Geology of the Killik-Itkillik Region Alaska

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

PART 3, AREAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 303-G

Prepared and published at the request of and in cooperation with the U.S. Department of the Navy, Office of Naval Petroleum and Oil Shale Reserves

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By WILLIAM W. PATTON, Jr., and IRVIN L. TAILLEUR

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By William W. Patton Jr., and Irvin L. Tailleur

ABSTRACT

The Killik-Itkillik region is located on the Arctic Slope of Alaska along the north front of the Brooks Range. It extends in a 25-mile wide belt from the Killik River eastward to the Itkillik River, a distance of 115 miles. Most of the mapped area lies in the foothills, but at the south edge it includes a narrow strip of the mountains.

The rocks that are exposed in the Killik-Itkillik region include 11 sedimentary rock formations ranging from Mississippian to Cretaceous in age, 3 types of surficial deposits of Quaternary age, and 1 igneous rock unit apparently of Jurassic age. The oldest rocks are along the southern margin of the mapped area, with a general northward progression of successively younger strata. The oldest rocks, of Mississippian age, belong to the Lisburne Group, a massive sequence of limestone 2,000 to 3,000 feet thick, comprising two formations, the Wachsmuth and the Alapah Limestones. In the western half of the mapped area the Lisburne Group is overlain disconformably by the Siksikpuk formation, a 300-foot unit of variegated shale and siltstone of probable Permian age. The Shublik Formation of Triassic age rests disconformably on the Lisburne Group in the eastern half of the mapped area and upon the Siksikpuk Formation in the western half. The Shublik is comprised of 200 to 750 feet of fossiliferous dark shale, limestone, and chert, and includes strata of Early(?), Middle, and Late Triassic age.

Above the Shublik is a thick sequence of sparsely fossiliferous clastic rocks of graywacke type that has been subdivided into four formations: the Tiglukpuk, Okpikruak, Fortress Mountain, and Torok. The Tiglukpuk Formation of Late Jurassic age occurs at the base of the sequence and consists of a 1,500-foot section of sandstone, siltstone, and shale with subordinate chert. In a few places the Tiglukpuk is succeeded by a unit of tuffaceous graywacke, probably of latest Jurassic age, which for mapping has been included in the Tiglukpuk. In most places, however, the Tiglukpuk is overlain by the Okpikruak Formation, a 2,000-foot section of rhythmically alternating sandstone, siltstone, and shale of earliest Cretaceous age. Above the Okpikruak is the Fortress Mountain Formation of late Early Cretaceous age, consisting of conglomerate, sandstone, and shale which have an aggregate thickness of 10,000 feet at the type locality. The Torok formation, which has a minimum thickness of 6,000 feet and is composed predominantly of shale, crops out north of the belt of the Fortress Mountain Formation. It is also of late Early Cretaceous age and is thought to be at least in part a fine-grained facies of the Fortress Mountain Formation. The Torok is overlain conformably at the northern edge of the mapped area by a thick sequence of interfingering shallow marine and nonmarine sedimentary rocks that comprise the Nanushuk Group. Three formations of the Nanushuk Group crop out in the mapped area: (1) the Tuktu, a 1,000-foot section composed predominantly of marine sandstone, (2) the Chandler, a 2,800-foot nonmarine coal-bearing sequence, and (3) the Ninuluk, a 1,200-foot section of marine sandstone. The Tuktu and Ninuluk Formations are abundantly fossiliferous and are dated as late Early Cretaceous and early Late Cretaceous, respectively. The Chandler Formation is largely unfossiliferous and cannot be dated precisely.

Heavy minerals from Jurassic and Cretaceous coarse clastic rocks were studied to determine whether the heavy-mineral content of the various formations could be used for correlation and comparison. Results show that, although the distribution of the heavy minerals is not sufficiently definitive to permit stratigraphic identification of single samples, certain heavy-mineral assemblages tend to be characteristic of different formations or parts of formations.

Numerous small sill-like bodies and several large poorly defined masses of mafic igneous rock are found in the southern half of the mapped area west of the Anaktuvuk River. They intrude the Tiglukpuk and older formations and are believed by the writers to be of latest Jurassic age. Some of the igneous rock may be extrusive.

The rocks of the mapped area have been deformed by tectonic forces acting from south to north. The structural grain of the rocks is east-west and the overall intensity of deformation decreases from south to north. At the mountain front the massive Lisburne Group is sliced by southward-dipping imbricate faults, and in several places it has been thrust upon the foothills strata. Adjoining the mountain front is an eastward-trending belt of relatively incompetent interfolded upper Paleozoic and Mesozoic strata which are characterized by small tightly appressed folds and small closely spaced high-angle southward-dipping reverse faults. This belt is bounded on the north by a belt of Fortress Mountain strata which, although highly folded and faulted, are less complexly deformed than the rocks to the south. North of the Fortress Mountain belt is a band of crenulated shale that constitutes the Torok Formation. This is succeeded at the northern edge of the mapped area by a belt of gently folded strata of the Nanushuk Group.

A reflection seismograph survey that crossed the belt of Torok strata shows that although the incompetent shale at the surface is highly crenulated, the subsurface strata are nearly flat lying. As no seismic work was done south of the belt of

the Torok, the character of the subsurface structure is uncertain. However, indirect evidence suggests that at least some of the prevalent high-angle faults in that area may flatten in the subsurface and merge into large sole faults beneath thrust plates of limestone of the Lisburne Group. Such a fault pattern has been found in the foothills of the Alberta Rockies, where the surface structure, stratigraphy, and geologic history is remarkably similar to the foothills of the Brooks Range.

The depositional history of the Paleozoic and Mesozoic strata can be divided into two phases: a shelf phase that extended through late Paleozoic and Triassic and a geosynclinal phase that occurred during Late Jurassic and Cretaceous. The shelf-phase sediments are marine and are composed chiefly of fine clastics and carbonates that apparently were derived largely from the north. The geosynclinal phase sediments were derived mainly from the south and consist of marine graywacke flysch deposits overlain by littoral marine and nonmarine coal-bearing molasse deposits. Several periods of emergence and erosion interrupted the shelf and geosynclinal deposition, and there is evidence that some folding and faulting occurred during the deposition of the flysch. The principal deformation seems to have coincided with the Laramide orogeny in Late Cretaceous or Tertiary time. In Pleistocene time the Brooks Range was intensively glaciated, and at times of maximum advance, ice tongues pushed northward into the foothills along the major river valleys.

Interest in the mineral resources of the Brooks Range foothills has centered around the search for petroleum. No oil seeps have been found in the mapped area, but asphaltic shale and seams of asphaltic matter occur at many localities. The limestone and dolomite of the Lisburne Group are considered to be the most promising reservoir rocks, although their character, extent, and thickness in the subsurface of the foothills are unknown. The complex structure of the mapped area does not preclude the possibility of petroleum. Notable quantities of oil and gas have been produced in areas of similar structure in hills of the Canadian Rockies.

Deposits of low- and medium-grade phosphate rock occur in the upper part of the Lisburne Group along the mountain front, and bituminous coal occurs in the Nanushuk Group in the northern part of the mapped area.

INTRODUCTION

GENERAL

In 1923 a 35,000-square-mile tract of public land on the Arctic Slope of Alaska was set aside by President Harding as Naval Petroleum Reserve No. 4 (fig. 66). Between 1923 and 1926 geologic reconnaissance was carried out in this tract and in adjoining areas by the U.S. Geological Survey under the auspices of the U.S. Navy. The results of these studies and a preliminary evaluation of the petroleum resources were published by P. S. Smith and J. B. Mertie, Jr. (1930). During the next 20 years no further geologic investigations were undertaken. Near the end of World War II, however, the U.S. Navy, recognizing the strategic importance of Alaska, deemed it advisable to reopen petroleum explorations. Accordingly, in 1944 an intensive program of geological and geophysical surveys and well drilling was begun in NPR–4 and adjoining areas and continued

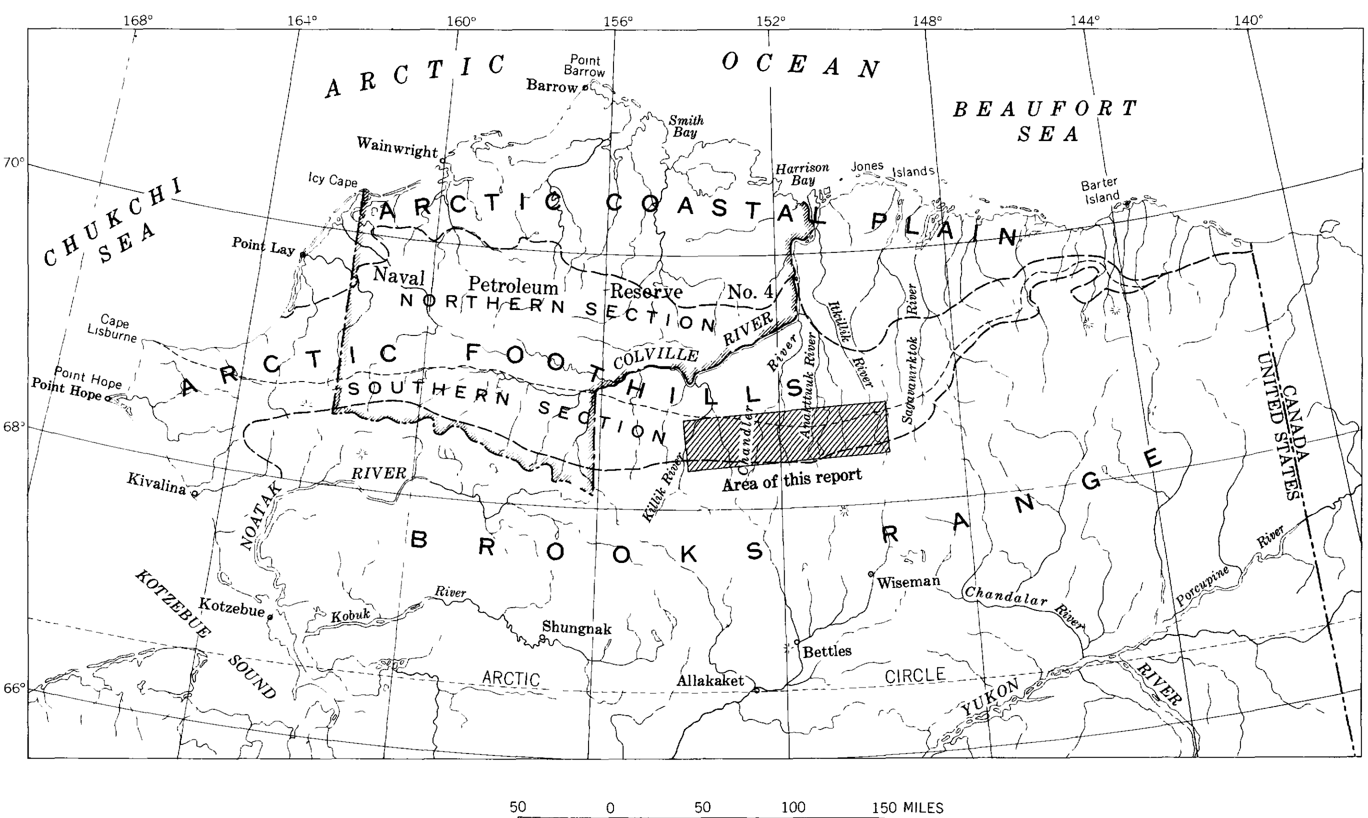

FIGURE 66.—Index map showing location of Killik-Itkillik region and the physiographic provinces of northern Alaska.

until 1953. This report is one of a series of reports that describes the results of geologic field investigation conducted as part of the exploration program by the U.S. Geological Survey in cooperation with the U.S. Navy.

LOCATION AND SIZE OF AREA

The mapped area, herein designated the Killik-Itkillik region, is located on the Arctic Slope of Alaska along the north front of the Brooks Range (fig. 66). It covers about 2,500 square miles and extends in a 25-mile-wide belt from the Killik River 115 miles eastward to the Itkillik River. It includes parts of the Killik River, Chandler Lake, and Philip Smith Mountains Topographic Series quadrangles of Alaska at a scale of 1:250,000.

ACCESSIBILITY AND TRANSPORTATION

Northern Alaska is without roads or railroads, and the only practical means of access the year round is by aircraft. The Arctic coast is ice free and open to boat traffic for only a short period during midsummer. The settlements of Livengood and Circle, 220 miles to the south, are the northern terminuses of the Alaska road system; and Fairbanks, 300 miles to the south, is the nearest railhead. Permanent airfield facilities capable of handling multiengine airplanes as well as single-engine "bush planes" are located at Barrow and Barter Island on the Arctic coast, Umiat on the Colville River, and Bettles on the Koyukuk River. Arctic Contractors, under contract to the Navy, maintained Umiat as a construction camp which served as the principal base of operations for the U.S. Geological Survey during the period of geologic investigations of NPR-4 and adjoining areas from 1944 to 1953.

Transportation of men and supplies between the Umiat base camp and the Killik-Itkillik region was by "bush plane" and tracked vehicles. During the winter a "bush plane" equipped with skis can land on snow or ice almost anywhere in the mapped area. In summer a "bush plane" with pontoons can land on any of the lakes that are at least 2,000 feet long. None of the rivers in the mapped area are suitable for pontoon landings, but a skilled pilot can land a small plane with wheels on a few of the gravel and sand bars. Amphibious vehicles, both the "weasel" and the larger "LVT," were used between Umiat and the mapped area. When the ground is snow covered, the overland trip can be made easily in one day. In the summer, however, when the ground is bare and the rivers are flowing, the trip is considerably more difficult and usually requires several days.

Travel within the mapped area was chiefly by "weasel" and boat and on foot. The "weasel" was found to be the most efficient method of transporting personnel and equipment over large areas. If the route is picked with some forethought, a "weasel" can be taken almost anywhere in the mapped area, although special care is necessary when crossing hummocky and boulder-strewn areas of glacial drift and when fording the larger rivers during high water. Except in a few places, such as along river bars and stream terraces, "weasel" travel seldom exceeds 3 miles per hour, and because of the ruggedness of the tundra, it is almost always arduous.

Small boats were used for downstream transportation on the Killik, Okpikruak, Okokmilaga, Chandler, Siksikpuk, Anaktuvuk and Nanushuk Rivers. The passage through the rapids, which invariably occur where the rivers cross glacial moraines, is apt to be difficult and even hazardous, and it was often necessary to "line" or "track" the boat through these stretches. All the rivers are too shallow to permit use of an outboard motor.

OBJECTIVES

Between 1944 and 1948 the geologic investigations in NPR-4 and adjoining areas were concentrated chiefly in the northern part of the Arctic Slope and were directed primarily toward testing the petroleum resources of mid-Cretaceous and younger strata. In 1949 the area of interest was enlarged to include the southern part of the Arctic Slope, where the primary objective was the evaluation of the petroleum resources of limestone of Paleozoic age. This report is based upon field studies made during 1949 and 1950 and represents one of the first studies devoted entirely to the belt of premiddle Cretaceous rocks that crop out in the southern part of the Arctic Slope. The immediate objectives of the fieldwork were (1) subdivision and description of the little known premiddle Cretaceous strata and (2) preparation of a reconnaissance geologic map with special emphasis on the delineation of structures in which Paleozoic limestone is within drillable depth.

MAPPING METHODS

The geologic map (pl. 50) was compiled from field data and supplementary photogeologic data. The inset on plate 50 shows the parts of the mapped area that were covered by the field investigations. As time did not permit tracing out all the contacts, faults, and structural axes in the field, they have been joined or extended by photogeology, where possible. Those parts of the mapped area that were not visited in the field have been mapped entirely by photogeologic methods.

The density of geologic information on plate 50 varies markedly from place to place. This, of course, is partly because of differences in the number and extent of the rock exposures. However, it also reflects the fact that to gather essential stratigraphic data, it was necessary to map certain parts in greater detail than others. In an attempt to unravel the stratigraphic succession, weeks were spent in detailed mapping and measuring sections in small areas of well-exposed but structurally complex pre-Nanushuk Group strata on Tiglukpuk Creek, Cobblestone Creek, the Kiruktagiak River, and around Castle Mountain. More data were gathered in these localities than can be plotted on the map. On the other hand, only a few scattered observations were necessary in order to map, with the aid of aerial photographs, the large tract of gently deformed rocks of the Nanushuk Group along the northern edge of the mapped area.

Data collected in the field were plotted directly on vertical aerial photographs at a scale of 1:20,000 and later transferred, together with photographic observations, planimetric maps at a scale of 1:96,000. Of the many strike and dip readings recorded in the field, only a few representative ones are shown on plate 50.

The altitudes used to construct the profiles on plate 50 were determined by aneroid barometer.

Stratigraphic sections a few hundred feet or less in thickness were measured by tape. The measurements of thicker sections generally were computed graphically or trigonometrically. For this purpose, horizontal distances were scaled from aerial photographs or measured on the ground by alidade or Brunton compass. Vertical distances were determined by aneroid barometer or measured by alidade or Brunton compass.

PREVIOUS INVESTIGATIONS

Two reports of the early reconnaissance traverses of the Arctic Slope include descriptions of the rocks in the Killik-Itkillik region. The first of these reports records the traverse by F. C. Schrader (1904) across the Brooks Range and Arctic Slope by way of the John, Anaktuvuk, and Colville Rivers during the summer of 1901. Schrader subdivided the rocks that crop out along the Anaktuvuk River within the Killik-Itkillik region into two mapping units: the Lisburne Formation, which he assigned to the Devonian, and the Anaktuvuk Series, which he assigned to the Lower Cretaceous.

The second report describes a traverse along the Alatna and Killik Rivers by P. S. Smith and J. B. Mertie, Jr. This was one of several reconnaissance traverses of the Arctic Slope that were carried out between 1923 and 1926 in conjunction with the U.S. Geological Survey's preliminary exploration program of NPR-4. The results of all the traverses are incorporated in a comprehensive geologic report on northwestern Alaska (Smith and Mertie, 1930). This report includes a geologic map, at a scale of 1:500,000, in which the rocks of the Killik-Itkillik region are subdivided into four mapping units: Lisburne Limestone (Mississippian); chert, limestone, and shale (Triassic); sandstone and shale (Early Cretaceous); and sandstone and shale (Late Cretaceous).

No further geologic investigations were undertaken in the Killik-Itkillik region until 1945; during that year three separate field parties of the U.S. Geological Survey traversed the foothills by way of the Killik, Chandler, and Anaktuvuk Rivers. The Killik River party was composed of L. A. Warner, chief, C. E. Kirschner, geologist, and O. Daiber and E. Lebert, assistants; the Chandler party of G. Gryc, chief, K. Stefansson and E. J. Webber, geologists, and J. Hipple, G. Hipple, W. G. Banks, and C. R. Metzger, assistants; and the Anaktuvuk party of R. E. Fellows, chief, R. M. Chapman and C. T. Bressler, geologists, and H. B. Post, O. T. Smith, S. P. Schoonover and A. N. Tetrault, assistants. The principal objective of the three parties was the study of middle Cretaceous and younger strata that crop out along the northern edge of the Killik-Itkillik region and in the adjoining foothills to the north. The present stratigraphic nomenclature of these rocks is based in part upon their work. Their observations in the belt of Early Cretaceous and older strata in the Killik-Itkillik region were limited, owing to the heavy mantle of glacial drift along the valleys of the rivers that were traversed. Nevertheless, their findings in this belt were of considerable value in planning the present field studies.

During the summers of 1947 and 1948 the mapping and stratigraphic studies of middle Cretaceous and younger strata in the northern foothills were continued. In 1947 E. J. Webber and R. L. Detterman traversed the Nanushuk and lower Anaktuvuk Rivers, and in 1948 R. L. Detterman and W. W. Patton, Jr., reexamined the exposures along the lower Chandler River between the Kiruktagiak River and the mouth.

PRESENT INVESTIGATIONS

This report is based principally on field investigations during the summers of 1949 and 1950. Supplemental field data were collected during parts of the 1951 and 1953 field seasons (pl. 50, East half). In 1949 the area that lies west of the Chandler River was mapped by a field party comprised of W. W. Patton, Jr., chief, I. L. Tailleur, geologist, B. H. Kent and D. A. White, field assistants, E. F. Wolfe, cook, and J. Rosebraugh, mechanic, using three "weasels" for transportation of personnel and equipment. During late April and early May while the ground was still snow covered, the "weasels" were driven from the base camp at Umiat to May Lake and seven caches of food and gasoline were placed along the proposed route of traverse by a "bush plane" equipped with skis. On May 23 the party landed on the ice at May Lake and began the traverse which led first westward to the Okpikruak River, then eastward along the mountain front to the Kiruktagiak River and north along the Kiruktagiak to the Tuktu Escarpment, where the traverse was completed on August 31. From the last camp on the Ayiyak River the "weasels" were returned to Umiat, arriving there on September 3.

