bedded, light-green to yellow-green, very fine to fine-grained, cross-bedded, iron-stained; few layers of siltstone interbedded; coarse-grained sandstone concretions with occasional chert and quartz pebbles and gastropods; pelecypods common in upper 10 feet of unit (USGS Mesozoic loc. 20399)----- 95 0

Lower part, Killik tongue (see page 375).

Tuktu formation:

23. Graywacke sandstone, shaly-bedded, very fine grained, light greenish yellow, carbonized plant fragments; moderately indurated; numerous ironstone nodules; a few layers of medium-gray silty shale interbedded; fossil horizon 5 ft above base (USGS Mesozoic loc. 20398 and field sample 47 AZ-605f)----- 20 0
22. Shale, carbonaceous, coaly----- 1 6
21. Graywacke sandstone conglomeratic, massive, fine- to coarse-grained, dark-greenish-yellow, spheroidal weathered; numerous fine-grained oval sandstone concretions 2 to 8 in. long; occasional chert and quartz pebbles----- 25 0
20. Limestone, pale-yellow, iron-stained, carbonaceous----- 9
19. Graywacke sandstone, fine- to medium-grained, dark-green, soft, friable, cross-bedded----- 6 0

Total----- 148 3

Lower part, Killik tongue (see page 375).

Tuktu formation:

Feet

18. Subgraywacke sandstone, thin- to medium-bedded, very fine to fine-grained, light-greenish-yellow, well-indurated, crossbedded; ironstone concretions; with interbedded silty carbonaceous shale in upper 35 ft of section-- 100

Tuktu formation—Continued

Feet

17. Interbedded sandstone, siltstone, and silty shale; thin-bedded, very fine grained, crossbedded, ripple-marked; clay-gall conglomerate, scattered pelecypods (field sample 46 ACh 130f). Rubble; computed thickness approximately-- 255
16. Covered; computed thickness approximately----- 205
15. Sandstone, shaly bedded, very fine to fine-grained, light-yellow-red, crossbedded; few chert and white quartz pebbles ½ to ¾ in. in diameter; petrified logs 6 to 10 in. in diameter----- 5
14. Graywacke sandstone, medium-bedded, fine- to medium-grained, greenish-yellow, with numerous elliptical graywacke concretions 1 to 4 in. in diameter; crossbedded; few lenticular 4- to 6-in. beds of black chert-grit conglomerate--- 20
13. Carbonaceous shale----- 2
12. Covered; computed thickness approximately----- 130
11. Conglomeratic sandstone, thin- to medium-bedded, fine- to coarse-grained, light-yellow to green-yellow, crossbedded; fair induration. Conglomeratic constituents include chert and shale fragments, grit to pebble size----- 24
10. Graywacke, fine-grained, interbedded with fissile silty shale; abundant carbonaceous laminae; soft----- 11
9. Coal, low-grade bituminous----- 1
8. Sandstone, medium-bedded to massive; green to light-yellow-green, sandstone concretions as much as 3 ft in diameter----- 25
7. Sandstone, conglomeratic, and sandstone, siltstone, silty shale, and clay shale. Conglomeratic constituents are black and green chert pebbles; rubble; computed thickness approximately----- 240
6. Silty shale, medium-gray----- 20
5. Sandstone, thin- to medium-bedded, fine-grained, light-gray, crossbedded, ripple-marked; clay galls; fossiliferous (USGS Mesozoic loc. 20412)--- 80
4. Sandstone, medium-bedded, very fine grained, laminated; fissile in part; crossbedded----- 10
3. Sandstone, similar to unit 5----- 35
2. Sandstone, siltstone, and silty shale rubble in covered interval; computed thickness approximately----- 40
1. Sandstone, medium-bedded to massive, very fine to fine-grained, greenish-yellow, iron-stained, crossbedded----- 25

Total----- 1,376

Torok formation.

The Oolamnagavik River section (pl. 48, column 3) was measured along the west bank of the Oolamnagavik River, where the river cuts through the Tuktu escarpment. The formation crops out in two bluffs on the south limb of the Oolamnagavik syncline. The dip of the strata decreases toward the north from 14° to 5° N. The section is incomplete because the lower contact with the Torok formation is not exposed.

Section of Tuktu formation along the Oolamnagavik River

Lower part, Killik tongue.

Tuktu formation:

- | | |
|---|------|
| | Feet |
| 23. Sandstone, shaly-bedded to massive, light-yellow-green, very fine grained; shaly to thin-bedded in lower part, massive in upper part; carbonaceous, crossbedded; some ironstaining; calcareous in shaly part; contains a few chert pebbles, with a few interbedded layers of siltstone and silty shale..... | |
| 22. Covered interval; computed thickness approximately..... | |
| 21. Sandstone, irregular bedding; greenish-yellow; very fine to fine grained, calcareous, with few black chert granules; fossiliferous (USGS Mesozoic loc. 20395)..... | |
| 20. Sandstone, shaly-bedded, light greenish-yellow, very fine grained, crossbedded; platy with few chert pebbles $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter; worm trails, scattered pelecypods (USGS Mesozoic loc. 20394)..... | |
| 19. Covered interval; computed thickness approximately..... | |
| 18. Sandstone, conglomeratic; primarily chert pebbles $\frac{1}{2}$ in. in diameter; few white quartz pebbles..... | |
| 17. Sandstone rubble in covered interval; computed thickness approximately..... | |
| 16. Sandstone, thin-bedded to massive, conglomeratic, light greenish-yellow, fine-grained, soft crossbedded, calcareous, with few subround black and green chert pebbles; ridge-forming unit; scattered pelecypods (46A Ch 66f)..... | |
| 15. Covered interval; computed thickness approximately..... | |
| 14. Sandstone, conglomeratic, medium-bedded to massive, light yellow-red, highly iron stained, crossbedded; intraformational sandstone and tabular and roller-shaped shale pebbles..... | |
| 13. Ironstone, sandy..... | |
| 12. Sandstone, conglomeratic medium-bedded, medium-gray to green, fine to medium-grained; subround chert pebbles with long axis parallel to bedding..... | |
| 11. Covered interval; computed thickness approximately..... | |
| 10. Sandstone, shaly-bedded, dark-greenish-yellow, fine-grained, soft; white salt efflorescence; rare black chert and soft black shale pebbles; pelecypod fragments, (46 ACh 61f)..... | |
| 9. Covered interval; computed thickness approximately..... | |
| 8. Shale, dark-gray, silty interbedded with massive medium-gray medium-grained sandstone; crossbedded; few intraformational shale pebbles..... | |
| 7. Covered interval; computed thickness approximately..... | |
| 6. Sandstone and silty shale similar to unit 8..... | |
| 5. Sandstone, massive, very fine grained, medium-gray, hard; siliceous cement..... | |
| 4. Sandstone and silty shale, medium-gray..... | |
| 3. Sandstone..... | |

Tuktu formation—Continued

Feet

- | | |
|---|-----|
| 2. Sandstone, shaly to medium-bedded, very fine grained, pale-greenish-yellow, crossbedded; weathered light gray; bedding undulatory; oscillation ripple marks..... | 40 |
| 1. Sandstone similar to unit 2, with a minor amount of silty shale interbedded; mostly rubble; computed thickness approximately..... | 50 |
| Total..... | 903 |

The Colville River section at Killik Bend (pl. 48, column 4) was measured on the south bank of the Colville River in the first bluff downstream from the mouth of the Oolamnagavik River. The formation was brought to the surface by a low-angle underthrust fault on the south flank of the overturned thrust-faulted Killik Bend anticline; only the upper 130 feet are exposed. The strata dip 30° S. The exposed rock is a dark-green medium-grained sandstone similar to the sandstone 150 feet below the top of the Killik River section; consequently the contact with the Killik tongue may be a fault contact.

Section of part of the Tuktu formation at Killik Bend, Colville River

- | | | |
|-----|--|------|
| 20 | Lower part, Killik tongue. | |
| | Tuktu formation: | Feet |
| 175 | 2. Sandstone, massive, dark-green, fine to medium-grained; weathers red brown; highly fractured friable..... | 90 |
| 36 | 1. Sandstone, medium-bedded, greenish-gray, fine-grained, laminated; a few layers of silty shale interbedded; pelecypods (U.S.G.S. Mesozoic locality 20406)..... | 40 |
| 25 | Total..... | 130 |

Fault.

The Killik River section (pl. 48, column 5) was measured in the first bluff south of the axis of the Kurupa anticline, on the east bank of the Killik River. At this locality the formation is exposed in a series of bluffs in which the strata are folded into numerous small east-plunging drag folds on the flanks of the anticline. The strata are cut by high-angle reverse faults that are generally parallel to the bedding planes; maximum displacement probably does not exceed 200 feet. A 940-foot section was measured between two faults. The dip decreases from 40° S. at the north end of the outcrop to 28° S. at the south end. A detailed description of this section is given in Detterman, Bickel, and Gryc (1963, p. 239).

Age and correlation.—The marine Tuktu formation has a varied megafauna that is found primarily in the sandstone and conglomeratic sandstone facies. The megafauna is abundant but not well preserved; it consists for the most part of internal molds. Most of the species are thick shelled and suggestive of a littoral environment that is confirmed by the rock types in which the fossils are found. The fossils are more

formation. Imlay (1961) identified three genera: *Paragastrophites*, *Cleoniceras* (*Neosaynella*?), and *Cleoniceras* (*Grycia*). Gastropods and echinoderms from three collections, and an imprint of a squid in one collection from the Colville River were identified.

The fossils identified by Imlay from the Tuktuk formation are shown in table 8. Some fossil localities are shown on plate 43 that are not included in table 8, because the material from the unlisted collections had not been identified at the time of this writing. Concerning the age and possible correlation of the megafauna, R. W. Imlay (written communication) stated: "A distinct assemblage of mega- and microfauna appears in the upper third of the Torok formation, is abundant in the Tuktuk formation, persists in reduced numbers in the Grandstand formation, and then terminates rapidly. This assemblage can be divided into a lower zone characterized by the ammonite *Paragastrop-*

[Identifications by R. W. Imlay. Field samples 46 ATh 106, 46 ACh 115, 124, 120, 137, Kurupa River; 46 ACh 184, 46 ATh 80, 211, 209, 219, 222, 229, 230, 53 AB1 9, 108, Colville River; ATh 55, 60, 67, 46 ACh 57, 60, 67, 68, Oolamnagavik River; 45 AWa 72, 45 AKr 82, 53 AB1 9, 13, 14, 48, Kulik River]

[illegible]

A total of 85 microfossil samples were collected from strata of the Tuktu formation in the Killik-Etiviluk Rivers region. The samples are about evenly divided between the lower part of the Tuktu and the upper part that intertongues with the Chandler formation. Sixty-five of the samples were fossiliferous, the highest percentage of fossiliferous samples coming from the intertonguing upper part of the formation.

Table 9 .-Microfossil chart

	Upper Cretaceous	Lower Cretaceous
Fossil	Ninuluk formation and Niakogan tongue of Chandler formation	Nanushuk group Chandler formation Upper part of Killik tongue
Number and interval of samples	1 1 1 2 1 1 1 1 2	1 1 1 1 1 1 1 1 1 1 1
Bathysiphon broegei Tappan		
B. vitta Nauss	R	
Saccamina lathrami Tappan	A R	
Reophax minuta Tappan		
Involutina rotalaria (Loeblich and Tappan)		
Glomospira gaultina (Berthelin)		
Haplophragmoides topagorukensis Tappan		
Ammobaculites fragmentarius Cushman		
A. wenonahae Tappan		
Siphotextularia? rayi Tappan		
Verneuilinoidea borealis Tappan		
Uvigerinammina manitobensis (Wickenden)		
Gaudryina canadensis Cushman		R
G. irenensis Stelck and Wall		
Gaudryinella irregularis Tappan		
Miliammina awunensis Tappan		
M. manitobensis Wickenden		
Psamminopelta bowsheri Tappan		
Spiroloculina ophiunea Loeblich and Tappan	R A	R
Trochammina rutherfordi Stelck and Wall		
Lenticulina erecta (Perner)		

While no direct age correlations were attempted from the small microfauna of the Tuktu formation in the Killik-Etiviluk Rivers region, it is significant that the fossils are part of the *Verneuilinoides borealis* faunal zone (Bergquist, 1958, p. 199), for most of the fossils from this faunal zone are from beds of Albian age.

CHANDLER FORMATION

The Chandler formation as mapped in the Killik-Etiviluk Rivers region is the same unit as redefined by Detterman (1956, p. 237-241); it consists of two tongues, Killik and Niakogon, the Killik being the lower and thicker. The type localities for both tongues are on the east bank of the Killik River (pl. 43), 5 to 12 miles downstream from the mouth of the Okpikruak River.

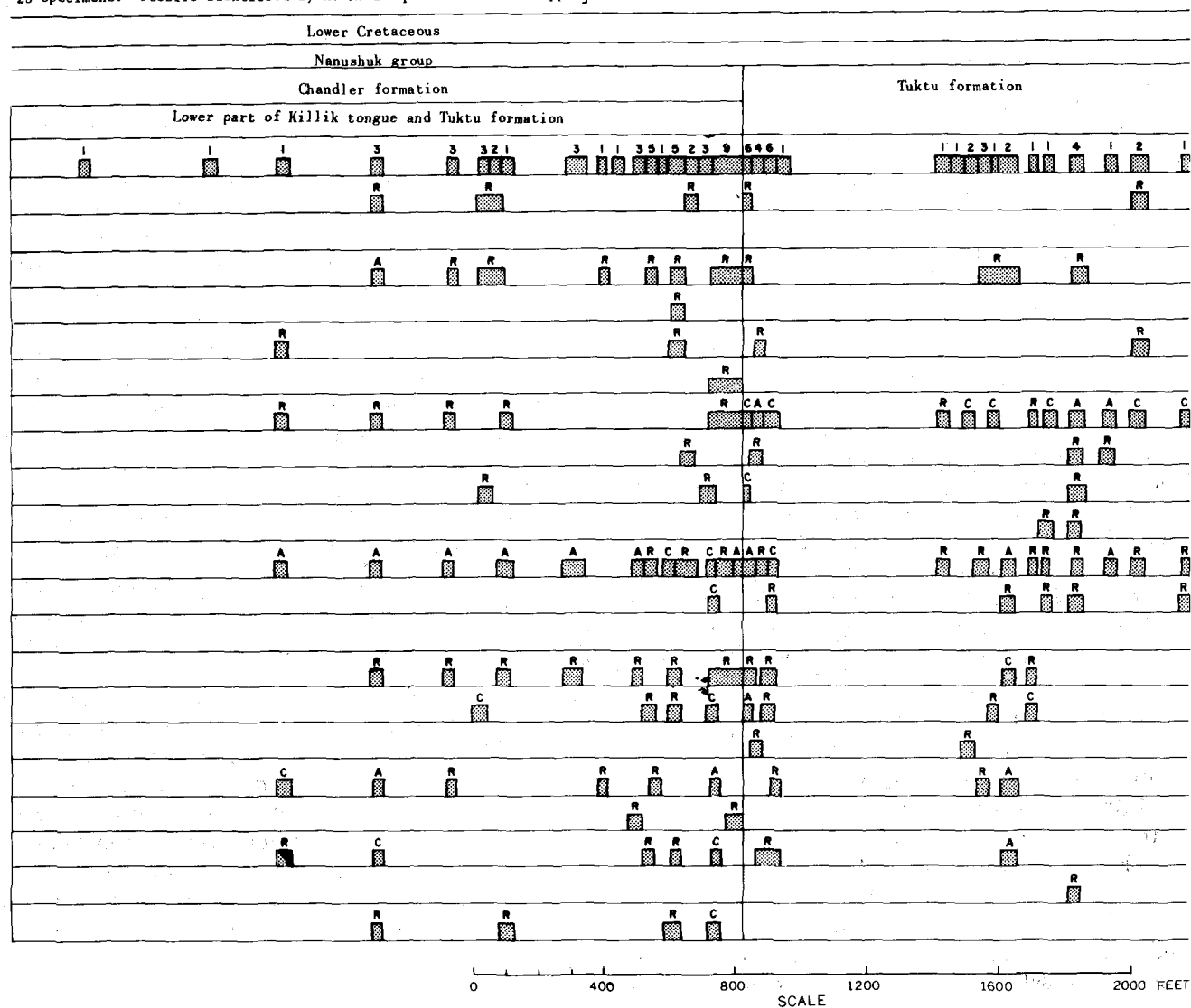
Most of the exposed rocks of the Nanushuk group in the Killik-Etiviluk Rivers region are in the Chandler

formation. The Killik tongue is the most widespread and persistent unit of the Chandler; it forms the cap rock for the Tuktu escarpment and is the main ridge-forming unit in the northern foothills section. The formation is present in broad, open folds throughout most of the region; it is faulted locally along Kurupa, Killik Bend, and Aupuk anticlines, but in general the stratigraphic displacement is only a few hundred feet.

The two tongues of the Chandler formation are in contact in the Killik-Etiviluk Rivers region, except along the Killik River, where a 40-foot section of marine Ninuluk formation separates the tongues. In the Chandler River region, just east of the area under discussion, a section of Ninuluk formation varying in thickness from 40 to several hundred feet is always found between the two tongues (Detterman, Bickel, and Grye, 1963). The almost complete absence of Ninuluk

for the Nanushuk group

25 specimens. Fossils identified by H. R. Bergquist and H. N. Tappan]



formation in the Killik-Etiviluk region is due to a south-westward facies change from marine to nonmarine strata. The two tongues, although in contact, are distinct mappable units and are described separately.

KILLIK TONGUE

Occurrence.—The Killik tongue of the Chandler formation is the lower and thicker of the two tongues of the formation; it is 2,815 feet thick at the type locality along the east bank of the Killik River between lat 68°51' N. and 68°55' N. Westward from the type locality the tongue becomes thicker; it is 3,318 feet thick along the Oolamnagavik River, 3,760 feet thick along the Kurupa River, and 3,450 feet thick along the Colville River.

The beds interfinger with the Tuktu formation in the northwestern part of the region. Rocks representing three marine transgressions, two of which extended as far east as the Kurupa River, were mapped along the Colville River. Marine rocks are present in addition to the ones mapped, but the stratigraphic intervals are too small to be shown at the scale used on plate 43. The Killik tongue by definition is a nonmarine and marginal unit, so it should be borne in mind that marine strata are included with the tongue only as a mapping convenience.

The best exposures of the Killik tongue are in a belt 5 to 8 miles wide just north of the Tuktu escarpment where the strata are folded into the Kurupa anticline and Oolamnagavik syncline. In general, the strata dip gently from 5° to 15°; the beds are faulted locally and may dip as much as 30°. The anticline is more complex structurally than is the syncline; several low-angle axial thrust faults offset the beds and small oblique slip faults are present near the anticlinal axis both east and west of the Kurupa River. The northern belt of Killik tongue is one of low relief, generally less than 200 feet, and is partly obscured by a gravel terrace. The beds dip less than 20° for the most part, except in the structurally complex zone at Killik Bend, where the Killik Bend anticline is overturned and offset by numerous west-trending high-angle reverse faults and a low-angle underthrust fault with associated drag folding.

The Killik tongue can be divided into an upper and a lower part which are lithologically distinct. The two units were mapped throughout the Killik-Etiviluk Rivers region and are described individually.

At the type locality the lower part of the Killik tongue is 1,095 feet thick. Well-indurated ridge-forming sandstone constitutes the bulk of the exposed section. The sandstone is predominantly medium bedded to massive and fine to coarse grained; it ranges in color from salt-and-pepper to various shades of

yellow red, and has a characteristic rust-brown-weathered surface. Lenticular beds of pebble conglomerate are present locally in the lower part. The pebbles are about 40 percent white quartz; this is the first occurrence of white quartz as a major conglomeratic constituent in the stratigraphic sequence of the Cretaceous of northern Alaska. The remainder of the pebbles are predominantly black, gray, and green chert, with minor hematite nodules and limestone pebbles. In addition to the sandstone and conglomerate, other constituents of the lower part of the Killik tongue include gray to brown micaceous carbonaceous siltstone, sandy silty shale, and coal. Ferruginous nodules commonly containing plant fossils are found in the siltstone and silty shale beds. The ironstone beds also contain abundant plant remains.

The thickest section of the lower part of the Killik tongue is at the mouth of the Oolamnagavik River, where about 1,600 feet was measured or inferred; the upper 670 feet is poorly exposed, but the remainder is well exposed in a bluff at Killik Bend on the south bank of the Colville River just downstream from the mouth of the Oolamnagavik. Well-indurated ridge-forming sandstone is present, but sandstone is subordinate to siltstone and silty shale along the Oolamnagavik River. The sandstone is predominantly thin to medium bedded, fine grained, and dark yellow red to salt and pepper; it has a characteristic rust-brown-weathered surface. Coal is more abundant than at the type locality; 15 beds were measured, the thickest of which is 6.5 feet. The siltstone and silty shale are quite carbonaceous and contain abundant plant fossils and ironstone concretions. A few conglomeratic pebbles and lenticular beds of pebble conglomerate are present in the sandstone. The section exposed just north of the Tuktu escarpment on the Oolamnagavik River has abundant conglomerate beds, but very little conglomerate is present in the section at the mouth of the river, 13 miles north of the escarpment.

West of the Oolamnagavik River the lower part of the Killik tongue becomes thinner and the upper part becomes thicker, owing partly to a facies change. The sequence becomes more marginal-marine with an increase in the siltstone and silty shale content at the expense of the sandstone. The latter is dominantly thin to medium bedded, very fine to fine grained, and medium gray to light yellow red. Ironstone concretions are abundant and one limestone bed is present in the Colville River section. Pebble-granule conglomerate is a fairly common constituent of the tongue along the Colville and Kurupa Rivers; it generally occurs as lenticular beds, but may form concretions and nodules associated with a coarse-grained salt-and-pepper sandstone.

The upper part of the Killik tongue is 1,720 feet thick at the type locality along the Killik River. This part of the tongue is not as well exposed as is the lower part, but is characterized by massive ledge-forming conglomerate. White quartz constitutes about 40 percent of the conglomerate. Most of the pebbles are slightly oblong, well rounded, $\frac{1}{4}$ to $1\frac{1}{4}$ inches in length, with a few cobbles as much as 4 inches in length. The sandstone is thinner bedded, finer grained, and more argillaceous than in the lower part. Siltstone and silty shale are common; both are carbonaceous and micaceous. Coal float was noted, but is not abundant. Plant fossils are moderately abundant, particularly in the ironstone beds.

The conglomerate bed that forms the contact between the upper and lower parts of the Killik tongue can be traced from the Killik River to the western boundary of the mapped area, as can some of the other conglomerate beds of the type section. The conglomerate beds in the upper part of the Killik tongue are more persistent laterally than are those of the lower part.

The upper part of the Killik tongue is similar to the lower part in that it becomes more marginal toward the western part of the area where it intertongues with the Tuktu formation. The siltstone and silty shale content increase in the western part of the area, and several black carbonaceous limestone beds were noted on both the Kurupa and Colville Rivers. The siltstone and silty shale are similar to that in the lower part of the tongue, and the sandstone is dominantly medium bedded, medium grained, salt-and-pepper to light yellow red. Some of the sandstone is crossbedded and ripple marked.

The thickest measured section is on the Kurupa River, where the upper part of the tongue is 2,474 feet thick; it is 2,176 feet thick along the Colville downstream from the mouth of the Etivluk River. At the latter location the Tuktu formation reaches its greatest thickness in the mapped area; consequently, the total thickness of the Killik tongue and Tuktu formation is greatest in the western part of the area. The westward component of thickening of the Killik and Tuktu sequence is about 25 feet per mile, or about 1,500 feet between the Killik and Etivluk Rivers. This increase in the stratigraphic sequence may indicate a deepening of the depositional basin northwest of the mapped area.

The Colville River section (pl. 48, column 1) was measured along both banks of the Colville River between the Etivluk and Awuna Rivers, where the Colville cuts across the Tuktu escarpment. The best outcrops are in a series of river bluffs formed by the big meanders in the Colville River near the mouth of Kucher Creek. The lower part of the tongue was

measured in the escarpment, and the upper part was measured along the Colville River 5 miles upstream from the mouth of the Awuna River. The section was measured by Thurrell and Zumberge in 1947.

Section of Killik tongue along the Colville River, between the Etivluk and Awuna Rivers

Niakogon tongue.