The area that lies east of the Chandler River was selected for mapping during the summer of 1950. Assigned to this task was a field party composed of W. W. Patton, Jr., chief, A. S. Keller, geologist, J. P. Minard and R. A. Hackman, assistants, E. F. Wolfe, cook, and G. W. Engel, mechanic. During the late spring, in accordance with the procedures of the previous year, three "weasels" were driven to the first campsite on the Itkillik River, and food and gasoline caches were set out along the route of traverse. On May 22 the party landed at a small lake near the Itkillik. The first 2 months were spent in the area between the Itkillik and Anaktuvuk Rivers and the last 1½ months in the area between the Anaktuvuk and Chandler Rivers. H. N. Reiser, geologist, and J. H. Downs, assistant, joined the party for 2 weeks on upper Tiglukpuk Creek. Fieldwork was completed near Gunsight Mountain on the Siksikpuk River on August 30, and on September 2 the party returned to Umiat.

In the 1951 season, during the course of a traverse across the Brooks Range, about 25 square miles were mapped along the Okokmilaga River at the south edge of the mapped area by Patton, W. P. Brosgé, and M. D. Mangus (pl. 50). In addition, the upper Kiruktagiak River and Monotis Creek area was revisited for several days to gather additional stratigraphic data and to augment the collection of Mississippian and Triassic fossils.

During the summer of 1953 the upper Kiruktagiak River and Monotis Creek area was visited again for 8 days by Patton and A. L. Bowsher, and 10 days were spent by Patton and M. V. Carson on the Tiglukpuk Creek. The work at both localities was devoted chiefly to sampling and logging the phosphatic beds in the Lisburne Group. However, additional fossils and stratigraphic data were gathered from Permian, Triassic, and Jurassic rocks.

Also during the summer of 1953 the Killik River was traversed by boat by R. L. Detterman and R. S. Bickel. Their mapping has been incorporated on plate 50.

Office compilation and laboratory study of the field data and rock collections were carried out by Patton, Tailleur, and Keller during the winters of 1950 and 1951. Patton wrote most of the report and prepared the illustrations at intervals between 1952 and 1957. Tailleur wrote the discussions of the mafic igneous rock and heavy-mineral studies and was available for consultation and review during preparation of the report.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the U.S. Navy and Arctic Contractors for their assistance and support during the investigations of the upper Killik-Itkillik region. Special thanks are also due R. L. Miller and George Gryc, who supervised the U.S. Geological Survey's Navy Oil program. Many colleagues in the U.S. Geological Survey generously gave assistance during the field operations and during preparation of this report; the authors would like especially to acknowledge the help of W. E. Berguist, A. L. Bowsher, W. P. Brosgé, R. L. Detterman, A. S. Keller, M. D. Mangus, and H. N. Reiser.

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GEOGRAPHY

PHYSIOGRAPHY

REGIONAL SETTING

The Arctic Slope of Alaska consists of three physiographic provinces: the Brooks Range, the Arctic Foothills, and the Arctic Coastal Plain (Payne, and others, 1951). (See fig. 66.) The Brooks Range, the Alaskan counterpart of the Rocky Mountains, extends westward across northern Alaska from the international boundary nearly to Cape Lisburne on the Arctic coast. It includes several ill-defined mountain groups, namely, the Romanzof, British, and Davidson Mountains at the eastern end, the Endicott Mountains in the central part, and the Baird and De Long Mountains at the western end. The Brooks Range is adjoined on the north by the Arctic Foothills province except near the international boundary where it extends northward to the Arctic Coastal Plain. The Arctic Foothills province is divisible into a southern section characterized by variously shaped maturely dissected hills, which have been carved out of the complexly deformed upper Paleozoic and Mesozoic (pre-Late Cretaceous) strata, and a northern section of long parallel ridges and valleys of the "Appalachian" type, which have been carved out of gently deformed upper Lower and Upper Cretaceous strata. The Arctic Coastal Plain, a vast featureless waste dotted with hundreds of small lakes, extends north from the foothills to the Arctic Ocean.

The Killik-Itkillik region is located largely within the southern section of the Arctic Foothills province, but at the northern edge it laps onto the northern section and at the southern edge it includes a narrow strip of the Brooks Range (fig. 66).

KILLIK-ITKILLIK REGION

Except for glaciated areas along the major river valleys, the topography of the mapped area is largely an expression of the lithologic character and structure of the underlying bedrock. For this reason and because no contours are shown on plate 50, it is convenient for physiographic description to subdivide the mapped area into five eastward-trending physiographic belts that can be referred to five different belts of rock on plate 50. From south to north these belts are (1) the Brooks Range belt of Paleozoic strata, (2) the foothills belt of complexly deformed upper Paleozoic and Mesozoic strata, (3) the foothills belt of the Fortress Mountain Formation, (4) the lowland belt of the Torok Formation, and (5) the foothills belt of the Nanushuk Group.

BROOKS RANGE BELT OF PALEOZOIC STRATA

Although the mountains that form the southern edge of the mapped area have a maximum relief of only 5,000 feet, they are exceptionally rugged, owing to glacial sculpturing and the lack of vegetative cover. No glaciers are found in this part of the Brooks Range at present, but judging from the freshness of the glacial features, the ice must have lingered until late Pleistocene time (Detterman and others, 1958). Steep-walled cirques, serrate ridges, hanging valleys, and broad deep glacial troughs characterize the north flank of the mountains. Near the mountain front, lakes impounded behind morainal dams are common along the floors of the glacial troughs; the largest of these lakes are Chandler and Shainin. The north front of the mountains, composed of massive Paleozoic limestone, forms a bold scarp that rises abruptly 2,000 to 3,000 feet above the maturely dissected foothills of less resistant Mesozoic strata (fig. 67.)

FOOTHILLS BELT OF COMPLEXLY DEFORMED UPPER PALEOZOIC AND MESOZOIC STRATA

Bordering the mountain front is a foothills belt, 5 to 14 miles wide, that has been carved out of complexly deformed upper Paleozoic and Mesozoic strata. Dominating the belt are broad gently undulating upland surfaces that slope northward along the interstream divides from an altitude of 3,500 feet at the mountain front to 2,500 feet at the north edge of the belt. Few topographic features rise above these surfaces. Along the drainages, where the upland surfaces have been dissected, are clusters of irregularly shaped hills separated by broad featureless lowlands (fig. 68). The hills are characterized by discontinuous rubble-covered ridges of Jurassic and Cretaceous sandstone and by

FIGURE 67.—North front of mountains at the head of Cobblestone Creek. Mountains are composed of imbricate thrust-faulted limestone of the Lisburne Group (Mississippian). Foothills are underlain by highly deformed Mesozoic strata. Outlier of Lisburne Group in right background. Photograph by U.S. Navy.

FIGURE 68.—View of foothills and north front of Brooks Range, looking southwestward from near junction of Castle Creek and Kiruktagiak River. Shows upland surfaces and hilly areas in belt of highly deformed upper Paleozoic and Mesozoic strata. Photograph by U.S. Navy.

small buttes, knobs, and pinnacles of mafic volcanic rock, Jurassic chert, and Paleozoic limestone.

The major rivers cross the belt through glacial troughs that have been cut as much as 1,500 feet below the upland surfaces. Broad areas along the river are mantled with fresh glacial drift and have a typical poorly drained knob-and-kettle topography, locally dotted with numerous small lakes. Bedrock exposures are few within these drift-covered areas.

The best exposures of bedrock in the belt occur along the small unglaciated tributaries which locally are incised in steep-walled gorges as much as 100 feet deep.

FOOTHILLS BELT OF THE FORTRESS MOUNTAIN FORMATION

The belt of foothills, 4 to 10 miles wide, in which the Fortress Mountain is exposed, stretches westward across the center of the mapped area. It has a maximum relief of 2,000 feet and is characterized by long westward-trending rubble-covered ridges and bluffs of sandstone and conglomerate separated by wide lowland expanses carved out of shale. Two massive mesas, Fortress Mountain and Castle Mountain, dominate the belt between the Okokmilaga and Chandler Rivers (fig. 69). Wide drift-covered glacially reduced areas interrupt the foothills along the Killik, Anaktuvuk, and Nanushuk Rivers.

Bedrock is exposed on Castle and Fortress Mountains and along a few scattered river bluffs. Elsewhere, the foothills are covered with rubble or tundra.

LOWLAND BELT OF THE TOROK FORMATION

The lowland belt of the Torok Formation separates the foothills belt of the Fortress Mountain Formation from the foothills belt of the Nanushuk Group and extends from the northwest corner of the mapped area eastward to the Itkillik River. Between the Killik and Anaktuvuk Rivers the belt varies from 5 to 8 miles in width, but east of the Anaktuvuk River it gradually narrows and is less than a mile wide at May Creek. The lowland is a gently rolling nearly featureless surface underlain by soft shale. A few low sandstone ridges occur near the northern margin of the belt, but elsewhere in the interstream areas no bedrock is exposed. Bedrock crops out in small cutbanks along the streams that cross the belt except for the glaciated Killik, Anaktuvuk, Nanushuk, and Itkillik River valleys. The maximum relief along the belt is 500 feet and occurs along the drainage divides between the Siksikpuk River and Pediment Creek.

FOOTHILLS BELT OF THE NANUSHUK GROUP

The belt of foothills along the northern margin of the mapped area is typified by synclinal mesas and long hogback ridges and cuestas which reflect the gently dipping intercalated sandstone, conglomerate, and shale of the Nanushuk Group. Between the Okokmilaga and Kanayut Rivers the belt is 1 to 3 miles wide and consists of a single south-facing cuesta, the Tuktu Escarpment that rises 1,000 to 2,000 feet above the

FIGURE 69.—View eastward along southern margin of the belt of the Fortress Mountain Formation. Fortress Mountain on left, Castle Mountain in middle background. Low hills of complexly deformed pre-Fortress Mountain strata in right middle distance. Photograph by U.S. Navy.

FIGURE 70.—Gently dipping conglomerate and sandstone ledges of the Chandler Formation along the axis of Arc Mountain syncline. Arc Mountain in left background. View eastward from the Kanayut River. Photograph by U.S. Navy.

Torok lowland. Eastward from the Kanayut River the belt widens to 8 miles, and the Tuktu Escarpment continues along the southern margin as far as May Creek where it dwindles to a low ridge. North of the escarpment between the Kanayut and Itkillik Rivers, a series of benched mesas of sandstone and conglomerate occur along the axis of the broad Arc Mountain syncline (fig. 70). North of the syncline the sharply creased Arc Mountain anticline is outlined by inward facing hogback ridges, and along the core of the anticline a lowland has been carved out of the Torok Formation.

DRAINAGE

The mapped area is drained by four large tributaries of the Colville River: the Killik, Chandler, Anaktuvuk, and Itkillik Rivers. All four tributaries head near the divide of the Brooks Range, flow northward across the mountains and foothills, and join the Colville near the edge of the coastal plain. The Colville, in turn, empties into the Arctic Ocean. Other important but less extensive rivers draining the mapped area are, from west to east: the Okpikruak and Okokmilaga, tributaries of the Killik; the Ayiyak, Kiruktagiak, and Siksikpuk, tributaries of the Chandler; and the Kanayut and Nanushuk, tributaries of the Anaktuvuk. None of these rivers show evidence of structural control except locally. Apparently their courses were superimposed on the present eastward-trending structural grain of the foothills from a preglacial piedmont surface.

The Killik, Okokmilaga, Chandler, Anaktuvuk, Nanushuk, and Itkillik Rivers flow across the north flank of the mountains and southern foothills through broad deep glacial troughs. In the mountains they meander along flat-floored alluviated valleys. However, from the mountain front northward their courses are marked by white-water rapids as they drop over a succession of terminal recessional moraines.

The smaller streams have not been so extensively glaciated. They head high in the mountains a few miles from the north front, flow down through steep-walled canyons over cataracts and waterfalls, and then, with an abrupt decrease in gradient, meander out across the foothills. Their courses in the foothills are heavily alluviated with gravels ranging from cobble size near the mountains to pebble size at the northern edge of the mapped area. Locally, the streambed gravels have spread out across the valley to widths of a mile or more, and the course of the stream is diverted into a network of braided channels. Such places are commonly the sites of perennial aufeis fields.

VEGETATION

Except for ridge tops and steep declivities, the Arctic Foothills are everywhere cloaked with a thick growth consisting of sedges, grasses, mosses, lichens, prostrate bushes, and small flowering plants. In the mountains the tundra covers the valley bottoms and extends up the slopes a few hundred feet, where it gives way to bare rock or talus. Commonly the tundra vegetation, particularly the sedges, grows in tussocks that locally are more than 2 feet high. The tussocks are generally unstable and spaced so that one cannot step from one tussock to another. As the ground between the tussocks is usually soft and swampy, walking across the tundra is difficult and arduous. Tracked vehicles can travel over small tussocks with relative ease, but where the clumps exceed a foot in height, travel is slow and rough, especially early in the summer when the tussocks are still frozen. Grassy meadows occur in swales in the upland areas and along the marshy valley bottoms of the main rivers. Lichens and mosses grow most abundantly in stony areas, such as gravel terraces and rubbly ridge tops and slopes where the soil mantle is thin.

No trees grow in the mapped area except stunted willows along the stream bottoms. The willows are 5 to 20 feet high and as much as several inches in diameter. They increase in size and density northward across the mapped area, and locally, as along the Ayiyak River, occur in nearly impenetrable thickets.

SEDIMENTARY ROCKS

GENERAL FEATURES

Rocks ranging in age from Mississippian to Recent are exposed in the Killik-Itkillik region. They include upper Paleozoic and Mesozoic sedimentary bedrock, Mesozoic igneous rocks, and Cenozoic surficial deposits. A summary of the stratigraphic sequence is listed in the table below.

Five of the formations listed in the table were defined as a result of the present stratigraphic studies on the Killik-Itkillik region and are fully described for the first time in this report. They are the Siksikpuk Formation (Permian?), Tiglukpuk Formation (Jurassic), Okpikruak Formation, Fortress Mountain Formation, and Torok Formation (Cretaceous).* A brief description of each of these formations has already been published (Gryc, Patton, and Payne, 1951, p. 159–162) (Patton, 1956a; b, p. 213–223; 1957, p. 41–43).

In the rock descriptions that follow, a standard terminology has been adapted for color, bedding, and grain size. Color names conform as nearly as possible with the National Research Council "Rock-Color Chart" (Goddard and others, 1948). Stratigraphic units are described as follows: Thin bedded, 1 to 4 inches; medium bedded, 4 to 12 inches;. and thick bedded, more than 12 inches. The grain size and textural terminology is based on the Wentworth scale.

MISSISSIPPIAN ROCKS

LISBURNE GROUP

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Lisburne Group includes the oldest rocks exposed in the Killik-Itkillik region. Nowhere in the foothills does the Lisburne crop out in a complete and continuous sequence, but it is well exposed along the entire southern margin of the mapped area where it forms the north front of the Brooks Range (fig. 67).

*See footnotes, p. 442, 444, 449.

Stratigraphic sequence in the Killik-Itkillik Rivers region

System	Series	Stage	Unit name		Character	Approximate thickness (feet)
Quaternary	Recent		Flood-plain deposits		Gravel, sand, and silt	?
	Pleistocene		Glacial deposits		Till and outwash gravel	0–50
			Upland gravel depoists		Outwash gravel	0–50
Cretaceous	Upper ?	Cenomanian ?	Nanushuk Group	Ninuluk Formation	Marine sandstone	1,200
	Upper and (or) Lower ?	Cenomanian and (or) Albian ?		Chandler Formation; Killik Tongue	Sandstone, siltstone, shale, conglomerate, and coal, predominately nonmarine	2,800
	Lower	Albian		Tuktu Formation	Marine sandstone	950–1,350
			Torok Formation ? Fortress Mountain Formation		Shale, siltstone, and subordinate sandstone; Sandstone(?), conglomerate, shale, and siltstone	6,000 ? 10,000
		Neocomian	Okpikruak Formation*		Shale, siltstone, and sandstone	2,200
Jurassic	Upper	Portlandian(?)	Igneous rocks; Tuffaceous graywacke unit*		Mafic intrusive and extrusive(?) rocks; Tuffaceous graywacke, chert, indurated siltstone, and shale	? ?
		Portlandian, Kimmeridgian, Oxfordian	Tiglukpuk Formation*		Shale, siltstone, sandstone, and chert	1,500
Triassic	Upper	Norian, Karnian(?)	Shublik Formation	Limestone member; Chert member	Dark limestone, chert, and shale	175–250
	Middle, Lower(?)	Anisian, Scythian(?)		Shale member	Dark shale	0–500
Permian(?)			Siksikpuk Formation		Shale and siltstone	250–350
Carboniferous: Mississippian	Upper		Lisburne Group	Alapah Limestone	Limestone and subordinate shale, dolomite, and chert	1,700
	Lower			Wachsmuth Limestone		530

*See footnotes p. 442, 444, 449.

Most of the exposures of Lisburne in the foothills are small fault blocks so intensely crumpled that they are of little value for detailed stratigraphic study. However, several thick relatively uncomplicated sections of the Lisburne Group crop out close to the mountain front. One of these section occurs along the Tiglukpuk Creek anticline between the Siksikpuk River and Natvakruak Lake about 5 miles north of the Brooks Range. Another forms the west-plunging nose of a folded thrust plate of the Lisburne on the Nanushuk River, 1 to 2 miles north of the range. Another, probably a klippe, makes a narrow east-trending ridge 2 miles north of the mountains between the Anaktuvuk River and Tiglukpuk Creek.

A characteristic light-gray weathered surface distinguishes the Lisburne exposures from all other rocks in the foothills. The large outliers of Lisburne close to the mountains form prominent ridges with as much as 1,500 feet of relief. Generally, their lower slopes are completely buried by talus, and bedrock is exposed only along the crests. The small fault blocks of the Lisburne are usually enclosed by less resistant Mesozoic strata and typically crop out as isolated pinnacles, buttes, or abrupt wall-like ridges similar to the one shown in figure 90, which crosses the valley of the Kiruktagiak River at The Notch.

PREVIOUS WORK

The Lisburne was first described by F. C. Schrader (1902, p. 241; 1904, p. 62–66) as the Lisburne Formation. He designated a type locality at the head of the Anaktuvuk River in the central Brooks Range, although the name Lisburne was taken from exposures at Cape Lisburne on the Arctic coast, 350 miles west of the type locality.

Further details of the character and distribution of the Lisburne were added by A. J. Collier (1906, p. 21–26) in the Cape Lisburne area, by E. de K. Leffingwell (1919, p. 108–113) in the Canning River region, and by P. S. Smith and J. B. Mertie, Jr. (1930), in the central Brooks Range. Smith and Mertie changed Schrader's term Lisburne Formation to Lisburne Limestone.

During the summer of 1949, in connection with the geologic investigations of NPR–4, A. L. Bowsher and J. T. Dutro, Jr., systematically examined in considerable detail stratigraphic sections of the Lisburne at Shainin, Nanushuk, and Itkillik Lakes in the central Brooks Range. In 1950, 1951 and 1952 studies of the Lisburne were continued by W. P. Brosgé, H. N. Reiser, J. T. Dutro, Jr., M. D. Mangus, and others at selected localities in the Brooks Range eastward to the headwaters of the Sheenjek River and westward to the Arctic coast. As a result of these investigations the Lisburne has been elevated to the status of a group and subdivided into two formations, the Wachsmuth and Alapah Limestones, which have their type localities at Shainin Lake (Bowsher and Dutro, 1957, p. 6).

LITHOLOGY

The Lisburne Group in the Killik-Itkillik region is predominantly a light-colored clastic fossiliferous limestone with varying but subordinate amounts of dark shaly limestone, dark shale, chert, and dolomite. The clastic limestone occurs in beds several inches to several feet thick and is most commonly brownish gray and fine to coarse grained. It consists essentially of an aggregate of calcareous detritus including a large percentage of fossil fragments; brachiopods, echinoderms, bryozoans, and corals are abundant throughout, and several horizons are rich in gastropods and trilobites. Locally, the limestone has been dolomitized to a varying extent so that the fossil fragments are partly or entirely destroyed and, in the advanced stages, a light coarsely crystalline dolomitic limestone has resulted. Nodules and lenses of dark chert are an important constituent in many horizons where they may make up as much as 80 percent of the rock. Freshly broken pieces of the limestone usually give off a strong bituminous odor.

The overall aspect of the Lisburne Group is one of lithologic homogeneity. Along the north slope of the Brooks Range it has been possible by detailed lithologic and paleontologic study of numerous well-exposed sections to differentiate and map the Wachsmuth and Alapah Limestones (Bowsher and Dutro, 1957). Locally, members of these units also can be mapped. In the Killik-Itkillik region, however, because the exposures of Lisburne are incomplete and commonly badly crumpled, it has not been possible to delineate any of these cartographic subdivisions on plate 50.

THICKNESS

The base of the Lisburne Group is not exposed in the Killik-Itkillik region. The most nearly complete section, which is approximately 2,200 feet thick, is exposed on the Tiglukpuk Creek anticline. Based upon correlations with measured sections of the Lisburne Group to the south in the Brooks Range (W. P. Brosgé and H. N. Reiser, written communication, 1951), this one is judged to be nearly the full thickness of the group.

CONTACTS

Along the mountain front west of the Anaktuvuk River, where the upper contact is best exposed, the Lisburne is succeeded disconformably by the Siksikpuk Formation. East of the Anaktuvuk River, however, the Siksikpuk apparently is missing and the Shublik Formation disconformably rests on the Lisburne Group. North of the mountains the stratigraphic relations of the Lisburne and the younger formations of the foothills are obscure, for the contact is generally faulted. On Autumn Creek at lat 68°28′ N. and at The Notch on the Kiruktagiak River, beds of the Tiglukpuk apparently rest disconformably upon the Lisburne Group. The exposures at both localities are incomplete, however, and perhaps some of the beds are missing because of unseen faults.

STRATIGRAPHIC SECTIONS

The thickest sequence of the Lisburne Group north of the mountains in the Killik-Itkillik region crops out on the Tiglukpuk Creek anticline at lat 68°21′ N. and long 151°51′ W. A section approximately 2,200 feet thick was measured on the south flank of the anticline along the canyon of Tiglukpuk Creek by H. N. Reiser in 1950, as a part of the detailed stratigraphic investigations of the Lisburne Group (W. P. Brosgé, and H. N. Reiser, written communication, 1950). Reiser logged the section in considerable detail and, by correlations with other measured sections in the Brooks Range, was able to draw the Alpah-Wachsmuth contact. The section includes the full thickness of the Alapah Limestone, nearly 1,700 feet, and 530 feet of the Wachsmuth Limestone. Probably not more than a few hundred feet of lowermost Wachsmuth is missing.

The upper 450 feet of the section is shown graphically in figure 71 for comparison with other sections of the upper part of the Alapah Limestone in the mapped area. The 15-foot black chert and shale member of the Alapah is 400 feet below the top of the formation.

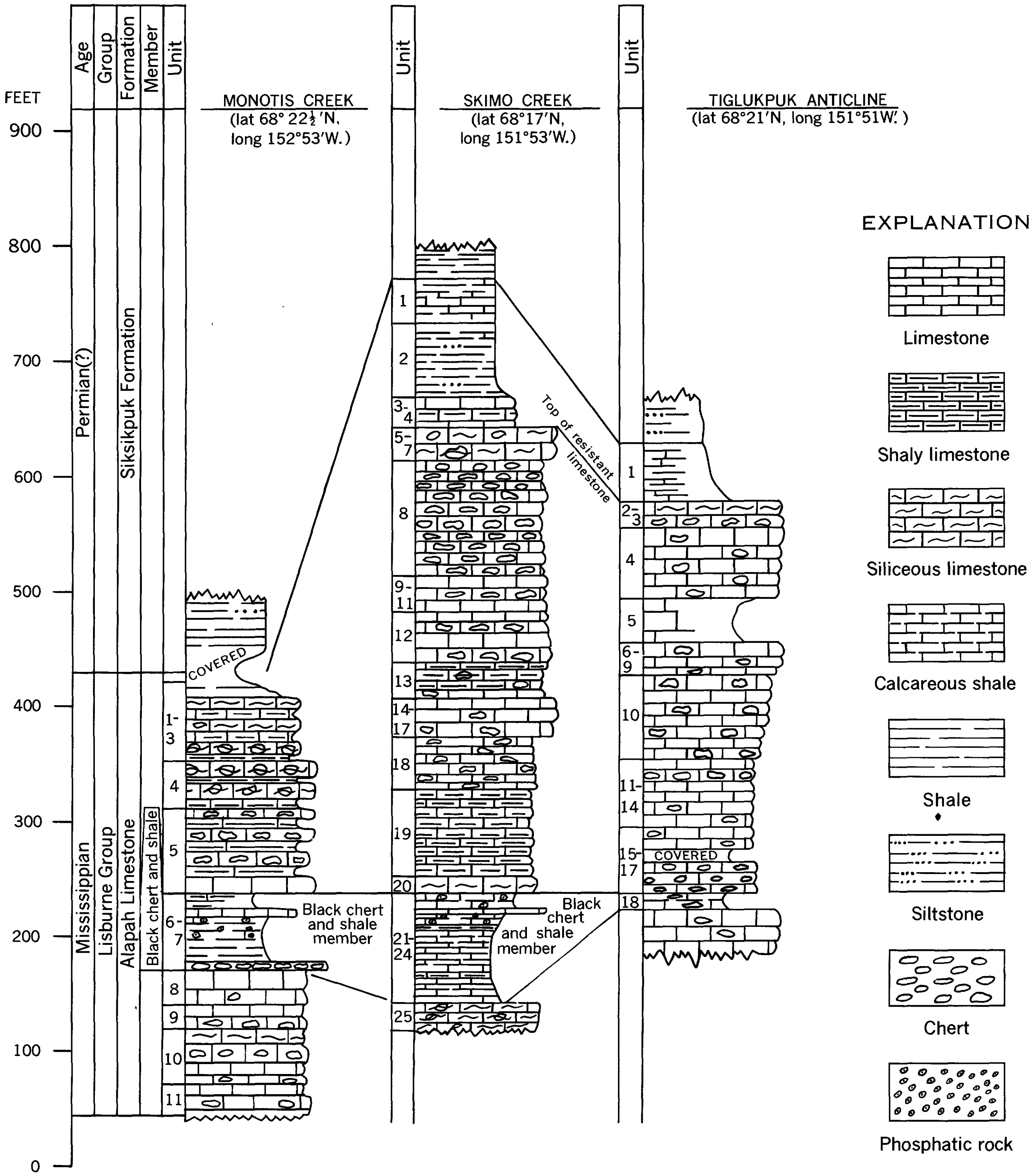

FIGURE 71.—Correlated columnar sections, upper part of the Lisburne Group.

Section of Lisburne Group on south flank of Tiglukpuk Creek anticline on Tiglukpuk Creek, at lat 68°21′ N., long 151°51′ W.

[Measured with tape by H. N. Reiser, 1950. Graphic section of upper 450 ft, fig. 71]

Permian(?).
Siksikpuk Formation.
Unconformity.
Largely covered. Several slumped cutbanks of red and green siltstone and shale, locally siliceous.
Mississippian.
Lisburne Group:
Alapah Limestone:

	Thickness (feet)
1. Largely covered. Talus of dark limy shale	50±
2. Limestone, massive, light-brownish-gray, fine-grained, silicified in part; abundant nodules of silicified limestone and chert 3 in. to 2 ft in diameter	20
3. Limestone, pale-brownish-red, fine-grained	3
4. Limestone, thick-bedded, light-brownish-gray to dark-gray, fine-grained; 10 percent grayish-black chert	61
5. Largely covered. Talus of dark-gray very coarse grained limestone weathering light brownish gray	39
6. Limestone, medium-bedded, brownish-gray, fine- to medium-grained; a little chert	10
7. Limestone, massive, dark-grayish-brown, coarse grained; 20 percent grayish-black chert	4
8. Limestone, thick-bedded, light-olive-gray, medium-grained; nodules of white to pale-brown siliceous limestone 1 to 1½ ft in diameter	4
9. Limestone, thin- to medium-bedded, dark-gray, fine-grained. Interbedded with 10 percent dark-grayish-black chert	10
10. Limestone, thin bedded at bottom to thick bedded at top; brownish gray to dark gray, fine grained; 35 percent interbedded brownish-gray nodular siliceous limestone	73
11. Limestone, thick-bedded, brownish-gray, fine- to medium-grained	12
12. Limestone, thin-bedded, dark-gray, fine-grained; 80 percent grayish-black nodular chert	12
13. Limestone, thin- to medium-bedded, brownish-gray, fine-grained	10
14. Limestone, thin- to medium-bedded, dark-gray, fine-grained; 30 percent interbedded grayish-black chert	26
15. Limestone, thin- to medium-bedded, black, very fine grained; 10 percent interbedded grayish-black chert	18
16. Covered	11
17. Limestone, thin- to medium-bedded, dark-grayish-black, fine-grained; 50 percent interbedded black chert	29
18. Black chert and shale member: Limestone, thin- to medium-bedded, shaly, dark-gray, fine-grained; 20 percent interbedded black chert, float of phosphate rock	15

Section of Lisburne Group on south flank of Tiglukpuk Creek anticline on Tiglukpuk Creek, at lat 68°21′N., long 151°51′W.—Continued

Mississippian—Continued
Lisburne Group—Continued
Alapah Limestone—Continued

	Thickness (feet)
19. Limestone, thick-bedded, brownish-gray, coarse-grained; 8 percent interbedded nodular chert	21
20. Limestone, thick-bedded, grayish-orange, very coarse grained; 4 percent interbedded chert	6
21. Limestone, thick-bedded, light-olive-gray to pinkish-gray, coarse-grained to very coarse grained	21
22. Limestone, biohermal, crossbedded at top; thick-bedded, massive, pale-yellowish-brown, coarse grained	58
23. Limestone, thick-bedded, light-olive-gray, coarse-grained; interbedded with thin bands of siliceous limestone and chert	14
24. Limestone, thick-bedded, moderate-yellowish-brown, medium- to coarse-grained	24
25. Chert, grayish-black with silicified limestone	1
26. Limestone, thick-bedded, light-grown, medium-grained	9
27. Limestone, medium-bedded, pale-yellowish-brown, medium-grained	2¼
28. Largely covered. Talus of brownish-gray medium- to coarse-grained limestone	142
29. Limestone, thick-bedded, brownish-gray, medium-grained; interbedded with thin nodular cherty limestone. Corals abundant	19
30. Limestone, thick-bedded, massive, brown, fine-grained; 4 percent siliceous limestone and chert; lithostrotionoid corals	13
31. Limestone, thick-bedded, massive, light-brown, medium- to coarse-grained; lithostrotionoid corals	10
32. Limestone, thick-bedded, massive, brownish-gray, fine-grained; 3 percent nodular bedded chert	33
33. Largely covered. Talus of fine- to medium-grained brownish-gray to pale-yellowish-brown thin-bedded limestone	85
34. Limestone, thin-bedded, shaly, dark-gray, fine-grained, siliceous; 2 percent chert	31
35. Limestone, coarse-grained, brownish-gray	⅓
36. Limestone, thin-bedded, dark-gray, fine-grained; weathers to fissile fragments; 5 percent grayish-black nodular chert	22
37. Limestone, thin-bedded, dark-gray, fine-grained; interbedded with brownish-gray medium-grained limestone	8
38. Limestone, thick-bedded, pale-yellowish-brown, coarse-grained; 1 percent grayish-black chert nodules	4
39. Limestone, medium- to thick-bedded, dark-brownish-gray, fine-grained; 1 percent chert	4

Section of Lisburne Group on south flank of Tiglukpuk Creek anticline on Tiglukpuk Creek, at lat 68°21′ N., long 151°51′ W.—Continued

	Thickness (feet)
Mississippian—Continued	
Lisburne Group—Continued	
Alapah Limestone—Continued	
40. Limestone, massive, thick-bedded, medium brown, fine-grained	7
41. Partly covered. Chiefly dark-gray to brown thin- to thick-bedded fine-grained limestone	50
42. Limestone, thin- to medium-bedded, brownish-gray, fine-grained; chert nodules, 5 percent	22
43. Covered	7
44. Limestone, shaly, brownish-gray, very fine grained	14
45. Limestone, very thick bedded, coarse-grained, pale-yellowish-brown; interbedded with medium-bedded brownish-gray fine-grained limestone; lithostrotionoid corals	21
46. Limestone, thick-bedded, brownish-gray, fine-grained; about 7 percent black nodular chert	4
47. Limestone, thick-bedded, light-olive-gray, coarse-grained	6
48. Limestone, medium-bedded, fine-grained, brownish-gray to grayish-black; lithostrotionoid corals	21
49. Limestone, medium- to thick-bedded, brownish-gray, fine-grained; interbedded with thin beds of very light gray cherty limestone	32
50. Limestone, thin-bedded, fine-grained, brownish-gray; interbedded with thin nodular cherty limestone	5
51. Covered	9
52. Limestone, thin-bedded, shaly, brownish-gray, fine-grained; interbedded with black nodular chert	19
53. Limestone, thick-bedded, olive-gray, coarse- to fine-grained; 10 percent grayish-black chert nodules	7
54. Limestone, thick-bedded, light-olive-gray, coarse-grained; 5 percent grayish-black nodular chert	10
55. Limestone, medium-bedded, brown, fine-grained	4
56. Limestone, thin-bedded, grayish-black, fine-grained, dolomitic; some chert nodules	9
57. Limestone, thick-bedded, brownish-gray, fine-grained	9
58. Covered	5
59. Dolomite, gray, very fine grained, highly fractured; calcite veinlets	25
60. Limestone, medium- to thick-bedded, brownish-gray, fine-grained	10
61. Limestone, medium-bedded, brownish-gray, fine- to medium-grained; partly silicified	12
62. Covered	8
63. Limestone, thick-bedded, brownish-gray, fine-grained	31

Section of Lisburne Group on south flank of Tiglukpuk Creek anticline on Tiglukpuk Creek, at lat 68°21′ N., long 151°51′ W.—Continued

	Thickness (feet)
Mississippian—Continued	
Lisburne Group—Continued	
Alapah Limestone—Continued	
64. Limestone, thin-bedded, brownish-gray, fine-grained	12
65. Limestone, thin- to medium-bedded, fine-grained, dark-gray; 60 percent silicified	9
66. Limestone, thick-bedded, coarse-grained, olive-gray. Corals. Less than 5 percent black nodular chert	6
67. Limestone, medium- to thin-bedded, grayish-black, coarse-grained; 30 percent grayish-black nodular chert	15
68. Dolomite, medium-bedded, pinkish-gray, fine- to medium-grained; 30 percent grayish-black, nodular chert	24
69. Chert, black, glassy	5
70. Limestone, dolomitic, thick-bedded, pinkish-gray, fine-grained; 40 percent nodular chert	18
71. Covered	30
72. Limestone, thick-bedded, pinkish-gray, fine-grained	6
73. Limestone, thin-bedded, fine-grained, grayish-black	4
74. Limestone, medium-bedded, nodular, brownish-gray, fine- to medium-grained; locally silicified	13
75. Covered	157
76. Limestone, thin-bedded, brownish-gray, fine-grained; grayish-black chert nodules and lenses	20
77. Limestone, brecciated	2
78. Covered	45
79. Limestone, shaly, brownish-gray to dark-gray, fine-grained	25
80. Limestone, thick-bedded, light-olive-gray, coarse-grained	3
81. Limestone, shaly, dark-gray, fine-grained	6½
82. Limestone, massive, dark-gray, fine-grained	4
Thickness of Alapah Limestone	1, 686±
Wachsmuth Limestone:	
83. Limestone, shaly, brownish gray, fine-grained	4
84. Limestone, shaly, dusky-brown, fine-grained; 15 percent interbedded grayish-black nodular chert	13
85. Limestone, thick-bedded, brownish-gray, fine- to medium-grained	2
86. Covered	3
87. Limestone, shaly, brownish-gray, fine-grained; 15 percent grayish-black nodular chert	10
88. Limestone, thick-bedded, brown, very fine to fine-grained. Abundant fossils	25
89. Limestone, thick-bedded, brownish-gray, fine-grained; interbedded with shaly nodular limestone	14

Section of Lisburne Group on south flank of Tiglukpuk Creek anticline on Tiglukpuk Creek, at lat 68°21′N., long 151°51′ W.—Continued

Mississippian—Continued
Lisburne Group—Continued
Wachsmuth Limestone—Continued

	Thickness (feet)
90. Limestone, thin-bedded, brownish-gray, nodular, fine-grained; 35 percent interbedded grayish-brown chert	22
91. Limestone, massive, thick-bedded, grayish-orange-pink, coarse-grained	3
92. Dolomite, thick-bedded, grayish-orange-pink, coarse-grained	10
93. Covered	14
94. Limestone, shaly, dark-gray, fine-grained	4
95. Covered	17
96. Limestone, shaly, dark-gray, fine-grained; 35 percent interbedded black nodular chert	14
97. Limestone, thick-bedded, olive-gray, coarse-grained; abundant fossils	2
98. Limestone, thin-bedded, dark-gray to grayish-black, fine-grained; 15 percent grayish-black nodular chert	17
99. Limestone, thick-bedded, olive-gray, fine- to medium-grained; 20 percent grayish-black nodular chert	8
100. Limestone, shaly, black, fine-grained. Possible small fault	1
101. Limestone, thin- to medium-bedded, brownish-gray, fine- to medium-grained; 15 percent nodular chert	8
102. Covered. Talus of limestone as in unit 97	19
103. Limestone, thin-bedded, nodular, silicified, dark-gray, fine-grained	2
104. Limestone, thick-bedded, brownish-gray, medium- to coarse-grained, interbedded with thin bands of nodular chert	10
105. Limestone, thin-bedded, nodular, dark-gray, fine-grained; 20 percent chert in thin nodular beds	35
106. Limestone, thick-bedded, olive-gray, coarse-grained, biohermal	4
107. Limestone, shaly, nodular, dark-gray, fine-grained; 60 percent interbedded grayish-black chert	7
108. Limestone, thick-bedded, olive-gray, coarse-grained, biohermal	4
109. Limestone, shaly, grayish-black, fine-grained; 15 percent interbedded nodular chert	35
110. Limestone, thick-bedded, olive-gray, medium- to coarse-grained; interbedded with thin bands of shaly limestone	13
111. Limestone, thin-bedded, dark-gray, fine-grained; 5 percent interbedded grayish-black chert	20
112. Limestone, medium-bedded, dark-gray, fine-grained; containing two massive beds of medium-gray fine-grained limestone	12
113. Covered	39
114. Limestone, thick-bedded, brownish-gray, fine-grained; calcite veinlets	24
115. Limestone, medium-bedded, brownish-gray, fine-grained; 20 percent interbedded grayish-black chert	5
116. Limestone, massive, thick-bedded, olive-gray, medium- to coarse-grained	18
117. Limestone, medium- to thick-bedded, brownish-gray, fine-grained; interbedded with thin bands of siliceous limestone and chert	15
118. Covered. Shaly limestone. Possible bedding fault	9
119. Chert, massive, brownish-gray	2
120. Limestone, thin-bedded, fine- grained, brownish-gray	12
121. Limestone, massive, thick-bedded, olive-gray, medium- to coarse-grained	6
122. Limestone, shaly, grayish-black, fine-grained	4
123. Limestone, massive, thick-bedded, dark-gray to grayish-black, fine- to medium-grained	15
124. Limestone, thin-bedded, nodular, dark-gray, fine-grained; 20 percent interbedded siliceous limestone and chert	20
125. Limestone, massive, thick-bedded, brownish-gray, very coarse grained	12
Not exposed, axis of Tiglukpuk Creek anticline. Thickness of partial section of Wachsmuth Limestone	533
Total thickness of measured section	2,219±

Two partial sections of the uppermost part of the Lisburne Group were measured in the Killik-Itkillik region, one in the Monotis Creek-Kiruktagiak River area (lat 68°22′30″ N., long 152°53′ W.) and the other on Skimo Creek in the Tiglukpuk Creek basin (lat 68°17′ N., long 151°53′ W.) They are of particular interest because they (1) show the nature of the upper contact of the Lisburne Group, (2) are composed predominantly of a dark limestone-shale-chert lithofacies in place of the normal light-colored bioclastic limestone facies, (3) contain a unique cephalopod fauna, and (4) contain deposits of low- and medium-grade phosphate rock. In figure 71 the two sections are shown graphically and are correlated with the uppermost beds of Reiser's Tiglukpuk Creek anticline section.

The dark limestone-shale-chert facies that characterizes these sections of the upper beds of the Lisburne Group apparently interfingers eastward with the light bioclastic limestone facies and, according to W. P. Brosgé and H. N. Reiser (written communication, 1951), pinches out entirely a short distance east of Shainin Lake. Within the dark limestone-shale-chert facies is a distinctive sequence of soft grayish-black shaly limestone and phosphate rock that contains an abundant goniatite fauna. This sequence makes an excellent marker horizon in the upper part of the Lisburne Group, and in the Shainin Lake area it has been referred to as the black chert and shale member of the Alapah Limestone by Bowsher and Dutro (1957, p. 6). In the Monotis Creek section the black chert and shale member is 67 feet thick, and in the Skimo Creek section it is 96 feet thick. However, it must thin northward rapidly, for in Reiser's measured section on the Tiglukpuk Creek anticline it is only 15 feet thick.

In the Killik-Itkillik region the black chert and shale member is especially significant, because the goniatite fauna contains a number of forms, including several new species, that have not been reported elsewhere in the Lisburne (Gordon, 1957). In addition, the exposures on Monotis and Skimo Creeks contain the thickest deposits of phosphate rock yet found in northern Alaska (see p. 497).

Section of Alapah Limestone, Lisburne Group, in cutbanks on Monotis Creek at lat 68°22½' N., long 152°53' W.