Upper part, Killik tongue:	Feet
80. Coal.....	6
79. Covered; computed thickness approximately.....	20
78. Sandstone, thin- to medium-bedded, medium-gray, very fine grained, crossbedded.....	10
77. Covered; computed thickness approximately.....	80
76. Sandstone, conglomeratic, massive with an occasional thin bed; light- to medium-gray; fine to medium grained; weathers to light yellow red; wood fragments common. Conglomeratic constituents primarily subrounded white quartz pebbles $\frac{1}{2}$ in. in diameter.....	15
75. Coal.....	1
74. Covered interval; computed thickness approximately.....	100
73. Sandstone, massive, medium-gray, fine-grained, crossbedded; weathers into layers 2 to 4 in. thick.....	20
72. Silty shale, ironstone concretions, and coal rubble; computed thickness approximately.....	50
71. Siltstone.....	10
70. Coal.....	3
69. Covered interval; computed thickness approximately.....	30
68. Sandstone, medium-gray, very fine grained, crossbedded.....	10
67. Covered interval; computed thickness approximately.....	10
66. Sandstone, medium-gray, very fine grained, and micaceous siltstone.....	15
65. Coal.....	1
64. Sandstone with interbeds of siltstone; similar to unit 66.....	30
63. Coal.....	1
62. Siltstone with thin-bedded very fine grained sandstone interbeds, ironstone beds, and concretions.....	25
61. Coal.....	2
60. Siltstone.....	10
59. Silty shale and coal rubble; computed thickness approximately.....	15
58. Sandstone, thin-bedded, medium-gray, very fine grained, silty, micaceous.....	10
57. Covered interval; computed thickness approximately.....	20
56. Sandstone, medium-dark-gray, very fine grained; weathers yellow red; calcareous; abundant fossil wood.....	5
55. Siltstone, silty shale, sandstone, and coal rubble; computed thickness approximately.....	60
54. Coal.....	2
53. Covered interval; computed thickness approximately.....	15
52. Sandstone, massive, medium-gray, fine- to medium-grained.....	30

Upper part, Killik tongue—Continued

	Feet
51. Silty shale rubble; computed thickness approximately.....	30
50. Sandstone, shaly-bedded, light-gray, very fine grained, silty; mud-ball concretions.....	20
49. Covered interval; computed thickness approximately.....	20
48. Coal.....	1
47. Siltstone, micaceous, and very fine grained sandstone.....	30
46. Sandstone, thin to medium-bedded, medium-gray to green, fine to coarse-grained; weathers yellow red; crossbedded; plant fossils.....	50
45. Silty shale with three 5-ft interbeds of massive fine-grained sandstone.....	50
44. Sandstone, massive, very fine grained, with interbeds of siltstone and ironstone; cross-bedded.....	30
43. Coal.....	1
42. Covered interval; computed thickness approximately.....	10
41. Sandstone, medium-gray, fine-grained; oscillation ripple marks with wave length of 1 in., amplitude of $\frac{1}{2}$ in.....	3
40. Silty shale.....	10
39. Sandstone, dark-gray, massive, medium-grained, calcareous, carbonaceous.....	5
38. Silty shale.....	15
37. Coal.....	3
36. Sandstone, medium-bedded, medium-gray, very fine grained, crossbedded.....	15
35. Covered interval; computed thickness approximately.....	20
34. Coal rubble; computed thickness approximately.....	2
33. Covered interval; computed thickness approximately.....	20
32. Sandstone rubble; computed thickness approximately.....	10
31. Silty shale and coal rubble; computed thickness approximately.....	10
30. Sandstone rubble; computed thickness approximately.....	10
29. Silty shale and coal rubble; computed thickness approximately.....	10
28. Sandstone and siltstone rubble; computed thickness approximately.....	10
27. Silty shale rubble; computed thickness approximately.....	10
26. Sandstone and siltstone rubble; computed thickness approximately.....	20
25. Covered interval; computed thickness approximately.....	20
24. Sandstone, massive, medium-gray, medium-grained, moderately porous, crossbedded.....	15
23. Covered interval; computed thickness approximately.....	30
22. Clay shale.....	10
21. Sandstone, massive, medium-gray, fine to medium-grained; weathers yellow red; calcareous; abundant fossil wood and mud-ball concretions.....	75
20. Coal and ironstone rubble; computed thickness approximately.....	15
19. Ironstone, limy.....	5

Upper part, Killik tongue—Continued

	Feet
18. Silty shale and coal rubble; computed thickness approximately.....	25
17. Sandstone rubble; computed thickness approximately.....	10
16. Covered interval; computed thickness approximately.....	100
15. Sandstone, massive, medium-gray to dark-green, fine-grained, carbonaceous.....	70
14. Covered interval; computed thickness approximately.....	40
13. Sandstone, thin to medium-bedded, gray, fine to medium-grained, crossbedded; contains minute specks of ferruginous material, lenses and beds of calcareous ironstone, and abundant fossil plant fragments.....	8
12. Covered interval; computed thickness approximately.....	20
11. Sandstone, massive, light-gray, fine-grained; weathers rust brown; hard, nonporous; rubble, computed thickness approximately.....	7
10. Covered interval; computed thickness approximately.....	40
9. Sandstone, medium-bedded, gray, fine to medium-grained; weathers orange brown; crossbedded, ferruginous. In part rubble; computed thickness approximately.....	15
8. Covered interval; computed thickness approximately.....	25
7. Sandstone, conglomeratic massive, gray, medium to coarse-grained, carbonaceous; contains fossil wood; conglomeratic constituents are subangular black chert pebbles scattered throughout unit.....	20
6. Covered interval; computed thickness approximately.....	25
5. Sandstone, conglomeratic, medium-bedded to massive, greenish-gray, fine-grained; weathers brownish black. Lenticular beds $\frac{1}{2}$ to 1 in. thick of subangular to subround chert and white quartz pebbles; predominately black chert.....	40
4. Covered interval; computed thickness approximately.....	190
3. Sandstone, medium-bedded, light-gray, fine-grained; weathers light tan; porous, cross-bedded; ironstone concretions.....	40
2. Covered interval; computed thickness approximately.....	210
1. Sandstone, conglomeratic, massive, greenish-gray, coarse-grained; fossil wood fragments. Conglomeratic constituents are primarily black chert pebbles with a few white quartz pebbles.....	100
Total.....	2,176

Tuktu formation (see page 364).

Lower part, Killik tongue:

35. Silty shale and coal rubble; computed thickness approximately.....	50
34. Sandstone, thin to medium-bedded, medium-gray, very fine grained; weathers to dark yellow red; silty.....	20

Lower part, Killik tongue—Continued

	Feet
33. Siltstone and silty shale; siltstone units 2 to 4 feet thick, silty shale units 5 to 8 feet thick; calcareous.....	25
32. Coal.....	2
31. Siltstone and silty shale with limestone and ironstone concretions.....	35
30. Sandstone, massive, medium-gray, very fine grained; weathers dark yellow red.....	3
29. Silty shale.....	10
28. Coal.....	2
27. Clay shale.....	2
26. Coal.....	3
25. Silty shale.....	10
24. Sandstone, massive, medium-gray, very fine grained.....	5
23. Siltstone and silty shale with numerous small ironstone concretions; rubble; computed thickness approximately.....	170
22. Sandstone, thin-bedded, dark-green, fine-grained; silty shale and coal interbedded with sandstone; rubble; computed thickness approximately.....	50
21. Conglomerate, massive, pebble-granule; primarily rounded chert with little white quartz; sandstone matrix.....	40
20. Limestone, black, carbonaceous.....	1
19. Silty shale, green, carbonaceous, with sandstone interbeds ½ to 2 in. thick; fine grained.....	20
18. Sandstone, thin-bedded, light- to medium-gray, fine-grained, ripple-marked; worm trails; few siltstone interbeds.....	10
17. Siltstone and silty shale with limestone concretions; fossil tree trunks standing upright in section; mostly rubble; computed thickness approximately.....	130
16. Sandstone, very fine grained, silty, crossbedded.....	10
15. Coal.....	6
14. Silty shale.....	15
13. Coal.....	2
12. Silty shale.....	40
11. Sandstone, conglomeratic, thin-bedded to massive, gray, fine to medium-grained; few siltstone interbeds. Conglomeratic constituents include angular to subangular pebbles of black chert and white quartz.....	60

Tuktu formation (see page 364).

Lower part, Killik tongue:

10. Coal.....	6
9. Claystone.....	1
8. Sandstone, medium-bedded, medium-gray, coarse-grained, very hard, crossbedded; limestone concretions.....	15
7. Coal.....	3
6. Silty shale, black; bony layers.....	8

Tuktu formation (see page 364).

Lower part, Killik tongue:

5. Subgraywacke sandstone and siltstone, massive, medium-gray, very fine grained; rubble; computed thickness approximately.....	20
4. Subgraywacke sandstone, siltstone, silty shale, and coal rubble; numerous ironstone concretions; computed thickness approximately.....	240

Lower part, Killik tongue—Continued

	Feet
3. Sandstone, massive, very fine grained, silty, hard, highly calcareous; rubble; computed thickness approximately.....	25
2. Sandstone, siltstone, silty shale, and ironstone concretions; rubble; computed thickness approximately.....	135
1. Sandstone, massive, medium-gray to light-yellow-red, fine-grained; carbonaceous material and plant fossils.....	100
Total.....	1, 274

Tuktu formation.

The Kurupa River section (pl. 48, column 2) was measured on the east bank of the Kurupa River between lat 68°54' N. and 68°57' N. near Heather Creek. The section is exposed in a series of discontinuous ledges and cutbanks on the north flank of Kurupa anticline where the strata dip 7° to 20° N. The exposed part of the section was measured. The computed stratigraphic thickness for the covered intervals should be accurate to within 10 percent. The section was measured by Chapman and Thurrell in 1946; it was reexamined in 1947 by Thurrell and Zumberge, and in 1950 by Eberlein and Reynolds.

Section of the Killik tongue along the Kurupa River

Niakogon tongue.

Upper part, Killik tongue:

	Ft	In
66. Sandstone, siltstone, silty shale, clay shale, coal, and ironstone; rubble in covered interval; computed thickness approximately.....	110	0
65. Sandstone, thin-bedded, light-yellow-red; very fine grained, interbedded siltstone and ironstone; numerous plant fossils.....	27	0
64. Sandstone, claystone, clay shale, silty shale, coal, and ironstone; rubble; computed thickness approximately.....	40	0
63. Sandstone, thin- to medium-bedded, pale-yellow-red, medium- to coarse-grained; ironstone beds and concretions.....	15	0
62. Siltstone, silty shale, clay shale, coal and ironstone; rubble; computed thickness approximately.....	50	0
61. Siltstone and claystone with a few thin layers of sandstone and ironstone interbedded.....	10	0
60. Sandstone, thin-bedded, medium-gray, very fine grained; weathers yellow red; crossbedded.....	8	0
59. Covered interval; computed thickness approximately.....	180	0
58. Sandstone, medium-bedded, medium- to coarse-grained, salt-and-pepper, weathers moderate yellow red; abundant wood fossils and coaly lenses.....	40	0
57. Sandstone, siltstone, and silty shale rubble in covered area; computed thickness approximately.....	75	0

Upper part, Killik tongue—Continued

	Ft	In
56. Sandstone, conglomeratic, massive, medium-grained, with lenticular beds of chert- and quartz-pebble conglomerate 3 ft thick.....	30	0
55. Conglomerate, massive, pebble-size, chert and quartz.....	8	0
54. Sandstone, medium-bedded, medium- to coarse-grained; few pebbles.....	6	6
53. Limestone, pale-yellow-brown.....		3
52. Claystone.....		3
51. Sandstone, thin- to medium-bedded, medium-gray, fine- to coarse-grained.....	4	0
50. Sandstone, thin-bedded, pale-yellow, very fine grained.....	15	0
49. Siltstone and claystone.....	8	0
48. Conglomerate; local unconformity between this and overlying unit.....	3	0
47. Covered; computed thickness approximately.....	85	0
46. Conglomerate, massive, pebble-cobble; predominantly ½ to 1 in. long with few cobbles as much as 4 in. long. Chert and quartz in about equal proportions.....	25	0
45. Sandstone, thin- to medium-bedded, medium- to coarse-grained.....	5	0
44. Siltstone, coal, and ironstone rubble in covered interval; computed thickness approximately.....	125	0
43. Coal.....	1	0
42. Clay shale and fire clay with thin coal seams.....	6	0
41. Sandstone, thin-bedded, pale-yellow-red, fine-grained, ironstone concretions.....	4	0
40. Covered interval; computed thickness approximately.....	50	0
39. Siltstone.....	5	0
38. Sandstone, pale-yellow-red, fine- to medium-grained, crossbedded; ironstone concretions.....	20	0
37. Siltstone and limestone rubble in covered interval; computed thickness approximately.....	30	0
36. Claystone.....	2	0
35. Covered; computed thickness approximately.....	10	0
34. Sandstone, thin-bedded, pale-yellow-red, fine- to medium-grained, crossbedded; wood fossils and ironstone concretion.....	8	0
33. Sandstone, siltstone, and ironstone, interbedded.....	4	0
32. Asphalt rock, or petroliferous black limestone.....		2
31. Coal.....	2	0
30. Siltstone and clay shale.....	2	0
29. Clay shale with bony partings.....	6	0
28. Siltstone.....	3	0
27. Limestone, pale-yellow, massive; abundant plant fossils.....	2	0
26. Covered; computed thickness approximately.....	70	0
25. Conglomerate, massive; pebbles ¼ to ½ in. in diameter; 80 percent subround, black and green chert, and 20 percent rounded		

Upper part, Killik tongue—Continued

	Ft	In
25. Conglomerate, massive—Continued white quartz; matrix is medium-grained salt and pepper sandstone; abundant wood fossils.....	6	0
24. Sandstone, medium-grained.....	6	0
23. Coal, soft, chunky.....	6	0
22. Sandstone and siltstone, with several thin beds of bone and ironstone.....	10	0
21. Covered; computed thickness approximately.....	65	0
20. Sandstone, thin-bedded, medium-gray, fine- to medium-grained, crossbedded; beds and concretions of ironstone.....	10	0
19. Clay shale, fire clay, and coal; rubble; computed thickness approximately.....	10	0
18. Sandstone, thin-bedded, very fine grained; grades into siltstone.....	10	0
17. Sandstone, siltstone, silty shale, and coal rubble; computed thickness approximately.....	215	0
16. Coal and underclay, rubble; computed thickness approximately.....	5	0
15. Sandstone, thin-bedded, light-gray, fine-grained, crossbedded, with considerable slickensided calcite; ironstone beds.....	10	0
14. Sandstone, siltstone, silty shale, ironstone beds, and several coal beds; rubble; computed thickness approximately.....	70	0
13. Sandstone, thin-bedded, light-gray, fine- to medium-grained, crossbedded, with scattered ironstone beds.....	20	0
12. Coal and siltstone rubble; computed thickness approximately.....	150	0
11. Sandstone, medium-grained, interbedded with siltstone and ironstone; abundant carbonaceous material.....	20	0
10. Sandstone, siltstone, silty shale, and coal rubble; computed thickness approximately.....	240	0
9. Coal, chunky.....	3	0
8. Sandstone, thin- to medium-bedded, light-yellow-gray, medium- to coarse-grained; weathers moderate yellow red; laminated, crossbedded; with slickensided calcite and abundant plant fossils.....	30	0
7. Sandstone, siltstone, silty shale, coal, and ironstone rubble; computed thickness approximately.....	240	0
6. Sandstone, conglomeratic, medium-bedded, medium-yellow-red, fine- to medium-grained; lenticular beds of pebble conglomerate; numerous plant fossils.....	10	0
5. Conglomerate; pebbles and cobbles of chert and white quartz.....	3	0
4. Sandstone, conglomeratic, fine- to coarse-grained; lenticular pebble-conglomerate beds; numerous plant fossils.....	15	0
3. Sandstone, pale-yellow-red, fine-grained, crossbedded.....	15	0
2. Sandstone, siltstone, silty shale, and coal; rubble; computed thickness approximately.....	200	0

Upper part, Killik tongue—Continued			Tuktu formation (see page 365).		
	Ft	In		Ft	In
1. Sandstone, conglomeratic, medium-bedded, light-gray, fine- to coarse-grained, with lenticular beds of pebble-conglomerate; consists of white quartz, black and green chert, and less than 5 percent gray quartzite.....	20	0	Lower part, Killik tongue:		
Total.....	2,484	2	3. Covered; computed thickness approximately.....	185	0
Lower part, Killik tongue:			2. Sandstone, thin to medium-bedded, pale-yellow to greenish-yellow, fine-grained, carbonaceous, with few medium-gray silty shale interbeds.....	15	0
19. Siltstone, silty shale, and coal rubble; computed thickness approximately.....	140	0	1. Sandstone, conglomeratic, massive, pale-greenish-yellow, very fine to fine-grained, with few widely scattered black chert and white quartz pebbles ½ to ¾ in. in diameter; numerous clay galls and carbonized plant fragments....	50	0
18. Sandstone, irregularly bedded, medium-gray salt-and-pepper, very fine grained; weathers light yellow red; crossbedded, ripple-marked.....	10	0	Total.....	1,286	0
17. Sandstone, siltstone, silty shale, and coal. Sandstone fine grained, dull yellow red to gray salt-and-pepper, crossbedded, ironstained; slickensided calcite. Mostly rubble; computed thickness approximately.....	220	0	Tuktu formation.		
16. Sandstone, subgraywacke; interbedded with soft fissile silty iron-stained shale and siltstone; carbonaceous layers in siltstone; ironstone concretions.....	20	0	The Oolamnagavik River section (pl. 48, column 3) was measured on the escarpment on the northwest bank of the river by Chapman and Thurrell in 1946. The section is on the south flank of the Oolamnagavik syncline in strata that dip 5° to 8° N. Only the lower 243 feet was measured.		
15. Covered; computed thickness approximately.....	150	0	<i>Section of part of the Killik tongue on the Oolamnagavik River</i>		
14. Sandstone, massive, light to moderate-yellow-red, very fine to fine-grained, well-indurated.....	10	0	Lower part, Killik, tongue: Feet		
13. Siltstone, silty shale, coal and bone, and ironstone concretions; rubble; computed thickness approximately.....	55	0	4. Sandstone, conglomeratic, thin to medium-bedded, pale-yellow-red, fine to coarse-grained; some beds fissile; crossbedded. Pebble conglomerate in beds 4 to 6 in. thick is 60 percent black chert, 30 percent white quartz, 10 percent colored chert and light-gray quartzite.....	18	
12. Sandstone, subgraywacke, and siltstone; irregular beds 1 to 3 ft thick; medium-gray; ironstone nodules.....	10	0	3. Sandstone, shaly-bedded, pale-yellow; weathers red brown; occasional pebble-conglomerate layer; chert and white quartz.....	95	
11. Coal, low-grade, bone, and coaly shale.....	4	6	2. Sandstone, light-gray, siltstone, and silty shale rubble; computed thickness approximately.....	80	
10. Siltstone and silty shale, medium-gray, carbonaceous, iron-stained; siltstone concretions in the shale.....	10	0	1. Sandstone, shaly-bedded, light-gray, very fine to fine-grained, with an occasional pebble.....	50	
9. Sandstone, siltstone, and silty shale rubble in covered interval; computed thickness approximately.....	40	0	Total.....	243	
Tutktu formation (see page 365).			Tuktu formation.		
Lower part, Killik tongue:			The section from the lower Oolamnagavik River and Killik Bend of the Colville River (pl. 48, column 4) was measured by Chapman and Thurrell in 1946, and by Detterman and Bickel in 1953. The lower part of the tongue is well exposed along the Colville River in beds that dip 22° to 25° S. The upper part of the tongue is represented by a series of discontinuous ledges and rubble traces along the Oolamnagavik River in strata that dip 10° to 16° S.		
8. Covered; computed thickness approximately.....	270	0	<i>Section of the Killik tongue on the Oolamnagavik River and at Killik Bend, Colville River</i>		
7. Clay shale rubble; computed thickness approximately.....	10	0	Niakogon tongue.		
6. Sandstone, conglomeratic medium-bedded to massive, pale-yellow-gray, fine- to very fine-grained; weathers moderate yellow red, with lenticular conglomerate beds 6 to 8 in. thick of subangular to subrounded black, gray, and green chert ½ to ¾ in. in diameter; some rounded white quartz pebbles. A few sandstone concretions and one 6-in. fissile shale bed in center of unit.....	60	0	Upper part, Killik tongue: Feet		
5. Carbonaceous shale.....	1	6	17. Sandstone, thin- to medium-bedded, dark-yellow-red, fine-grained, argillaceous; interbedded with micaceous carbonaceous siltstone, silty shale, coal, and ironstone. Rubble; computed thickness approximately.....	25	
4. Covered; computed thickness approximately.....	25	0			

Upper part, Killik tongue—Continued		Feet	Lower part, Killik tongue—Continued		Ft	In
16. Covered interval; computed thickness approximately-----		110	92. Covered interval; computed thickness approximately-----		25	0
15. Sandstone, medium-bedded, light-gray, fine- to medium-grained, crossbedded; abundant plant and fern fossils; 6-in. ironstone bed at base----		10	91. Sandstone, medium- to heavy-bedded, dark-gray to yellow-red, fine-grained, carbonaceous-----		15	0
14. Clay shale, coal, siltstone, and ironstone rubble; computed thickness approximately-----		30	90. Silty shale, dark-gray, fissile, carbonaceous-----		4	0
13. Sandstone, thin- to medium-bedded, light-gray to yellow-red, fine- to medium-grained; interbedded with siltstone, silty shale, coal, and ironstone both as beds and concretions; exposed as a series of rubble traces; computed thickness approximately-----		590	89. Siltstone and sandstone, dark-gray, very fine-grained-----		5	0
12. Sandstone, massive, fine-grained, dark-yellow-red, argillaceous; abundant plant fossils-----		8	88. Covered; computed thickness approximately-----		5	0
11. Covered interval; computed thickness approximately-----		140	87. Sandstone, heavy-bedded, dark-yellow-red, fine-grained-----		29	0
10. Sandstone, thin-bedded to massive, dark-yellow-red, fine- to medium-grained, argillaceous, carbonaceous; several layers of siltstone and silty shale containing ironstone nodules interbedded-----		20	86. Siltstone and silty shale, carbonaceous-----		7	0
9. Sandstone, siltstone, silty shale, and ironstone rubble in covered interval; computed thickness approximately-----		380	85. Covered; computed thickness approximately-----		10	0
8. Sandstone, thin-bedded, fine-grained, salt-and-pepper-----		5	84. Coal-----		1	0
7. Conglomerate, massive; pebble and cobbles $\frac{1}{4}$ to 3 in. in length, average about 1 in.; 50 percent white quartz, 40 percent black chert, 10 percent colored chert and elliptical hematite nodules with flat axis parallel to bedding; one petrified log 10 feet long-----		50	83. Sandstone-----		2	0
6. Sandstone, thin-bedded, fine-grained, salt-and-pepper, conglomeratic; siltstone and silty shale interbedded-----		15	82. Coal-----			6
5. Sandstone, medium-bedded to massive, salt-and-pepper, coarse-grained, conglomeratic-----		10	81. Siltstone, silty shale, and fine-grained dark-yellow-red carbonaceous sandstone-----		15	0
4. Sandstone, siltstone, silty shale, ironstone, few chert and quartz pebbles, mostly rubble; computed thickness approximately-----		180	80. Covered; coal rubble; computed thickness approximately-----		20	0
3. Sandstone, shaly to thin-bedded, fine- to medium-grained; weathers dark yellow red; interbedded lenticular siltstone and silty shale, and ironstone; few thin coal seams; in part rubble; computed thickness approximately-----		55	79. Silty shale, coal stringers-----		6	0
2. Sandstone and siltstone rubble in covered interval; computed thickness approximately-----		65	78. Sandstone, heavy-bedded, dark-yellow-red, fine- to medium-grained-----		12	0
1. Sandstone, conglomeratic, medium-bedded, salt-and-pepper, medium-grained; rubble; computed thickness approximately-----		20	77. Covered; computed thickness approximately-----		5	0
Total-----		1,713	76. Siltstone and sandstone, dark-yellow-red with greenish cast, fine-grained; carbonaceous, argillaceous-----		5	0
			75. Covered; computed thickness approximately-----		5	0
			74. Sandstone, siltstone, and silty shale; ironstone concretions-----		19	0
			73. Siltstone, sandy-----		11	0
			72. Covered; computed thickness approximately-----		5	0
			71. Sandstone, dark-yellow-red very fine grained, silty-----		5	0
			70. Covered; computed thickness approximately-----		3	0
			69. Siltstone and silty shale-----		5	0
			68. Siltstone, carbonaceous-----		5	0
			67. Covered; computed thickness approximately-----		8	0
			66. Coal-----		1	8
			65. Silty shale-----		6	0
			64. Coal-----		2	4
			63. Siltstone, dark-yellow-red, silty shale, and sandstone; medium bedded, fine grained; weathers rust brown to maroon-----		9	0
			62. Covered; computed thickness approximately-----		4	0
			61. Sandstone, heavy bedded, dark-gray with greenish cast; fine grained-----		10	0
			60. Siltstone, dark-yellow-red; silty shale, and fine-grained sandstone-----		22	0
			59. Covered; computed thickness approximately-----		7	0
			58. Sandstone, medium bedded, dark-gray with greenish cast, fine grained, silty--		13	0
Lower part, Killik tongue:						
96. Covered interval; computed thickness approximately-----	Ft	In				
95. Sandstone, shaly-bedded, medium-gray fine-grained, crossbedded-----	665	0				
94. Sandstone, conglomeratic, massive, medium- to coarse-grained with lenticular conglomerate beds of chert and quartz pebbles-----	5	0				
93. Silty shale-----	10	0				
	10	0				

Lower part, Killik tongue—Continued			Lower part, Killik tongue—Continued		
	Ft	In		Ft	In
57. Silty shale.....	1	0	13. Coal.....	1	2
56. Sandstone.....	2	0	12. Siltstone and silty shale, sandstone lenses.....	50	0
55. Covered; computed thickness approximately.....	6	0	11. Covered; computed thickness approximately.....	20	0
54. Sandstone, medium-bedded dark-yellow-red.....	15	0	10. Siltstone and silty shale.....	6	0
53. Coal.....		4	9. Covered; computed thickness approximately.....	6	0
52. Silty shale and siltstone.....	25	0	8. Silty shale, siltstone, and dark-gray sandstone, weathers brown.....	20	0
51. Coal.....	1	10	7. Silty shale.....	15	0
50. Siltstone, silty shale, and massive, dark-gray to yellow-red, fine-grained, argillaceous sandstone.....	40	0	6. Covered; computed thickness approximately.....	10	0
49. Siltstone with ironstone concretions.....	4	0	5. Siltstone.....	30	0
48. Silty shale.....	4	0	4. Coal.....	6	6
47. Coal.....		8	3. Sandstone, massive medium-green, fine-grained; plant fragments.....	9	0
46. Siltstone and silty shale.....	5	0	2. Coal.....	1	2
45. Silty shale, ferruginous, fissile.....	5	0	1. Siltstone and silty shale, carbonaceous.....	8	0
44. Sandstone, massive, dark-yellow-red, fine-grained.....	7	0			
43. Covered; computed thickness approximately.....	6	0	Total.....	1,605	7
42. Sandstone.....	1	0	Tuktu formation		
41. Covered; computed thickness approximately.....	5	0	The type section of the Killik tongue (pl. 48, column 5) was measured along the east bank of the Killik River between lat 68°52' N. and 68°55' N. The section is exposed in a series of discontinuous ledges and cutbanks on the north flank of Kurupa anticline in strata that dip 13° to 15° N. Quaternary terrace deposits cover parts of the section. The exposed parts of the section were measured. As horizontal and vertical control are good, the computed thickness for the covered intervals should be accurate to within 10 percent. Details of the section are described in Detterman, Bickel, and Gryc (1963, p. 249).		
40. Sandstone, massive, rusty-brown, fine-grained.....	8	0	Age and correlation.—The age of the nonmarine-marginal strata of the Killik tongue cannot be determined precisely from fauna; however, it can be ascertained indirectly from fossils in the underlying Tuktu formation, and in the overlying Ninuluk formation. One collection of invertebrate fossils was obtained from the Killik tongue. The pelecypods were identified by Imlay as <i>Unio</i> sp., a long-ranging, brackish- to fresh-water pelecypod of no value for correlation.		
39. Covered; computed thickness approximately.....	12	0	Fossils from beds of the Tuktu are correlated by Imlay (1961) with the middle Albian of Europe; these include the following diagnostic forms: <i>Inoceramus anglicus</i> Woods, <i>Panope? elongatissima</i> (McLearn), <i>Entolium utukokensis</i> Imlay, <i>Tancredia kurupana</i> Imlay, and the ammonite <i>Cleonicerias</i> (<i>Neosaynella?</i>) <i>whittingtoni</i> Imlay. The <i>Cleonicerias</i> sp. may indicate an early middle Albian age, but the preponderance of faunal evidence indicates a middle Albian age. In the Killik River area the marine Ninuluk formation conformably overlies the Killik tongue. The Ninuluk contains <i>Inoceramus dunveganensis</i> McLearn. This fossil is present also in the Dunvegan formation of Canada.		
38. Sandstone, massive, dark-yellow-red, fine-grained.....	10	0			
37. Silty shale, ferruginous.....	1	0			
36. Coal.....	3	8			
35. Sandstone, shaly-bedded, fine-grained.....	2	0			
34. Coal.....		9			
33. Siltstone and sandstone.....	16	0			
32. Silty shale.....	2	0			
31. Coal.....	1	0			
30. Siltstone, thin to heavy bedded, salt-and-pepper to dark-yellow-red, silty shale, and sandstone; fine grained.....	23	0			
29. Coal.....	2	0			
28. Siltstone and sandstone.....	28	0			
27. Silty shale.....	2	0			
26. Sandstone, massive, salt-and-pepper to dark-yellow-red, fine-grained; weathers brown; clean, ripple marked.....	30	0			
25. Covered, coal float; computed thickness approximately.....	2	0			
24. Siltstone, silty shale, and sandstone.....	23	0			
23. Covered, silty shale, and coal float; computed thickness approximately.....	12	0			
22. Sandstone, siltstone, and silty shale.....	20	0			
21. Silty shale.....	6	0			
20. Covered; computed thickness approximately.....	6	0			
19. Sandstone and siltstone.....	5	0			
18. Silty shale and siltstone.....	12	0			
17. Covered; computed thickness approximately.....	18	0			
16. Sandstone, massive, dark-yellow-red, fine-grained, hard; weathers brown.....	11	0			
15. Siltstone and silty shale.....	5	0			
14. Sandstone, silty shale, and siltstone.....	35	0			

and is no older than Cenomanian. Thus, the Killik tongue is at least as old as middle Albian and no younger than Cenomanian; the possibility of its being equivalent in part to the late Albian can neither be proved or disproved.