[Measured with tape by W. W. Patton, Jr., 1949. Graphic section, fig. 71]

	Thickness (feet)
Permian(?).	
Siksikpuk Formation: Grayish-red and dusky yellow-green shale and siltstone.	
Covered interval	30
Mississippian.	
Lisburne Group:	
Alapah Limestone:	
1. Shale, black, pyritiferous, fossiliferous	6
2. Limestone, thin- to medium-bedded, dense, dark-gray, siliceous. Subordinate grayish-black silty shale	11
3. Limestone, medium-bedded, dense, dark-gray, siliceous. Subordinate dark-gray shaly limestone. Nodular chert becomes abundant near base	52
4. Limestone, thick-bedded, dense, dark-gray, blocky weathering, siliceous. Subordinate dark-gray shaly limestone. Black chert nodules and lenses abundant	42
5. Limestone and shale. Interbedded dark-gray thick-bedded fine-grained limestone and grayish-black calcareous shale. Black nodular chert abundant	71

Section of Alapah Limestone, Lisburne Group, in cutbanks on Monotis Creek at lat 68°22½' N., long 152°53' W.—Continued

	Thickness (feet)
Mississippian—Continued	
Lisburne Group—Continued	
Alapah Limestone—Continued	
6, 7. Black chert and shale member:	
6. Shale, limestone, phosphate rock. Poorly exposed. Dark-gray to grayish-black calcareous shale, shaly limestone, phosphatic shale, phosphatic limestone, and oolitic phosphate rock. Grayish-black dense siliceous fossiliferous concretions as much as 4 ft in diameter 59	
7. Chert, massive, dark-gray 8	
Thickness of black chert and shale member	67
8. Limestone, thick-bedded, coarse-grained, light-brownish-gray, clastic. Minor black chert nodules. Subordinate dark-gray thin-bedded limestone. Upper surface slightly undulatory and nongradational	30
9. Limestone, medium-bedded, grayish-black, fine-grained; 50 percent lenses and nodules of black chert	21
10. Limestone. Interbedded medium- and thick-bedded brownish-gray coarse-grained clastic limestone and thin- to medium-bedded dark-gray fine-grained siliceous limestone; 30 percent black chert and cherty limestone lenses and nodules	48
11. Limestone, massive, brownish-gray, coarse-grained, clastic. Near base are lenses of light- to dark-gray chert that weather white	27
Not exposed, center of anticline.	
Total thickness of Alapah Limestone exposed	375

Section of Alapah Limestone, Lisburne Group, on Skimo Creek at lat 68°17' N., long 151°53' W.

[Measured with tape by H. N. Reiser, 1950, and W. W. Patton, Jr., 1953. Graphic section, fig. 71]

	Thickness (feet)
Permian(?).	
Siksikpuk Formation: Shale, grayish-red and dusky yellow-green.	
Unconformity.	
Mississippian.	
Lisburne Group:	
Alapah Limestone:	
1. Shale, calcareous, dark-gray, iron-stained	38
2. Shale and siltstone, calcareous, dark-gray	64
3. Limestone, glauconitic, coarse-grained, light-gray, green-weathering	1
4. Limestone, thin- to medium-bedded becoming shaly toward top, dense, dark-gray	24
5. Limestone, medium- to thick-bedded, light-olive-gray; interbedded siliceous limestone	6
6. Limestone, thick-bedded, dusky-brown, fine-grained; 10 percent siliceous limestone nodules	5

Section of Alapah Limestone, Lisburne Group, on Skimo Creek at lat 68°17′ N., long 151°53′ W.—Continued

	Thickness (feet)
Mississippian—Continued	
Lisburne Group—Continued	
Alapah Limestone—Continued	
7. Limestone, medium-bedded, dark-gray, fine-grained; 15 percent siliceous limestone, 10 percent nodular chert	18
8. Limestone, thin-bedded, dark-gray, fine-grained, partly silicified; 50 percent grayish-black nodular chert	100
9. Limestone, medium- to thick-bedded, dark gray, fine-grained; minor nodular chert	15
10. Limestone, thin-bedded, grayish-black, fine-grained; 30 percent interbedded nodular chert	12
11. Limestone, thick-bedded, dark-gray, fine-grained; minor chert nodules	5
12. Limestone, thin- to medium-bedded, brownish-gray, very fine grained; 20 percent interbedded nodular brownish-gray chert	44
13. Limestone, shaly, dark-gray, very fine grained; 15 percent interbedded nodular grayish-black chert	30
14. Limestone, thick-bedded, dark-gray, fine-grained; minor bedded chert	5
15. Limestone, medium-bedded, dark-gray, fine-grained; 15 percent nodular chert	4
16. Limestone, thin-bedded, fine-grained, dark-gray, hackly fracturing; 30 percent black nodular chert	21
17. Limestone, thick-bedded, pinkish-gray, medium-grained	5
18. Limestone, thin-bedded, dark-gray, fine-grained; 30 percent nodular bedded chert	45
19. Limestone, shaly, fine-grained, dark-gray	76
20. Interbedded thick-bedded siliceous dark-gray fine-grained limestone and dark-gray fine-grained shaly limestone	15
21–24. Black chert and shale member:	
21. Grayish-black calcareousshale, limestone, and oolitic phosphate rock — 12	
22. Limestone, grayish-black, massive — 5	
23. Dark-gray to grayish-black shaly limestone, phosphatic shale, phosphatic limestone, and oolitic phosphatic rock — 20	
24. Interbedded grayish-black calcareous shale and grayish-black shaly limestone — 59	
Thickness of black chert and shale member	96
25. Limestone, dolomitic, coarse-grained, pinkish-gray; 40 percent interbedded grayish-black siliceous limestone and chert. Top contact undulating	25
Base of measured section.	
Total thickness of measure section of Alapah Limestone	654

The stratigraphic interval between the black chert and shale member and the top of the Lisburne is about 200 feet in the Monotis Creek section and 530 feet in the Skimo Creek section (fig. 71). The difference appears to be due, at least in part, to differential erosion before deposition of the Siksikpuk Formation.

Another important exposure of the upper part of the Lisburne Group occurs along a narrow belt that crosses the valley of the Kiruktagiak River at The Notch (fig. 90). Here the outcrops of the Lisburne, which appear to be along the upthrust edge of a south-dipping fault block, are so crumpled and broken that no stratigraphic measurements could be made. Both the light bioclastic limestone facies and the dark limestone-shale-chert facies are present. The black chert and shale member containing a well-preserved goniatite fauna (colln. 49APa399, 45AGr16) is partly exposed.

Strata of the uppermost part of the Lisburne Group also crop out as a series of sharp jagged discontinuous ridges along two narrow east-striking bands between the Okpikruak River and Verdant Creek. Although there are no exposures between Verdant Creek and the Okokmilaga River, outcrops of similar rock in the Okokmilaga valley indicate that these two belts probably extend as far east as the Okokmilaga. The sequence exposed along these two bands is chiefly the dark limestone-shale-chert facies and is abundantly fossiliferous (colln. 49ATr399).

AGE

The Lisburne Group was originally assigned by Schrader to the Devonian (1904, p. 62–67). A few years later, however, Collier established the age as Mississippian on the basis of his collections from Cape Lisburne (1906, p. 21–26). Bowsher and Dutro (1957, p. 6) assigned the Wachsmuth Limestone an Early Mississippian age and the Alapah Limestone a probable Late Mississippian age.

Fossil collections from the stratigraphic section of the Tiglukpuk Creek anticline are representative of the fauna of the Lisburne Group in the Killik-Itkillik region. The collections listed below with Paleozoic locality numbers, were identified by A. L. Bowsher (written communication, 1951).

Collections from stratigraphic section of the Lisburne Group on the south flank of the Tiglukpuk Creek anticline on Tiglukpuk Creek (p. 421)

50ARrF43, USGS 11801, unit 10:
Echinoconchus sp.

50ARrF48, USGS 11800, unit 31:
"*Buxtonia*" cf. "*B.*" *muir-woodi* Paeckelmann
Munella? *adonis* (Bell)

50ARrF49, USGS 11799, unit 34:
Bellerophon sp.
Naticopsis cf. *Naticopsis suturicompta* Yochelson and Dutro

50ARrF53, USGS 11798, unit 41:
Cystodictya sp.
"*Dictyoclostus*" sp.

Collections from stratigraphic section of the Lisburne Group on the south flank of the Tiglukpuk Creek anticline on Tiglukpuk Creek (p. 421)—Continued

50ARrF53, USGS 11798, unit 41—Continued
- *Echinoconchus* aff. *E. biseriatus* (Hall)
- *Spirifer* n. sp.
- *Camarophoria explanata* McChesney
- *Bairdia cestriensis* Ulrich
- *Glyptopleura* sp.

50ARrF54, USGS 11796, unit 79:
- *Spirifer* sp. indet.
- Pectenid pelecypod, indet.

50ARrF55, USGS 11797, unit 75:
- *Lithostrotion* aff. *L. asiaticum* Yabe and Hayasaka

50ARrF56, USGS 11795, unit 88:
- "*Zaphrentis*" sp.
- "*Dictyoclostus*" aff. "*D.*" *crawfordsvillensis* (Weller)
- *Brachythyris suborbicularis* (Hall)

50ARrF62, USGS 11793, unit 100:
- "*Buxtonia*" cf. "*B.*" *viminalis* (White)
- *Spirifer* sp.
- *Brachythyris suborbicularis* (Hall)

50ARrF63, USGS 11792, unit 106:
- *Spirifer floydensis* (Weller)
- *Spirifer* sp.
- Pectenid pelecypod, indet.
- *Phillipsia* sp.

50ARrF64, USGS 11791, unit 111:
- *Brachythyris* aff. *B. suborbicularis* (Hall)
- *Torynifer* aff. *T. pseudolineata* (Hall)

50ARrF65, USGS 11790, unit 125:
- "*Zaphrentis*" cf. "*Z.*" *konincki* Milne Edwards and Haime
- *Spirifer* cf. *S. subaequalis* (Hall)
- *Spirifer* sp.

Fossil collections from exposures of the uppermost part of the Lisburne Group are listed below with Paleozoic locality numbers. Collections 50AKe226, 228, 233, 243, and 50ARr57 were examined and identified by A. L. Bowsher (written communication, 1951). The brachiopods in collections 49APa384, 389, 390, 391, 399, 49ATr399, 51ABe7F, and 50ARr59 were identified by J. T. Dutro, Jr., and the cephalopods by Mackenzie Gordon, Jr. (written communications, 1953, 1957).

Collections from stratigraphic section of the Alapah Limestone on Monotis Creek (p. 424)

49APa384, USGS 10862, base of unit 5:
- *Leiorhynchus* cf. *L. carboniferum* Girty
- *Moorefieldella?* sp.
- *Quadratia* cf. *Q. hirsutiformis* (Walcott)
- *Martinia* aff. *M. glaber* (J. Sowerby)
- *Bembexia? inumbilica*, Yochelson and Dutro

49APa389, USGS 10863, unit 1:
- *Leiorhynchus* sp.
- *Chonetes* aff. *C. oklahomensis* Snider
- *Quadratia* cf. *Q. hirsutiformis* (Walcott)

49APa390, USGS 10864, and 53APa103, USGS 14149, unit 6;
- *Moorefieldella* cf. *M. eurekensis* (Walcott)
- *Caneyella* cf. *C. percostata* Girty
- *Aviculopecten* sp.
- *Bactrites? carbonarius* Smith?

Collections from stratigraphic section of the Alapah Limestone on Monotis Creek (p. 424)—Continued

49APa390, USGS 10864 and 53APa103, USGS 14149, unit 6—Continued
- *Knightoceras pattoni* Gordon
- *Beyrichoceras micronotum* (Phillips)
- *Goniatites crenistria* Phillips (wide form)
- *Girtyoceras arcticum* Gordon
- *Entogonites borealis* Gordon
- *Dimorphoceras algens* Gordon

49APa391, USGS 10865, within interval of units 2 to 5:
- *Productus* sp.
- Productoid brachiopod, indet.

51ABe7F, USGS 12780, unit 6:
- *Platycrinites* sp. (columnal)
- *Entogonites borealis* Gordon

Collections from stratigraphic section of the Alapah Limestone on Skimo Creek (p. 424)

50AKe226, USGS 12342, basal 10 ft of unit 4:
- Undetermined solitary coral
- *Crurithyris?* sp. indet.
- "*Avonia*" *moorefieldana* (Girty)
- *Quadratia* aff. *Q. hirsutiformis* (Walcott)
- *Euphemites* sp.
- *Bembexia? inumbilica* Yochelson and Dutro

50AKe228, USGS 12343, upper 38 ft of unit 2:
- *Linoproductus* sp.
- "*Avonia*" *moorefieldana* (Girty)
- *Quadratia* aff. *Q. hirsutiformis* (Walcott)

50AKe233, USGS 12344, basal 10 ft of unit 4:
- Several undetermined solitary corals.
- *Bembexia?* aff. *B.? inumbilica* Yochelson and Dutro

50AKe243, USGS 12345, interval of units 2–4:
- *Orbiculoidea* sp. undet.
- *Leiorhynchus carboniferum* Girty
- "*Avonia*" *moorefieldana* (Girty)

50ARrF57, USGS 11805, unit 5:
- *Gigantoproductus* aff. *G. latissimus* (Sowerby)

50ARrF59, USGS 11804, interval of units 21 to 24:
- *Euloxoceras* sp.
- *Sudeticeras alaskae* Gordon
- *Eothalassoceras aurorale* Gordon

Collections from the black chert and shale member of the Alapah Limestone, east side of Kiruktagiak River at The Notch, lat 68°25′ N., long 152°49′ W. (p. 425)

49APa399, USGS 10866, and 45AGr16, USGS 9188:
- *Spirifer* sp.
- *Aviculopecten* sp.
- *Posidonia* cf. *P. wapanuckensis* (Girty)
- Gastropod, indet.
- *Rayonnoceras*? sp.
- *Bactrites*? *carbonarius* Smith
- *Kionoceras*? sp. C
  - sp. D
- *Dolorthoceras medium* Gordon
- *Dolorthoceras*? aff. *D. crebriliratum* (Girty)
- *Adnatoceras alaskense* Gordon
- *Stroboceras crispum* Gordon
- *Beyrichoceras micronotum* (Phillips)
  - sp.
- *Goniatites crenistria* Phillips (wide form)

Collection from east side of Middle Fork of Okpikruak River, lat 68°33′ N., long 153°31′ W. (p. 425). Stratigraphic position uncertain

49ATr399, USGS 10868:
- Fragments of zaphrentoid coral, indet.
- *Leiorhynchus* cf. *L. carboniferum* Girty
- *Leiorhynchus* sp.
- *Moorefieldella* cf. *M. eurekensis* (Walcott)
- *Chonetes* sp.
- *Quadratia* aff. *Q. hirsutiformis* (Walcott)
- *Ambocoelia*? sp.
- *Leda* sp.
- Pelecypod, indet.
- *Glabrocingulum*? sp.
- *Loxonema*? sp.
- Cephalopod?, indet.
- Ostracode, indet.

Of particular interest are the cephalopods from the black chert and shale member of the Alapah Limestone, which have been described in detail by Gordon (1957) in a separate report. On the basis of the cephalopods, Gordon can date the black chert and shale member with certainty as late middle Viséan and early late Viséan. Gordon (p. 15) states:

> The beyrichoceratids have their closest counterparts in the upper part of the *Goniatites maximus* (B_2) zone of the British Isles. The rocks with *Goniatites crenistria* Phillips and associated cephalopods seem to be equivalent to the *G. crenistria* (P_{1a}) subzone. Of interest is the occurrence of *Beyrichoceras micronotum* (Phillips) with *G. crenistria* at two Alaskan localities. Most of the British records place *B. micronotum* in the *Goniatites maximus* (B_2) zone several tens of feet below the earliest occurrence of *G. crenistria.*
>
> * * * * *
>
> *Sudeticeras alaskae* Gordon n. sp. appears to be nearest to *S. regina* Bisat from the *Goniatites elegans* (P_{1c}) subzone. *Sudeticeras* is not found in lower beds in England, but is rather common in the higher *Goniatites granosus* (P_2) zone.
>
> * * * * *
>
> *Goniatites* correlating with the *G. crenistria* (P_{1a}) subzone (zone IIIα of Schmidt) are widespread in Europe and North Africa. In the United States they occur in the Moorefield Formation of Arkansas and the lower part of the Chainman Shale in western Utah and eastern Nevada.

Dutro (written communication, 1953) also notes the similarity of the black chert and shale member fauna and the Moorefield Formation fauna of Arkansas. He states: "The Moorefield, in recent years, has been considered of Meramec age and the correlation among these faunas is important in suggesting the relationship between British and North American mid-continent lower Carboniferous sequences."

PERMIAN(?) ROCKS

SIKSIKPUK FORMATION

The name Siksikpuk Formation has been introduced to designate the sequence of shale and siltstone that occurs above the Lisburne Group and below the Shublik Formation (Triassic) in the central Arctic Foothills and Brooks Range provinces of northern Alaska (Patton, 1957). This sequence forms a well-defined stratigraphic unit and has been mapped from the Anaktuvuk River as far west as the Kiligwa River. It is typically exposed in a series of cutbanks on Tiglukpuk Creek and its tributaries, and derives the name from the Siksikpuk River, to which Tiglukpuk Creek is a major tributary.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

In the Killik-Itkillik region the Siksikpuk Formation is exposed west of the Anaktuvuk River, principally along a narrow belt at the front of the mountains. Outcrops are also scattered north of the mountains on the Tiglukpuk Creek anticline and flanking the two bands of the Lisburne Group that extend eastward from the Okpikruak River to the Okokmilaga River, 10 miles north of the mountain front. A small patch of the Siksikpuk Formation is surrounded by glacial drift a short distance east of the Killik River at lat 68°31′30″ N.

The Siksikpuk Formation and the overlying Shublik Formation have not been differentiated in most places on plate 50. Both formations are structurally incompetent and everywhere are complexly infolded and infaulted. Since they are also nonresistant to erosion and are therefore poorly exposed, it is practically impossible to map them separately at a reconnaissance scale, particularly in the interstream areas.

Of the few outcrops that are found in the mapped area, most occur along steep cutbanks. Even these exposures, however, generally have slumped to such an extent that bedding and structure are not discernible. In the interstream areas outcrops are confined to small patches of chert rubble.

The Siksikpuk is sufficiently well exposed to allow stratigraphic measurement at only two localities, Tiglukpuk Creek and Kiruktagiak River. The series of cutbanks on Tiglukpuk Creek and its eastern tributaries is the more complete section and has been designated the type locality (Patton, 1957).

The Siksikpuk and Shublik Formations, composed predominantly of soft shales, are everywhere deeply eroded. The east-trending belt of these two formations along the mountain front is marked topographically by a series of saddles, draws, and subsequent stream valleys bordered on the south by the massive escarpment of the Lisburne Group and on the north by irregular foothills composed of Jurassic and Cretaceous sandstone and conglomerate.

PREVIOUS WORK

Before the recent geologic investigations of Naval Petroleum Reserve No. 4, no rocks younger than the Lisburne Group and older than the Shublik Formation had been recognized in the central foothills. In the Canning River region of the eastern Brooks Range, Leffingwell (1919, p. 113–115) described a sequence of "about 300 feet of light sandstone or dark quartzites" that occurs between the Lisburne Group and the Shublik Formation, which he named the Sadlerochit Sandstone. Although both the Sadlerochit and Siksikpuk occupy the same stratigraphic position relative to the underlying Lisburne Group and the overlying Shublik Formation, neither the lithology nor the fauna of the two formations is alike.

LITHOLOGY

The Siksikpuk Formation is composed chiefly of variegated green, gray, and dark-red shale and siltstone that locally are notably calcareous, cherty, or ferruginous. All gradations from thin fissile clay shale to 6-inch beds of siltstone occur. Ellipsoidal concretions of barite as much as several feet in maximum diameter characterize the lower two-thirds of the sequence. The variegated nature and the bright-yellow and orange weathering of the ferruginous beds serve to distinguish, even at a distance, the Siksikpuk Formation from the gray limestone and dark shale and chert of the underlying Lisburne Group and from the dark shales of the overlying Shublik Formation.

THICKNESS

At the type locality on Tiglukpuk Creek the Siksikpuk Formation is 350 feet thick. It thins westward to between 200 and 250 feet in the area of the Kiruktagiak River, apparently because of pre-Shublik erosion.

CONTACTS

Everywhere, the Siksikpuk Formation appears to rest disconformably upon rocks of the Lisburne Group. Several feet of thoroughly oxidized clay and silt mark the lower contact at the type locality.

In most places the Siksikpuk is overlain disconformably by the Shublik Formation, although locally inconclusive evidence suggests that the Siksikpuk may be overlain by formations of Jurassic or Cretaceous age. At the type locality the top few feet of the Siksikpuk are oxidized and the upper 115 feet appear to have been silicified (fig. 72).

STRATIGRAPHIC SECTIONS

The Siksikpuk Formation is not completely exposed at any one locality. The type section is a composite of two outcrops, about 2 miles apart, along a narrow belt of exposures of the Siksikpuk Formation that parallels and lies immediately adjacent to the north front of the Brooks Range. Both outcrops have enough distinctive marker horizons so that the two can be correlated and a complete section compiled. The composite thickness totals 354 feet, of which the basal 62 feet was measured in the cutbank on the east side of Skimo Creek at lat 68°17′ N., long 151°53′ W. The remainder of the section was measured in the cutbank on the east side of a small tributary to Tiglukpuk Creek at lat 68°17′ N., long 151°48′ W.

Composite type section of Siksikpuk Formation, Tiglukpuk Creek area. Basal 62 feet at lat 68°17′ N., long 151°53′ W.; upper 292 feet at lat 68°17′ N., long 151°48′ W.

[Measured with tape by A. S. Keller and W. W. Patton, Jr., 1950. Graphic section, fig. 72]

	Thickness (feet)
Triassic.	
Shublik Formation: Shale, grayish-black, brittle; subordinate lenses of intercalated gray siliceous limestone.	
Unconformity.	
Permian(?):	
Siksikpuk Formation:	
1. Shale, medium- to dark-gray and dusky-yellow-green, silty and cherty; breaks with a hackly fracture; subordinate grayish-red shale and medium-gray calcerous siltstone that weathers grayish-orange	75
2. Siltstone, dark-greenish-gray and medium-gray to medium-dark-gray, cherty, medium-bedded; subordinate interbedded dark-gray shale; locally weathers dark yellowish orange	40
3. Shale, dusky-yellow-green at base becoming dark gray near top, silty; scattered ellipsoidal barite concretions as much as 2 ft long and 10 in. thick	32
4. Shale and siltstone; grayish-red and dusky-yellow-green calcareous shale interbedded with medium-bedded grayish-red-weathering, dusky-yellow-green cherty siltstone; minor amounts of medium- to dark-gray siltstone and shale	145
5. Siltstone, medium-gray to dusky-yellow-green, calcareous, medium-bedded; pyrite nodules and pyritized fossils	30
6. Shale, grayish-red and dusky-yellow-green	32
Total thickness of Siksikpuk Formation	354
Unconformity.	
Mississippian:	
Lisburne Group:	
Alapah Limestone: Shale, calcareous, dark-gray.	

A second section was measured on the upper Kiruktagiak River and its tributary, Monotis Creek, near the mountain front. A covered interval obscures both upper and lower contacts, but the overlying Shublik Formation and the underlying Lisburne Group appear to be concordant with the Siksikpuk, and there is no indication of faulting between them.

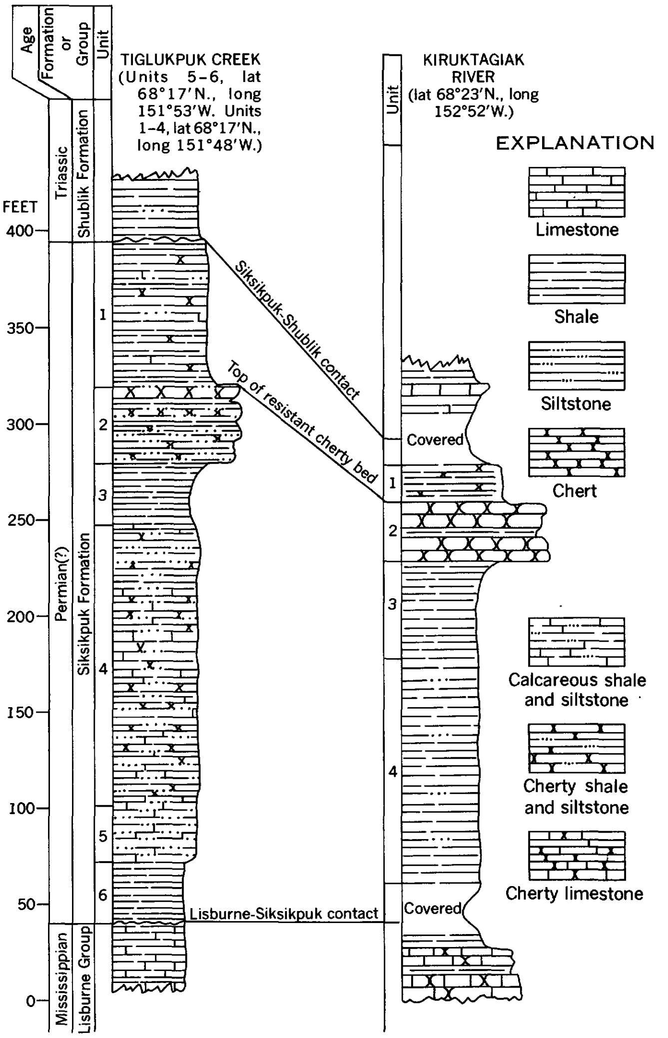

FIGURE 72.—Correlated columnar sections of the Siksikpuk Formation.

Section of Siksikpuk Formation, upper Kiruktagiak River area, lat 68°23' N., long 152°52' W.

[Measured with tape by W. W. Patton, Jr., 1949. Graphic section, fig. 72]

	Thickness (feet)
Triassic.	
Shublik Formation: Shale, grayish-black, rarely green, somewhat fissile; intercalated lenses and beds of dark gray fossiliferous limestone.	
Covered	30
Permian(?):	
Siksikpuk Formation:	
1. Shale, grayish-black, fissile, siliceous	20
2. Chert, dark-greenish-gray and medium-dark-gray, impure; subordinate interbedded grayish-black siliceous shale; carbonaceous matter abundant	30
3. Shale, grayish-black, fissile	50
4. Shale, grayish-red and dusky yellow-green; subordinate siltstone	115
Total exposed thickness of Siksikpuk Formation	215
Covered	30

Section of Siksikpuk Formation, upper Kiruktagiak River Area, lat 68°23' N., long 152°52' W.—Continued

Mississippian:
Lisburne Group:
Alapah Limestone: Shale, black, pyritiferous, fossiliferous.

The type section on Tiglukpuk Creek and the Kiruktagiak reference section are shown graphically in figure 72. A resistant 40-foot ledge of cherty siltstone 240 feet above the base of the Tiglukpuk Creek section appears to correlate with the 30-foot ledge of impure chert that occurs near the top of the Kiruktagiak section. The difference in thickness of the overlying shale sequence at the two localities is attributed to differential erosion before the deposition of the Shublik Formation.

AGE

A coral-brachiopod-gastropod faunule occurs in the basal 50 feet of the Siksikpuk Formation. The overall aspect of the fauna, particularly when compared with Permian fossil assemblages from elsewhere in Alaska, suggests a probable Permian age for the Siksikpuk Formation. Collections from Paleozoic localities, from the type section on Tiglukpuk Creek are listed below.

Collections from units 5 and 6 of type section of Siksikpuk Formation (p. 428)

50AKe238, USGS 11814:
- *Allotropiophyllum* sp. undet.
- *Ufimia*? sp. indet.
- *Sochkineophyllum* cf. *S. artiense* (Soshkina)
- Crinoid columnal, indet.
- Chonetid? brachiopod, indet.
- *Spiriferella*? sp.
- Martinioid brachiopod, genus indet.
- Phricodothyrid? brachiopod, indet.
- Brachiopod, genus indet.
- *Straparollus* (*Euomphalus*) *brooksensis* Yochelson and Dutro

50AKe240, USGS 11815:
- Crinoid colunnal, indet.
- *Spiriferella*? sp.
- Martinioid brachiopod, genus undet.
- *Straparollus* (*Euomphalus*) sp. indet.

50AKe242, USGS 11816:
- *Allotropiophyllum* cf. sp. in USGS 11814.
- *Tachylasma* sp. undet.
- Plerophyllid coral, genus undet.
- Crinoid columnals, indet.
- *Spiriferella*? sp.
- Martinioid brachiopod, genus undet.
- *Straparollus* (*Euomphalus*) *brooksenis* Yochelson and Dutro
- Pleurotomarian gastropod, undet.

53APa122, USGS 14152:
- *Euryphyllum* sp.
- *Sochkineophyllum* cf. *S. artiense* (Soshkina)
- Crinoid columnal, indet.
- Productoid brachiopod, genus undet.
- *Spiriferella*? sp.
- Martinioid brachiopod, genus undet.

Collections from units 5 and 6 of type section of Siksipuk Formation (p. 428)—Continued

53APa122, USGS 14152—Continued

Brachiopod, genus indet.
Straparollus (*Euomphalus*) *brooksensis* Yochelson and Dutro.

The corals were examined by Helen Duncan, who states, concerning their age significance (written communication, 1951):

The coral faunule known at present is small, but it contains nothing that casts doubt on its Permian affinities. Plerophyllid corals occur but are not common in the Carboniferous. If these rocks were of Mississippian or Early Pennsylvanian age, I should expect indications at least of characteristic Carboniferous types i.e., zaphrentoid or lophophyllid corals. Further, a study of the microscopic skeletal features in these specimens shows that the structure of septa and walls correspond to the type that is said to be characteristically developed in Permian corals. The most closely allied coral assemblages described in the literature occur in the Permian of China and Russia * * *.

Most of the gastropods appear to belong to a species which, because of its persistence throughout northern Alaska, may be considered a guide to this faunal zone. This species, *Straparollus* (*Euomphalus*) *brooksensis*, is described in a paper on late Paleozoic gastropods (Yochelson and Dutro, 1960).

The brachiopods have been examined by J. Thomas Dutro, Jr., whose comments (written communication, 1954) are included below.

In the type area of the Siksikpuk Formation, the most significant of several brachiopod forms is a small spiriferoid referred tentatively to the genus *Spiriferella*. This genus is found in Permian rocks in Russia, India, Oregon, and west Texas and is present in collections of Permian fossils from elsewhere in Alaska. Species of this genus are also found in Upper Pennsylvanian and upper Carboniferous rocks in various places. The martinioid and phricodothyrid types, not distinctive enough to indicate any definite age, are ubiquitous in late Paleozoic faunas.

Collections made near Galbraith Lake in 1950 by W. P. Brosgé and H. N. Reiser, although not in the type area of the Siksikpuk Formation, are undoubtedly from that unit and provide some additional information. A spiriferoid, perhaps assignable to *Purdonella*, occurs about 400–500 feet above the base of the section. Associated with it are a chonetid, perhaps *Chonetina*, and a martinioid species similar to that which is present in the type area. This fauna also contains a straparollid gastropod very like the species found in the lower zone. It seems to be a good Permian fauna.

The lower 50 feet of the Galbraith Lake section contains a faunule similar to that of the type area, where it also occurs near the base of the formation. There appears to be no reason to believe that this faunule is anything but Permian in age. The spiriferellid, phricodothyrid, and straparollid species are the same in both areas. It is probable that the fauna from the type area is also of Permian age.

Microfossils washed from the shale of the Siksikpuk Formation have been examined by H. R. Bergquist and are listed below. According to Bergquist (written communication, 1950), the large *Ammodiscus*, *Glomospira*, and whorls and specimens of a large *Spiroplectammina* are similar to forms of Pennsylvanian and Permian age in Texas.

Microfossil collections from the Siksikpuk Formation

Microfossils	50AKe229	50AKe230	50AKe231	50AKe232	50APa260	50APa262	50APa290
Bathysiphon	----	?	?	?	----	----	----
Bathysiphon? (possibly *Hy*-perammina)	----	----	----	----	×	×	×
Ammodiscus sp	×	×	×	×	----	----	----
Ammodiscus n. sp	----	----	----	----	----	×	×
Glomospira	×	?	----	?	----	----	×
"*Proteonina*" sp	----	----	----	×	----	×	----
Ammobaculites	----	[1] ×	----	----	×	----	----
Gaudryina ("heavy")	?	[1] ×	[1] ×	[1] ×	----	----	----
Trochammina sp. (large)	×	×	?	×	----	----	----
Reophax sp. (thick)	×	×	×	×	----	----	----
Reophax	----	----	----	----	×	×	----
Haplophragmoides	----	----	----	----	----	----	×
Verneuilinoides (large and heavy)	----	----	----	----	×	×	×
Pelosina	----	----	?	----	×	----	----
Spiroplectammina (large and heavy)	----	----	----	----	----	----	×
Spiroplectammina (small and slender)	----	----	----	----	×	----	----
Ammovertella?	----	----	----	----	×	----	×
Pelosina? (large flattened globular tests)	----	----	----	----	×	×	×
Hyperammina	----	----	----	----	×	----	----
Spines	----	----	----	----	×	×	×
"*Saccammina*"?	----	----	----	----	----	----	×
Fish teeth	----	----	----	----	----	×	----
Brachiopod	×	----	----	----	----	----	----

[1] Indicates species are not similar to any of the Mesozoic species.

CORRELATIONS

The Sadlerochit Formation of the Canning River region, originally assigned by Leffingwell (1919, p. 113–115) to the Pennsylvanian, is now regarded as partly Permian and partly Triassic (Keller and others, 1961). It is not known, however, whether any of the Sadlerochit is precisely correlative with the Siksikpuk Formation, for the faunal assemblages from the two formations are dissimilar and the collections from the Siksikpuk are not definitive beyond suggesting a probable Permian age. A. S. Keller, who has investigated the foothills east of the mapped area as far as the Canning River, believes that the basal unit of the Sadlerochit may be in part equivalent to the Siksikpuk (oral communication, 1956).

West of the Killik-Itkillik region, the Siksikpuk was identified and mapped as far as the Kiligwa River by Tailleur. E. M. Kindle (1909, p. 520–528) described a section at Cape Thompson on the Arctic coast, 350 miles west of the mapped area, believed to be correlative with the Siksikpuk Formation. This section consists of

600 feet of black, green, and red argillite and chert underlain by several thousand feet of light-gray limestone (Lisburne Group) and overlain by 25 feet of dark chert and limestone that contains a Late Triassic fauna (Shublik Formation).

TRIASSIC ROCKS

SHUBLIK FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Shublik Formation is exposed principally along a narrow east-trending belt at the mountain front. Thin bands of Shublik exposures also flank the Tiglukpuk Creek anticline, 5 miles north of the mountain front, and the two west-trending ridges of Lisburne Group between the Okpikruak and Okokmilaga Rivers, 10 miles north of the mountain front. A small mass of the Shublik crops out at the head of Autumn Creek, and several tiny slivers of the Shublik occur close to the thrust faults that bound the east-trending belt of the Fortress Mountain Formation. The best exposures of the Shublik Formation are near the mountain front in cutbanks on Cobblestone, Peregrine, Welcome, Tiglukpuk, and Monotis Creeks.

It was not possible to differentiate the Shublik Formation from the Siksikpuk Formation in many places (pl. 50) for the reasons given in the discussion of the Siksikpuk Formation. The relatively soft strata of the Shublik Formation have been deeply eroded and have little topographic expression, except for a few low rubble ridges of chert and limestone. Outcrops are confined chiefly to cutbanks (fig. 73).

FIGURE 73.—Exposure of the Shublik Formation on Monotis Creek.

PREVIOUS WORK

The Shublik Formation was named and described by E. de K. Leffingwell (1919, p. 115–118) from exposures in the Canning River region of northern Alaska, 110 miles northeast of the mapped area. The type locality is Shublik Island in the Canning River at the west end of the Shublik Mountains. According to Leffingwell, "the Shublik Formation which consists of about 500 feet of dark limestone, shale, and sandstone, overlies the Pennsylvanian Sadlerochit Sandstone and underlies the Lower Jurassic Kingak Shale".

No mention was made of Triassic strata on the Arctic Slope by Schrader (1904). Smith and Mertie (1930) described a belt of chert, limestone, and shale of Triassic age that stretches eastward from the Cape Lisburne region on the Arctic coast to beyond the Okokmilaga River in the Killik-Itkillik region. However, they did not believe these rocks should be called Shublik Formation, for Leffingwell's type section contains no chert. Furthermore, they thought the fauna in Leffingwell's Shublik was more varied than that in their Triassic strata. Recent mapping along the Arctic Foothills province has established that although the chert content increases westward, the gross lithologic and faunal characteristics of the Triassic rocks are sufficiently uniform to have justified application of the name Shublik throughout.

LITHOLOGY

The Shublik Formation is composed principally of highly carbonaceous grayish-black shale, chert, and fine-grained limestone. The dark color distinguishes it from the variegated rocks of the underlying Siksikpuk Formation. The Shublik can be subdivided into three members which, though varying in detail, seem to persist across the mapped area. They are, in ascending stratigraphic order: a shale member, a chert member, and a limestone member. The shale member consists of grayish-black and greenish-gray shale with subordinate intercalated lenses and thin beds of dark-gray, locally phosphatic, fossiliferous limestone and thinly bedded grayish-black chert. The chert member is comprised of grayish-black chert and cherty limestone interbedded with grayish-black paper shale and calcareous shale. Fossiliferous grayish-black cherty limestone concretions the size of golf balls are abundant. The limestone member is composed predominantly of medium-light-gray to dark-gray fossiliferous limestone that is rarely cherty and commonly weathers a characteristic grayish orange. The limestone may be capped by grayish-black shale and subordinate chert, depending upon the extent of pre-Tiglukpuk Formation erosion.

Two thin sections of calcareous chert from the top of the chert member were examined under the microscope. Quartz makes up 60 to 70 percent of the sections and occurs as a very fine aggregate with some large chalcedonic spherulites. Scattered minute grains and thin veinlets of calcite compose 25 to 35 percent of the sections. The remainder is largely opaque matter, partly fine pyrite dust and partly organic matter. Circular bodies of silica 0.01 mm in diameter, which may be fragments of Radiolaria, are common in one of the sections.

A thin section of chert from near the base of the chert member is composed of at least 85 percent very fine grained quartz. The rest of the section is chiefly calcite fossil fragments. Radiolaria-like siliceous bodies are also present in this thin section.

THICKNESS

The only completely exposed sequence of the Shublik Formation occurs on upper Tiglukpuk Creek, where the full thickness of the formation is about 750 feet. The lower 500 feet comprises the shale member and the upper 250 feet the chert and limestone members (fig. 74). However, in the upper Kiruktagiak River and Monotis Creek area, where a 250-foot sequence is exposed, the full thickness of the Shublik probably does not exceed 325 feet. About 175 feet of this section represents the limestone and chert members; the remainder represents the shale member (fig. 74). The differences in total thickness of the formation between the two sections is accounted for, chiefly in the shale member, which unfortunately is so poorly exposed that little is known about its regional character and extent; whether the variations in thickness are the result of nondeposition or erosion could not be determined.

CONTACTS

West of the Anaktuvuk River the Shublik rests disconformably upon the Siksikpuk Formation and east of the Anaktuvuk River it rests upon the Lisburne Group. Wherever the upper contact is exposed, the Shublik is overlain disconformably by the Tiglukpuk Formation of Jurassic age.

STRATIGRAPHIC SECTIONS

Four measured sections are shown in figure 74. The first section was measured on Erratic Creek, an eastern branch of the Kanayut River, 1 mile north of the mountains, at lat 68°23′ N., long 150°47′ W. There the upper 200 feet of the Shublik Formation is repeated in four tiny fault slivers (pl. 50). The top of the Shublik is marked by iron-stained grayish-black brittle shale in contact with soft dark-gray shale of the Tiglukpuk Formation. The section with a total exposed thickness of 214 feet includes 55 feet of the shale member, 103 feet of the chert member, and 56 feet of the limestone member.

Section of Shublik Formation in cutbank on east side of Erratic Creek at lat 68°23′ N., long 150°47′ W.

[Measured with tape by W. W. Patton, Jr., 1950. Graphic section, fig. 74]

	Thickness (feet)
Jurassic.	
Tiglukpuk Formation: Dark-gray shale.	
Unconformity.	
Triassic.	
Shublik Formation:	
Limestone member:	
1. Shale, grayish-black, indurated; stained by iron oxides. Several 3- to 5-in. layers of black chert	30
2. Limestone, dark-gray, arenaceous, medium- to thick-bedded; weathers moderate reddish brown	10
3. Limestone, shaly to thick-bedded, fossiliferous, dark-gray; weathers grayish orange. Subordinate interbedded grayish-black shale	16
Chert member:	
4. Shale, calcareous, grayish-black and thin-bedded. Near base, several beds of dark-gray shaly limestone that weather a dull grayish orange. *Halobia* sp., brachiopods	17
5. Limestone, shale, and chert. Thin-bedded fossiliferous dark-gray limestone; grayish-black shale; thin-bedded grayish-black cherty limestone concretions as much as 4 in. in diameter. *Halobia* sp	27
6. Limestone and shale. Medium-bedded dark-gray limestone, locally cherty; grayish-black shale. Massive lenses of dark-gray limestone near base. Grayish-black fossiliferous cherty limestone concretions as much as 4 in. in diameter. *Halobia* sp	18
7. Shale and limestone. Grayish-black shale and fossiliferous dark-gray locally cherty limestone that weathers grayish orange	41
Shale member:	
8. Shale, grayish-black; subordinate thin-bedded chert and medium-bedded fossiliferous shaly limestone. Chert and shale locally phosphatic near base. *Posidonia* sp	55
Total thickness of Shublik Formation exposed	214
Covered.	