Plant fossils are moderately abundant in the beds of both the upper and lower parts of the Killik tongue, particularly in the ironstone beds. Collections from 10 field samples made from beds in the tongue are shown in table 10; seven were identified by R. W. Brown, three by F. H. Knowlton, and one by Stewart Lowther. The plant fossils are tentatively considered to be Late Cretaceous in age.

Forty-four microfossil samples were collected from shale in the Killik tongue, 30 from the upper part and 14 from the lower part; all samples are barren. Thirty-four samples were collected from the marine Tuktuk formation that is intertongued with strata of the Killik; 29 of these samples are fossiliferous. The fossils were identified by H. R. Bergquist, who reported (written communication): "The combined fauna has 20 species

and is part of the *Verneuilinoides borealis* faunal zone." Thus, the microfossils indicate an Albian age for the beds. All microfossil samples are listed in table 9. Rocks that are in part equivalent to the Killik tongue of the Chandler formation in the Killik-Etiviluk Rivers region were mapped by C. L. Whittington (oral communication) as Corwin formation (Sable, 1956, p. 2641-2643), in the adjacent area to the north and west. The Corwin formation at the type locality is about 10,000 feet thicker than the Chandler formation in the Killik-Etiviluk Rivers region; however, the Chandler formation does become thicker toward the west at a rate of about 25 feet per mile. Lithologically the two formations are very similar, the dominant rock types being shale, siltstone, sandstone, conglomerate, and coal.

NIAKOGON TONGUE

Occurrence.—The Niakogon tongue is present only in the northern part of the Killik-Etiviluk Rivers region; it does not crop out south of lat 68°55' N. The tongue is exposed on both flanks of the Awuna syncline, with the best exposures being between the Oolamnagavik and Kurupa Rivers. In general the tongue is covered by terrace gravels between the Killik and Oolamnagavik and along the Kurupa and Colville Rivers.

The type section for the Niakogon tongue is on the east bank of the Killik River, 10 miles upstream from the confluence with the Colville River. The tongue is about 652 feet thick at the type locality, but is incomplete because the upper contact with the Seabee formation was not seen; however, this sequence of 652 feet is probably near the maximum thickness for the unit. The Niakogon is the upper tongue of the nonmarine Chandler formation, and is, at least in part, the age equivalent of the marine Ninuluk formation. In addition to the section at the type locality, two other sections of the tongue were measured: a 510-foot section on the east bank of the Kurupa River, and a 525-foot poorly exposed section along the south bank of the Colville River, opposite the mouth of the Awuna River.

At the type locality the Niakogon tongue overlies a 40-foot section of marine Ninuluk formation. The contact is conformable and well defined; the rusty-weathering yellow-red sandstone, with abundant interbedded coal and bentonite, changes abruptly to a greenish-gray marine fossiliferous sandstone and conglomerate. The Ninuluk formation was not mapped west of the Killik River; either it is absent owing to a rapid facies change from marine to nonmarine strata in a westerly direction, or else it was not recognized in the poor exposure on west side of river. The Niakogon is in contact with the Killik tongue throughout the rest of the region.

TABLE 10.—Plant fossils from Killik tongue

[Identifications: a, R. W. Brown; b, F. H. Knowlton (Smith and Mertie, 1930, p. 222-223); c, Stewart Lowther (unpublished Ph. D. thesis, Michigan Univ.). Field samples 53 AB1 18, 53 ADt 40, 53, 56, Killik River; others, Colville River]

Fossil	Stratigraphic position (from top)									
	Upper	950 ft	1750 ft	Lower						
	Field sample (USGS Mesozoic locality)									
	53 AB1 18	24 AS 36 and 37 (7445)	53 ADt 56 ¹	53 ADt 53 ¹	53 ADt 40	53 ADt 79	53 AB1 24	53 AB1 25	24 AS 29 (7742)	24 AS 32 (7744)
<i>Cephalotaxopsis heterophylla</i> Hollick	a						a			
<i>intermedia</i> Hollick			a						b	b
sp.....										
<i>Cladophlebis septentrionalis</i> Hollick							a	a		
sp.....									b	
<i>Coniopteris burejensis</i> (Zalassky) Seward						c				
<i>Ginkgo concinna</i> Heer							a			
<i>Nitazonia</i> sp.....		b								
<i>Podocarpites lanceolatus</i> (Lindley and Hutton) Braun		b	a						b	
<i>Pterophyllum?</i> sp.....										b
<i>Sequoia fastigiata</i> Heer									b	
<i>Sequoia</i> , cone									b	
<i>Tumion</i> sp.....				a						b
Stems.....					a					
Coniferous wood.....										

¹ Plate 48, column 5.

The contact between the two tongues is gradational and their gross lithologic features are similar; however, they can be differentiated, mainly owing to a greater amount of bentonite and limonitic material in the Niakogon tongue.

The Seabee formation overlies the Niakogon tongue along the Awuna syncline, between the Oolamnagavik and Kurupa Rivers. The contact between the two units is unconformable. The unconformity is well exposed on the east side of a small tributary of the Colville River, at lat 68°58' N., long 154°16' W. At this locality, beds of the Seabee formation truncate nearly the complete Niakogon sequence; elsewhere, the unconformity is not as well defined.

Character and thickness.—The nonmarine Niakogon tongue is dominantly a salt-and-pepper to yellow-red, highly iron stained conglomeratic sandstone at the type locality. The sandstone is fine to coarse grained, thin bedded to massive, and generally well indurated. The conglomeratic constituents are 90 percent chert and 10 percent white quartz pebbles. The limonitic material is mainly concentrated in the upper part of the section. Clay and silty shale constitutes about 40 percent of the section; subordinate constituents include coal, bentonite, siltstone, and ironstone concretions. Plant fossils are common throughout.

The Kurupa River section, 40 miles west of the type locality, exhibits a slightly different facies of the Niakogon tongue. The lower 300 feet of the 510-foot section is dominantly shale with interbedded siltstone and fine- to medium-grained pale-yellow-red sandstone. A few pebbles of chert and white quartz are present in the basal sandstone unit; these are the only pebbles in the Kurupa River section. Several limestone beds and numerous thin coal and fire clay beds are present in this part of the sequence.

The upper part of the Kurupa River section is predominantly sandstone, thin bedded to massive, fine grained, and light yellow red to greenish yellow. The conglomerate present in the Killik River is missing from this section. Subordinate constituents include coal, bentonite, ironstone concretions, and a black massive limestone or calcilutite.

The Colville River section is inferred to be 525 feet thick; it is poorly exposed and only the upper 90 feet crops out in a cut on the south bank opposite the mouth of the Awuna River. The sequence is composed of nearly equal parts of sandstone, siltstone, and shale, all of which are bentonitic and poorly consolidated. The sandstone is thin to medium bedded, fine grained, and medium gray. Fossil leaves of deciduous trees are common in the sandstone.

The tongue does not appear to thicken in a westerly direction as do some of the older units of the Nanushuk

group. On the other hand, the beds may have been eroded before deposition of the Seabee formation, for there is a well-developed unconformity between the two stratigraphic units. Much of the Niakogon tongue is overlain by terrace deposits and may have been eroded prior to the deposition of these terrace deposits.

The Colville River section (pl 48, column 1) was measured on the south bank of the Colville, about 1½ miles upstream from the mouth of the Awuna River. The section is on the south flank of the Awuna syncline in strata that dip 3° N. The upper 90 feet of the inferred 525-foot section crops out in one bluff; the computed thickness may be in error by as much as 15 percent.

Section of Niakogon tongue along the Colville River, 1½ miles upstream from the mouth of the Awuna River

Terrace deposits.

Unconformity.

	Feet
Niakogon tongue (section incomplete):	
5. Clay shale, bentonitic, sandy.....	15
4. Sandstone, medium-bedded, medium-gray, fine-grained, very friable, bentonitic.....	20
3. Sandstone, thin-bedded, medium-gray, fine-grained, bentonitic; contains abundant fossil wood and leaves of deciduous trees.....	15
2. Siltstone, silty shale, coal, and ironstone concretions; rubble; computed thickness approximately.....	40
1. Covered; computed thickness.....	435
Total.....	525
Upper part, Killik tongue.	

The Kurupa River section (pl. 48, column 2) is exposed on the east bank of the river, 4 to 6 miles downstream from the mouth of Heather Creek. The beds are exposed in a series of river bluffs on the south flank of the east-plunging Awuna syncline in strata that dip 5°, or less, to the north; this is the most complete exposure of the Niakogon tongue in the Killik-Etiviluk Rivers region.

Section of Niakogon tongue on the Kurupa River

Terrace deposits.

Unconformity.

	Ft	In
Niakogon tongue (section incomplete):		
50. Clay shale and coal rubble; computed thickness approximately.....	18	0
49. Sandstone, thin-bedded, pale-yellow, very fine grained; a few thin layers of siltstone interbedded.....	5	0
48. Sandstone, thin- to medium-bedded, pale-yellow, fine-grained; weathers yellow red; small ironstone concretions.....	25	0
47. Limestone, massive; black, weathers yellow red. Clay shale, silty shale, siltstone, and ironstone concretions. Rubble. Computed thickness approximately.....	40	0

Niakogon tongue—Continued

	<i>Ft</i>	<i>In</i>	Niakogon tongue—Continued	<i>Ft</i>	<i>In</i>
46. Sandstone, thin-bedded, pale-green-yellow, very fine grained, friable, cross-bedded; ironstone lenses	25	0	8. Coal		8
45. Sandstone, massive, pale-yellow-red, very fine grained	2	6	7. Siltstone	3	0
44. Sandstone, shaly-bedded, very fine grained, very friable, carbonaceous	1	3	6. Clay shale with numerous coal beds 3 to 6 in. thick	25	0
43. Clay shale and coal rubble; computed thickness approximately	10	0	5. Siltstone	25	0
42. Siltstone, laminated, micaceous; beds 1 to 2 in. thick, interbedded with claystone; few ironstone concretions and plant fragments	10	0	4. Siltstone and silty shale rubble in covered interval; computed thickness approximately	40	0
41. Sandstone, massive, pale-greenish-yellow, very fine grained, friable	8	0	3. Sandstone, medium-bedded, pale-yellow, medium-grained; crossbedded; few chert and quartz pebbles	8	0
40. Siltstone and claystone similar to unit 42, with 10 in. of bentonitic clay	17	0	2. Claystone	4	0
39. Coal	1	0	1. Coal		8
38. Covered; computed thickness approximately	10	0	Total	509	10
37. Sandstone, thin-bedded to massive, light-yellow-red, very fine to fine-grained, carbonaceous, crossbedded; fossil tree trunk 2 ft in diameter	25	0	Upper part, Killik tongue.		
36. Sandstone, siltstone, and silty shale rubble; computed thickness approximately	25	0			
35. Sandstone, thin-bedded, light-yellow-red, fine-grained, friable, carbonaceous, crossbedded	20	0			
34. Sandstone, massive, light-gray to salt-and-pepper, coarse-grained, weathers moderate yellow red; abundant wood fragments	3	0			
33. Coal, shaly		6			
32. Fire clay		8			
31. Siltstone with ironstone concretions	10	0			
30. Coal, shaly		8			
29. Fire clay		6			
28. Siltstone	5	0			
27. Siltstone, silty shale, and coal rubble; computed thickness approximately	30	0			
26. Siltstone with ironstone concretions 1 to 3 in. in diameter	6	0			
25. Limestone, massive, pale-yellow-gray	1	2			
24. Claystone	3	0			
23. Sandstone, medium-bedded, light-yellow-red, medium-grained, crossbedded	3	0			
22. Siltstone	5	0			
21. Clay shale and coal rubble; computed thickness approximately	35	0			
20. Siltstone	5	0			
19. Coal		6			
18. Claystone	8	0			
17. Siltstone, massive, crossbedded	1	0			
16. Claystone and ironstone, carbonaceous	11	0			
15. Siltstone, silty shale, and coal, rubble; computed thickness approximately	25	0			
14. Coal	1	10			
13. Fire clay		8			
12. Coal		6			
11. Limestone		6			
10. Clay shale	2	3			
9. Siltstone	1	0			

The type section of the Niakogon tongue (pl. 48, column 5) was measured on the northeast bank of the Killik River between camps D-June 25-53 and W-July 12-45. The section is on the south flank of the east-plunging Killik Bend anticline in strata that dip 4° to 5° S. The upper contact was not seen, but the 652 feet measured probably represents nearly the total thickness for the tongue. Error in compilation should be less than 10 percent and probably is no greater than 5 percent. The detailed description of the section is given in Detterman, Bickel, and Gryc (1963).

Age and correlation.—The nonmarine Niakogon tongue is barren of megafossils; however, it overlies a 40-foot section of fossiliferous Ninuluk formation at the type locality. Pelecypods from the 40-foot section include the diagnostic *Inoceramus dunveganensis* McLearn and *Arctica?* cf. *A. dowlingi* McLearn of Cenomanian age. The fossils were identified by Imlay. The Seabee formation of late Turonian age overlies the tongue. Thus, the age of the Niakogon is Late Cretaceous, no older than Cenomanian, and no younger than Turonian.

Eight microfossil samples were collected from shale beds in this tongue; six are barren. The fossils in the other two samples were identified by H. R. Bergquist, who reported (written communication): "A few specimens of *Saccamina lathrami* Tappan occur in 2 of the 8 samples collected from this nonmarine tongue. This Foraminifera, however, is a long-ranging, simple arenaceous species of brackish-water environment, and has no significance other than [that it offers] a suggestion that minor encroachment of lagoonal areas onto a lowland occurred during Niakogon time, or that the area where the samples came from may have been adjacent to the mouth of an ancient stream".

The microfossils are of no value in establishing the age of the beds, because the species found occurs in beds as old as the Fortress Mountain formation and

as young as the uppermost beds in the Cretaceous sequence.

Plant fossils are abundantly preserved in beds of the Niakogon tongue; unfortunately only one collection was made. This collection was from the upper part of the type section and was made by Mertie in 1924. The plants were identified by F. H. Knowlton as follows (Smith and Mertie, 1930, p. 222): *Ginkgo* sp. fragment; *Podozamites* cf. *P. lanceolatus* or *P. latipinnis*; *Sequoia* cf. *S. smidtii* Heer; *Sequoia* cf. *S. angusta* Heer; *Pterosperrmites* sp., probably new. Knowlton stated: "In seeking to determine the age of this material it is necessary to throw out all but the dicotyledon. According to our present knowledge the dicotyledon did not appear until middle or later Cretaceous time. Therefore this is presumably not older than middle Cretaceous, though it might be later in the Cretaceous".

NINULUK FORMATION

Occurrence.—The 40-foot section of the Ninuluk formation mentioned above is on the east bank of the Killik River, near camp D—June 29–53. The formation may be present on the west bank of the river, although it has not been found there; it thins rapidly in a southwesterly direction (Detterman, Bickel, and Gryc, 1963) and is believed to be absent in the remainder of the Killik-Etiviluk region. The formation is, at least in part, the time equivalent of the Niakogon tongue with which it is intertongued. The southwesterly facies change is from marine to nonmarine strata, and the nonmarine beds are part of the Niakogon tongue.

Character and thickness.—The formation is composed dominantly of sandstone and shale in about equal parts. The sandstone is medium bedded to massive, fine to medium grained, and greenish gray. The basal bed is conglomeratic with 85 percent of the pebbles being dark chert, 5 percent green and gray chert, 5 percent white quartz, and 5 percent broken shell material and shale fragments. Subordinate constituents include siltstone and ironstone. The beds are of marine origin and can be differentiated from the overlying Niakogon tongue; the contact is conformable and well defined, but is not as sharp as it is farther east in the Chandler River region (Detterman, Bickel, and Gryc 1963), where the Ninuluk attains its maximum thickness.

The following section (pl. 48, column 5) of Ninuluk formation was measured at camp D—June 29–53, on the east bank of the Killik River. The beds are on the north flank of the Awuna syncline and dip 5° S.

Section of Ninuluk formation on the Killik River

Niakogon tongue.

Ninuluk formation:

- | | |
|--|------------|
| 3. Sandstone, medium-bedded to massive, fine- to medium-grained..... | Feet
10 |
|--|------------|

Ninuluk formation—Continued

2. Silty shale, clay shale, siltstone, thin-bedded sandstone; ironstone bed near top; in part rubble; computed thickness approximately.....	Feet 20
1. Sandstone, conglomeratic, and pebble conglomerate with 85 percent dark chert, 5 percent white quartz, 5 percent green and gray chert, 5 percent broken shell material and shale fragments; sandstone hard, greenish gray; abundant fossils. (USGS Mesozoic loc. 24629).....	10
Total.....	40

Upper part, Killik tongue.

Age and correlation.—Three megafossil collections were obtained from beds on the east side of the Killik River. Two species of pelecypods were identified by Imlay from these collections; they were *Inoceramus dunveganensis* McLearn and *Arctica?* cf. *A. dowlingsi* McLearn. These mollusks are also found in the megafauna in the Chandler River region, which, based on a similarity of species, is correlated with the Dunvegan formation of British Columbia and Alberta (R. W. Imlay, written communication); the Dunvegan formation is of Cenomanian age.

As the diagnostic fauna is found in the basal beds, it is reasonable to assume that no part of the formation is older than Cenomanian; elsewhere in the Chandler River region the Ninuluk is unconformably overlain by the Seabee formation (Detterman, Bickel, and Gryc, 1963). The Seabee contains a megafauna indicative of an early Turonian age. Therefore, the Ninuluk is entirely of Cenomanian age, but it cannot be determined from present field evidence whether the entire stage is present.

Fifteen microfossil samples were collected from the shale beds of the formation; seven are fossiliferous. The fossils were identified by Bergquist and are listed in table 9. Concerning these fossils Bergquist wrote (written communication): "Samples from this formation were all collected along the Killik River. Seven of the 15 samples collected are fossiliferous, but only one sample is typical of the fossiliferous beds of the formation, as it has abundant specimens of two species of Foraminifera, *Gaudryina irenensis* Stelck and Wall and *Trochammina rutherfordi* Stelck and Wall. Most of the specimens are flattened but fairly well preserved. Another sample has abundant specimens of *T. rutherfordi* but only a few specimens of *G. irenensis* and a few fragments of *Bathysiphon brosegi* Tappan. The other samples from the Ninuluk yielded only a few poorly preserved and crushed specimens of *Trochammina?* sp., *G. irenensis?*, and *Saccammina lathrami* Tappan."

COLVILLE GROUP

Sedimentary rocks of the Colville group probably are present along the axial trace of the doubly plunging Awuna syncline, between the Oolamnagavik River and Aupuk Creek. The rocks are in an east-trending belt 10 miles long and 5 miles wide. This particular part of the Killik-Etivluk Rivers region has not been explored by a field party; the rocks shown as the Colville group were mapped entirely from aerial photographs, and while their identity cannot be positively proved, there is good reason to believe they belong to the Colville group. Rocks of the Seabee and Prince Creek formations are known to be present in a structural low along the Awuna syncline just east of the Killik River (Detterman, Bickel, and Gryc, 1963), 20 miles east of the inferred occurrence in the Killik-Etivluk region. As seen on the photographs, an unconformable relation exists between beds of the Niakogon tongue and the younger rocks, and is particularly evident along the east bank of a small tributary of the Colville River, at lat 68°57' N., long 154°16' W. The only known unconformity in that part of the stratigraphic sequence is between the Nanushuk and Colville groups; consequently, the strata overlying the unconformity must be Colville group.

Further evidence for mapping the Colville group at this locality is obtained from the topographic expression of the rocks. The Seabee formation is dominantly a shale unit in which small streams are deeply entrenched. The basal bed of the Tuluvak tongue of the Prince Creek formation is a conglomerate that forms mesas above the shale lowlands (Detterman, Bickel, and Gryc, 1963); both conditions are present in the belt in the Awuna syncline.

The limits of the Seabee and Prince Creek formations in the Awuna syncline, between the Oolamnagavik River and Aupuk Creek, coincide with the extreme western boundary of the Colville group south of the Colville River. Although the lithologic character of the two formations in the Killik-Etivluk Rivers region is unknown, it can be reasonably assumed that the rocks are similar to those exposed in the Chandler River region. The Seabee formation is undoubtedly a shale sequence with a maximum thickness not in excess of 400 feet. The exposed Tuluvak tongue of the Prince Creek formation is believed to be about 100 feet thick in the Killik-Etivluk region. Only the basal conglomerate is present as cap rock on the hills near the synclinal axis.

QUATERNARY SYSTEM

Some of the most extensive deposits in the Killik-Etivluk Rivers region are the Quaternary, including those now in the process of formation. About one-third of the area was mapped as Quaternary. Most of the

Quaternary deposits are fluvial and (or) glacial; those of lacustrine and eolian origin are of subordinate size. In some localities deposits of different origin merge so intricately as to make their identification virtually impossible; however, in most of the region it was possible to separate the deposits and map them according to origin. The following four classifications, in order of abundance, were used in mapping the Quaternary: fluvial deposits, subdivided into high-level terraces and alluvium; glacial deposits; lacustrine deposits; and eolian deposits.

Various thicknesses of unconsolidated deposits mantle the underlying bedrock. The terrace deposits generally about 20 to 30 feet thick, but may reach 50 feet in some places. Although the thickness of alluvium is unknown in this region, it is probably similar to that in the Chandler River region where it is known to be 110 feet thick at one locality (Detterman, Bickel, and Gryc, 1963). The deposits of glacial origin are several hundred feet thick in isolated localities, but in general are only a few tens of feet thick. The river has cut lake deposits in the Killik River valley at the mountain front to a depth of at least 80 feet. Sand dunes on top of the lake deposits are as much as 30 feet high.

GLACIAL DEPOSITS

Glaciers formed during the Pleistocene probably covered about 1,700 square miles of the Killik-Etivluk Rivers region (pl. 49). Well-defined morainal deposits formed by these glaciers cover about 500 square miles; an additional 200 square miles along the Etivluk and Nigu Rivers are mapped as undifferentiated glacial and terrace deposits (pl. 43). The remaining 1,000 square miles is mapped as bedrock and terrace deposits (pl. 43), but erratics and small patches of possible drift indicate that this area or part of this area probably was glaciated at least once.