The second section shown in figure 74 is a composite of two separate cutbank exposures along upper Tiglukpuk Creek. The section totals 750 feet in thickness and includes about 500 feet of the shale member, 160 feet of the chert member, and 80 feet of the limestone member. The upper 400 feet of the section crops out on the south flank of the Tiglukpuk Creek anticline at lat 68°20′ N., long 151°51′ W. The basal 350 feet is covered at this locality but is exposed 5 miles to the south at the mountain front on a small tributary at lat 68°17′ N., long 151°48′ W. Measurements of the basal 350 feet at the mountain front are approximate, owing to structural complexities. At the base of the

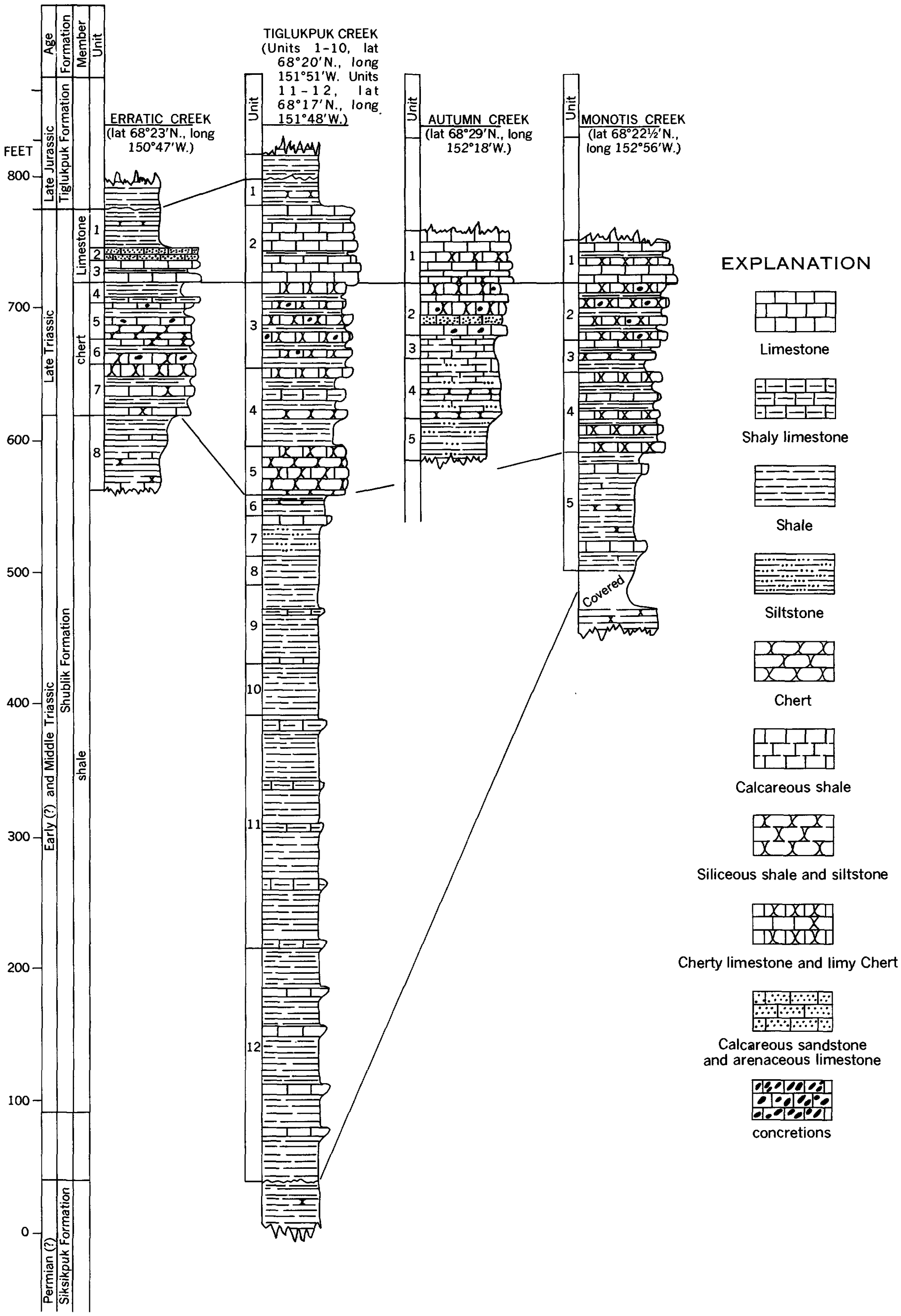

FIGURE 74.—Correlated columnar sections of the Shublik Formation.

section, several feet of heavily oxidized shale separate grayish-black shale of the Shublik Formation from variegated shale of the underlying Siksikpuk Formation. At the top, there is an abrupt change from grayish-black shale of the Suhblik Formation to softer dark-gray shale and siltstone of the overlying Tiglukpuk Formation.

Composite section of Shublik Formation on Tiglukpuk Creek: units 1–10 in cutbank on west side at lat 68°20′ N., long 151°51′ W.; units 11 and 12 in cutbank on east side of small tributary at lat 68°17′ N., long 151°48′ W.

[Measured with tape by W. W. Patton, Jr., 1950, 1953. Graphic section, fig. 74]

	Thickness (feet)
Jurassic.	
Tiglukpuk Formation: Shale, silty, dark-gray.	
Unconformity.	
Triassic.	
Shublik Formation:	
Limestone member:	
1. Shale, grayish-black, with subordinate 2- to 5-in. beds of limonite-stained grayish-black chert	20
2. Limestone, grayish-black, medium-bedded, fossiliferous; weathers grayish orange. Subordinate interbedded grayish-black shale	59
Chert member:	
3. Chert, grayish-black, calcareous, thin- to medium-bedded. Subordinate interbedded grayish-black shale. Fossiliferous, grayish-black, cherty calcareous concretions as much as 4 in. in diameter. *Halobia* sp., ammonites	64
4. Shale, limestone, and chert. Grayish-black shale; thin-bedded grayish-black cherty limestone; grayish-black chert; and grayish-black shaly limestone	59
5. Chert and cherty limestone. Thin- to medium-bedded medium-gray and greenish-grayish chert. Medium-bedded grayish-black cherty limestone that weathers grayish orange	37
Shale member:	
6. Shale and chert. Interbedded dark-gray silty shale; grayish-black shale; and subordinate thinbedded grayish-black chert. Section is heavily stained with iron oxide	15
7. Siltstone, thinbedded, grayish-black and greenish-gray banded. Subordinate interbedded grayish-black shale. Lenses, as much as 1 ft thick, of dense grayish-black fossiliferous limestone near top. *Posidonia* sp	30
8. Shale, paper, grayish-black, heavily stained with iron oxide	21
9. Shale and limestone. Greenish-gray silty shale and clay shale. Finely crystalline silty limestone. At base, a 1-ft bed of greenish-gray limestone that weathers grayish orange	61
10. Shale, grayish-black. Section heavily stained with iron oxides	40
11. Shale, grayish-black, brittle; heavily stained with iron oxides. Subordinate intercalated thin lenses, beds, and concretions of medium-dark-gray and greenish-gray shaly limestone with strong fetid odor; weathers moderate brown	175±

Composite section of Shublik Formation on Tiglukpuk Creek units 1–10 in cutbank on west side at lat 68°20′ N., long 151°51′ W.; units 11 and 12 in cutbank on east side of small tributary at lat 68°17′ N., long 151° 48′ W.—Continued

	Thickness (feet)
Triassic—Continued	
Shublik Formation—Continued	
Chert member—Continued	
12. Shale, as above. Subordinate intercalated lenses and beds of siliceous dense laminated medium-light-gray and dark-gray limestone that weathers moderate brown. Phosphatized vertebrate remains	175±
Total thickness of Shublik Formation	750±
Unconformity.	
Premian(?).	
Siksikpuk Formation: Shale, medium to dark-gray and dusky-yellow-green, silty and cherty; weathers grayish orange.	

The third section shown in figure 74 was measured in a small cutbank at the head of Autumn Creek, lat 68°29′ N., long 152°18′ W. The exposed section is 175 feet thick and includes the chert and limestone members. The bottom and top contacts of the Shublik are not exposed. The section is 10 miles north of the mountain front and differs in several respects from the other measured sections, which lie close to the mountain front: (1) the percentage of chert in the chert member is less; (2) siltstone and sandstone occur in the chert member; and (3) the limestone of the limestone member is lighter colored.

Section of Shublik Formation on Autumn Creek in cutbank at lat 68°29′ N., long 152°18′ W.

[Measured with tape by W. W. Patton, Jr., 1950. Graphic section, fig. 74]

	Thickness (feet)
Triassic.	
Shublik Formation:	
Limestone member:	
Covered.	
1. Limestone, thin- to medium-bedded, light-brown to medium dark-gray, locally cherty; weathers grayish orange. *Entomonotis subcircularis* Gabb	40
Chert member:	
2. Chert and limestone. Medium-bedded grayish-black calcareous chert and thin-bedded dark-gray limestone. Fossiliferous grayish-black cherty limestone concretions as much as 4 in. in diameter. Several 1-in. beds of grayish-orange calcareous sandstone. *Halobia* sp	39
3. Shale, grayish-black, calcareous	18
4. Siltstone, calcareous, fossiliferous, medium-bedded, light-gray; shaly limestone; and grayish-black bedded chert. *Halobia* sp	46
5. Siltstone and shale. Banded gray and green siltstone and grayish-black silty shale. Section is stained heavily with iron oxides	32
Total thickness of Shublik Formation exposed	175
Covered.	

The fourth section in figure 74 was measured on Monotis Creek, a small mountain-front tributary of the Kiruktagiak River at lat 68°22½′ N., long 152°56′ W. Gently north-dipping beds of Shublik form a bluff 1½ miles long along the north side of the creek (fig. 73). At the top of the bluff the uppermost beds of the Shublik Formation are covered. The lowest exposed beds crop out at creek level, and on the opposite side of the creek Siksikpuk strata that appear to dip north under the Shublik with no angular discordance are exposed in several small cutbanks.

The total thickness of the exposed sequence at Monotis Creek is 250 feet, of which the shale member is 90 feet, the chert member is 127 feet, and the limestone member is 33 feet.

Section of Shublik Formation on Monotis Creek in cutbank on north side of creek at lat 68°22½′ N., long 152°56′ W.

[Measured with tape by I. L. Tailleur, 1949, and W. W. Patton, Jr., and M. D. Mangus, 1951. Graphic section, fig. 74]

	Thickness (feet)
Triassic.	
Shublik Formation:	
Limestone member:	
Covered.	
1. Limestone, thin- to medium-bedded, medium-light-gray to dark-gray, finely crystalline, fossiliferous, in part cherty; weathers grayish orange. Interbedded grayish-black shale and cherty shale. *Entomonotis subcircularis* Gabb is abundant	33
Chert member:	
2. Chert, thin- bedded, grayish-black, locally calcareous. Interbedded grayish-black shale. Dense grayish-black cherty limestone concretions as much as 4 in. in diameter	42
3. Shale, limestone, and chert. Grayish-black paper shale; dark-gray limestone and chert	25
4. Chert, shale, and limestone: Thin- to medium-bedded dark-gray calcareous chert interbedded with grayish-black, rarely green, shale and dark-gray fossiliferous limestone	60
Shale member:	
5. Shale, grayish-black, rarely green, somewhat fissile; locally bituminous, calcareous, or cherty. Several lenses and beds of dark-gray fossiliferous limestone	90
Total thickness of Shublik Formation exposed	250
Covered	30

Permian(?).

Siksikpuk Formation: Grayish-black siliceous shale and dark-greenish-gray and medium-dark-gray impure chert.

FACIES CHANGES

Although the character of the Shublik is remarkably uniform throughout the Arctic Foothills province, two broad facies changes occur: a westward increase in chert and a northward and eastward increase in clastic rocks. Chert is not found in the type area of the Shublik in the Canning River region (Leffingwell, 1919, p. 115–118), but it is an important constituent in the mapped area west of the Anaktuvuk River and in the foothills west of the mapped area. Clastic beds are abundant in the Shublik Formation east of the mapped area. On Gilead Creek, 70 miles northeast of the Itkillik River, Keller (written communication, 1952) reports that below the limestone member the Shublik consists primarily of calcareous siltstone. Leffingwell (1919, p. 116) records 30 feet of sandstone in the section on Camp 263 Creek in the Canning River region. Whittington and Sable (written communication, 1948) state that sandstone and siltstone comprise the basal part of the Shublik in the Sadlerochit River area. A few clastic beds occur in the eastern part of the mapped area, as, for example, the arenaceous limestone beds of the limestone member in the Erratic Creek section (fig. 74). In the northernmost exposures, examples are the siltstone and calcareous sandstone beds in the chert member of the Autumn Creek section (fig. 74).

AGE AND CORRELATIONS

Neither the shale member of the Shublik nor its associated invertebrate and vertebrate fauna has been reported elsewhere on the Arctic Slope. They are here assigned to the Middle Triassic but may also be in part of Early Triassic age.

The chert and limestone members—which have been mapped along the entire extent of the Arctic Foothills province—are assigned to the Late Triassic on the basis of the widespread occurrence of *Entomonotis subcircularis* Gabb and *Halobia* sp.

Collections from stratigraphic section of Shublik Formation on Erratic Creek (p. 432).

[Identifications by Ralph W. Imlay (written communication, 1951)]

50APa242, unit 3:
- *Entomonotis subcircularis* Gabb
- *Monotis alaskana* Smith
- Brachiopods

50APa246, unit 6:
- *Aulacoceras?*

50APa247, unit 7:
- *Halobia* sp.
- *Trachyceras* sp.

Collections from stratigraphic section of Shublik Formation on Tiglukpuk Creek (p. 434)

50APa277, unit 2:
- *Entomonotis subcircularis* Gabb [1]
- Belemnites, indet.[1]
- Brachiopods [1]

53APa113, unit 8:
- *Posidonia* sp. [2]

53APa115, unit 9:
- *Posidonia* sp. (juveniles) [2]

53APa116, unit 9:
- *Posidonia* sp.[2]

See footnotes on p. 436.

Collections from stratigraphic section of Shublik Formation on Tiglukpuk Creek (p. 434)—Continued

53APa119, unit 11:
- ?*Rhynchonella* sp.[2]

53APa120, unit 11:
- *Posidonia* sp.[2]

53APa121, unit 11:
- *Posidonia* sp. (juveniles)[2]

Collection from stratigraphic section of Shublik Formation on Autumn Creek (p. 434)

50APa333, unit 2:
- *Arcestes* sp.[1]
- *Trachyceras* sp.[1]

[1] Identified by Ralph W. Imlay, written communication, 1951.
[2] Identified by Bernhard Kummel, written communication, 1954.

Collections from stratigraphic section of Shublik Formation on Monotis Creek (p. 435)

[Identifications by Bernhard Kummel (written communications, 1950, 1952, 1953, and 1954)]

49ATr475, USGS Mesozoic loc. 21535, interval of units 2 to 3:
- *Halobia* sp. (juveniles)

53APa101, unit 4:
- *Entomonotis subcircularis* Gabb

49ATr464, USGS Mesozoic loc. 21533, unit 5:
- *Posidonia* n. sp.

49ATr465, USGS Mesozoic loc. 21828, unit 5:
- *Gervilleia*?
- *Posidonia*?
- Brachiopods, indet.

49ATr466, USGS Mezosoic loc. 21534, unit 5:
- *Posidonia* n. sp.
- *Hungarites* sp. indet.
- "*Orthoceras*" sp.
- *Leiophyllites* sp. indet.
- *Proteusites* n. sp. indet.
- *Pseudaplococeras* n. sp. cf. *P. parvus* (Smith)

51APa505, USGS Mesozoic loc. 23614, unit 5:
- *Leiophyllites* sp. indet.
- *Hungarites* sp. indet.
- "*Orthoceras*" sp.
- *Posidonia* n. sp.

Collection 50APa43 from chert member of Shublik Formation on May Creek about 9 miles north of the mountains, lat 68°32′30″ N., long 150°07′ W.

[Identifications by Ralph W. Imlay (written communication, 1951).]

- *Halobia* sp.
- *Dictyoconites*
- *Arcestes* sp.
- *Rhacophyllites*? sp.
- *Polycyclus*? sp.
- Brachiopods, indet.

Collection 49ATr397, USGS Mesozoic loc. 21834, from the east side of Okonagun Creek. A bank of talus occurring just north of the northernmost band of the Lisburne Group, lat 68°32′30″ N., long 153°31′ W. Stratigraphic position within the Shublic not known

[Identification by Bernhard Kummel (written communication, 1950)]

- *Halobia* sp. indet.
- *Monotis* sp.
- *Monotis* cf. *alaskana* Smith
- *Placunopsis* sp.
- *Entomonotis subcircularis* Gabb
- One, possibly two, genera of pelecypods, indet.

Collection 49APa275, USGS Mesozoic loc. 21835 from low ridge of rubble a short distance south of Fortress Mountain, lat 68°33′30″ N., long 152°58′ W. Stratigraphic position within the Shublik not known

[Identifications by Bernhard Kummel (written communication, 1950)]

- *Entomonotis subcircularis* Gabb
- *Halobia* aff. *alaskana* Smith
- *Halobia* cf. *gigantea* Smith

Collection 50APa98 from a poorly exposed cutbank on Peregrine Creek at the mountain front, lat 68°23′30″ N., long 150°18′ W. Complexly folded and faulted. Stratigraphic position within the Shublik not known

[Identifications by Ralph W. Imlay (written communication, 1951)]

- *Entomonotis subcircularis* Gabb
- *Posidonia* cf. *P. blatchleyi* Gabb
- Ammonites, indet.
- Fish remains?

The shale member of the Shublik Formation is characterized by the widespread occurrence of *Posidonia*, a long-ranging pelecypod of little stratigraphic significance. On Monotis Creek, however, *Posidonia* is associated with a distinctive Middle Triassic (Anisian) fauna (colln. 49ATr466, 51APa505). This fauna was examined by Bernhard Kummel, who reports (written communication, 1952):

> *Proteusites* is confined to the Anisian, *Leiophyllites* is mainly Anisian in age but with a few late Early Triassic species. *Pseudaplococeras* is confined to the Anisian. This Middle Triassic fauna has affinities with the western American (Nevada) and the Tethyian (Alpine-Himalayan) faunas. The Middle Triassic fossils (*Daonella* cf. *D. lommelii* and *Ceratites* (*Gymnotoceras*) sp. in Martin, (1926) from Brooks Mountain, Seward Peninsula, are probably correlative with the Middle Triassic lots reported here.
>
> The Middle Triassic (Anisian) fossils of lots 49ATr464, 49ATr466, and 51APa505 have not previously been reported from Alaska. The specimens of *Proteusites* were compared with topo-type material from Yugoslavia in the British Museum of Natural History. *Proteusites* is known only from Anisian strata of Yugoslavia, Greece, and the Himalayas. *Pseudaplococeras* cf. *P. parvus* compares very closely with *P. parvus* (Smith) from the Middle Triassic of Nevada, the only previous reported occurrence of the genus. *Leiophyllites* sp. indet. is represented by only

juvenile specimens, but the suture pattern is distinctive and relates these Alaskan specimens with Anisian Leiophyllitids from Tibet and the uppermost Lower Triassic of the Island of Chios off the coast of Turkey. The genus *Hungarites* is recognized through several badly crushed specimens. The composite characters present in these specimens strongly suggest this identification. The species or affinities of these Alaskan specimens of *Hungarites*, however, cannot be recognized. *Posidonia* is a long-ranging pelecypod but not at all uncommon in the Middle Triassic.

The only reported occurrence of Middle Triassic fossils in Alaska in addition to that at Monotis Creek is the collection from Brooks Mountain on the Seward Peninsula to which Kummel referred. The authenticity of the Brooks Mountain collection is now in considerable question. It was originally given to E. M. Kindle by a prospector, but subsequent search of the Brooks Mountain area by several geologists failed to reveal additional fossils or other evidence of Triassic strata (Martin, 1926, p. 116–117).

Two collections (53APa114, 53APa118) of vertebrate remains were found in the shale member in unit 11 of the measured section on Tiglukpuk Creek. Another collection (53APa104) was found in the shale member on the Kiruktagiak River, 2 miles above the confluence of Monotis Creek. Owing to poor exposures, the position of the latter collection within the shale member is uncertain. All three collections have been examined by D. H. Dunkle, who reports (written communication, 1953):

Collection 53APa114 is a caudal body section from a coelacanthine fish of indeterminate generic and specific identity.

Collection 53APa118 is the incomplete and macerated skeleton of the marine paleoniscoid fish *Boreosomus*. This individual does not show the detailed structural features upon which specific definitions within this genus have been based and for convenience it can be tentatively referred to the genotype species *B. arcticus* Stensio. Indisputable remains of *Boreosomus*, insofar as now known, are restricted to the Lower Triassic (Otoceratan and Gyronitan).

Collection 53APa104 includes a series of postsacral vertebrate and a portion of a hind leg of a reptile. It is very probable that these are derived from one of the aquatically adapted ichthyosaurs—a group which made its first appearance at the beginning of the Middle Triassic.

The occurrence of *Boreosomus* in the Tiglukpuk Creek section indicates the possibility that the shale member may include beds of Early Triassic as well as Middle Triassic age. Recently Keller (oral communication, 1954) found conclusive evidence of Lower Triassic strata in the foothills northeast of the Itkillik River.

The chert member of the Shublik is characterized by a distinctive faunal assemblage that includes *Halobia, Arcestes*, and *Trachyceras*, and the limestone member is characterized by *Entomonotis subcircularis* Gabb. Both faunal zones have been recognized in Upper Triassic strata elsewhere in Alaska; the lower zone has been regarded as Karnian in age by G. C. Martin (1926, p. 119–131) and others, because of the similarity of the *Halobia* to *H. superba* Mojsisovics and because of the overall Karnian aspects of the other elements of the zone. The upper zone is dated as Norian on the basis of *E. subcircularis* Gabb, a worldwide guide fossil. Furthermore, Martin postulates a widespread disconformity between the two zones in southern Alaska.