In general, glaciation was not as severe in the mapped region as it was east of the Killik River, owing partly to the lower altitude of the mountains in the accumulation area. The well-defined glacial deposits present today are in large part the product of alpine glaciers that probably coalesced locally to form piedmont lobes. The older, poorly defined deposits that cover most of the glaciated parts of the region probably were deposited by a larger mass of ice; this mass of ice apparently covered most of the mountainous parts of the region, with the exception of the higher peaks.

The well-defined glacial deposits are primarily confined to the Killik River drainage, because of a large and rugged accumulation area. Several small glaciers are present today in cirques near the head of Easter and April Creeks; cirques at the head of the Kurupa River also contain small masses of ice.

The glaciated parts of the Killik-Etivluk Rivers region and the glacial deposits are shown on plate 48. The plate does not show fluvial deposits formed by streams issuing from the glaciers, but does show the glacial lakes, Killik and Kurupa, and the active sand dune areas in the Killik River valley. Plate 43 also shows glacial deposits, but, because it is primarily designed to show the bedrock geology of the region, the only glacial material that is shown is in areas where it completely obscures the bedrock.

In order to show the source areas for some of the deposits that are present in the Killik-Etivluk region and to present a more complete glacial history of the region, the glacial map includes some areas that are not shown on plate 43. The areas of sculpturing and erratics shown on plate 48 are above the level of definite glacial moraine; the upper contact is the level to which the valley was filled with ice. The glaciers formed typical U-shaped valleys with hanging tributaries, truncated spurs, and scour marks on the bedrock. The broad valleys and low rounded hills show fewer signs of sculpturing, but erratics are common to abundant and give conclusive proof that the parts of the region in which they occur were covered by ice at least once.

The part of the mountains mapped as being ice-free was above the general level of the glaciers; however, it does show evidence of glacial sculpturing in the form of cirques, cols, aretes, and faceted spires. Many of the tributary streams leading into the major river valleys undoubtedly contained small glaciers at one time or another, but the amount of sculpturing is minor as compared to that in the main valleys and these tributaries have been included, in part, with the ice-free areas.

The direction of movement of ice is self evident for the most part. Near the passes between the present-day north and south drainage, the direction is somewhat more conjectural, particularly in the Howard Pass area where some evidence indicates that the ice came from the Noatak River drainage to the south of the mapped area.

The mass of debris dropped by the glaciers in the mapped region has diverted some streams into new channels and changed the direction of flow of others. The exact channels of former streams can only be tentatively identified, but the wide stream valleys now occupied by small modern streams show evidence that some of the streams were formerly much larger. The changes in stream direction are plotted on plate 48.

Evidence for three stages of glaciation, Anaktuvuk (pre-Wisconsin), and Itkillik and Echooka (early Wisconsin) (Detterman, 1953, p. 11-12), is present in the Killik-Etivluk Rivers region. The Sagavanir-

tok stage (pre-Wisconsin) of glaciation (Detterman, 1953, p. 11) may be present, but cannot be positively identified. Deposits of Alapah Mountain (late Wisconsin) and Fan Mountain (Recent) (Detterman, Bowsher and Dutro, 1958, p. 54-57) may be present also in the mountain valleys near the headwaters of the major rivers.

From the limited glacial studies made in northern Alaska it is impossible to correlate positively the advances with the major episodes in the United States. Little is known concerning the weathering characteristics produced by semiarid Arctic climate as compared to morainal weathering in more moderate climates. However, on the basis of a tentative correlation with glaciations in southern Alaska that have been dated by carbon-14 analysis, Karlstrom (1957, p. 73-74) dated the Anaktuvuk stage as Nebraskan, the Itkillik as Illinoian and Sangamon, and the Echooka as Wisconsin.

The authors believe the Itkillik glaciation should be correlated with the early Wisconsin rather than with the Illinoian because physical characteristics of deposits of the Echooka and Itkillik advances are very similar; both are relatively fresh and only slightly altered by weathering. Deposits of the Anaktuvuk glaciation are highly weathered and obviously much older. The Anaktuvuk glaciation probably should be correlated as pre-Wisconsin rather than with any specific episode, for the only evidence for correlation are physical characteristics of the deposits.

ANAKTUVUK GLACIATION

Morainal deposits and till of the Anaktuvuk glaciation are present on the Killik River, just upstream from the junction with the Okpikruak River, and along the Etivluk and Nigu Rivers from Howard Pass area to within about 18 miles of the Colville River. The morainal character of the deposits along the Etivluk and Nigu Rivers is considerably altered by terrace deposits that, at least in part, postdate the Anaktuvuk glaciation. In addition to the areas mentioned, the area between the Killik and Etivluk Rivers from the north front of the Brooks Range almost to the latitude of the Tuktu escarpment probably was covered with ice of the Anaktuvuk glaciation. The evidence for this postulation is the erratic boulders of rock types that are present only within the mountains and the low rounded hills of debris that appear to be weathered hummocky till. A few of these erratics are scattered throughout this area, but the main concentration is in the present stream valleys where possibly they have been moved from farther south by the streams.

The till of the Anaktuvuk glaciation is extremely weathered, lateral and end moraines are not identi-

fiable, the drainage is well-integrated, and most of the kettle lakes are filled. The amount of surficial modification of the till, the presence of a weathered rind on the erratics, and the partial covering of the till by terrace deposits all indicate that the Anaktuvuk glaciation represents an extremely old period of glaciation.

Till of the Anaktuvuk glaciation extends farther north than any of the moraines of more recent advances; the northernmost limit is about 35 miles from the north front of the Brooks Range and about 70 to 80 miles from the crest of the Brooks Range. Thus, the Anaktuvuk glaciation was apparently more extensive than any of the subsequent glaciations and may have formed an ice sheet over most of the area between the Killik and Etivluk Rivers. An ice sheet of sufficient thickness to cover the area in front of the mountains to the latitude of the Tuktu escarpment would probably require a greater thickness of ice than is indicated by the upper limit of valley sculpturing in the mountains. Most of the criques, cols, aretes, and spires probably were formed by more recent glaciations, or at least were considerably modified by them.

The accumulation area required to supply the amount of ice necessary to form an ice sheet of this magnitude would be greater than the area available at the headwaters of the present north-flowing rivers. Numerous erratics of granite are present in the Howard Pass area. Smith and Mertie (1930, p. 245) believed they were derived from the granite in the Noatak River area, 30 miles south of Howard Pass, and had been transported by glaciers to the Howard Pass area. The higher mountains in the Noatak River area could have been part of the accumulation area for an ice sheet as extensive as would be required to cover the area north of the Brooks Range.

The lack of till of the Itkillik glaciation in the Etivluk River area can be considered, for several reasons, as added proof that the main source for the Anaktuvuk glaciation was in the higher mountains of the Noatak River area. The mountains near the headwaters of the Killik River are about 2,500 feet higher than the ones near Howard Pass, and the greatest mass of Itkillik till is along the Killik River, whereas the Etivluk River is apparently free of Itkillik till; therefore, the logical conclusion seems to be that the lower mountains of the Howard Pass area could not have supplied the amount of ice necessary for the Anaktuvuk glaciation if they could not supply enough ice for a less extensive Itkillik glaciation. One other reason for the more extensive Anaktuvuk glaciation along the Etivluk River is the broad Howard Pass that would give access to glaciers from the south; the passes at the headwaters of the Killik and Nigu Rivers are more restricted.

ITKILLIK GLACIATION

Till of the Itkillik glaciation is present along the Killik River where it extends for a distance of 30 miles north of the Brooks Range, and at the headwaters of the Kurupa and Oolamnagavik Rivers. The till forms a small lobe that extends about 10 miles north of Kurupa Lake. This stage of glaciation has not been positively identified in the Etivluk River drainage, but some of the valley sculpturing and erratics along the Etivluk and Nigu Rivers may have been caused by Itkillik glaciation.

The till sheet and moraines of this glaciation are more extensive along the Killik River than they are in the Kurupa-Oolamnagavik Rivers area, because of the larger accumulation area tributary to the Killik River. Moraines occur along the valley walls of the Killik River as much as 1,200 feet above the present river. The ice was apparently thicker than 1,200 feet, for the upper limit of valley sculpturing at the mountain front is about 1,800 to 2,000 feet above the present river level at altitudes of 3,800 to 4,000 feet. The depth of ice in the accumulation area near the headwaters of the Killik River, as determined by valley sculpturing, was about 1,200 to 1,400 feet, with the upper limit of sculpturing at an altitude of about 5,200 feet. A gradient of about 23 feet per mile on the upper surface of the ice is indicated for the Killik River glacier.

Till of the Itkillik glaciation is relatively fresh. The end moraine consists of an arcuate zone of slightly modified knob-and-kettle topography in which lakes are present, undrained depressions are abundant, and drainage is poorly integrated. Six arcuate recessional moraines 1 to 3 miles apart are present behind the end moraine in the Killik valley. The time lapse between the formation of the end and the recessional moraines was relatively short, because there is no apparent difference in the amount of weathering or surficial modification. Lateral moraines are well developed along the valley walls at about 700 to 900 feet above the river, and scattered glacial debris is found as much as 1,200 feet above the river. Lateral moraines for each of the successive stages of recessional moraine occur at slightly lower elevations.

The southernmost recessional moraine, at camp D, June 8-53, dammed the river and formed a large glacial lake that extended up the valley as far as Easter Creek. Ground moraine occurs in this part of the valley along the margins of the lake deposit. The knob-and-kettle topography is only slightly modified and has many lakes on the moraine. Numerous lakes that are vestigial remnants of the glacial lake are present on the lake deposit.

Ice-marginal stream channels are present on both east and west walls of the Killik valley. Those on the east side are perhaps better defined and more persistent than the ones on the west side, and are cut to a depth of

80 to 90 feet through solid bedrock in numerous places. The ice marginal channels occur only in the area of recessional moraines, and probably were formed by the increased melt water during the general retreat of the valley glacier. These channels are 300 to 500 feet above the present river level.

The Itkillik moraines in the Kurupa Lake area are relatively fresh and only slightly altered, but still not as fresh as the Itkillik stage in the Killik River valley. These morainal remnants may be older than the Itkillik glaciation, perhaps as old as the Sagavanirktok glaciation. As present field evidence is inconclusive, the till is correlated as Itkillik glaciation, with the possibility that it may be as old as the Sagavanirktok.

ECHOOKA GLACIATION

The Echooka glaciation was a relatively minor advance of Alpine-valley glacier type that was confined to the major river valleys and did not reach the north front of the Brooks Range. The main glacial deposits are confined to the valleys of the Nigu and Killik Rivers and of Easter and April Creeks, tributaries of the Killik River. Several small glaciers also occupied parts of the Kurupa River valley and its tributaries, notably Outwash Creek. The till in the Kurupa River system is the farthest north deposit of the Echooka glaciation in the mapped area, but the actual distance from its source area is much less than that of the deposits along the Killik and Nigu Rivers.

The deposits of this glaciation are relatively thin, probably not more than 100 feet thick at the maximum and generally not more than 50 feet thick. The source areas were apparently in the higher mountains at the headwaters of the Killik, Nigu and Kurupa Rivers, and the ice probably did not reach the upper limit of valley sculpturing, so the glaciers of the Echooka glaciation probably did not greatly alter the valley form as established by earlier glacial advances.

Moraines and till of the Echooka glaciation are fresh and show little surficial modification due to weathering. The knob-and-kettle topography is only slightly altered; the drainage is poorly integrated, and undrained depressions and lakes are numerous. The end moraines are not well developed and are missing in many places where the present rivers have washed out the till.

The difference in the amount of surficial weathering of the moraine is in general much less between the Echooka and Itkillik glaciations than it is between the Itkillik and Anaktuvuk glaciations. The similarity of the Echooka to the Itkillik may suggest that the Echooka was another recessional phase of the Itkillik glaciation similar to the six recessional moraines mapped on the Killik River. The evidence to refute this assumption may be in the Nigu River valley, which contains

the largest deposits of Echooka till but does not contain any identifiable till of the Itkillik glaciation.

Evidence of minor glacial advances that postdate the Echooka glaciation probably can be found near the cirques and in the small valleys near the headwaters of the Killik and Nigu Rivers; no fieldwork has been done in that part of the region. Small rock moraines a short distance in front of the cirque glaciers near the headwaters of the Kurupa River probably represent minor advances that occurred within the last several hundred years.

FLUVIATILE DEPOSITS

The most extensive surficial deposits are of fluvial origin and include material that is definitely glacio-fluvial and possible some deposits that are of glacial origin, but the latter are so weathered that positive identification is impossible with present field information.

The deposits are divided into high-level terrace deposits and alluvium. Those mapped as Quaternary terrace gravels or high-level terraces are about 250 feet above the present stream level. A system of low-level terraces, as much as 30 feet above the streams, is present on most of the rivers; for the purpose of this report these low terrace deposits are included with the alluvium.

HIGH-LEVEL TERRACE DEPOSITS

High-level terrace gravels cover an area of about 1,150 square miles, and are present along all the major streams in the Killik-Etivluk Rivers region. The main concentration of terrace gravel is in the western part of the region, along the Etivluk River and its tributaries, and along the Colville River in the northern part of the area. A similar, but less extensive deposit is present along the lower 40 miles of the Killik River. Some of the deposit along the upper part of the Etivluk River is of glacial origin, as attested by numerous lakes and by the uneven topography apparently of weathered moraine. The deposits mapped as undifferentiated terrace and glacial deposits extend from Howard Pass to near the junction of the East Fork with the Etivluk River.

In general, the terrace deposits between the Killik and Etivluk Rivers can be divided into two belts that were probably deposited contemporaneously. The southern and more extensive belt lies between the north front of the Brooks Range and the Tuktu escarpment; it is particularly well developed in the lowlands underlain by shale of the Torok formation adjacent to the Tuktu escarpment. The northern belt is best developed along the Colville River, and is present along all streams for a distance of 5 to 10 miles south of the Colville River.

The areas covered by terrace gravels are almost uniformly regions of low relief. Lakes commonly dot the surface, and streams are entrenched in the gravel or

have cut through it to expose bedrock. The gravel unconformably overlies rocks that are Mississippian to Cretaceous in age.

The terraces are composed dominantly of well-rounded slightly roller-shaped cobbles 4 to 12 inches in length, with a considerable amount of smaller rock fragments. Pebbles and silt are locally abundant, but in general are not important constituents of the terrace deposits. Gray quartzite, white quartz, and colored chert constitute the bulk of the deposits; also included are limonitic quartzite, graywacke, and quartz-pebble conglomerate. Limestone, where present, is extremely weathered. The deposits are light to medium gray with a buff to rusty-brown weathered zone.

The terrace gravels were probably formed contemporaneously with glaciation of the region during Pleistocene time. The earlier, more extensive glacial advances probably account for most of the glacio-fluvial deposits. Some of the gravel may be remnants of a veneer on a pediment surface that predates the Pleistocene; it was probably formed in late Tertiary time. The field information on surficial deposits is not sufficiently detailed to allow determination of the extent of any possible pediment surface. The pediment, if present, would be confined to the southern belt of terrace deposits.

The terrace along the Etivluk River appears to overlie, in part, the glacial till of the Anaktuvuk glaciation; both the till and the terrace are weathered, but the relation suggests that the terrace may in part postdate the Anaktuvuk glaciation and that it was formed as an outwash plain.

The high-level gravel terrace deposits are about 150-250 feet above the streams throughout most of the region, and their gradient is similar to that of the present streams. Near the mountain front the stream gradient is greater than that of the terrace, and the difference in elevation between the two becomes less. In Howard Pass the Etivluk River is entrenched in the terrace. On the other hand, outwash gravel forming the terrace on the west side of the Killik River lies about 500-700 feet above the present river. The Killik valley was extensively glaciated during the Itkillik glaciation, and the valley was scoured to a greater depth than were the other river valleys. Till of the Echooka stage of glaciation did not reach the mountain front; consequently, outwash from this stage of glaciation probably did not affect the formation of the high-level terrace.

ALLUVIUM

Those deposits mapped as Quaternary alluvium include all material on the flood plains of the modern streams. The active zone generally occupies less than 10 percent of the total flood-plain area on the larger

streams; on some of the smaller streams near the mountains, the active zone may include 50 percent of the flood plain. Oxbow lakes, cutoff meanders, abandoned channel scars, and low terraces are common features of the inactive fossil flood-plain zone. The Killik River has five distinct terrace levels, each level being about 5 feet higher than the preceding. Some of the levels are being destroyed by lateral erosion at the present time.

The alluvial deposits consist of debris from all rock types found along the stream. Most rock fragments are waterworn and well rounded except for the material recently added from cutbank exposures of bedrock. Most of the rock fragments range in size from 2 to 8 inches, with silt and small pebbles forming lenticular deposits in lagoons and along the downstream end of bars. Large glacial erratics of conglomeratic quartzite are common on the Killik River, wherever the river cuts one of the arcuate recessional moraines. The top of the low terraces in the stream valleys probably marks the maximum postglacial aggradation of the streams, and the numerous levels either are the result of minor adjustments during the present stage of degradation or were formed when the river cut through the successive recessional moraines upstream from the low terraces and released large quantities of debris and water.

LACUSTRINE DEPOSITS

A glacial lake, approximately 29 miles long, once occupied the Killik River valley between the junction of Easter Creek with the Killik River and camp D-June 8-53. Numerous vestigial ponds and lakes from 100 feet to 1½ miles in width are present in the area today as remnants of the former lake. The lake was apparently dammed by the southernmost recessional moraine that crosses the valley at camp D-June 8-53. This recessional moraine was formed during the retreat of the Itkillik glaciation.

The glacial lake area today is one of sand, silt, muck, and peat through which the Killik is cutting a wide

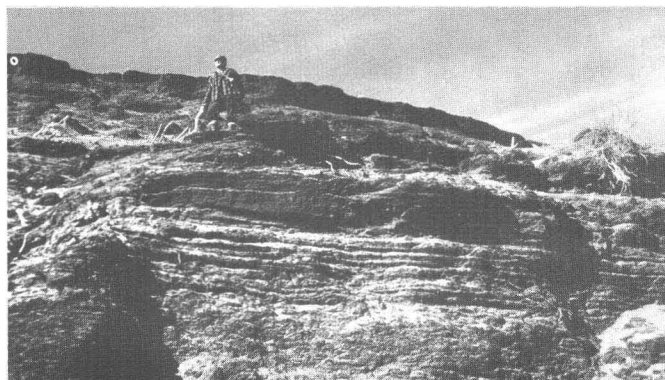


FIGURE 63.—Horizontal view of Killik River cutbank in glacial lake deposit on the upper Killik River. Photograph by R. L. Detterman.

channel. The river has cut about 80 feet through this deposit (figs. 63 and 64) at a point $1\frac{1}{2}$ miles south of camp D—June 2–53. The exposed section consists of alternating layers of silt and peat that have the appearance of varves. The layers range in thickness from $\frac{3}{4}$ to 3 inches, but any given pair of silt and peat layers are generally of about equal thickness. The amount of time that elapsed during the formation of one of these pairs cannot definitely be stated from present field information; it is quite possible, however, that a set represents a yearly cycle of sedimentation.

The peat layers are commonly oxidized to an orange red as the result of weathering. The silt is light gray to buff, and at the base of the exposed section there is a loosely consolidated sand that appears to be admixed with gray rock flour.

The peat does not have the strong organic odor common to most peat deposits; in fact, it is quite dry and burns readily. The layers contain fragments of wood that appear to be willow or alder and other species of plants similar to those growing in the region today.

EOLIAN DEPOSITS

The Killik River is wide and sluggish where it meanders through the glacial lake deposit; during most of the year it carries very little water. The meandering course of the river exposes a maximum of the lake deposit to wind action. The silt is blown away and leaves the sand to form dunes. The sand dunes give the general appearance of a miniature desert. The dunes occupy the same general area as the glacial lake; the most numerous and the largest are in the area between

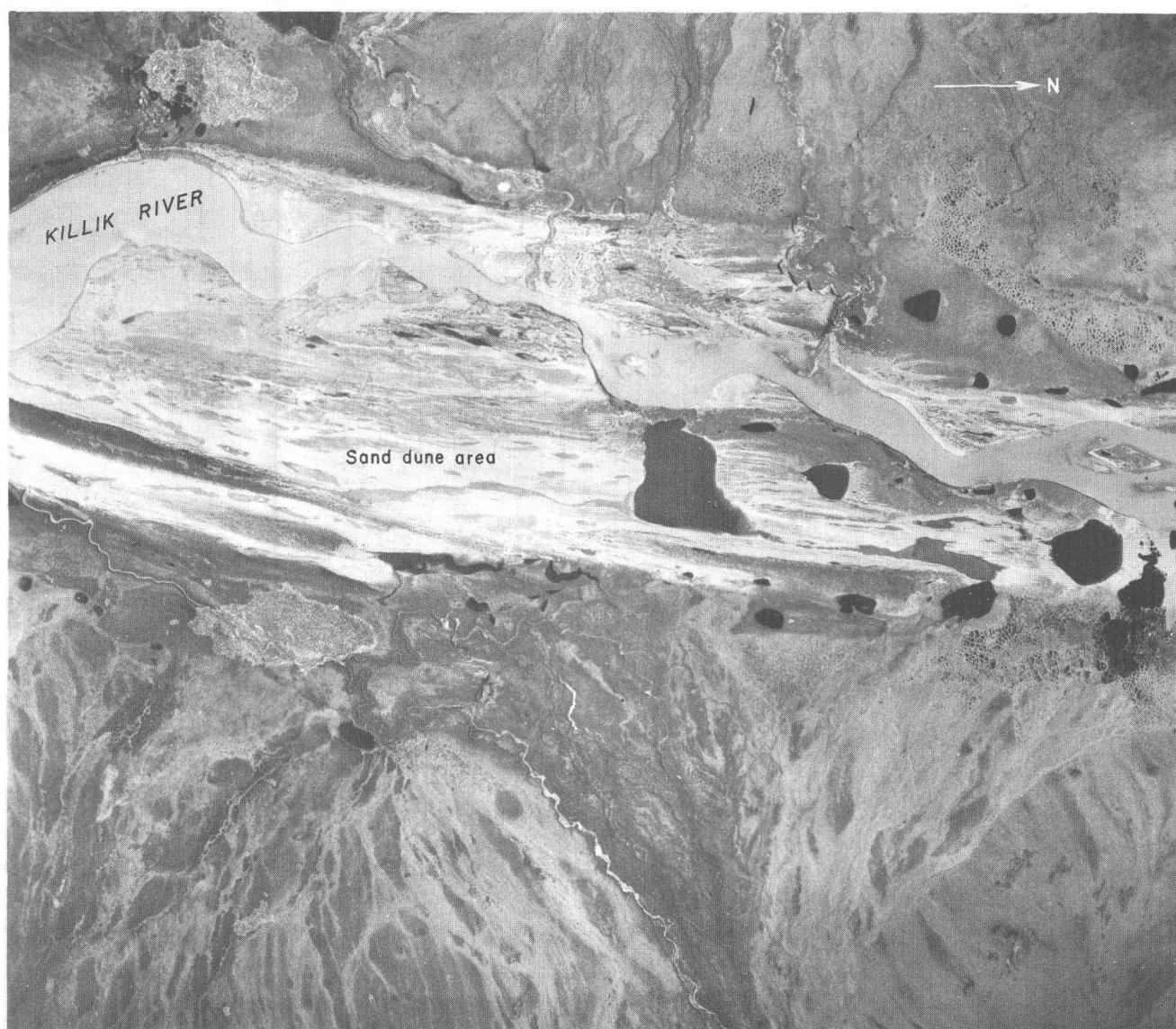


FIGURE 64.—Vertical view of sand dune area on glacial lakebed in upper Killik River area. Photograph by U.S. Navy.

Aniakvik and Akmalik Creeks near the north front of the Brooks Range. The prevailing winds are from the south and most of the cutbanks have "blow outs" that slope up toward the north; however, a few of the "blow outs" slope in the opposite direction.

The dunes are 10 to 30 feet high and strongly cross-bedded. The sand grains are commonly "frosted," and larger rock fragments show the effects of wind scour and faceting. Dead and dry stumps of willow groves that were killed by the sand are partly exposed on many of the dunes. Some of the dunes have a thin vegetation cover, but the ones closest to the river are being actively eroded and generally are barren.

Nearly all the "blow outs" are formed on south-facing river bluffs, and the active part is generally less than 1,000 feet long and 150 feet wide. Many were formerly larger, and the fact that the down-wind ends are covered with a thin layer of vegetation at present and are no longer active may indicate a more arid or colder condition in the late Pleistocene.

Much of the glacial lake deposit in the Killik valley consists of silt of a buff color that is similar to loess deposits. The thermokarst lakes on the surface of the terrace and the poorly integrated streams indicate that the high-level terrace, particularly along the Colville River, is probably covered by loess similar to the deposit in the Chandler River region (Detterman, Bickel, and Gryc, 1963). The southern belt of terrace deposits does not have the numerous thermokarst lakes, but one drained lake on the west bank of the Kurupa River (fig. 58), at lat 68°46' N., long 155°14' W., exposed 15 feet of silt and muck in the outlet drainage channel, which had been cut only a few years previous to the time of examination. The deposit had all the characteristics of a loess deposit.

The gravel terrace in the Howard Pass area is covered by a silt deposit that may be in part of wind-blown and in part of fluvial origin. The Pass does not appear to have been glaciated during the Itkillik and Echooka glaciations, but considerable melt water must have been diverted through the pass during that time.

IGNEOUS ROCKS

OCCURRENCE AND DISTRIBUTION

Three large areas and many scattered small outcrops of finely crystalline igneous rocks of the basalt-gabbro clan are present in the Killik-Etiviluk Rivers region. These igneous bodies lie within rocks of Kayak through Tiglukpuk formations. They are believed to be sills, but possibly some are plugs.

Field evidence indicated a concordant relation of the igneous bodies to the enclosing rock. The possibility that some of the bodies formed as flows was considered, but no conclusive evidence was seen. Such marginal

structures as flow phenomena, vesicle or amygdule elongation and alinement, and variolitic and related structures were not observed either in hand specimen or thin section.

The largest igneous mass in the mapped region is along Flora and Fauna Creeks and several miles south of camp M-July 24-49 at Howard Pass. It has been mapped for a distance of 18 miles and is from 2 to 5 miles across. Neither the western nor eastern boundaries of the body were mapped. The mass probably was intruded along a major fault zone. The rocks were previously mapped as lavas (Smith and Mertie, 1930, p. 258-263), but in the 1949 fieldwork no evidence to support this origin was found. The petrographic properties of these rocks are similar to those of sills and dikes in the rest of the mapped region. Megascopic study shows the rocks to be gabbros and basalts and to range in color from dark green to black. They are fine to medium grained, weather dark red brown, and effervesce with hydrochloric acid. The effervescence is probably due to the alteration of the feldspars rather than to carbonate from associated rocks.

Metamorphism has taken place to a minor extent along the contacts of the igneous body with the Wachsmuth limestone and the Siksikpuk and Shublik formations. Along the northern contact with the Wachsmuth limestone, the limestone is marmorized for 25 to 30 feet. Along the southern contact of the igneous rocks and Siksikpuk and Shublik formations the shale has been metamorphosed to slate with well-developed north-dipping cleavage.

A second large igneous mass in the mapped region is at the head of Fay Creek and 5 miles west of camp M-May 28-49 and the Etiviluk River. This body is approximately 6 square miles in area and is thought to be intruded along large thrust faults. In many places limestone of the Kayak and Wachsmuth formations has been assimilated by the gabbro and basalt, and in the field it was extremely difficult to distinguish the limestone from the replacing igneous rocks because in many instances features such as bedding and sedimentary texture of the limestone have been preserved in the igneous rocks.

The third large igneous body forms Kikiktat Mountain 2 miles south of camp C-June 22-50 and between the Killik River and Immaitchiak Creek. It is apparently in conformable contact with a sequence of graywacke and conglomerate of the Tiglukpuk formation. The upper contact was not seen. No mineralized zones in the adjacent rock were seen. In talus blocks, all gradations of alteration between true crystalline igneous rock and slightly altered graywacke are found.

The remaining igneous rocks occur as numerous small sills or plugs in the southern foothills section.

These smaller bodies are usually more resistant than the surrounding country rock and form sharp hogbacks and hillocks. In some places the contact between the igneous and sedimentary rocks was exposed. There is little metamorphism of the enclosing rocks near the contact, except for a charred baked appearance with locally colors such as black, red, and orange in the weathered rock near the contact. The greatest thickness of the contact zone was 20 feet, but in most places it was less than 10 feet.

PETROLOGY

Eberlein, who made the petrographic study of the igneous rocks reported:

In hand specimen these mafic igneous rocks are typically equigranular, medium to fine grained, and compact. Their color ranges from dusky yellow green to dark greenish gray. These features make it difficult to distinguish some of these rocks in the field from medium- to fine-grained graywacke-type sedimentary rocks with which they are in contact. An igneous origin of most of these rocks is shown, however, by a well-developed igneous texture (often diabasic) and the local presence of amygdules.

A suite of 16 thin sections, prepared from representative specimens collected from igneous rocks in the Imnaitchiak Creek and Etivluk Rivers areas, were studied by means of the petrographic microscope. The following general comments pertain to the petrology of the igneous rocks as a whole and are based on information obtained from this thin-section study and on the megascopic study of these and other specimens both in the laboratory and in the field.

Most of these rocks are dolerite or microgabbro. Plagioclase and clinopyroxene are the dominant pyrogenic minerals. Although some of the rocks are ideally fresh, most are altered to a greater or lesser degree.

The texture of the dolerite is variable. Normally it is microophitic, due to the partial or complete enclosure of unoriented idiomorphic plagioclase microlites by typically anhedral clinopyroxene or its alteration products. The texture of some of the specimens is similar to the groundmass texture of some basalts in which small grains of pyroxene are crowded between lathlike plagioclase crystals, to the exclusion of any glass or its alteration products.

Mineralogically the dolerite is simple, although the proportions of constituent minerals apparently vary considerably. The common feldspar is andesine, but a range in plagioclase composition from oligoclase (An_{27}) to labradorite (An_{50}) has been observed among the thin sections studied. Feldspar zoning generally is not well developed. Where present, it is almost all of the progressive type. In most of the specimens plagioclase is more abundant than clinopyroxene and in some is present almost to the exclusion of the pyroxene.

Although augite is the common pyrogenic ferromagnesian mineral, it locally is a titaniferous variety (titanaugite). The augite is frequently schillerized parallel to (001), and some of it shows a distinctive herringbone structure owing to additional twinning on (100). Among the several species of accessory opaque minerals that may be present are magnetite, ilmenite, and titanomagnetite. Ilmenite, often in the form of characteristic skeletal crystals, is common in coarser grained dolerite and may be reconstituted as sphene and (or) leucosene. Quartz, if present, is interstitial and may be intergrown with plagioclase in the form of

myrmekite. Calcite, celadonite, delessitic chlorite, and various zeolites have been identified as amygdale fillings. Although rhombic pyroxene, olivine, and pyrogenic amphibole may be expected to occur in rocks of this type, these minerals were not present in any of the thin sections studied.

As suggested above, the dolerite has been subject to alteration which in some rocks has effected the complete replacement of almost all original mineral constituents. In extreme examples the rock consists of carbonate (usually calcite) pseudomorphs after plagioclase which are set in a groundmass consisting almost entirely of several species of chlorite. Other feldspar alteration products include prehnite, white mica, several zeolites, and aggregates of clinozoisite and albite (saussurite). It is of interest to note, however, that in the thin sections studied plagioclase has generally survived the alteration better than pyroxene, and the development of zeolites and saussurite through the breakdown of the feldspar does not appear to be common.

Under the microscope, augite generally shows some degree of alteration to acicular actinolite of the uralite variety, with associated disseminated magnetite. Where alteration has been more or less complete, the pyroxene may be changed to chlorite (commonly penninite) and various serpentine minerals. Chlorite also occurs locally in interstitial areas between relatively fresh plagioclase and augite. In these places it probably has formed either as a primary mineral or through the breakdown of glass. Ilmenite, if originally present, may disappear entirely during alteration and be represented by clusters of magnetite grains and sphene. Under less drastic alteration, ilmenite alters to leucosene.

The above assemblages and relationships suggest that alteration is principally related to deuteric or paulopost processes. It should be pointed out that with the development of good ophitic texture, these igneous rocks are perhaps better termed diabase. Transitions to gabbro occur and are manifest by an increase in grain size, the development of coarse ophitic texture, and a strong tendency for the clinopyroxene to exhibit 'striations' parallel to (100) (diallage structure) and (001) (salite structure). Such transitions appear to be local, however, and for the most part are restricted to small areas within the larger dolerite bodies. All these types are perhaps best considered under the general term of dolerite or microgabbro.

With the introduction of subordinate amounts of late quartz, there are also local transitions to rocks with quartz dolerite affinities. The quartz may be interstitial or intergrown with plagioclase (myrmekite). The occurrence of quartz in these rocks may reflect a magma somewhat oversaturated with respect to silica (tholeiitic), but it is more likely related to the assimilation of silica by dolerite during intrusion into chert, cherty siltstone, and other more or less siliceous sedimentary rocks.

STRUCTURE

The major geologic structural features of the Killik-Etivluk Rivers region are grouped into three structural belts, which roughly coincide with the physiographic provinces of the region, as follows: the Brooks Range province and the southern and the northern sections of the Arctic foothills province. Although the structure of the area is relatively complex, a major pattern of east-trending fold axes and large fault systems is apparent.

BROOKS RANGE PROVINCE

The structure of the Brooks Range province is characterized by large thrust faults and overturned folds.

The outstanding structural features in this province are two major thrust faults that extend for miles along the northern front of the mountains (pl. 43). Imbricate thrust faults are also apparent, as are large overturned and recumbent folds in the Kanayut and Hunt Fork formations in the south-central part of the mapped area. The prevailing dip of the rocks is south, but progressively younger rocks are exposed to the north owing to these thrust faults and overturned folds.

The longest thrust fault occurs along the northern edge of the Kanayut conglomerate and extends the entire length—an airline distance of about 78 miles—of the mapped region. This thrust is believed to have occurred in the axial zone of an overturned anticline whose south limb was thrust northward onto the younger rocks in the north limb. Between Kutchiakruak River and Outwash Creek, the Kanayut and Kayak formations appear to have overridden the younger rocks for 1 to 3 miles.

The other conspicuous thrust fault is along the north front of the main Lisburne group belt at the mountain front. This fault extends from east of the Killik River westward to Kutchiakruak River, a distance of more than 30 miles. The Lisburne group is deformed into a large overturned anticline, with the south limb thrust over the north limb at a high angle. A transverse fault sharply offsets the Lisburne belt at Kurupa Lake. Several other transverse faults are present west of Kurupa Lake; the largest offset along these faults has been mapped 6 miles west of Kurupa Lake on a fork of Kurupa River. Here the easterly fault block is thickened as a result of imbricate thrust faults. The westerly fault block is narrow, and just west of Kutchiakruak River it is cut off where the Kayak shale has been thrust over it. From this point westward to the Nigu River, the thrust fault lies along the northern edge of the belt of Kayak shale. Between the Nigu River and Fay Creek, near camp M—May 28–49, on the Etivluk River, the faulting is more complex; the Lisburne group is again present only in a few scattered mounds and hillocks.

In the upper Killik, Kurupa, and Kutchiakruak Rivers valleys the Paleozoic rocks have been deformed into large appressed overturned and recumbent folds broken by stretch and imbricate thrust faults. In general, these fault planes dip 20° to 60° S. and are 1 to 15 miles in length.

Near Howard Pass, in the southwestern part of the mapped region, rocks ranging in age from Devonian through Triassic are exposed in an area characterized by considerable faulting and a regional south dip. Along the southern edge of this area the Devonian rocks are thrust over Mississippian and Permian rocks and most of the Mississippian is absent. A large mafic

body that was intruded possibly along one of the fault zones lies near the center of this area. The mafic body is in contact with Mississippian and Triassic rocks along its northern border, and with Permian and Triassic rocks along the southern edge. Although the upper Mississippian, Permian, and Triassic rocks are highly faulted north of Flora and Fauna Creeks, the Devonian and Lower Mississippian appear to dip beneath the younger rocks there.

At the northern edge of this area the Kanayut formation in Kavaksurak, Kivliktort, and Isikut Mountains appears to be part of an isoclinal anticline overturned to the north. The Hunt Fork shale is present in the center of this anticline on the east side of the Etivluk River, but, owing either to west plunge or to stretch faulting, is absent on the west side of the Etivluk River.

SOUTHERN FOOTHILLS SECTION

The structure of the southern section of the Arctic foothills province is characterized by isoclinal folds, isolated infolded synclines of Okpikruak and Fortress Mountain formations, thrust faults, and high-angle reverse faults. In this section the rocks are more crushed and shattered by folding and faulting than those in the Brooks Range province; many areas are so complex structurally that it is impossible to differentiate the formations. Associated with these complexly folded and faulted areas are many small mafic intrusions (15 square feet to 2 square miles).

In the southern foothills section there are three major thrust faults that bring Paleozoic rocks as old as Late Devonian to the surface. These three faults are believed to have formed within overturned anticlines whose south limbs were thrust over the north limbs onto younger rocks.

The southernmost thrust fault begins east of Ivotuk Creek (about 1½ miles east of camp E—July 20–50) and extends 20 miles west to the Nigu River. Along this same fault between Ivotuk and Kutchaaurak Creek, the Lisburne group is thrust over Mesozoic rocks. Between Outwash Creek and the Nigu River, the Lisburne is thought to be absent at the surface and the Siksikpuk formation to be thrust over undifferentiated Paleozoic and Mesozoic and Lower Cretaceous rocks. From the Nigu River to the west side of Etivluk River near Tukuto Creek camp M—June 11–49, the thrust is inferred along several isolated outcrops of Devonian, Mississippian, Permian, and mafic igneous rocks, which crop out through a gravel mantle. Mafic intrusive bodies occur at several localities along this thrust fault and probably came in along this zone of weakness.

The second thrust fault is approximately 25 miles long and extends from Iteriak Creek at lat 68°31' N.

and long 155°50' W. slightly northwest to camp M-June 14-49, and five miles west of the Etivluk River into Puvakrat Ridge. From Iteriak Creek west to about lat 68°33' N., long 155°10' W., undifferentiated Permian and Triassic rocks are thrust onto Triassic and Jurassic rocks. From this location to the western extremity of the fault, the Lisburne group is in thrust fault contact with Mesozoic rocks.

The third and northernmost fault occurs along the north front of Lisburne Ridge, 4 miles northwest of Etivluk River camp M-June 14-49. This fault extends for 7 miles to the west boundary of the mapped region. Here the Lisburne group is thrust over Mesozoic rocks. Several north-trending transverse faults cut Lisburne Ridge and displace the limestone. The largest transverse fault is about 5 miles west of the Etivluk River.

A thrust fault, inferred largely by interpretation from aerial photographs, extends westward along lat 68°41' N., from the Oolamnagavik River area to the Etivluk River. This fault and associated complex, tightly folded structural features are within a belt of shale, sandstone, and conglomerate of the Fortress Mountain formation. Another fault, which may account for the isolated exposure of Triassic rocks near the confluence of Travelair Creek and the Oolamnagavik River, is interpreted to lie between the East Fork of the Oolamnagavik River and the Kurupa River, and about 3 miles south of the previously mentioned fault.

A number of isolated synclines in rocks of Fortress Mountain and Okpikruak formations lie between the north front of the Brooks Range and the belt of Fortress Mountain formation along lat 68°41' N. These synclines are all west trending, and suggest a major west-trending synclinorium within this belt.

The structure of the low featureless belt of Torok formation, including the Torok and Fortress Mountain formations undifferentiated, between the belt of Fortress Mountain formation and the Tuktu escarpment is poorly known because the uniform nonresistant thick shale sequence affords little topographic expression and few good outcrops. Stream bank outcrops along the Oolamnagavik River and Heather Creek show some small complex folds and minor faults. Most of the beds in the southern part of this belt dip southward, and a few widely scattered outcrops in the northern part close to the Tuktu escarpment show north-dipping beds. On the basis of this meager evidence, a west-trending anticline in the Torok formation between the Oolamnagavik and Kurupa Rivers may be inferred. Along Kucher Creek exposures of the Torok formation are more extensive; an anticline about 2 miles south of the Tuktu escarpment and a syncline 2 to 4 miles farther south have been mapped.

NORTHERN FOOTHILLS SECTION

The northern foothills section of the Arctic Foothills province is in general an area of simple folds in rocks of the Nanushuk and Colville groups. The southern boundary of the northern foothills section coincides with the Tuktu escarpment, which rises abruptly above the lowland to the south that is underlain by Torok formation.

Five major structural features are present in the northern foothills section: the Oolamnagavik and Awuna synclines and the Kurupa, Aupuk, and Killik Bend anticlines. The two synclines are broad, open folds that are uncomplicated by faults or drag folds. The Aupuk and Killik Bend anticlines are believed to be parts of the same structure, but this cannot be proved. The Kurupa anticline is a major structure that extends both east and west beyond the boundaries of the mapped region. The anticlines are asymmetrical, the north flank being the steeper. Low-angle axial thrust faults, high-angle reverse faults, and oblique slip faults are present locally in the anticlines. Drag folding is commonly associated with the faulting and folding. Killik Bend anticline is locally overturned to the north in the Killik Bend area. The folds are parts of regional structural features that are 72 to 200 miles in length; they extend beyond both the east and west boundaries of the mapped area.

The strike of the folds is about N. 80° W. between the Killik and the Kurupa Rivers; between the Kurupa River and the west boundary of the mapped area the strike is about N. 60° W. The Tuktu escarpment is roughly parallel to these axial trends.

Northward deflections of the axial trends from their regional strike form an undulatory pattern and are present on all five features in such a manner as to suggest deep transverse regional structures. One such feature is indicated by the northward swing of the axes between the Killik and Oolamnagavik Rivers; the strike of the transverse trend is approximately N. 25° E. Another northward swing of the axes occurs between the Oolamnagavik and Kurupa Rivers; the strike of this transverse trend is about N. 50° W. Minor cross faulting of the anticlines observed in surface outcrops is probably a result of stress set up along these transverse trends. A pair of small oblique slip faults on the Kurupa anticline 6 to 8 miles west of the Kurupa River show this feature.

OOLAMNAGAVIK RIVER STRUCTURAL HIGH

A north-trending structural high just east of the Oolamnagavik River is reflected in the folds of the southern foothills section of the Arctic Foothills province and the Brooks Range province, as well as in the five folds of the northern foothills section. In

both the southern foothills and the Brooks Range, the rocks exposed across this line of culmination are older than those adjacent to it; detailed information is not available on most of the folds, but they probably are doubly plunging. The anticlines in the northern foothills are definitely doubly plunging.

The age of the Oolamnagavik River structural high cannot be determined from present field evidence; it probably started to form in pre-Nanushuk time and may predate the deposition of the Fortress Mountain formation, because all post-Okpikruak sediments have a greater proportion of coarse-grained clastic rocks near the line of culmination. A change in lithologic character is not readily apparent in pre-Okpikruak formation rocks overlying the high. Uplift along the high continued at least through Nanushuk time, for these rocks are exposed in doubly plunging folds.

KURUPA ANTICLINE

The Kurupa anticline is a major feature about 64 miles long and 8 to 9 miles wide; it extends beyond both the eastern and western boundaries of the mapped area where the beds flatten out and merge with monoclinal north-dipping strata. Three reversals of plunge occur in the mapped area, with a structural high near the point where the axis crosses the north-trending line of culmination along the Oolamnagavik River; a secondary high is present near the Killik River, and another near the Kurupa River. The anticline has closure on the three structural highs, but sufficient data for structure contouring is lacking and thus the exact amount of closure is unknown. The maximum closure is probably no greater than 1,000 feet. The economic possibilities of any closure are materially affected by the breaching of reservoir beds by the rivers. The strata are breached into the Tuktu formation on all structural highs, and not more than 400 feet of the Tuktu remains. These beds of the Tuktu formation are dominantly a graywacke sandstone facies with interbedded siltstone, shale, and lenticular conglomerate; they may be potential reservoir rocks. The Tuktu formation is underlain by at least 4,000 to 6,000 feet of shale of the Torok formation that would be of little value as reservoir rock, although some sandy facies may be present locally.

The Kurupa anticline is an asymmetrical structure; the beds on the north flank have dips 10° to 20° steeper than those on the south flank. The maximum observed dip of strata near the axis is 45° ; in general the dip is much less than that, the average in the axial zone being 20° to 25° . Structural relief between Kurupa anticline and Awuna syncline is about 4,500 feet, but probably does not exceed 400 feet between the anticline and Oolamnagavik syncline.

A high-angle normal fault, in part delineated by photo-interpretation, cuts the anticlinal axial trace near Heather Creek; it is 6 miles long, and the maximum displacement is at the west end. Throw is probably about 600 to 800 feet. An axial thrust fault is indicated between Quandary Creek and the Killik River. Throw cannot be determined because the bedding traces are not well enough exposed. A structurally complex zone is exposed near the axial plane on the east bank of the Killik River in beds of the Tuktu and Chandler formations. Three small high-angle reverse faults occur south of the axial plane, and three north of the axial plane. Small east-plunging drag folds, some of which are overturned to the south, are associated with the faults. The lateral extent of these folds and faults cannot be determined, but they may be part of the same complex zone that is mapped on the east bank of the Oolamnagavik River, for some faulting is evident between the two rivers. A pair of oblique slip faults cut the axial plane in the area 6 to 8 miles west of the Kurupa River. These faults are about 2 miles long and converge toward the south to form a triangular fault block. Movement of the block was toward the north. The east fault strikes east and the west fault strikes N. 12° W. Horizontal displacement along these oblique slip faults probably does not exceed 200 feet. The small west-plunging anticline and syncline near the western fault may be the result of compression during faulting. Two other oblique faults cut the anticlinal axial trace; one is 4 miles west of the Oolamnagavik River, and the other is 7 miles west of the Killik River. They are less than 2 miles long and strike N. 45° W.; the east sides of both have moved north. The displacement along them is minor.

AUPUK AND KILLIK BEND ANTICLINES

The Aupuk and Killik Bend anticlines are parts of a major anticlinal trend that extends at least 200 miles across northern Alaska. This anticlinal trend is one of the major structural features of the northern foothills section, and may be associated with a deep-seated fault or zone of persistent uplift.

The Aupuk and Killik Bend anticlines are mapped on plate 43 as two features, although the writers believe that they are probably parts of one anticline. The easternmost outcrops exposing the axial plane of the Aupuk anticline and the westernmost outcrops showing the axial plane of the Killik Bend anticline are on the south bank of the Colville River 3 miles upstream and 4 miles downstream, respectively, from the mouth of Aupuk Creek. Outcrop observations or any other evidence that would delimit the position of the axial plane in this 7-mile interval are indefinite. The attitude of the bedding can be measured in one bluff,

at camp D-July 4-53, in this interval; the dip is low, generally less than 10° , and the strike is northwest. Crossbedding in the rocks somewhat complicates the picture, but 7 of the 9 dip-and-strike readings taken in the vicinity of this bluff indicate the presence of a northwest-trending axial plane between the ends of the two anticlines. The remainder of the area on the south side of the Colville River in the 7-mile interval is covered by surficial deposits and tundra that effectively conceal any evidence that might give a clue to the structure.

Dip and strike readings taken on strata in two bluffs on the north side of the Colville River 2 miles upstream from camp D-July 4-53 indicate that the axial plane of the Aupuk anticline extends across the Colville River in a northeasterly direction and does not join the Killik Bend anticline. These dips and strikes, however, may be a reflection of the east-trending fault that is just north of the trace of the axial plane in the vicinity of the Aupuk gas seeps, rather than of the axial plane.

One objective of the 1950 Geological Survey field party in the Killik-Etiviluk Rivers region was to make a structure-contour map of the Aupuk anticline. The map was not made because not enough data was obtained, owing to the paucity of bedrock exposures along the Colville River and small tributaries and to the surficial mantle of tundra and Quaternary terrace gravels that conceals any bedding traces in the area adjacent to the Colville valley.

The Aupuk anticline is believed by the authors, on the basis of limited outcrop data, to have two small structural highs, one about 1 mile west of the Kurupa River and the other on the Colville River 5 miles upstream from the mouth of Aupuk Creek. West plunge of the western high cannot be proved; the beds may be closed against the faults known to be present about 1 mile north of camp T-Aug. 23-47 on the Colville River, but the amount of closure is unknown. It is estimated that approximately 2,000 feet of the Chandler and Tuktu formations underlies the western high; the estimate is based upon projection of the stratigraphic sequence as measured along the Kurupa River on the north flank of Kurupa anticline, and does not take into account the normal northward gradation to shale or any thinning of the stratigraphic units. The south flank of the Aupuk anticline, at the western high, may have about 3,000 feet of structural relief.

The eastern high is also poorly defined and closure cannot be proved. The Aupuk anticline apparently has an overall west plunge between the eastern and western highs; consequently the eastern high is about 500 to 600 feet lower stratigraphically than the western high. This difference was determined by projecting the con-

tact between the upper and lower parts of the Killik tongue northward from a point on the Kurupa River 2 miles south of the Colville River. The contact is at the base of a conglomerate bed that is fairly well defined and persistent. The beds at the surface over the high would be about 500 feet above the Tuktu-Chandler formations contact; a total of 1,400 to 1,500 feet of Tuktu and Chandler formations underlies the high.

A longitudinal fault was mapped 1,000 feet north of the anticlinal axis near the gas seeps, 2 miles upstream from the mouth of Aupuk Creek. A shear zone with anomalous dips is exposed in a bluff on the Colville River 2 miles downstream from camp C-August 14-46. This shear zone may be a westward extension of the fault; if it is, the fault would cut the axial trace of the Aupuk anticline west of the eastern high. The amount of movement along the fault cannot be determined from available field evidence. The two gas seeps are apparently in the fault zone and on the high. The presence of the gas may be interpreted as evidence that the anticline has closure on the eastern high.

Intense folding and faulting was apparently confined to the Killik Bend area for the Killik Bend anticline is structurally more complex than other anticlines in the northern foothills section of the mapped region. It is overturned to the north, and a thrust fault, numerous high-angle reverse faults, and drag folds are localized in the axial zone. The faulted zone is confined to an area about 1 mile wide, and the greatest displacement is near the axial trace. The exact amount of throw cannot be determined, but it is probably no more than 200 feet, and generally less than that on the north and south sides of the disturbed zone. Most of the faults and folds are confined to beds of the Tuktu formation and to the basal 400 feet of the Killik tongue of the Chandler formation.

East of the complex zone at Killik Bend the anticline plunges east, and west of Killik Bend it plunges slightly west. The east plunge is about 90 feet per mile, and west plunge is perhaps as much as 30 feet per mile. The structural high coincides with the complex zone, and approximately 700 to 800 feet of Tuktu formation is present at the crest.

GEOLOGIC HISTORY

The geology of the Killik-Etiviluk Rivers region is insufficiently known to provide the basis for a detailed analysis of its history, but some of the broader phases of the sequence and nature of the events in this region can be summarized. Many of the statements in the following eight paragraphs, however, are subject to reevaluation; they should serve only as guides for future investigations.