Everywhere in northern Alaska that the Shublik Formation has been studied in detail, except on Monotis Creek, *E. subcircularis* is reported at a higher level than *Halobia* (A. S. Keller, E. G. Sable, and J. T. Dutro, Jr., oral communications, 1952). However, in the Monotis Creek, section *E. subcircularis* (colln. 53APa101) [1] was found below the lowest occurrence of *Halobia* in the chert member and about 85 feet below the limestone member. This seems to suggest that both the chert and limestone members may be entirely Norian in age. As *E. subcircularis* always occurs in the medium-light-gray to dark-gray medium-bedded grayish-orange-weathering limestone, and *Halobia* always occurs in the black paper shale, cherty limestone, or thin-bedded grayish-black limestone, it is probable that the distribution of the two fossils is ecologically controlled and they may not be of different ages.

Samples of shale from the Shublik Formation were washed for microfossils and a checklist of the collections recovered is given below. Identifications are by H. R. Bergquist (written communication, Feb. 4, 1953). Several of the species listed have been described recently by Helen Tappan (1951).

[1] The fossils from collection 53APa101 have been reidentified by N. J. Silberling (oral commun., 1964) as *Daonella frami* Kittl and *D.* cf. *D. degeeri* Boehm of Ladinian age and therefore do not conflict with the occurrence of *Halobia* stratigraphically higher in the chert member. No attempt is made to bring up to date the other identifications of Triassic fossils which as listed are generally indicative of the correct stage according to Silberling.

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Checklist of microfossils from the Shublik Formation

Microfossils	50APa209	50APa210	50APa213	50APa215	50APa248	50APa57	50APa51	50APa270	50APa271	50APa272	50APa273	50APa274	50APa292	50APa293	50APa294
Bathysiphon or *Hyperammina*	X	X						X	X	X					X
Verneuilinoides sp	X							X	X	X					
Hyperamminoides sp		X													
Glomospira sp	X	X					X		X	X		X			
Spiroplectammina sp. (large, heavy)	X	X			X		X								X
Spiroplectammina sp. (small, slender)	X								X	X				X	X
Trochammina sp	X	X													
Marginulina prisca Tappan			X		X	X									
Vaginulinopsis acrulus Tappan			X		X										
Astacolus connudatus Tappan		X	X	X	X	X		X	X		X	X			
Frondicularia sp		X	X	X											
Lagena sp					X										
Pseudoglandulina simpsonensis Tappan		X	X	X	X	X									
Pseudoglandulina lata Tappan				X											
Nodosaria shublikensis Tappan	X		X	X	X	X	X			X	X	X			
Nodosaria larina Tappan			X	X	X	X									
Nodosaria sp			X	X	X										
Ammodiscus n. sp	X	X	X				X	X	X					X	
Pelosina sp							X								
Ammobaculites								X	X					X	X
Gaudryina sp				X					X	X					
Ammovertella? sp													X		
Marginulina? sp												X			X
Pseudoglandulina sp								X	X						
Spines	X		X	X	X	X			X	X	X	X		X	
"*Saccammina*"?								X	X	X				X	
Flat spotted discs			X			X		X		X	X				
Pelecypods (tiny pyrite casts)	X							X	X						
Reptile tooth			X												
Fish bones			X												
Radiolaria					X										

Collections:
50APa209, 210, 213, and 215, from cutbanks on Welcome Creek, lat 68°23' N., long 150°42' W. Stratigraphic position uncertain.
50APa248, from the measured section of the chert member on Erratic Creek (p. 432).
50APa51 and 57, from cutbanks on Cobblestone Creek, lat 68°24' N., long 150°13' W.
50APa271, 272, 292, 293, and 294, from the shale member; 50APa273, from the shale and chert members; 50APa274, from the chert and limestone members from the measured section on Tiglukpuk Creek (p. 434).

Four of the microfossil samples contain conodonts which were sent to W. H. Hass (written communication, 1951) for identification:

50APa271: One indeterminable conodont fragment
50APa272: *Gondolella* sp.
50APa293: *Gondolella* sp.
50APa294: One indeterminate conodont fragment

Mr. Hass states (written communication 1951, 1958):

Gondolella is the only genus present in the collections that can be recognized; this is due to the fragmentary nature of the material examined. The range of *Gondolella* is now known to be Pennsylvanian (Des Moines) to Middle Triassic. The genus is also present in Upper Cretaceous material from the Cameroons, West Africa. However, the natural occurrence of conodonts in the Cretaceous needs to be confirmed by additional finds from other parts of the world. None of the characteristic and easily recognized conodonts commonly associated with *Gondolella* in the Pennsylvanian and Lower Permain has been found.

JURASSIC ROCKS

TIGLUKPUK FORMATION

The Tiglukpuk Formation has been introduced (Patton, 1956a) to include the section composed predominantly of sandstone, siltstone, and shale that disconformably overlies the Shublik Formation and underlies the Okpikruak Formation (Cretaceous) in the central and western Arctic Foothills province. It has been mapped as far east as the Lupine River, 50 miles east of the Itkillik River, by A. S. Keller (written communication, 1951) and as far west as the Nuka River, 130 miles west of the Killik River, by Tailleur. It is typically exposed in the mapped area on Tiglukpuk Creek, 3 miles north of the mountains.

A unit of tuffaceous graywacke, chert, and indurated siltstone and shale, herein called the tuffaceous graywacke unit, occurs in several isolated localities in the mapped area and is closely associated with the mafic intrusive and extrusive rocks. The stratigraphic relationships of this unit could not be determined with certainty, but it appears to overlie the bulk of the Tiglukpuk Formation. Present information is not sufficient to warrant establishing this unit as a new formation. For mapping, it has been included with the Tiglukpuk Formation (pl. 50), but it is described separately on pages 443–445.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Tiglukpuk Formation underlies about 25 percent of the Killik-Itkillik region and is widely exposed along a belt of complexly deformed upper Paleozoic and Mesozoic strata immediately adjacent to the mountain front. Less extensive exposures occur farther north within the belt of the Fortress Mountain Formation, chiefly as narrow bands along major thrust faults.

The Tiglukpuk and Okpikruak Formations are composed of nearly identical rock types and therefore can be separated only where exposures are extensive. They have not been differentiated over large parts of the mapped area (pl. 50).

The Tiglukpuk Formation crops out in many cutbanks along the north-flowing rivers that traverse the belt of complexly deformed upper Paleozoic and Mesozoic strata. In the interstream areas, however, outcrops are confined to the massive sandstone and conglomerate and to the cherty zones near the base of the Formation. The sandstone and conglomerate characteristically form low even-sloping rubble-strewn ridges, none extending more than a few miles along the strike owing to the lenticularity of the beds. The cherty zones, also lenticular, produce narrow sharp-crested rubbly ridges dotted here and there with fantastically shaped pinnacles.

PREVIOUS WORK

Schrader (1904, p. 74–76), in his report of the Anaktuvuk River area, did not record a rock unit comparable with the Tiglukpuk Formation, nor did he find Jurassic fossils. However, the occurrence of rocks which he believed to be Jurassic along the western Arctic coast led him to suggest that his Anaktuvuk Series (Lower Cretaceous) in the central Arctic Foothills province might include Jurassic rocks. P. S. Smith and J. B. Mertie, Jr. (1930), made no mention of Jurassic rocks along the Killik River. The strata now assigned to the Tiglukpuk were apparently partly included in their Triassic system and partly in their Lower Cretaceous Series.

LITHOLOGY

Sandstone, siltstone, and shale are the principal components of the Tiglukpuk Formation, although in the basal part there are notable sections of bedded chert, siliceous black shale, variegated shale and siltstone, and a coquinoid limestone composed largely of compacted specimens of *Buchia*. The sandstone is of graywacke type as defined by Pettijohn (1957, p. 301); that is, it consists of more than 25 percent unstable rock and mineral detritus and more than 15 percent interstitial matrix.

Sandstone, siltstone, and shale.—The sandstone is typically a greenish-gray very fine grained to fine-grained muddy graywacke that locally contains thin intraformational conglomerate lenses composed of angular pebbles and granules of chert. The sandstone occurs in massive highly lenticular bodies, 5 to 40 feet thick, enclosed in shale and siltstone. Bedding is usually poorly defined, but where discernible, beds range in thickness from 1 to 8 feet. In many places the bedding-plane surfaces are coated with a thin film of finely comminuted carbonized wood detritus and shale chips. Curly bedding structures are common. In the lower half of the formation "cannonball" concretions of calcareous siltstone are scattered through the sandstone.

Several samples of sandstone from the Tiglukpuk Formation, examined in thin section, are composed of from 20 to 40 percent quartz; 10 to 20 percent feldspar, chiefly sericitized and calcitized plagioclase; and 10 to 20 percent lithic fragments including chert, slate, and siltstone; the remainder of the rock is an argillaceous matrix composed chiefly of chlorite, clay, and fine silt. Calcite is commonly present and may make up as much as 20 percent of the rock; it occurs both as detrital fragments and as a cementing material in the matrix. The sandstone probably owes it characteristic greenish cast to the presence of finely divided chlorite in the matrix. Porosity of the sandstone averages about 5 percent, but permeability is negligible.

Dark-gray silty shale and siltstone, although less conspicuous than the sandstone, make up the bulk of the formation. The shale and siltstone are soft and nonresistant to erosion except locally where they have been indurated. Enclosed in the shale and siltstone are a variety of nodules, concretions, and small lenses. Most abundant are calcareous and noncalcareous dark-gray ferruginous siltstone concretions, several feet long, that weather a typical moderate red. Less common, but equally characteristic of the formation, are dark-gray cherty ferruginous nodules and lenses that weather gunmetal blue. The nodules are discoidal or ellipsoidal and are as much as 8 inches in diameter. The lenses are as much as a foot thick and several feet long and generally are concentrated along certain horizons.

Chert.—Bedded chert occurs in the Tiglukpuk Formation everywhere except in the northeastern corner of the mapped area. It is confined principally to a zone several hundred feet above the base of the formation where it may be as much as 300 feet thick. Above and below this zone are scattered lenses of chert, a very few more than 20 feet thick. The maximum thickness of the chert appears to be along an eastward-trending band that borders the southern margin of the Fortress Mountain Formation. Cutbank exposures are extensive where this band is transected by Peregrine and Welcome Creeks and the Siksikpuk and Okokmilaga Rivers. Most exposures, however, are structurally so complex as to preclude stratigraphic measurement.

The chert occurs in beds 2 to 8 inches thick and has a variety of colors and textures, depending upon the amount and kind of impurities. Most commonly it is vitreous, light brown, or banded green and gray and weathers to bright hues of green, brown, and blue. Fine silt and clay appear to be the most abundant impurities, and all gradations occur from soft silty shale and siltstone through cherty siltstone to pure vitreous chert. Calcite, another important impurity, may constitute as much as 40 percent of the chert, and where it occurs in large amounts, gives the chert the texture and appearance of a porcelanite. Other impurities include sericite, feldspar, barite, organic matter, and iron oxides.

Under the microscope the pure vitreous chert appears to be composed almost wholly of a very fine aggregate of chalcedony, with scattered rosettes of spherulitic chalcedony, fine veinlets and irregular masses of fibrous chalcedony, and circular bodies of clear quartz, probably Radiolaria. Some of the pure vitreous chert has a weathered rind, as much as half an inch thick, of coarse fibrous chalcedony which gives the rock the appearance of unglazed porcelain.

Asphaltic shale.—Black asphaltic shale is intercalated with the chert in 2- to 3-inch beds and in podlike masses as much as 1 foot thick. Locally, asphaltic matter impregnates the chert along a network of hairlike cracks. The asphaltic shale can be ignited easily with a match and burns readily, giving off a strong petroliferous odor. Freshly broken pieces of the asphaltic shale are brittle and friable, but the shale weathers into tough pliable pebbles and cobbles that are ubiquitous in the younger Fortress Mountain Formation (Cretaceous) and in the present-day stream gravels.

Black siliceous shale.—A distinctive sequence, several hundred feet thick, of black siliceous shale was found in the northeastern corner of the mapped area infolded and infaulted with the Fortress Mountain Formation. It occurs in the lower part of the Tiglukpuk Formation and appears to be a facies of the bedded chert. Unlike the common dark-gray silty shale of the Tiglukpuk Formation, the black siliceous shale is resistant to erosion and forms low ridges and massive cutbanks. Everywhere exposures of the siliceous shale are recognizable by the brilliant yellow, orange, and peacock-hued iron oxides that coat the weathered surfaces.

The shale is brittle, friable, calcareous, siliceous, and locally infiltrated with stringers of pyrite. Thin beds of cherty siltstone are intercalated with the shale in subordinate amounts. A thin-section examination shows that about 45 percent of the shale consists of chalcedony and calcite occurring in irregular elongated blebs arranged along the shale laminae.

Variegated shale and siltstone.—Variegated shale and siltstone were seen at several localities west of the Anaktuvuk River in the lower part of the Tiglukpuk Formation. A 50-foot section is exposed on the west side of the Kiruktagiak River 1 mile north of the mountain front, and a 100-foot section crops out on the east side of Tiglukpuk Creek 1½ miles north of the mountains. Small outcrops of the variegated shale and siltstone were observed on the Kiruktagiak River between 10 and 15 miles north of the mountains.

The variegated shale and siltstone is distinguished by alternating grayish-red, grayish-green, and dark-gray laminations. Siltstone makes up from 30 to 60 percent of the outcrops and occurs in lenticular beds 4 to 8 inches thick. Penecontemporaneous slump structures and curly bedding characterize some of the siltstone.

Well-rounded pebbles, 1 to 2 inches in diameter, are embedded in the variegated shale in exposures along the Kiruktagiak River and Tiglukpuk Creek. The pebbles are composed of a variety of igneous and metamorphic rocks including felsic and mafic intrusive and extrusive rock and quartzite. The source and mode of deposition of these pebbles is puzzling, especially since similar rock types have not been identified in any of the widespread conglomerates that occur in the succeeding lower Cretaceous sedimentary formations.

Coquinoid limestone.—A medium-gray dusky-red-weathering coquinoid limestone, composed almost entirely of mollusk shells, occurs in subordinate amounts intercalated with shale in the Tiglukpuk Formation. The coquinoid limestone is exposed principally in cutbanks and commonly makes conspicuous float where it has weathered out of the less resistant shale. It occurs in beds 1 to 3 inches thick and forms ledges as much as 20 feet thick. The shell material is chiefly crushed and fragmented *Buchia* valves, most of which appear to be oriented with their convex side upward. Belemnite phragmacones were found with the *Buchia* in several localities.

THICKNESS

The total thickness of the Tiglukpuk Formation is not known, for a complete section in which both top and bottom contacts are exposed has not been found. The type section, about 1,500 feet thick, is the most complete of those exposed in the mapped area and may represent nearly the full thickness of the formation. From scattered outcrops along the Lupine River, 75 miles east of the mapped area, A. S. Keller (1951 written communication) compiled a composite section totaling about 1,800 feet which, although the top of the formation is not exposed, is the thickest sequence of the Tiglukpuk Formation recorded to date.

CONTACTS

The Tiglukpuk Formation rests upon the Shublik Formation with little or no angular discordance, and can readily be distinguished from the dark organic shale and limestone that characterize the Shublik Formation.

The Tiglukpuk Formation is overlain, in some places with angular discordance, by the Okpikruak Formation or by younger Cretaceous rocsk. In many places it is difficult to distinguish the Tiglukpuk Formation from the Okpikruak, for both are typified by beds of sandstone, siltstone, and shale of similar appearance and composition. In the Okpikruak Formation, however, these beds are well stratified and generally occur in rhythmic alternation, whereas in the Tiglukpuk Formation such bedding characteristics are rare. This difference is the most useful criterion for separating the two formations in places where none of the more distinctive chert, black siliceous shale, or coquinoid limestone of the Tiglukpuk Formation are found.

STRATIGRAPHIC SECTIONS

Two measured stratigraphic sections of the Tiglukpuk Formation are shown in figure 75. The more complete section, which is about 1,500 feet thick, was designated by Patton (1956a, p. 215) as the type.

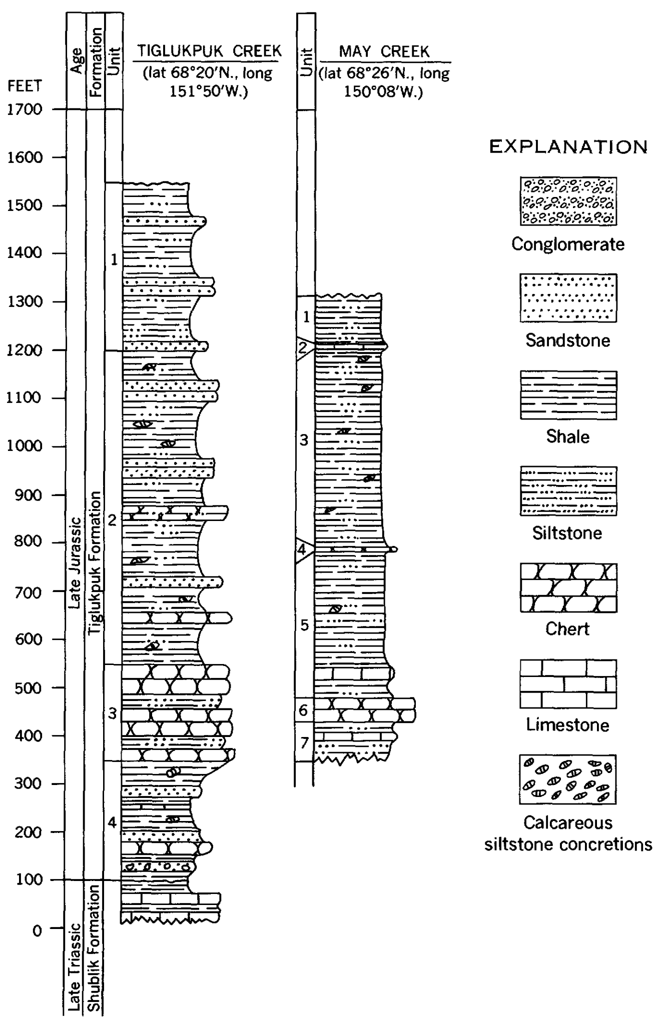

FIGURE 75.—Columnar sections of the Tiglukpuk Formation.

It crops out in cutbanks on the east side of Tiglukpuk Creek, 3 miles north of the mountain front, at lat 68°20′ N., long 151°50′ W.[2] About 20 percent of the type section is not exposed, but the lithologic character of the covered sequences can be inferred from talus or float. The section is on the south flank of the Tiglukpuk Creek anticline and dips 35° to 70° S. The base rests disconformably upon the Shublik Formation, but the top appears to be cut off by a reverse fault. The cherty sequence several hundred feet above the base contains two diabase sills of flows. The lower of these is about 200 feet thick and the upper one about 75 feet thick.

Some details of the type section are listed here in descending stratigraphic order. Thicknesses given are approximate.

Type section of Tiglukpuk Formation, in cutbank on east side of Tiglukpuk Creek, at lat 68°20′ N., long 151°50′ W.

[Measured with tape by A. S. Keller, 1950, and W. W. Patton, Jr., 1953. Grahpic section, fig. 75]

	Thickness (feet)
Jurassic.	
Tiglukpuk Formation: Sandstone, siltstone, and shale.	
Fault.	
Tiglukpuk Formation:	
1. Sandstone, siltstone, and shale. Greenish-gray fine-grained sandstone in lenticular masses 5 to 40 ft thick; locally calcareous. Interbedded dark-gray silty shale and medium-dark-gray siltstone. Minor calcareous siltstone lenses that weather moderate red. Highly sheared and faulted	350
2. Predominantly sandstone, siltstone, and shale as above. Shale locally hackly fracturing. Lenticular masses of greenish bedded chert and cherty siltstone as much as 20 ft thick in minor amounts. Highly sheared and faulted	650
3. Chert and siltstone. Greenish to grayish glassy bedded chert, greenish to brownish cherty siltstone and dark-gray highly calcareous siltstone that weathers grayish orange	200
4. Shale and sandstone. Chiefly dark-gray silty shale; locally hackly fracturing. Greenish-gray lenticular masses, as much as 30 ft thick, of very fine grained sandstone in subordinate amounts. Minor dark-greenish-gray siltstone. Several coquinoid limestone lenses as much as 5 ft thick composed chiefly of *Buchia* sp. Several lenses of greenish chert and cherty siltstone as much as 10 ft thick. A few 2- to 6-in. layers of granule conglomerate. Cherty siltstone concretions that weather gun-metal blue. Cannonball concretions of siltstone as much as 8 in. in diameter	250
Total thickness of measured section approximately	1, 500
Unconformity.	
Triassic:	
Shublik Formation: Shale, grayish-black with subordinate 2-to 5-in. beds of limonite-stained grayish-black chert.	

[2] The coordinates previously given by Patton (1956a, p. 215) have been amended to agree with the revised base used in plate 50. However, the type locality remains the same.