During Paleozoic time the probable source area for the sediments was to the north. Deposition was

probably almost continuous from Late Devonian through Mississippian time. The Upper Devonian limestone and the Hunt Fork shale are believed to have been deposited in a marine environment. The contact between these formations was not seen. The Hunt Fork shale is apparently gradational into the overlying Kanayut formation which is predominantly a non-marine quartzitic sandstone and conglomerate sequence. The Kayak shale is a marine unit that overlies the Kanayut conglomerate. The contact may be gradational, although it is suggested (Bowsher and Dutro, 1957) that in the Shainin Lake area about 100 miles east of the Killik River, the contact is disconformable. The Kayak shale appears to be conformable with the overlying marine limestone of the Lisburne group, although it has not been established whether the contact in this region is disconformable or gradational. The clastic and bioclastic nature of the rocks in the small northernmost exposures of the Lisburne group in this region perhaps indicate that these rocks were derived from a northern source area and that deposition took place in a sea that may have deepened southward.

No rocks of Pennsylvanian age have been identified in this region, and the hiatus may represent a time of quiescence and nondeposition or of some uplift and erosion. The events in Permian time in this region are poorly understood, and the distribution of the rocks are not known. Apparently deposition here during Permian time was in a marine environment.

An unconformity is present between the upper Paleozoic rocks and the Triassic rocks. Apparently the next significant deposition took place in Middle or Late Triassic time, and the meager evidence available gives little information on events during the time between the Permian and Middle Triassic. Presumably there was no significant orogeny at this time, as there is no known angular relation between the Siksikpuk and Shublik formations in this region. It was likely a time of relative quiet in a marine or littoral environment, and it was during this time that at least part of the phosphatic deposits were formed. The abundantly fossiliferous Triassic limestone, chert, and shale, and also some beds of oil shale were deposited in a quiescent marine environment. Little can be deduced from this region about events during Jurassic time. Probably orogenic movement began in a source area to the south, and some sandy and pebble-cobble conglomerate as well as fine clastic material were deposited, probably in a rapidly shifting shallow marine and littoral environment.

The events in Late Jurassic and Early Cretaceous time in this region are not easily determined. It seems clear that orogenic activity continued at least through Okpikruak time; a mountain area in or just south of

the present Brooks Range, flanked by a west-trending geosyncline in the present southern foothills province area, is suggested. The Okpikruak rocks were deposited in the geosyncline during this time, and in places may rest with disconformity on Jurassic rocks but in other places may lie on Triassic or Permian rocks. The environment fluctuated between shallow marine and littoral.

Marine shale, graywacke sandstone, and conglomerate, locally in excess of 10,000 feet thick, were deposited in the geosyncline during Early and Middle Albian time; these rocks are divided into the Fortress Mountain, Torok, and Tuktu formations. This thick marine sequence was deposited on a differentially eroded surface, for the Fortress Mountain formation unconformably overlies rocks of Permian(?) to Early Cretaceous age.

The region has been generally emergent since the deposition of the Tuktu formation in middle Albian time. Minor transgressions and regressions of the sea occurred during this time of general emergence, but the rocks are dominantly nonmarine-marginal in character and consist of about 4,000 feet of conglomerate, sandstone, coal, siltstone, and shale.

A period of igneous activity, probably in late or post-Okpikruak time, formed sills, plugs, and perhaps some flows of basalt.

Two periods of folding followed the intense Late Jurassic and Early Cretaceous orogeny. The first period of folding, which was probably more severe than the second, occurred at the end of Cenomanian time; rocks of middle to late Turonian age unconformably overlie the Cenomanian strata. The folded late Cretaceous beds indicate that the last period of folding to affect the region probably took place during Tertiary time. The present Brooks Range and many of the structural features in the foothills section probably date from the Tertiary orogeny; however, only minor folding took place in the northern part of the region at this time. The uplift along the positive or transverse high that strikes northward in the Oolamnagavik area probably began no later than pre-Fortress Mountain time; it continued through Cretaceous or Tertiary time.

ECONOMIC GEOLOGY

PETROLEUM POSSIBILITIES

No oil seepages have been reported within the Killik-Etiviluk Rivers region; however, two seepages, believed to be of natural gas, are present in valley-floor lakes adjacent to the Colville River and about 1¼ miles west of the mouth of Aupuk Creek. Oil shale, probably part of the Triassic Shublik formation, occurs in the southern foothills section, but the thickness of the beds and their areal extent are unknown. Owing to faults,

complex structure, and apparent paucity of favorable reservoir beds, this area in general does not appear to offer attractive possibilities for petroleum exploration. No seismic work or drilling has been done in this region, and little information can be gathered from the relatively poor and isolated outcrops of bedrock. Thus, interpretations of subsurface structure and stratigraphy are conjectural, and subsurface exploration will be required before an adequate evaluation of the petroleum possibilities of this region can be made.

PALEOZOIC ROCKS

The Hunt Fork shale, Kanayut conglomerate, and Kayak shale formations are exposed within the Brooks Range province in the mapped region, and in the outcrops appear to be unfavorable petroleum reservoir rocks; they are essentially nonporous and impermeable sandstone and conglomerate that are in part metamorphosed to quartzite, slate, and slaty shale. The lithologic character of these formations at depth and northward from the mountain front in this region is unknown. If, as has been postulated, the source area for these sediments was to the north near the present Arctic coast, some change in lithology is to be expected; however, chert conglomerate, shale, and claystone of Middle (or Lower?) Devonian age was encountered at a depth of 10,040 to 10,503 feet in Topagoruk test well 1 (Collins, 1958), approximately 160 miles north of the mountain front. This conglomerate sequence from the well is similar in age and lithology to the Kanayut conglomerate in this region, and is the only proven occurrence of Devonian rocks north of the Brooks Range, for none of the other wells were drilled deep enough to penetrate Devonian rocks and none are known to crop out. No section that can be correlated with the Kayak shale was recognized in Topagoruk test well 1.

Where exposed in the Brooks Range province, these Paleozoic formations are structurally complex, although at depth in the Foothills province the complexity may decrease northward from the mountains; furthermore, they are probably below a depth of at least 10,000 feet in the northern foothills section of this region. Presumably the Kanayut conglomerate, at least, underlies all the Foothills province in the mapped region.

The Lisburne group was not studied in detail in the Killik-Etiviluk Rivers region, but within the Brooks Range it appears to be structurally and lithologically unfavorable for petroleum accumulation. Only a few thin zones of the limestone exposed near Kurupa Lake show any visible porosity. The Lisburne group in its northernmost exposures on the East Fork of the Etiviluk and the Oolannagavik Rivers is more dolomitic, vuggy, and elastic than it is in the mountains, and the possibility that the porosity increases northward from

the mountain front is suggested. The absence of limestone or of any identifiable Mississippian strata above the Middle Devonian chert conglomerate sequence in Topagoruk test well 1 and the presence of a marked angular unconformity between this sequence and red beds of Permian(?) age (Collins, 1958) further complicate the problem of the northward extent of the Lisburne group. Conceivably the Lisburne group might offer good petroleum reservoir possibilities within the foothills province of the mapped region, but, until some indication of its depth, lateral extent, lithology, and structure can be obtained, it would be a nebulous drilling target.

The unnamed Carboniferous and Permian formation and the Siksikpuk formation of Permian age are present in the southern foothills section and in the mountains near Howard Pass. Some limestone and clean, moderately porous quartz sandstone and conglomerate, all of which might have reservoir potential, are included in these formations, but much of the section is chert, siltstone, and shale. In the mapped region, these formations are exposed only in the southern part of the southern foothills section, and their structure and lithology farther north are unknown. The only observations of Permian rocks north of the outcrop belt are those from Topagoruk test well 1, where a Permian sequence has been identified between 9,380 and 10,040 feet. The rocks in this interval are siliceous or calcareous sandstone (in part dolomitic), siltstone, conglomerate, and claystone, with some shale (Collins, 1958). Thus, a northward change to a more clastic and less cherty Permian section between the southern foothills and Topagoruk test well 1 is indicated. A sandstone bed at 9,420 feet in the well has a porosity of 6.61 to 6.9 percent and is impermeable to air (Collins, 1958, p. 282). Presumably most of the foothills province in the mapped region is underlain, generally at considerable depth, by the Permian formations, and some potential reservoir beds may be included.

TRIASSIC AND LOWER CRETACEOUS ROCKS

The Triassic Shublik formation, the Jurassic Tiglukpuk formation, and the Lower Cretaceous Okpikruak formation, which crop out in the southern foothills section of this region, are not well defined. The complex structures formed by these rocks, the abundant and poorly delimited faults, and the generally poor reservoir characteristics of the chert, shale, siltstone, dense limestone, and some tightly cemented sandstone and nonporous graywacke units, make these formations in their outcrop area unfavorable for petroleum accumulation. On the basis of present knowledge of these formations elsewhere in the foothills province of northern Alaska, they show little, if any, evidence of petroleum potential. Three samples of sandstone that were

collected on the east side of Imnaitchiak Creek between camps C-June 16-50 and C-June 22-50 have a maximum of 2.85 percent porosity and are impermeable.

Oil shale occurs in the southern foothills section of the Killik-Etiviluk region, but it does not appear to be abundant and has been found chiefly as float. Howard (Stoney, 1900, p. 69) noted that the Eskimos gathered pieces of this float for fuel near the upper Etiviluk River; the field party in 1949 found leathery oil shale pebbles along ridges formed by the Okpikruak formation west of camp M-June 6-49. Pebbles and cobbles of oil shale are also known to occur in conglomerate of the Okpikruak formation in the upper Utukok and Kuna Rivers area 100 miles to the west of the Etiviluk River. Oil shale has been found in place with Triassic rocks in the Kiruktagiak-Okpikruak Rivers area 20 to 30 miles east of the Killik River. A weathered and largely vegetation-covered conglomerate of the Okpikruak formation may be the source of some of the oil-shale float in the Killik-Etiviluk region. In view, however, of the relatively poor outcrops in much of this region and of the known Triassic oil shale near Imnaitchiak Creek and farther east, it is reasonable to assume that more oil shale than is apparent is present in the Shublik formation in the mapped region.

The Tiglukpuk formation is poorly exposed in the mapped region, and an evaluation of the reservoir potential of this formation is necessarily indefinite. Beds of graywacke-type sandstone, conglomeratic sandstone, and conglomerate, many of which are 10 feet or more thick, and limestone coquina are included in the Tiglukpuk formation. The depth to this formation, its thickness, lithologic character, and distribution in the subsurface in the mapped region are unknown. In outcrop, the coarser clastic units mentioned above showed little visible porosity. In Topagoruk test well 1, a section of Jurassic rocks consisting mainly of marine clay shale with a minor amount of siltstone and glauconite sandstone are present at a depth of 6,600 to 8,640 feet (Collins, 1958).

The Okpikruak formation includes some beds of micaceous graywacke-type sandstone, grit, and pebble conglomerate. In the outcrops these clastic rocks showed little visible porosity, and two samples collected from either the Tiglukpuk or the Okpikruak formation show 2.09 and 1.23 percent porosity. Nothing is known of the subsurface character or extent of this formation in the mapped region.

The Fortress Mountain formation of Early Cretaceous age includes a large proportion of graywacke-type sandstone and conglomerate in addition to siltstone and shale. All the coarse clastic rocks are poorly sorted and "dirty," and show little or no visible porosity. Because of the generally poor visible porosity, only

three samples were collected for testing. Two from Smith Mountain have 0.8 and 3.4 percent porosity and are virtually impermeable. One from along the Kurupa River about 27 miles south of its mouth has 7.8 percent porosity, which is probably about the maximum in this region. The subsurface extent and lithologic character of the Fortress Mountain formation north of its surface outcrops is unknown; the coarse clastics may have shale equivalents.

The Torok formation is predominantly shale, with minor amounts of siltstone, graywacke sandstone, and conglomeratic sandstone. None of the coarser clastic beds are known to have visible porosity.

Only general correlations between the Lower Cretaceous formations in the Killik-Etiviluk Rivers region and those in Topagoruk test well 1 have been suggested (Gryc and others, 1956, p. 214). Much more sandstone and conglomerate is present in the outcrops of these formations than is found in their time equivalents in the Topagoruk well. Facies changes from sandstone to shale and pinch-outs of sandstone and conglomerate beds in a northerly direction, forming potential stratigraphic traps, may be inferred. The only known indication of petroleum in this sequence of rocks in either of the above-mentioned regions is a slightly oil stained sandstone at 5,960 to 5,987 feet in the well. This sandstone is impermeable, and a formation test showed no oil or gas (Collins, 1958, p. 269).

LOWER AND UPPER CRETACEOUS ROCKS NANUSHUK GROUP

The Tuktu formation includes sandstone, siltstone, silty shale, conglomerate, and clay shale, listed in approximate order of abundance, and is dominantly marine. In general the porosity of the sandstone and conglomerate, as determined visually, is low. Laboratory determinations on 25 samples show an average of 8.67 percent porosity and a range from 2.05 to 15.9 percent; nine samples were found to be impermeable. A representative porosity-sampling program was not attempted—many of the 25 samples were selected because of their visible porosity, and these porosity and permeability values are nearly a maximum; thus the Tuktu formation does not give promise of good reservoir beds. Winnowed phases of this formation would have more favorable porosity and permeability, but the location of such rocks is difficult to predict.

Possible changes in thickness and facies of the Tuktu formation should be considered in evaluating its petroleum possibilities. The amount of sandstone and conglomerate apparently decreases to the north in this area, perhaps owing to actual thinning of the formation or, more likely, to a facies change from coarse clastic to silty and clayey rocks. Lacking knowledge of sub-

surface control, this change cannot be evaluated quantitatively.

The unit of Tuktu formation and lower part of the Killik tongue undifferentiated, is limited, as far as known, to the northwestern part of the mapped region and is exposed only in the Kurupa anticline and in the westernmost part of the Oolamnagavik syncline. It is a mapping unit made up of marine sequences similar in type to those of the Tuktu formation, and of sequences of chiefly nonmarine siltstone, shale, sandstone, and conglomerate of the lower part of the Killik tongue. The subsurface extent and thickness of this unit is unknown, but presumably it is present in the western part of the Aupuk anticline within about 1,000 feet of the surface. Some of the sandstone in this unit has fair porosity; four samples that were tested average 13.5 percent and range from 9.4 to 19.2 percent. Permeability was not determined. If proper structural conditions were determined to exist in the western part of the Aupuk anticline, this unit would be worthy of subsurface exploration.

The lower part of the Killik tongue of Early Cretaceous age is chiefly a nonmarine unit that intertongues with the Tuktu formation in the northwestern part of this region. Siltstone, silty and clayey shale, sandstone, conglomeratic sandstone, conglomerate, and coal, in approximate order of abundance, are included. The coarser clastic rocks are a dirty graywacke type that have generally low porosity, although some fairly porous rocks are present. The 38 samples tested have average porosity of 8.04 percent, and range from 1.54 to 21.0 percent.

The lower part of the Killik tongue is exposed throughout the length of the Kurupa and Killik Bend anticlines and is nearly or entirely breached. In the Aupuk anticline, as far as known, only this tongue is exposed in the axial zone, and probably a minimum thickness of 500 feet is present on the crest of the anticline. Thus, structurally as well as lithologically, the petroleum possibilities of this formation are quite limited.

The upper part of the Killik tongue is a dominantly nonmarine unit, and its lithologic characteristics and stratigraphic relationships are very similar to those of the lower part. This unit occurs in the center of the Oolamnagavik syncline between the Kurupa and Oolamnagavik Rivers, and in the Awuna syncline. It has been completely eroded from the anticlines in the mapped region, unless possibly it is present in the axial zone of the extreme western end of the Aupuk anticline; it therefore appears to have no significance in this region as a petroleum reservoir.

Seventeen rock samples from the upper part of the Killik tongue that were tested have an average porosity

of 11.10 percent, and range from 4.5 to 20.6 percent. All the samples that were collected along the lower Kurupa River (table 11) have higher than average porosity. Two of these samples that have 12.4 and 15.69 percent porosity show respectively 4.6 and 27.0 millidarcys permeability.

The Niakogon tongue of Late Cretaceous age is a dominantly nonmarine unit composed of sandstone, conglomerate, siltstone, and shale. Within this area it is limited to the Awuna syncline, and this structural setting precludes it from consideration as a petroleum prospect. Seven samples from three widely separated localities have an average porosity of 10.06 percent and range from 5.44 and 14.6 percent.

The Ninuluk formation of Late Cretaceous age is chiefly a marine formation containing siltstone, silty and clayey shale, sandstone in part conglomeratic, and a minor amount of bentonite. It has been identified only along the Killik River in the Awuna syncline, and on the north side of the Colville River northeast of the mouth of the Killik River in the Killik Bend anticline. Within this area this unit is apparently not in a favorable structural position to form a petroleum reservoir. Some of the sandstone beds may have fair porosity. The only sample tested, which is from the Killik Bend anticline, has 13.2 percent porosity.

COLVILLE GROUP

The Seabee and Prince Creek formations of Late Cretaceous age were not examined in the field in this area. Their presence in the Awuna syncline between Aupuk Creek and Oolamnagavik River was interpreted from aerial photographs. Owing to their structural positions, they have no apparent petroleum potential.

TABLE 11.—Porosity-permeability of selected samples

Field sample	Formation	Porosity (percent)	Permeability (millidarcy)	Location
50 A Re 73	Siksikpuk, Shublik and Tiglukpuk.	2.85	Impermeable.	Imnaitehiak Creek.
50 A Re 88	Siksikpuk, Shublik, Tiglukpuk, and Okpikrauk.	2.09	do	Do.
50 A Re 95	do	1.23	do	Do.
49 A Lac 2	Fortress Mountain.	3.4	do	Etivluk River, Smith Mtn.
49 A Lac 5	do	.8	do	Do.
46 A Ch 99	do	7.8	do	Kurupa River, middle
45 A Wa 56	Tuktu	7.7	do	Killik River, lower.
45 A Kr 72	do	6.0	do	Do.
46 A Ch 53	do	12.2	do	Oolamnagavik River, lower.
46 A Ch 60	do	8.3	do	Do.
46 A Ch 67	do	9.0	do	Do.
46 A Ch 81	do	3.1	do	Do.
46 A Ch 111	do	11.0	do	Kurupa River, lower.
46 A Ch 125	do	14.4	do	Do.
46 A Ch 131	do	10.6	do	Do.
46 A Ch 188	do	7.1	do	Colville River, Killik Bend.
46 A Th 115	do	8.8	do	Kurupa River, lower.
46 A Th 120	do	7.2	do	Do.
46 A Th 215	do	3.2	do	Colville-Oolamnagavik Rivers.
47 A Th 17	do	13.5	do	N. Colville-Etivluk Rivers.
47 A Th 23	do	14.8	do	Do.

TABLE 11.—Porosity-permeability of selected samples—Con.

Field sample	Formation	Porosity (per cent)	Permeability (millidarcy)	Location
47 ATh 28	do	10.9		S. Colville-Etiviluk Rivers.
47 ATh 28a	do	11.3		Do.
50 AE 126	do	2.05	Impermeable.	Kurupa River, lower.
50 AE 127	do	3.71	do	Do.
50 AE 128a	do	8.16	do	Do.
50 AE 128b	do	9.54	do	Do.
50 AE 128c	do	8.20	do	Do.
50 AE 129	do	7.62	do	Do.
50 AE 131	do	2.56	do	Do.
47 ATh 35	Tuktuk and lower part of the Killik tongue, undifferentiated.	11.5		S. Colville River-Kucher Creek.
47 ATh 37	do	9.4		Do.
47 ATh 38	do	14.2		Do.
47 AZ 612a	do	19.2		Kurupa River, lower.
45 AWa 57	Lower part of Killik tongue.	6.8		Killik River, lower.
45 AWa 70	do	7.2		Do.
45 AKr 84	do	9.2		Do.
45 AKr 85	do	10.6		Do.
46 ACh 71	do	5.3		Oolamnagavik River, lower.
46 ACh 77	do	3.8		Do.
46 ACh 148	do	9.3		Colville-Kurupa Rivers.
46 ACh 151	do	6.5		Do.
46 ACh 159	do	15.0		Colville River-Aupuk Creek.
46 ACh 169	do	6.2		Do.
46 ACh 176	do	6.5		Colville River-Aupuk Creek.
46 ATh 110a	do	8.6		Kurupa River, lower.
46 ATh 114	do	21.0		Do.
46 ATh 153	do	4.7		Do.
46 ATh 155	do	4.1		Colville-Kurupa Rivers.
46 ATh 169	do	5.3		Colville River-Aupuk Creek.
46 ATh 187	do	6.2		Do.
46 ATh 197	do	9.9		Colville River, Killik Bend.
46 ATh 221	do	12.6		Colville-Oolamnagavik Rivers.
46 ATh 232	do	11.3		Do.
47 ATh 29	do	14.7		Colville-Etiviluk River.
47 AZ 607	do	14.9		Kurupa River, lower.
47 AZ 613	do	19.5		Do.
47 AZ 614	do	10.0		Do.
47 AZ 615	do	20.3		Do.
50 AE 113	do	4.48	Impermeable.	Do.
50 AE 114	do	6.44	do	Do.
50 AE 132a	do	4.25	do	Do.
50 AE 132b	do	1.94	do	Do.
50 AE 134a	do	4.93	do	Do.
50 AE 134b	do	4.61	do	Do.
50 AE 137	do	6.98	do	Colville-Kurupa Rivers.
50 AE 144	do	1.86	do	Colville River-Aupuk Creek.
50 AE 151	do	3.32	do	Do.
50 ARe 269	do	1.54	do	Colville-Kurupa Rivers.
50 ARe 288	do	1.74	do	Do.
50 ARe 295	do	3.55	do	Do.
47 AZ 617	do	19.3		Kurupa River, lower.
47 AZ 557	Upper part of Killik tongue.	9.6		Colville River-Kucher Creek.
46 ACh 92	do	7.8		Oolamnagavik River, lower.
46 ATh 135	do	20.6		Kurupa River, lower.
47 ATh 53	do	7.7		Colville-Awuna Rivers.
47 ATh 61	do	8.4		Do.
47 ATh 62	do	13.5		Do.
47 ATh 62a	do	7.9		Do.
47 ATh 64	do	10.0		Do.
47 ATh 66	do	11.0		Do.
47 ATh 67	do	4.5		Do.
47 ATh 67a	do	4.9		Do.
46 ATh 123	do	10.3		Kurupa River, lower.
47 AZ 618	do	15.3		Do.
47 AZ 618a	do	12.9		Do.
50 AE 118	do	12.4	4.6	Do.
50 AE 135	do	15.69	27	W. Kurupa River, lower.
50 AE 142	do	13.91	>1	Colville River-Aupuk Creek.
45 AWa 95	Ninuluk.	13.2		Colville Killik Rivers.
45 AWa 75	Niakogon tongue.	7.4		Killik River, lower.
45 AWa 78	do	9.7		Do.
45 AKr 90a	do	11.2		Do.
46 ACh 146	do	10.5		Kurupa River, lower.

TABLE 11.—Porosity-permeability of selected samples—Con.

Field sample	Formation	Porosity (per cent)	Permeability (millidarcy)	Location
47 AZ 565	Niakogon tongue.	14.6		Colville-Awuna Rivers.
47 ATh 56	do	11.6		Do.
50 AE-123	do	5.44	Impermeable.	Kurupa River, lower.

STRUCTURE

The anticlines, synclines, faults, and associated structural and stratigraphic traps within the Killik-Etiviluk Rivers region afford a number of conditions that could be favorable for petroleum accumulation. The present knowledge of the structure and the structural-stratigraphic features within this region is inadequate to make more than a general evaluation of their effect on oil accumulation.

The structural and topographic setting of the Brooks Range province are unfavorable for oil accumulation of any consequence, and would be inhospitable for most types of exploration. The structure within this province is complex. The intensity of deformation and the resulting partial metamorphism of the formations appear to be incompatible with oil accumulation.

The structure of the southern foothills section, on the basis of present knowledge, appears to be generally unfavorable for petroleum accumulation. Most of the anticlines in the southern half of the province are sharply folded and of unknown linear extent. Faults, a number of which appear to be major thrusts, are numerous and important features in this province, and may, together with the folds, produce fault traps and fractures that would hold oil. In the northern half of this province, folding and faulting presumably were less intense; in the outcrop belt of the Fortress Mountain and Torok formations, anticlines of apparently greater linear continuity were mapped. Geophysical exploration might reveal the nature of the Paleozoic and older Mesozoic rocks in this part of the province.

Structural and stratigraphic traps in the pre-Torok formations are unknown, but the possibility that they exist in both the southern and northern foothills sections should not be overlooked. Facies changes and unconformities northward from the mountain front are indicated by comparison of sections from the outcrop area and in Topagoruk test well 1. Structural and stratigraphic traps might be expected also along the flank of the north-trending high near the Oolamnagavik River. The same possibilities exist in the pre-Torok formation rocks in the northern foothills section, except that there these older formations will be at considerable depth. Three major anticlines, the Kurupa, the Aupuk

and the Killik Bend, have potential for petroleum accumulation. Facies changes are known to occur in the Tuktu and younger formations in this section so stratigraphic traps are also likely to occur.

The Tuktu formation is not entirely unfavorable structurally for petroleum potential. The Tuktu undoubtedly underlies all the northern foothills section in this region, and is exposed in the Kurupa anticline and in the Killik Bend anticline. The top of the Tuktu is believed to be within about 500 feet of the surface in the Aupuk anticline.

Part of the Tuktu formation at the Oolamnagavik River and between the Oolamnagavik and Killik Rivers, and most of the Tuktu at the Kurupa River is breached over structural highs on the Kurupa anticline, so most of this fold is unfavorable for exploration of post-Torok formation rocks. Further work might delimit closure near the western end of the Kurupa anticline between the Awuna and Colville Rivers. The Killik Bend anticline shows doubtful possibilities for petroleum in the post-Torok formation rocks, owing to the fact that the Tuktu formation is both faulted and partly breached in the high at Killik Bend and the mouth of the Oolamnagavik River.

The Aupuk anticline may offer exploration possibilities, but subsurface data are needed to evaluate it properly. Outcrop control is poor and discontinuous, but a west-trending structural high of undetermined closure is interpreted to lie about $3\frac{1}{2}$ miles west of the mouth of Aupuk Creek. A west-trending fault, which has undetermined but apparently small displacement, lies just north of and parallel to the axial trace in the high. Another high, centering about 1 mile west of the mouth of the Kurupa River, has apparent eastern closure. The western extension is believed to trend into an anticlinal zone that includes longitudinal and transverse faults; field data are insufficient to prove or disprove closure to the west.

GAS SEEPS

Two gas seeps in small valley-floor lakes adjacent to the Colville River northwest of the mouth of Aupuk Creek (pl. 43) are known. They are near the crest and east end of the Aupuk anticline.

The Aupuk seep, which is the more active, is 1.7 miles northwest of the mouth of Aupuk Creek and in the eastern end of a small meander-scar lake at the base of a low bluff on the south side of the Colville River valley. It was originally mapped by a U.S. Navy geological party in 1945 and was examined and sampled in August 1946 by Chapman and Thurrell. At the time of the 1946 investigation, gas bubbles rose to the lake surface at the rate of about one per second at 20 or more spots within an area of 150 square feet. It was reexamined and resampled by Thurrell in May

1947 when the lake was frozen. When visited in August 1950 by Eberlein and Reynolds, the seep apparently was more active, and the area of seepage included approximately 300 square feet of lake surface. Bubbles rose continuously at five spots and were rising at a rate of one every 2 or 3 seconds in two other spots. No trace of oil was observed at the surface or around the lake.

In May 1947 Thurrell reported a gas seep, here called the North Colville seep, in the east end of a small lake near the north edge of the Colville River valley floor and about 4.8 miles northwest of the mouth of Aupuk Creek (pl. 43). The lake was frozen at the time of his visit, and a small area of open water led to the discovery. Gas bubbles were observed to rise intermittently, and a sample was collected. The field party in 1950 attempted to locate this seep, but could not find it. Bubbles rose occasionally to the surfaces of several lakes in the vicinity, but no obvious seepage was noted.

TABLE 12.—Analyses of gas from Aupuk and North Colville seeps
Analyses by Fred L. Mohler, National Bureau of Standards. Samples from Aupuk seep analyzed 1946; A, on dry basis, but including air, owing to air leak in type of container used; B, on a dry, air-free basis. Sample from North Colville seep analyzed 1947.]

Analysis factor	Aupuk seep		North Colville seep
	A	B	
Methane.....	195. (4)	198. (8)	289.1
Ethane.....	.06	.07	...
Nitrogen.....	3.3	.7	8.7
Oxygen.....	.77
Argon.....	.1	.06	.2
Carbon dioxide.....	.4	.4	1.3
Total.....	99.96	100.03	100.0
Heating value..... Btu per cu ft.....	...	986.7	889
Specific gravity.....5622	.609

¹ Figures in parentheses questionable.

² Methane obtained from difference. Total hydrocarbon heavier than methane probably less than 0.005 percent.

³ Hydrocarbons heavier than ethane are less than 0.1 mole percent.

The source of this gas is undetermined; however, it may be significant that the seeps are on the interpreted structural high and are very closely aligned with the fault that nearly coincides with the axial trace of the Aupuk anticline. Analyses of the three gas samples (table 12) are similar. The presence of a small amount of ethane in the Aupuk seep samples and the persistence of the seep over a period of at least 5 years are indicative of a bedrock reservoir source. Conversely, the North Colville seep may be marsh gas that finds release under a lake where permafrost and seasonal frost are absent.

COAL

The coal-bearing strata in the Killik-Etiviluk Rivers region are confined mainly to the Chandler formation in the northern foothills section (fig. 65). The beds are more abundant, of greater thickness, and of better

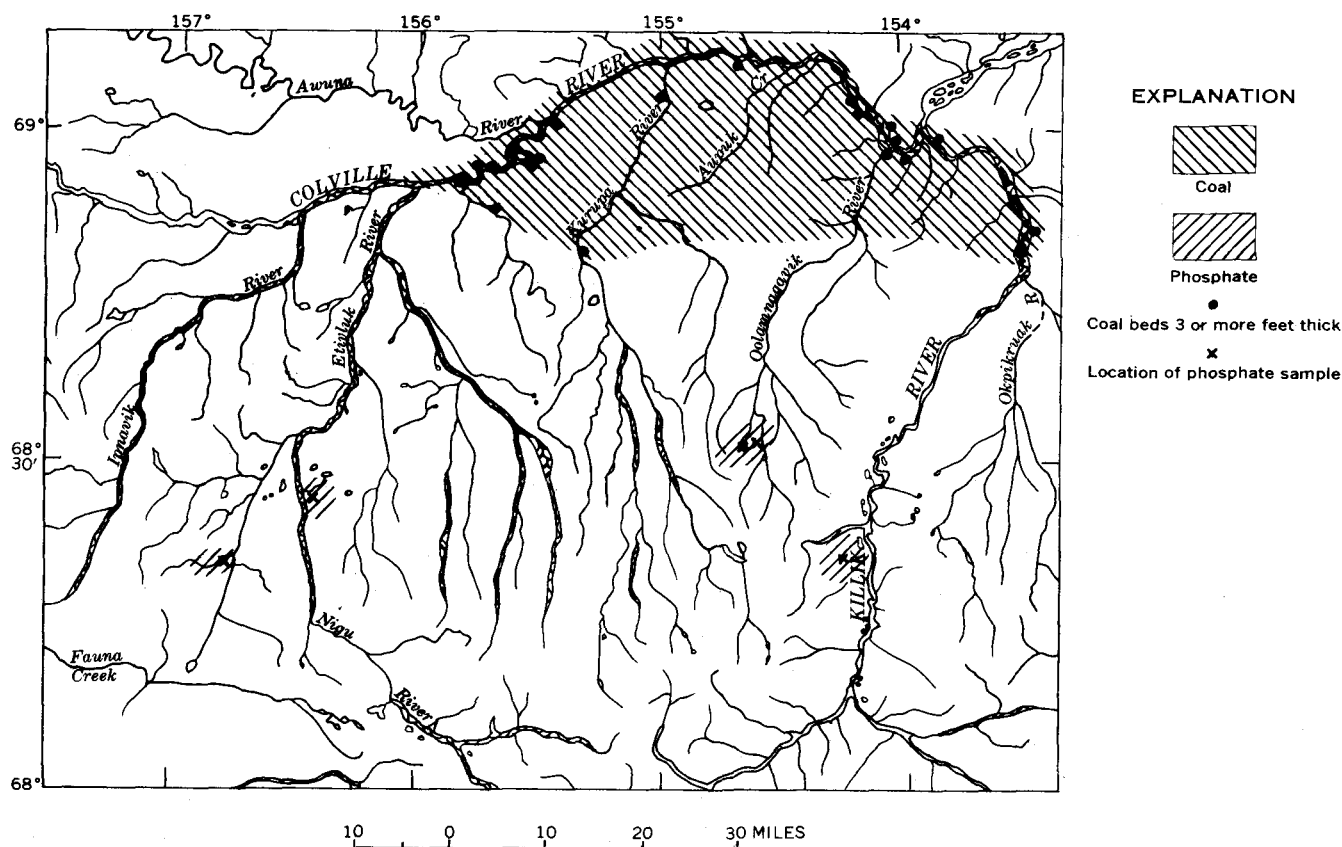


FIGURE 65.—Geographic occurrence of coal- and phosphate-bearing strata in the Killik-Etiviluk Rivers region, Alaska.

quality in the lower part of the Killik tongue than in the upper part of the Killik tongue or in the Niakogon tongue. Most of the coal is of bituminous rank; however, it may vary from subbituminous to bituminous. Beds sampled for analysis are principally of bituminous rank. Beds 3 feet or more in thickness are noted on figure 9; they are concentrated at two localities on the Colville River, one between Kucher Creek and the Awuna River, and the other at Killik Bend. Many beds ranging from 1 foot to 3 feet in thickness also were measured at these localities.

COLVILLE RIVER

Coal is present in nearly all outcrops of the Chandler formation along the Colville River between the Etiviluk and Killik Rivers. The best beds are in the lower part of the Killik tongue. The dips are generally less than 20°, although some beds dip as much as 65°. Although samples were collected from only a few beds along the Colville River, the analyses probably are typical and give a fair indication of the quality of coal present. The beds were seen only in river bluff out-

crops, and their lateral extent is unknown except at one point in Killik Bend. At this locality on the south side of the Colville River, 1 mile downstream from the mouth of the Oolamnagavik River, many coal beds were measured (pl. 48, column 4); the same section is exposed where the river swings south again about 1½ miles farther east. The same coal beds were measured in both cutbanks, and it can be reasonably assumed that the beds are continuous between the two points. Thus, a fair estimate of the coal for this small area (approximately 2 square miles) can be obtained by computing the reserve for a strip-mine operation in which the maximum overburden to be removed would not exceed 100 feet (20 feet of gravel and 80 feet of bedrock). About 796,000 tons could be mined from beds 2½ or more feet thick. In removing the overburden to reach these beds, other coal beds of less than the 2½-foot thickness would be encountered. The total recoverable coal for this locality would then be just over 1,000,000 tons; this figure probably represents only a small fraction of the coal reserves along the Colville River between the Etiviluk and Killik Rivers.

The coal from the Killik Bend area is of slightly higher quality than the other two samples from the Colville River area; it is from beds that are more deformed than the beds from which the other two samples were taken, and the higher quality probably is a result of more intense folding of the beds.

KURUPA RIVER

Coal is present in most of the outcrops of nonmarine Cretaceous strata along the Kurupa River, north of the Tuktu escarpment. Rocks of the lower part of the Killik tongue are better exposed than those of the upper part of Killik tongue and the Niakogon tongue; consequently, most of the samples are from the lower part of the Killik tongue. The coal is found in beds that dip 5° to 20° , and they occupy approximately the same stratigraphic position as the beds along the Colville River. The lateral extent of the beds is unknown. In general the beds are overlain by shale, and so would be more suited to strip mining than underground mining because the shale is not strong enough to stand without considerable timbering.

OOLAMNAGAVIK RIVER

The nonmarine sequence of rocks on the Oolamnagavik River includes numerous beds of coal similar to those on the Colville and the Kurupa Rivers; the coal is not as well exposed and for the most part is found as float associated with rubble traces. Two of the samples collected from the Oolamnagavik River area were analyzed.

KILLIK RIVER

Coal is present along the Killik River from about 3 miles above the junction of the Okpikruak River to the Colville River. Coal beds without bone or partings are locally as much as 4 feet thick. One sample from the Killik River collected by Mertie was analyzed by the Bureau of Mines (Smith and Mertie, 1930, p. 314). Field sample 24AMt65 is from the type section of the Niakogon tongue on the east bank of the river 1 mile east of camp D—June 29–53. The strata dip 4° to 5° S. Coal beds are more numerous in strata of the Killik tongue, but none of the samples were analyzed.

Beds of burned coal are present along both banks of the Colville River between Aupuk Creek and the Oolamnagavik River and along the right bank of the Killik River about 2 miles upstream from the mouth. The largest outcrop of burned coal is on the right bank of the Colville about $1\frac{1}{2}$ miles above the Oolamnagavik River. The rocks surrounding the burned coal beds

are altered to a bright brick red and cream white, and clinkers and slag are abundant in the interval formerly occupied by the coal bed.

The coal samples were obtained from surface exposures and were not protected in sealed cans. Consequently, the moisture content of the sample as received by the Bureau of Mines was undoubtedly lower than that of the coal in the bed. Other chemical and physical properties probably were changed somewhat by exposure to air, so that the data listed in table 13 should be considered only as approximate.

The carbonization products for all coal samples were determined by the Fischer low-temperature carbonization assay and are included in table 14. The chemical and physical properties of the gases obtained from the coal are shown in table 15.

PHOSPHATE-BEARING ROCKS

Phosphate-bearing rocks of various grades occur in the Lisburne group of Mississippian age and the Shublik formation of Triassic age in the Brooks Range and southern foothills section of northern Alaska. They are confined chiefly to the black chert-shale part of the Alapah limestone (Patton, 1959).

In the Killik-Etiviluk Rivers region some phosphate-bearing rocks occur in the Lisburne group, the unnamed Permian formation, and the Shublik formation. Very little work was done on identifying or collecting such rock in this mapped region; an intensive search would be necessary to evaluate the quality and extent of phosphate-bearing rocks. Five samples were collected at random; the results of analyses of these samples are given in table 16. In addition, some visual determinations of phosphate were made in the field. The low P_2O_5 content of the five samples tested, the complex structure and poor outcrops of the possibly phosphate-bearing rocks, and the relative inaccessibility of the region appear to preclude it for commercial development of phosphate.

Four samples from the Alapah limestone show less than 5 percent P_2O_5 . These are from limestone, calcareous silty shale, black sooty siliceous siltstone, and chert sections. One sample collected from the unnamed Permian formation along the Nigu River is a calcareous mudstone from a contact zone between igneous rock and a green shale-chert section; it yielded 5 percent P_2O_5 . Phosphate, occurring as flat pebbles or nodules 0.5 to 2 inches in diameter and in beds 2 to 4 inches thick, was identified visually in the Shublik formation.

Table 13.—Analyses of samples of coal from the Killik-Etiviluk Rivers region, Alaska

[Analyses by H. M. Cooper, Pittsburgh Laboratory, U.S. Bureau of Mines. Sample condition: A, as received; B, moisture free; C, moisture and ash free (the "as received" probably represents an air-dried condition because samples were not preserved in air-tight containers)]

Number			Occurrence			Sample Condi- tion	Constituents in percent					Heat value (Btu)
Fischer assay	Coal	Field Sample	Stratigraphic unit	Area	Description		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	
45909	69396	46ATH69A	Killik tongue lower part	Oolamagavik River 68° 53' N., 154° 11' W.	2-foot bed in 30 feet of fine-grained sandstone and siltstone	A	2.3	43.7	40.2	13.8	0.4	11,400
						B	-----	44.7	41.2	14.1	.4	11,600
						C	-----	52.0	48.0	-----	.4	13,570
45910	69397	46ATH105	-----do-----	Kurupa River 68° 51' N., 155° 15' W.	3-foot bed overlying massive salt-and-pepper sandstone	A	4.3	33.0	45.7	17.0	.5	10,580
						B	-----	34.5	47.8	17.7	.5	11,060
						C	-----	41.9	58.1	-----	.6	13,440
45911	69398	46ATH113	-----do-----	-----do----- 68° 52' N., 155° 18' W.	2-foot bed in sandstone, siltstone, and shale	A	6.6	34.8	54.3	4.3	.4	11,410
						B	-----	37.3	58.1	4.6	.4	12,220
						C	-----	39.1	60.9	-----	.5	12,800
45912	69399	46ATH151	Killik tongue upper part	-----do----- 69° 02' 30" N., 155° 04' 30" W.	3-foot bed in sandstone, siltstone, and conglomerate	A	3.1	24.6	42.5	29.8	.3	8,920
						B	-----	25.4	43.9	30.7	.3	9,200
						C	-----	36.7	63.3	-----	.4	13,290
45914	69401	46ACH82	Killik tongue lower part	Oolamagavik River 68° 50' N., 154° 14' W.	Float from bed of uncertain thickness in sandstone and conglomerate	A	2.4	35.2	41.6	20.8	.5	11,030
						B	-----	36.0	42.7	21.3	.5	11,300
						C	-----	45.8	54.2	-----	.6	14,350
45915	69402	46ACH152	-----do-----	Colville River 69° 04' 30" N., 155° 04' W.	2-foot bed in sandstone and claystone	A	3.3	31.2	45.9	19.6	.3	10,430
						B	-----	32.3	47.4	20.3	.3	10,780
						C	-----	40.5	59.5	-----	.4	13,530
45916	69403	46ACH170	-----do-----	-----do----- 69° 04' 30" N. 154° 33' W.	2½-foot bed in shale and siltstone	A	2.7	33.1	46.3	17.9	.4	11,060
						B	-----	34.0	47.6	18.4	.4	11,370
						C	-----	41.6	58.4	-----	.5	13,930
45917	69404	46ACH183	-----do-----	-----do----- 69° 00' N., 154° 00' W.	2-foot bed in sandstone, siltstone, and shale. Numerous other coal beds ½ to 3 feet thick	A	2.3	35.4	51.9	10.4	.5	12,600
						B	-----	36.2	53.2	10.6	.5	12,890
						C	-----	40.5	59.5	-----	.5	14,420
-----	A6848	24AMt65 ¹	Niakogon tongue	Killik River 68° 52' N., 153° 29' W.	3-foot bed in sandstone, siltstone, and shale	A	16.4	29.9	41.9	11.8	.3	8,450
						B	-----	35.7	50.2	14.1	.3	10,110
						C	-----	41.6	58.4	-----	.4	11,770

¹Smith and Mertie, 1930, p. 314.

TABLE 14.—Yields of carbonization products by Fischer low-temperature carbonization assay at 500°C, as received coal basis

[Analysis by W. H. Ode, U.S. Bur. of Mines. Gas yield: percent, by difference, H₂S-free, scrubbed for light oil; cubic feet, H₂S-free, scrubbed for light oil (saturated at 60°F and under pressure equivalent to 30 inches of mercury)]

Field sample	Laboratory No.	Yield (percent by weight of coal)						Yield (per ton of coal)		
		Carbonized residue	Tar	Light oil	Water	Hydrogen sulfide	Gas	Gas (cu- bic feet)	Tar (gal- lons)	Light oil (gallons)
46 ATH 69A	45909	73.2	11.2	0.72	6.9	0.01	8.0	2,710	26.8	2.27
46 ATH 105	45910	75.6	7.0	.51	10.3	.09	6.5	2,270	16.8	1.61
46 ATH 113	45911	70.7	4.0	.41	14.1	.07	10.7	3,030	9.6	1.29
46 ATH 151	45912	85.6	4.0	.27	7.3	.06	2.8	1,200	9.6	0.85
46 ACH 82	45914	76.2	11.7	.73	7.1	.11	4.2	1,850	28.0	2.30
46 ACH 152	45915	79.5	6.3	.45	9.0	.07	4.7	1,810	15.1	1.42
46 ACH 170	45916	78.7	8.6	.52	7.9	.08	4.2	1,870	20.6	1.64
46 ACH 183	45917	75.8	10.7	.73	7.0	.09	5.7	2,110	25.6	2.30

TABLE 15.—*Chemical and physical properties of gas by Fischer low-temperature carbonization assay at 500°C.*[Analysis by W. H. Ode, U.S. Bur. Mines. Gross heating value: H₂S-free, scrubbed for light oil (saturated with water vapor at 60°F and under a pressure equivalent to 30 inches of mercury)]

Field sample	Laboratory No.	Composition, dry (percent by volume)							H ₂ S in gas before removal	Gross heating value	
		Carbon dioxide	Illuminants	Hydrogen	Carbon monoxide	Methane	Ethane	Nitrogen		Btu per cu ft	Btu per lb of coal
46 ATh 69A.....	45909.....	31.2	3.3	15.5	6.1	28.9	12.3	2.7	0.1	653	880
46 ATh 105.....	45910.....	28.3	3.3	8.1	13.3	31.2	13.0	2.8	.9	686	780
46 ATh 113.....	45911.....	45.9	2.2	7.7	12.9	20.7	8.1	2.5	.5	467	770
46 ATh 151.....	45912.....	28.3	3.5	8.8	11.7	35.6	12.1	4.5	1.0	717	430
46 ACh 82.....	45914.....	12.9	4.8	8.7	9.3	44.8	15.8	3.7	1.3	897	830
46 ACh 152.....	45915.....	24.1	3.9	8.1	12.4	36.0	13.0	2.5	.8	746	680
46 ACh 170.....	45916.....	17.0	4.0	9.8	9.4	42.0	14.2	3.6	.9	826	770
46 ACh 183.....	45917.....	13.9	4.2	9.8	8.5	46.0	14.4	3.2	1.0	870	920

TABLE 16.—*Analysis of field samples showing percent P₂O₅ and equivalent uranium*

Field sample	Formation	Location		P ₂ O ₅		eU	
		North latitude	West longitude	Percent	Assayer	Percent	Assayer
49 ADt 41.....	Unnamed Permian formation.	68°29.5'	156°28'	5	J. Matzko.....	0.004	J. Matzko.
49 ADt 134.....	Alapah limestone.....	68°23'	154°09'w	.4	Audrey Smith.....	.004	Do.
49 ALa 8.....	do.....	68°20.5'	156°49'	<5	J. Matzko.....	.005	Do.
50 ACh 63.....	do.....	68°32'	154°31'	<5	do.....	.001	Do.
50 ACh 55.....	do.....	68°32'	154°31.5'	<1.4	Audrey Smith.....	.005	Do.

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INDEX

A	Page
Accessibility	328, 331
Acknowledgments	328
Aerial photography	327
Alapah limestone, contact with Shublik formation	349
description	346
Alluvium	386
<i>Ammobaculites fragmentarius</i>	368
<i>wenonahae</i>	368
sp.	348, 349
Ammonites	357
Anaktuvuk glaciation	383
Animals	333
<i>Arcestes</i> sp.	350
Archeology	333
<i>Arctica dowlingsi</i>	380, 381
sp.	367
<i>Astarte</i> sp.	367
<i>Athyris lamellosa</i>	346
sp.	346
<i>Atractile</i> ssp. indet.	350
<i>Atrypa</i> sp.	334
<i>Aucellina dowlingsi</i>	357
Aupuk anticline, description	392
petroleum possibilities	399
Aupuk seep	399
<i>Avonia</i> sp.	342

B	Page
<i>Bairdia</i>	336
<i>Bathysiphon anomalocoelia</i>	349, 352
<i>braegei</i>	349, 368, 381
<i>vitta</i>	349, 368
Beetle elytrum	360
Bentonite, Nanushuk group	361
Niakogon tongue	379
Bergquist, H. R., fossil identification	368, 378, 380
quoted	360
<i>Beudanticeras</i> (<i>Grant ziceras</i>)	357
Brachiopods	337, 346
<i>Brachythyrus</i> sp.	346
<i>Bradfordoceras</i> sp.	337
Bryozoans	342, 346
Brittle star	367
Brooks Range province, structure	389
Brown, R. W., fossil identification	378
<i>Buchia</i> (<i>Aucella</i>) <i>concentrica</i>	351
(<i>Aucella</i>) <i>crassa</i>	352
(<i>Aucella</i>) <i>crassicolis</i>	352
<i>Buxtonia</i> sp.	346

C	Page
<i>Camartoechia chouteauensis</i>	342
sp.	337
Caninoid coral, undetermined	342
Carboniferous and Permian systems, stratigraphy	347
Carboniferous and Permian unit, unnamed. See Unnamed Carboniferous and Permian unit.	
Cephalopods	337
<i>Cephalotaxopsis heterophylla</i>	378
<i>intermedia</i>	378
sp.	378
Chalcopyrite veinlets, Fortress Mountain formation	356
Chandler formation, coal	399
contact with Tuktu formation	361
description	369

	Page
Chlorite, Hunt Fork shale	337
<i>Chonetes</i> sp.	342, 346
<i>Cladophlebis septentrionalis</i>	378
sp.	378
Cleavage, Hunt Fork shale	337
<i>Cleiothyrodina</i> sp.	342
<i>Cleoniceras</i> (<i>Grycia</i>) <i>sabiei</i>	367
(<i>Neosaynella</i>) <i>whittingtoni</i>	367, 377
<i>tailleuri</i>	359, 360
sp.	377
Climate	332
Coal, description of deposits	399
Kanayut conglomerate	338
Killik tongue	370, 371, 376, 377, 400
Nanushuk group	360
Niakogon tongue	379, 380
Torok formation	358
Tuktu formation	361
Colville group, description	382
petroleum possibilities	397
Colville River area, coal	400
Colville River section, Killik tongue	371
Niakogon tongue	379
Tuktu formation	363
Colville River section at Killik Bend, Tuktu formation	366
<i>Coltrilia crassicoelata</i>	357
<i>kenti</i>	357
<i>Contopteris burejensis</i>	378
Conodonts	348, 349
Corals	346
Cretaceous rocks, petroleum possibilities	395
Cretaceous system, stratigraphy	352
Crinoid debris	342, 367
<i>Cymbophora</i> sp.	367

D	Page
<i>Daonella dubia</i>	350
<i>moussoni</i>	350
Devonian system, stratigraphy	334
<i>Dicranodonta dowlingsi</i>	367
sp.	367
<i>Dictyodotus</i> sp.	346
<i>Dictyomitra</i> sp.	349
<i>Dielasma</i> sp.	346
<i>Dimyodon</i> sp.	350
<i>Ditrupe cornu</i>	367
Drainage	328
Dutro, J. T., Jr., fossil identification	334, 342, 346
quoted	334

E	Page
Eberlein, G. D., quoted	389
Echooka glaciation	385
Economic geology	394
<i>Entolium utukokensis</i>	367, 377
<i>Entomonotis subcircularis</i>	350
Eolian deposits	387
Etivluk Lake section, Kanayut conglomerate	339
Etivluk River section, Fortress Mountain formation	355
Torok formation	358
<i>Eumetria</i> sp.	346
<i>Eunemia speciosum</i>	337
<i>Eurycheilostoma robinsonae</i>	349, 360
Exploration, early	325

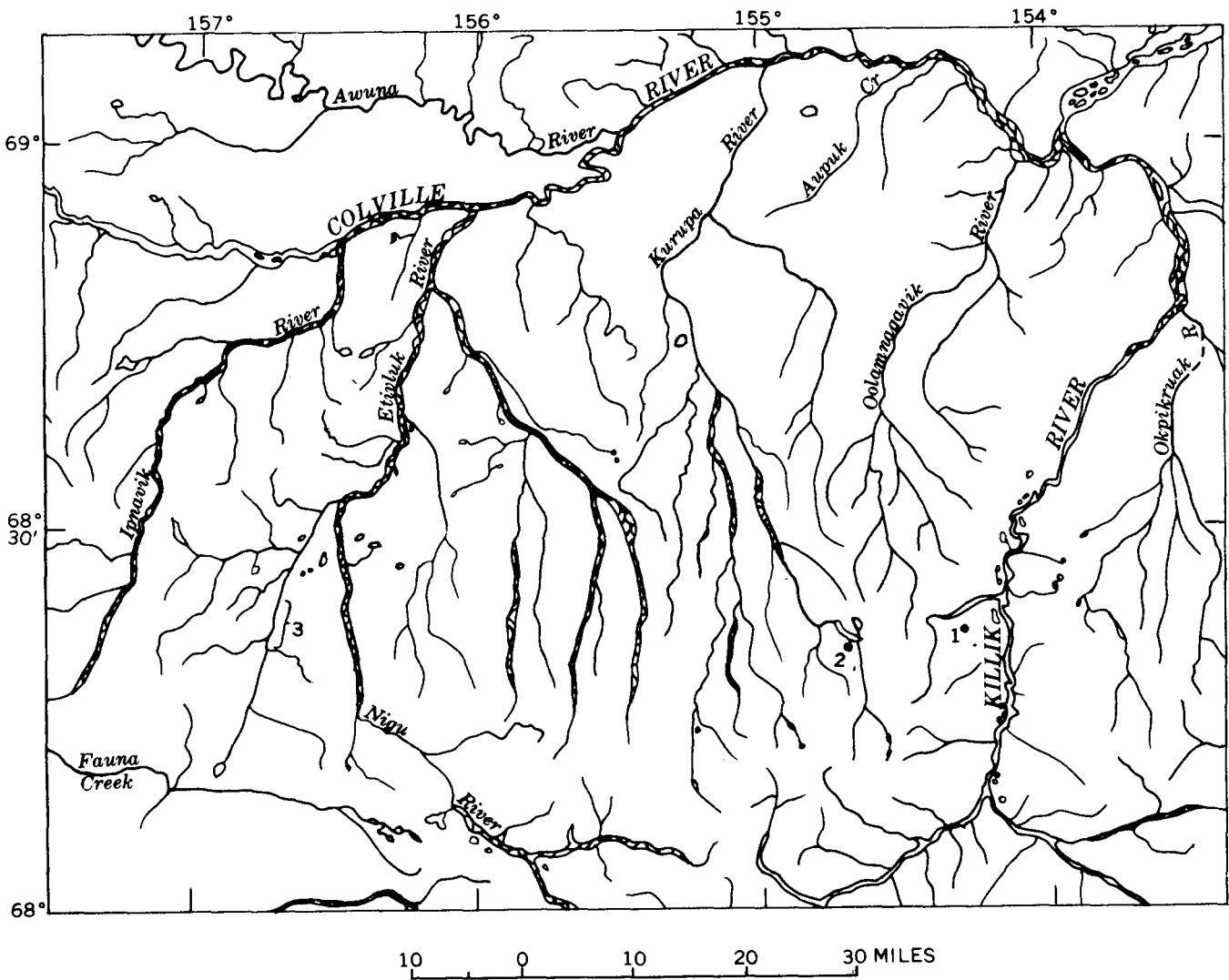
F	Page
Faults, Alapah limestone	346
Chandler formation	369
Fortress Mountain formation	356
Hunt Fork shale	337
Kanayut conglomerate	340
Kayak shale	340
Killik tongue	370
Lisburne group	341, 342
Shublik formation	348
Siksikpuk formation	348
Torok formation	357
Tuktu formation	361, 363, 366
Fenestrate bryozoan, undetermined	342
Fieldwork	326
Fish remains	342, 346, 350, 360
Fluvial deposits	385
Folds, Chandler formation	369
Hunt Fork shale	337
Kanayut conglomerate	340
Kayak shale	340
Shublik formation	348
Torok formation	357
Tuktu formation	361
Foraminifera	348, 352
Fortress Mountain formation, description	353
petroleum possibilities	396
Fossils, Alapah limestone	346
Fortress Mountain formation	357
Hunt Fork shale	337
Kayak shale	340, 342
Killik tongue	377, 378
limestone, Upper Devonian	334
Niakogon tongue	380
Ninuluk formation	381
Okpikruak formation	352
Paleozoic and Mesozoic formations	349
Shublik formation	348, 349, 350
Siksikpuk formation	348
Tiglupuk formation	351, 352
Torok formation	359, 360
Tuktu formation	363, 367
Wachsmuth limestone	346

G	Page
Galena, Hunt Fork shale	337
Gas seeps	393, 399
<i>Gastrolites</i> sp.	367
Gastropods	337, 346, 366, 366
<i>Gaudryina canadensis</i>	368
<i>irenensis</i>	368, 381
<i>kelleri</i>	349
<i>tailleuri</i>	349, 357
<i>Gaudryina irregularis</i>	368
<i>Gavelinella avunensis</i>	349
Geography	328
Geologic history	393
Geologic investigations	325
<i>Ginkgo concinna</i>	378
sp.	381
Glacial deposits, description	382
Glaciation	383
<i>Glomospira gaultina</i>	368
<i>Glomospirella</i> sp.	348, 349, 352
<i>Goniomya matonabbei</i>	367
<i>Gyroidina loetterlei</i>	349

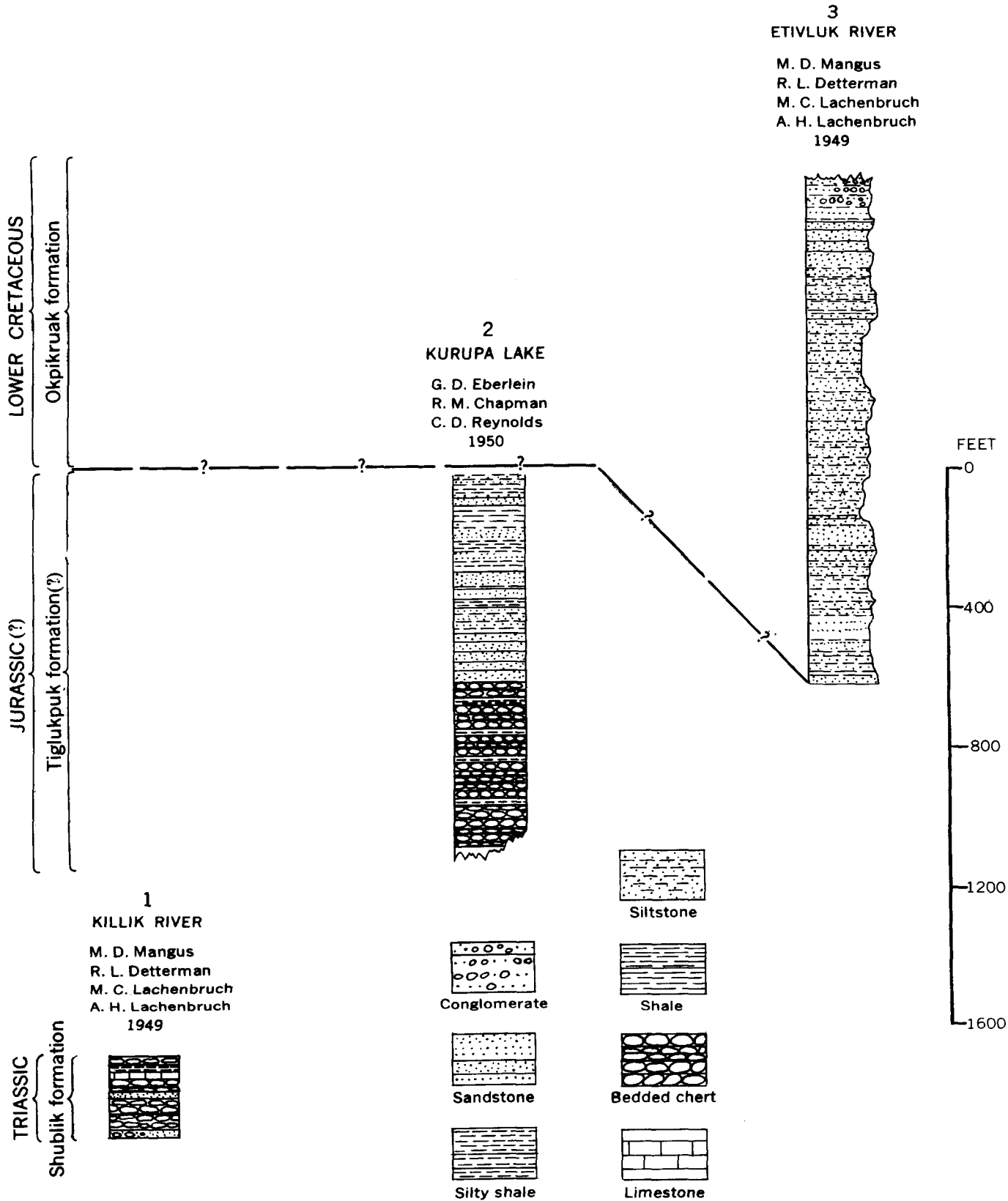
H	Page
<i>Halobia cordillerana</i>	350
<i>ornatissima</i>	350
<i>superba</i>	350
sp.	349, 350

	Page		Page		Page
<i>Haplophragmoides topagorukensis</i>	349, 352, 360, 368	Limestone, Upper Devonian, description.....	334	Okpikruak formation, description.....	352
Heather Creek section, Fortress Mountain formation.....	356	<i>Linoproductus lyelli</i>	346	petroleum possibilities.....	395
Hematite nodules, Killik tongue.....	370	Lisburne group, description.....	341	Oolamnagavik River area, coal.....	401
Howard Pass section, Kanayut conglomerate.....	339	petroleum possibilities.....	395	Oolamnagavik River section, Killik, tongue.....	375
Kayak shale.....	340	phosphate.....	401	Tuktu formation.....	366
Wachsmuth limestone.....	345	Lisburne limestone. See Lisburne group.		Oolamnagavik River structural high.....	391
Hunt Fork shale, contact with Kanayut conglomerate.....	339	<i>Lithocampe</i> sp.....	349	Oolamnagavik syncline, Killik tongue, relations.....	370
description.....	336	Lithology, Alapah limestone.....	346, 347	Ostracodes.....	334, 342
petroleum possibilities.....	395	alluvium.....	386	Outuk Creek section, Kayak shale.....	341
I		Colville group.....	382	<i>Overtonia</i> sp.....	346
Igneous rocks, description.....	388	Fortress Mountain formation.....	353	<i>Ozytoma camelli</i>	367
Imlay, R. W., fossil identification.....	350, 357, 360, 367, 380, 381	Hunt Fork shale.....	336, 337	P	
quoted.....	367	Kanayut conglomerate.....	337, 338	<i>Palaeoneilo</i> sp.....	337
<i>Inoceramus altifuminus</i>	357	Kayak shale.....	340	Paleozoic formations, fossils.....	349
<i>anglicus</i>	359, 360, 367, 377	Killik tongue.....	370	petroleum possibilities.....	395
<i>cadottensis</i>	367	limestone, Upper Devonian.....	334	<i>Palliamorphina ruckerae</i>	349
<i>duncoganensis</i>	377, 380, 381	Nanushuk group.....	361	<i>Panope elongatissima</i>	367, 377
sp.....	359, 360	Niakogon tongue.....	378	sp.....	367
Intrusive rocks, Shublik formation.....	348	Ninuluk formation.....	381	<i>Paragastrolites flexicostatus</i>	367
Wachsmuth limestone.....	345	Okpikruak formation.....	352	<i>spiekeri</i>	367
<i>Involutina rotalaria</i>	349, 368	Shublik formation.....	348, 349	Peat.....	387
sp.....	348, 349	Siksikpuk formation.....	347	<i>Pecten</i> n. sp.....	350
<i>Isognomon</i> sp.....	360	terrace deposits.....	386	Pelecypods.....	337, 342, 357, 364, 366, 367
Itkillik glaciation.....	384	Tiglukpuk formation.....	351	Permafrost.....	334
J		Torok formation.....	358	Permian system. See Carboniferous and Permian systems.	
Jurassic system, stratigraphy.....	350	Tuktu formation.....	361	Petroleum possibilities.....	394
<i>Jaculella elliptica</i>	349	unnamed Carboniferous and Permian unit.....	348	Petrology, igneous rocks.....	388, 389
K		Wachsmuth limestone.....	345	Phosphate-bearing rocks.....	401
Kanayut conglomerate, description.....	337	Lithostrotionid coral, undetermined.....	346	Phosphate pebbles, Shublik formation.....	349
petroleum possibilities.....	395	Location.....	325	Physiographic provinces.....	328
Kayak shale, contact with Wachsmuth limestone.....	345	Lowthor, Stewert, fossil identification.....	378	Pingalulgit Mountain section, Fortress Mountain formation.....	357
description.....	340	<i>Lucina</i> sp.....	367	<i>Pinna hagi</i>	367
Killik Bend anticline, Chandler formation, relations.....	369	M		Place names.....	332
description.....	392	<i>Macrodon</i> sp.....	350	<i>Placunopsis nuka</i>	357
Killik tongue, relation.....	370	Marcasite, concretions, Torok formation.....	358, 359	Plants.....	333
petroleum possibilities.....	399	crystals, Hunt Fork shale.....	337	Plant fossils.....	370, 373, 374, 376, 377, 379, 381
Tuktu formation exposures.....	361, 366	<i>Marginalina gatesi</i>	349	Plant remains.....	338, 352, 353, 365
Killik Bend area, coal.....	401	<i>planuscula</i>	349	<i>Platyceas</i> sp.....	342, 346
Killik Bend section, Killik tongue.....	375	Marmarization, Wachsmuth limestone.....	345	Platynerid columnals.....	342
Killik River area, coal.....	401	Mesozoic formations, fossils.....	349	<i>Pleuromya kelleri</i>	357
Killik River section, Kanayut conglomerate.....	338	Metamorphism, Hunt Fork shale.....	336	sp.....	367
Ninuluk formation.....	381	igneous rocks.....	388	<i>Podozamites lanceolatus</i>	378, 381
Shublik formation.....	349	Shublik formation.....	348	<i>latipinnis</i>	381
Wachsmuth limestone.....	345	<i>Miliammina avumensis</i>	368	Polygonal ground.....	334
Killik tongue, coal.....	400	<i>manitobensis</i>	368	Population.....	333
contact with Niakogon tongue.....	379	Mineralogy, igneous rocks.....	389	Porosity-permeability.....	396
description.....	370	Mississippian system, stratigraphy.....	340	<i>Posidonia stella</i>	350, 351
petroleum possibilities.....	397	<i>Modiolus archisikanni</i>	367	sp.....	350
Killik valley section, Kayak shale.....	341	sp.....	367	Previous work.....	325
Knowlton, H. F., fossil identification.....	378, 381	<i>Monotis subcircularis</i>	350	Prince Creek formation, petroleum possibilities.	397
<i>Krotovia</i> sp.....	346	sp.....	348, 349, 350, 351	See also Colville group.	
Kucher Creek section, Torok formation.....	359	<i>Moorefieldella</i> sp.....	346	<i>Productella</i> sp.....	342
Kummel, Bernard, fossil identification.....	350	<i>Myopheria</i> sp.....	350	<i>Productus</i> sp.....	342, 346
Kurupa anticline, Chandler formation, relations.	369	<i>Mytilarca</i> sp.....	342	<i>Psammisopella bowsheri</i>	368
description.....	392	N		<i>Pseudomonotis subcircularis</i>	350
Killik tongue, relation.....	370	Nanushuk group, description.....	360	<i>Pterophyllum</i> sp.....	378
petroleum possibilities.....	398	petroleum possibilities.....	396	<i>Pterospirites</i> sp.....	381
Tuktu formation, exposures.....	361, 366	Naticoid gastropods.....	367	<i>Punctospirifer subteza</i>	346
Kurupa Lake section, Alapah limestone.....	346	Niakogon tongue, coal.....	400	sp.....	337, 342, 346
Kurupa River section, Fortress Mountain formation.....	356	contact with Ninuluk formation.....	381	<i>Puzosia</i> sp.....	359, 360
Killik tongue.....	373	description.....	378	Pyrite, crystals, Hunt Fork shale.....	337
Niakogon tongue.....	379	petroleum possibilities.....	397	crystals, Siksikpuk formation.....	348
Tuktu formation.....	365	relation to Chandler formation.....	369	Torok formation.....	358
L		North Colville seep.....	399	nodules, Kanayut conglomerate.....	338
Lacustrine deposits.....	386	Northern foothills section.....	391	veinlets, Fortress Mountain formation.....	356
<i>Lenticulina erecta</i>	368	<i>Nuculona</i> sp.....	337	Q	
sp.....	349	O		Quartz, Hunt Fork shale.....	337
<i>Leptaena analoga</i>	342	Oil shale, Okpikruak formation.....	352	Killik tongue.....	370
		Shublik formation.....	349	Nanushuk group.....	360
				Tuktu formation.....	363
				Quaternary system, stratigraphy.....	382

R		Page			Page			Page
Radiolarians.....		348, 349	Stratigraphic section, Alapah limestone—Con.			Torok formation, description.....		357
Recent investigations.....		326	Shublik formation.....		349	petroleum possibilities.....		396
Relief.....		328	Siksikpuk formation.....		348	<i>Torynifera</i> sp.....		342
<i>Reophax minuta</i>		368	Tuktu formation.....		363	Transportation.....		328
Rhynchonellid brachiopod, undetermined.....		346	Wachsmuth limestone.....		345	Triassic rocks, petroleum possibilities.....		395
Rugosa coral, undetermined.....		334, 342, 346	Stratigraphy.....		334	stratigraphy.....		348
S			Structure, Alapah limestone.....		346	<i>Trigonocallista</i> sp.....		367
<i>Saccammina lathrami</i>		368, 380	Carboniferous and Permian systems.....		347	<i>Trochammina eilele</i>		349
Sand dunes.....		387	Chandler formation.....		369	<i>rutherfordi</i>		368, 381
<i>Schizodus</i> sp.....		337, 342	Colville group.....		382	sp.....		381
<i>Schuchertella</i> sp.....		342	description.....		389	Tuktu escarpment, location.....		361
<i>Scutellum tullum</i>		334	Fortress Mountain formation.....		356	Tuktu formation, contact with Torok formation.....		
Seabee formation, contact with Niakogon			Hunt Fork shale.....		337			358, 380
tongue.....		379	igneous rocks.....		388	description.....		361
petroleum possibilities.....		397	Kanayut conglomerate.....		340	petroleum possibilities.....		396, 399
See also Colville group.			Kayak shale.....		340	relation to Killik tongue.....		370, 371
<i>Sequoia angusta</i>		381	Killik tongue.....		370	<i>Tumion</i> sp.....		378
<i>fastigiata</i>		378	Lisburne group.....		341, 342	U		
<i>smithii</i>		381	Okpikruak formation.....		352	<i>Unio</i> sp.....		377
Shublik formation, description.....		348	petroleum accumulation.....		398	Unnamed Carboniferous and Permian unit,		
petroleum possibilities.....		395	Shublik formation.....		348	description.....		348
phosphate.....		401	Tiglupuk formation.....		350	petroleum possibilities.....		395
Siksikpuk formation, description.....		347	Torok formation.....		357	<i>Uvigerinammina manitobensis</i>		368
petroleum possibilities.....		395	Tuktu formation.....		361	V		
<i>Siphotextularia rayi</i>		368	<i>Subarthrophites bickeli</i>		359, 360	Valley sculpturing.....		383, 384
Size of area.....		325	<i>Syringothyris</i> sp.....		342, 346	Veins, quartz, Hunt Fork shale.....		337
Smith Mountain section, Fortress Mountain			T			<i>Veniella</i> sp.....		367
formation.....		355	<i>Tancredia kurupana</i>		367, 377	<i>Verneulinoides borealis</i>		360, 368, 378
<i>Solecurtus chapmani</i>		367	Terebratulid brachiopod.....		350	W		
<i>Solemya</i> sp.....		342	Terrace deposits, high-level.....		385	Wachsmuth limestone, description.....		345
Southern foothills section, structure.....		390	<i>Thracia kissoumi</i>		357	Weathering, Anaktuvuk glacial deposits.....		383
<i>Spinatrypa</i> sp.....		334	<i>stelcki</i>		367	Fortress Mountain formation.....		356
<i>Spirifer adonis</i>		346	sp.....		367	glacial deposits.....		383
<i>minnewankensis</i>		342	Tiglupuk formation, contact with Okpikruak			Hunt Fork shale.....		336, 337
<i>missouriensis</i>		346	formation.....		352	igneous rocks.....		388
<i>platynotus</i>		342	description.....		350	Kanayut conglomerate.....		337, 339
<i>striatiformis</i>		342	petroleum possibilities.....		395	Kayak shale.....		340
<i>subaequalis</i>		346	Topography, Carboniferous and Permian sys-			Killik tongue.....		370
<i>tenuicostatus</i>		346	tems.....		347	limestone, Upper Devonian.....		334
<i>torncensis</i>		342	Colville group.....		382	Okpikruak formation.....		352
<i>yukonensis</i>		350	Cretaceous system.....		352	Siksikpuk formation.....		348
sp.....		337, 342, 346	Fortress Mountain formation.....		353	Tiglupuk formation.....		350
<i>Sproloculina ophionea</i>		368	general.....		328	Torok formation.....		357
Squid imprint.....		367	Hunt Fork shale.....		336	Wachsmuth limestone.....		345
Stratigraphic section, Alapah limestone.....		346	Itkillik glaciation.....		384	Wood fragments.....		358
Fortress Mountain formation.....		355	Kanayut conglomerate.....		337	Wood, petrified.....		363, 365
Hunt Fork shale.....		336	Kayak shale.....		340	Worm, boring.....		360, 367
Kanayut conglomerate.....		338, 339	Lisburne group.....		341, 342	trails.....		352, 355, 364, 366
Kayak shale.....		340, 341	Killik tongue.....		370	Z		
Killik tongue.....		371	Okpikruak formation.....		352	<i>Zaphrentis konincki</i>		346
Niakogon tongue.....		379	Tiglupuk formation.....		351			
Ninuluk formation.....		381	Torok formation.....		357			

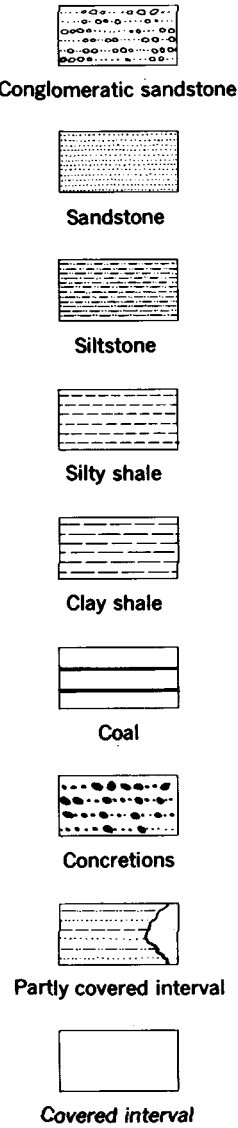


INDEX MAP SHOWING LOCATION OF SECTIONS



COLUMNAR SECTIONS OF EARLY MESOZOIC FORMATIONS,
KILLIK-ETIVLUK RIVERS REGION, ALASKA

EXPLANATION



Numbers to left of columns
indicate stratigraphic
intervals described in
text



LOWER CRETACEOUS

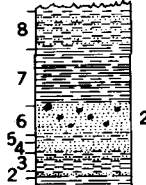
Torok formation

Tuktu formation

1
ETIVLUK RIVER
M. D. Mangus
R. L. Detterman
M. C. Lachenbruch
A. H. Lachenbruch
1949
R. S. Bickel
1953

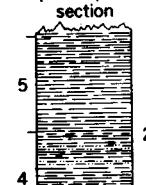
68°51' N to
68°56' N
156°09' W
A

Top of exposed
section



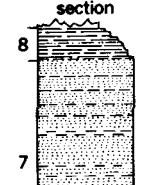
Base of exposed
section

B
Top of exposed
section



Base of exposed
section

C
Top of exposed
section



Base of exposed
section

2
KUCHER CREEK
G. D. Eberlein
C. D. Reynolds
1950

68°53' N
155°35' W

21

20

19

18

17

16

15

14

13

12

11

10

9

8

7

6

5

4

3

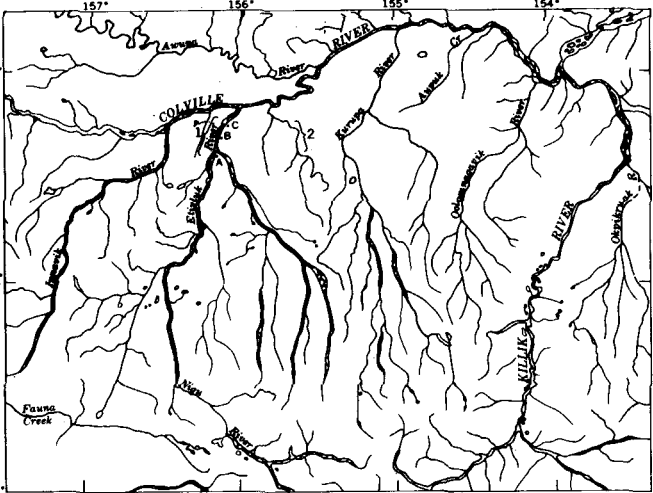
2

1

3200 ft break in
section, covered

Base of exposed
section

50 AE 110



INDEX MAP SHOWING LOCATION OF SECTIONS

COLUMNAR SECTIONS OF THE TOROK FORMATION,
KILLIK-ETIVLUK RIVERS REGION, ALASKA