The other section of the Tiglukpuk Formation (fig. 75), about 950 feet thick, was measured on the east side of May Creek, lat 68°26′ N., long 150°08′ W. The top and bottom of the section are cut off by faults. Some details of the section are listed below in descending stratigraphic order. Thicknesses given are approximate.

Section of Tiglukpuk Formation, in cutbank on east side of May Creek at lat 68°26′ N., long 150°08′ W.

[Measured with tape by A. S. Keller, 1950. Graphic section, fig. 75]

	Thickness (feet)
Jurassic.	
Tiglukpuk Formation: Sandstone, siltstone, and shale.	
Fault.	
Tiglikpuk Formation:	
1. Silty shale and siltstone, dark-gray and hackly fracturing. Calcareous siltstone concretions	100
2. Limestone, coquinoid. *Buchia* sp	10
3. Silty shale and siltstone, dark-greenish-gray to dark-gray, hackly fracturing. Calcareous siltstone concretions	410
4. Chert, bedded, glassy, green; weathers dark reddish brown	5
5. Silty shale and siltstone, dark-greenish-gray and dark-gray, hackly fracturing. Some beds weather gun-metal blue. Coquinoid limestone with *Buchia* sp. near base	310
6. Chert, bedded, glassy, greenish-gray	50
7. Silty shale and siltstone, dark-greenish-gray and dark-gray, hackly fracturing. Coquinoid limestone	80
Total thickness of measured section, approximately	950
Fault.	
Cretaceous.	
Fortress Mountain Formation: Conglomerate, sandstone, and shale.	

AGE AND CORRELATIONS

The Tiglukpuk Formation is assigned a Late Jurassic (late Oxfordian to early Portlandian) age, chiefly on the basis of several species of *Buchia.*[3]

Although the Tiglukpuk Formation appears to be almost entirely of marine origin, fossils are scarce and poorly preserved. Two species of *Buchia*, *B. concentrica* (Sowerby) and *B. rugosa* (Fischer), are by far the most common megafossils. Closely compacted specimens of *Buchia* make up the coquinoid limestone, and molds and casts of single specimens occur in sandstone. One ammonite, *Lytoceras*? sp., was found together with *B. rugosa* in a sandstone bed on Peregrine Creek, and several specimens of the belemnite *Cylindroteuthis* sp. were collected on Cobblestone Creek in a coquinoid limestone composed predominantly of *Buchia*. Fossil collections and Mesozoic locality numbers from the Tiglukpuk Formation are listed below. They have been identified by R. W. Imlay (1955, p. 77–81).

50AKe93, USGS 22578, from east side of Cobblestone Creek, lat 68°27′ N., long 150°12′ W., coquinoid limestone float:
Buchia concentrica (Sowerby)

50AKe97, USGS 22579, from cutbank on west side of Cobblestone Creek, lat 68°27′ N., long 150°12′ W., coquinoid limestone:
Buchia rugosa (Fischer)

50AKe109, USGS 22580, unit 7 from measured section of Tiglukpuk Formation on May Creek:
Buchia rugosa (Fischer)

50AKe114, USGS 22581, from cutbank on east side of May Creek, lat 68°26′ N., long 150°08′ W., coquinoid limestone:
Buchia rugosa (Fischer)

50AKe121 USGS 22582, from cutbank on west side of Peregrine Creek, lat 68°28′ N., long 150°18′ W., coquinoid limestone:
Buchia concentrica (Sowerby)

50AKe132, USGS 22584, from cutbank on west side of Peregrine Creek, lat 68°27′ N., long 150°18′ W., sandstone:
Buchia rugosa (Fischer)(?)

50AKe135 and 50AKe136, from cutbank on east side of Peregrine Creek, lat 68°27′ N., long 150°18′ W., sandstone.

50AKe135, USGS 22585:
Buchia rugosa (Fischer)(?)
Lytoceras? sp.

50AKe136, USGS 22586:
Buchia rugosa (Fischer)(?)

50AKe174 and 50AKe175, from cutbank on Cobblestone Creek, lat 68°31′ N., long 150°18′ W., coquinoid limestone.

50AKe174, USGS 22587:
Buchia rugosa (Fischer)

50AKe175, USGS 22588:
Cylindroteuthis sp.

In addition to the collections listed above, Buchias were noted in the Tiglukpuk Formation at many other localities. In the area east of the Nanushuk River the Buchias, although most abundant near the base of the Tiglukpuk Formation, range upward to within a few feet of the Okpikruak Formation. West of the Nanushuk River, however, they appear to be confined to the lowest third of the Tiglukpuk Formation.

According to R. W. Imlay (1955, p. 73–75), *Buchia rugosa* (Fischer) and *Buchia concentrica* (Sowerby) are both indicative of the Late Jurassic but are of slightly different ages: *B. rugosa* ranges from middle Kimmeridgian to lower Portlandian, and *B. concentrica* from upper Oxfordian to middle Kimmeridgian. Whether *B. rugosa* generally occurs at a higher stratigraphic level than *B. concentrica* in the mapped area could not be determined, owing to the small number of collections and the lack of stratigraphic control within the Tiglukpuk Formation.

A characteristic arenaceous Foraminifera fauna, including many new species, occurs in the lower part of the Tiglukpuk Formation. The following samples were identified and described by Helen Tappan (1955, p. 24–25).

[3] All *Buchia* collections from the Tigulukpk Formation have been reidentified by D. L. Jones (oral commun., 1964) as *Buchia* cf. *B. sublaevis* of probable Valanginian age. Thus the Tiglukpuk Formation may be partly or entirely Early Cretaceous rather than Jurassic in age and possibly younger than the Okpikruak Formation (see footnote 6, p. 449).

50APa241, from cutbank on east side of Erratic Creek, near base of Tiglukpuk Formation, lat 68°23′ N., long 150°47′ W.:
Glomospira pattoni Tappan
Gaudryina milleri Tappan
Lenticulina wisniowskii (Myatliuk)

50APa84, from cutbank on west side of Cobblestone Creek, near base of Tiglukpuk Formation, lat 68°26′ N., long 150°12′ W.:
Glomospira pattoni Tappan
Gaudryina milleri Tappan
Lenticulina wisniowskii (Myatliuk)

50AKe173, from cutbank on east side of Cobblestone Creek, near base of Tiglukpuk Formation, lat 68°31′ N., long 150°18′ W.:
Ammodiscus cheradospirus Loeblich and Tappan
Glomospira pattoni Tappan

50APa172, from cutbank on tributary east of Cobblestone Creek, near base of Tiglukpuk Formation, lat 68°32′ N., long 150°15′ W.:
Glomospira pattoni Tappan
Gaudryina topagorukensis Tappan

50APa344, from cutbank on Desolation Creek, Tiglukpuk Formation, lat 68°34′30″ N., long 151°42′ W.:
Bathysiphon anomalocoelia Tappan
Glomospira pattoni Tappan
Lenticulina wisniowskii (Myatliuk)

50APa239, from cutbank on east side of Erratic Creek, near base of Tiglukpuk Formation, lat 68°23′ N., long 150°47′ W.:
Bathysiphon anomalocoelia Tappan
Glomospira pattoni Tappan
Haplophragmoides canui Cushman
Spiroplectammina sp.
Gaudryina milleri Tappan
G. topagorukensis Tappan
Lenticulina wisniowskii (Myatliuk)
Astacolus sp.

50APa214, from cutbank on east side of Welcome Creek, near base of Tiglukpuk Formation, lat 68°24′ N., long 150°43′ W.:
Ammodiscus cheradospirus Loeblich and Tappan
Glomospira pattoni Tappan
Gaudryina milleri Tappan

50APa216, from cutbank on east side of Welcome Creek, near base of Tiglukpuk Formation, lat 68°24′ N., long 150°43′ W.:
Glomospira pattoni Tappan
Gaudryina milleri Tappan

In the Canning River region near the eastern end of the Arctic Foothills province, Leffingwell (1919, p. 119–125) described two Jurassic formations, the Kingak Shale and the Ignek Formation. There the Kingak directly overlies the Shublik Formation and is succeeded by the Ignek. Subsequent investigations of these two formations in their type area (Keller and others, 1961) has shown that the Kingak ranges in age from Early to Late Jurassic, but that the Ignek is of Cretaceous age. It has been demonstrated in the Shaviovik and Sagavanirktok Rivers region by Keller and others (1961) that the upper part of the Kingak is probably a fine-grained facies of the Tiglukpuk Formation.

TUFFACEOUS GRAYWACKE UNIT AND CORRELATIVE(?) ROCKS

TUFFACEOUS GRAYWACKE UNIT

The tuffaceous graywacke unit consists of a lithologically anomalous group of rocks including tuffaceous graywacke, chert, and indurated shale and siltstone. This unit crops out in only a few isolated localities and, for mapping, has been placed in the Tiglukpuk Formation. Owing to cover and structural complexities, the precise stratigraphic position of these strata cannot be determined, but gross relationships suggest that they overlie the Tiglukpuk Formation and underlie the Okipikruak Formation. They appear to be closely associated with the mafic igneous rocks.

The most extensive exposure of the tuffaceous graywacke unit occurs at the head of Fortress Creek between lat 68°28′ N. and lat 68°31′ N., where it forms an isolated group of northwestward-trending ridges. Complex structure precludes stratigraphic measurements, but, judging from the size of the exposure, the thickness of the unit could hardly be less than several hundred feet and probably is considerably greater.

Another exposure occurs in a cutbank on Tiglukpuk Creek at lat 68°20′ N., a short distance south of the type locality of the Tiglukpuk Formation. The sequence, consisting of tuffaceous graywacke, chert, and cherty siltstone, appears to be faulted against Tiglukpuk strata on the north and to dip beneath Okpikruak strata to the south. Half a mile east of Tiglukpuk Creek the same sequence of rocks is interbedded with mafic volcanic rock.

The tuffaceous graywacke ranges from fine grained to conglomeratic, and is dark greenish gray in color. Sorting is very poor, and, in the coarse-grained rock, bedding is scarcely apparent. Visible detrital material includes angular to subangular grains of feldspar, volcanic rock, shale chips, pyroxenes, and amphiboles. Several thin sections of the fine-grained graywacke have been examined. They show an aggregate of angular grains, 0.2 to 0.5 mm, set in a highly altered matrix that appears to be tuffaceous. Plagioclase, chiefly albite and oligoclase with subordinate andesine, composes 30 percent of the rock and occurs in individual grains or in lithic fragments. The plagioclase commonly is partly or wholly replaced by sericite, calcite, or, as in one sample, by zeolite. Quartz is present but only in amounts less than 5 percent. Augite, and less commonly hornblende, may aggregate as much as 5 percent of the rock. Lithic fragments including chert, shale, and mafic volcanics make up about 10 percent of the rock. Matrix material accounts for more than 50 percent of the rock and consists predominantly of finely divided chlorite, clay, and silt.

Hard brittle siltstone and shale that locally grade into nearly pure chert are interbedded with the tuffaceous graywacke. The siltstone and shale are dark gray to black, but they weather a characteristic dusky yellow-green and commonly are splotched with orange and yellow ferruginous stains. Dusky red-weathering gray silty limestone is intercalated with the siltstone and shale in subordinate amounts.

CORRELATIVE(?) ROCKS

An anomalous rock sequence of indurated and variegated shale, siltstone, and sandstone that may correlate with the tuffaceous graywacke unit occurs in the upper Okpikruak River area. It forms low ridges between Verdant and Okonagun Creeks and is exposed in cutbanks at several localities along Okonagun Creek between lat 68°29′ N. and lat 68°34′ N. The contacts of the sequence are covered, but gross relations suggest that it occurs stratigraphically between the Tiglukpuk and Okpikruak Formations. The shale, which makes up about 60 percent of the sequence, is well indurated and weathers to small blocky fragments. It is dark gray, grayish red, and grayish green. The siltstone is also well indurated and generally is pale olive to light gray. It occurs in beds 4 to 8 inches thick but may be as much as 2 feet thick locally. Flow casts and wavy interstratal laminations occur in some of the siltstone. Intercalated very fine grained pale-olive to medium-dark gray sandstone and dense dark silty carbonate rock are present in subordinate amounts. The total thickness of the sequence may be as much as 1,700 feet.

The clastic rock interlayered with mafic igneous rocks at Horseshoe Mountain, lat 68°36′ N., long 152°47′ W., may also correlate with the tuffaceous graywacke unit. Horseshoe Mountain is composed of a 200- to 300-foot succession of layered rocks. In the field the succession was thought to be entirely mafic sills or flows, but microscopic examination showed that 7 of the 15 samples collected from Horseshoe Mountain are clastic rocks. The clastic rocks range from angular breccias of volcanic material through aggregates of slightly rounded volcanic and nonvolcanic detritus to a sandstone of graywacke type. Apparently they include all variations from tuffs to moderately sorted sedimentary rock.

AGE

Fossils collected from exposures of the tuffaceous graywacke unit on Fortress and Tiglukpuk Creeks were examined by R. W. Imlay.

49ATr352, USGS Mesozoic loc. 21522, from cutbank on Fortress Creek, lat 68°31′ N., long 153°03′ W., tuffaceous graywacke:
Inoceramus sp.
Fragmentary ammonite

50AKe263, USGS Mesozoic loc. 22591, from cutbank on Tiglukpuk Creek, lat 68°20′ N., long 151°50′ W., tuffaceous graywacke:
Inoceramus sp.
Fragmentary ammonite

On the basis of a preliminary examination of these two collections, Imlay, (1955, p. 73–81, and written communication, 1951), tentatively assigned the fragmentary ammonites a Middle Jurassic age, which would make them older than the Tiglukpuk Formation. Subsequent to his examination new field data were collected which suggest that the tuffaceous graywacke unit probably overlies the Tiglukpuk Formation and therefore could not be older than Late Jurassic. This information was given to Imlay who commented (written communication, 1956):

> The physical evidence for placing the beds at localities 49ATr352 and 50AKe263 above the Tiglukpuk Formation and below the Okpikruak Formation should be given greater weight than the Middle Jurassic assignment of the fossils obtained from those localities because the specimens of *Inoceramus* do not belong to any known Jurassic species and the ammonites are immature and rather fragmentary. I do insist, however, that the ammonites are Jurassic rather than Cretaceous.
>
> The ammonite from locality 50AKe263 that I labeled *Parkinsonia?* sp. juv. has lateral and ventral tubercles and a ventral groove, which features occur in the Kimmeridgian genus *Aulacostephanus* and in several Portlandian genera, and are uncommon among genera of Early Cretaceous age.
>
> The ammonite from locality 49ATr352 has falcoid ribs and a keel, which features suggested reference to the Bajocian *Pseudolioceras*. However, it could be a fragment of the Kimmeridgian *Amoeboceras*. This ammonite in particular is good evidence for a Jurassic age because keeled ammonites are fairly common in the Jurassic and are very rare in the earliest Cretaceous (Berriasian to Barremian).[4]

A single specimen of *Buchia* was collected by L. A. Warner in 1945 on the upper Okpikruak River. The exact location and stratigraphic position of the collection is uncertain, but from Warner's description it is believed that the collection comes from an exposure of the indurated variegated shale, siltstone, and sandstone sequence and possibly is correlative with the fossil collections from the tuffaceous graywacke unit. In reference to the fossil collection Imlay states (written communication, 1956):

> The collection consists of a single, well-preserved specimen of *Buchia piochii* Gabb. This species has not been previously recorded in northern Alaska, but has been found at several localities elsewhere in Alaska, and is common in the Knoxville Formation in California. Its age in California on the basis of ammonites is middle to late Portlandian.

Although fossil evidence indicates that the tuffaceous graywacke unit and the correlative(?) rocks are no younger than Jurassic, gross stratigraphic evidence

[4] Restudy of collections 49ATr 352 and 50AKe263 by Imlay (written commun., 1964) indicates the presence of *Inoceramus* cf. *I. lucifer* Eichwald, *Pseudolioceras*? sp., and *Arkelloceras* cf. *A. Tozeri* Frebold suggesting a Middle Jurassic age for the enclosing beds.

suggests they are probably of post-Tiglukpuk age. The mafic volcanic rocks, which locally are intercalated with these strata, invade the Tiglukpuk and older formations, but they have not been found cutting the Okpikruak Formation or younger strata. Furthermore, lithic and mineral detritus of mafic igneous rock is abundant in the Okpikruak and succeeding formations, but it does not occur in significant amounts in the Tiglukpuk or older formations. Thus, the total weight of evidence suggests a latest Jurassic (Portlandian) age for the tuffaceous graywacke unit and the correlative(?) rocks.

CRETACEOUS ROCKS

OKPIKRUAK FORMATION

The name Okpikruak Formation represents the sequence of cyclically interbedded sandstone of graywacke type, siltstone, and shale that overlies the Tiglukpuk Formation and underlies the Fortress Mountain Formation (Cretaceous). The Okpikruak Formation has been traced eastward along the Arctic Foothills province to the Canning River (Keller and others, 1961) and westward to beyond the Nuka River (I. L. Tailleur, oral communication, 1953), a distance of more than 350 miles.

The Okpikruak Formation was described for the first time in 1951 (Gryc, Patton, and Payne, p. 159–160). However, subsequent mapping and stratigraphic studies now permit a closer definition of the limits and composition of the Formation. The type locality is on the Okpikruak River at about lat 68°35′ N., long 153°30′ W.,[5] but a more complete reference section has been found on Tiglukpuk Creek at lat 68°19′ N. long 151°50′ W.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Okpikruak Formation is found principally in the belt of complexly deformed upper Paleozoic and Mesozoic strata adjacent to the mountain front. In many places along this belt it has not been possible to differentiate the Okpikruak Formation from the underlying Tiglukpuk Formation. The two formations are intricately infolded and infaulted, and since they are lithologically similar, they cannot be separated in areas of poor exposure. Four localities where extensive outcrops permit the delineation of the Okpikruak Formation are: upper Cobblestone Creek, upper Tiglukpuk Creek, the Aucella-Speedway Creeks area in the Kiruktagiak River basin, and the Middle Fork-Verdant Creek area in the Okpikruak River basin.

North of the complex belt two small areas of the Okpikruak Formation can be outlined within the eastward-trending exposure belt of the Fortress Mountain Formation: (1) between the Kiruktagiak and Ayiyak Rivers at lat 68°36′ N. and (2) a short distance east of the Chandler River at lat 68°35′ N.

The Okpikruak Formation, in general, has no distinctive topographic expression. In a few places along the interstream divides, sandstone and siltstone beds form low rubble-covered ridges, but these are indistinguishable from ridges in the terrain of the Tiglukpuk or Fortress Mountain Formations. A soft poorly stratified basal conglomerate of local extent characteristically crops out in low irregularly shaped knobs and buttes.

PREVIOUS WORK

Judging from his map and description, Schrader (1904) apparently included the rocks now assigned to the Okpikruak Formation in his Anaktuvuk Series. He assigned his Anaktuvuk Series an Early Cretaceous age on the basis of the occurrence of *Buchia crassicollis* Keyserling, the characteristic fossil of the Okpikruak Formation.

Smith and Mertie (1930) did not use Schrader's Anaktuvuk Series but placed rocks now assigned to the Okpikruak Formation together with the Tiglukpuk and Fortress Mountain Formations in an informally designated time-stratigraphic unit, the Lower Cretaceous Series.

LITHOLOGY

The Okpikruak Formation is typified everywhere in the mapped area by a thick monotonous rhythmically interbedded succession of sandstone of graywacke type, shale, and siltstone. Conglomerate occurs at the base locally.

The sandstone is greenish gray to dark greenish gray, very fine to fine grained, and thinly bedded. It is highly argillaceous and has low porosity. Slump structures and flow casts are common. Thin sections of the typical sandstone show it to be composed of angular to subround grains of quartz, 10 to 25 percent; angular to subangular grains of feldspar, chiefly sericitized sodic plagioclase, 10 to 25 percent; calcite in irregular masses locally replacing plagioclase, as much as 3 percent; and finely divided clay, chlorite, and silt, as much as 50 percent. Fragments of chert, shale, siltstone, and mafic volcanic rock constitute 20 to 40 percent of the medium- and coarse-grained sandstone.

The siltstone is most commonly dark greenish gray to dark gray, calcareous, and thin bedded. Some highly calcareous siltstone is notably lenticular or concretionary and weathers to a characteristic moderate yellowish brown.

The shale, the most abundant component of the formation, ranges from a dark-gray silty shale to grayish-black fissile clay shale.

[5] The coordinates previously given by Gyrc and others, (1951, p. 159) have been amended to agree with the revised base used on plate 50. However, the type locality remains the same.

The ratio of sandstone, siltstone, and shale changes from place to place, although the rhythmic alternation of these rock types is present to some extent in every exposure that was examined. In the Tiglukpuk Creek section (fig. 76) sandstone makes up 10 to 15 percent of the lower 1,500 feet and about 25 percent of the upper 350 feet. In the 950-foot section on Aucella Creek (fig. 76) the lower half is 10 to 15 percent sandstone and the upper half 25 to 30 percent sandstone. In contrast to these two sections, however, the type section on the Okpikruak River (fig. 76) is about 60 percent sandstone. Sections measured in the Cobblestone Creek area (not shown in fig. 76) were also found to be more than 50 percent sandstone.

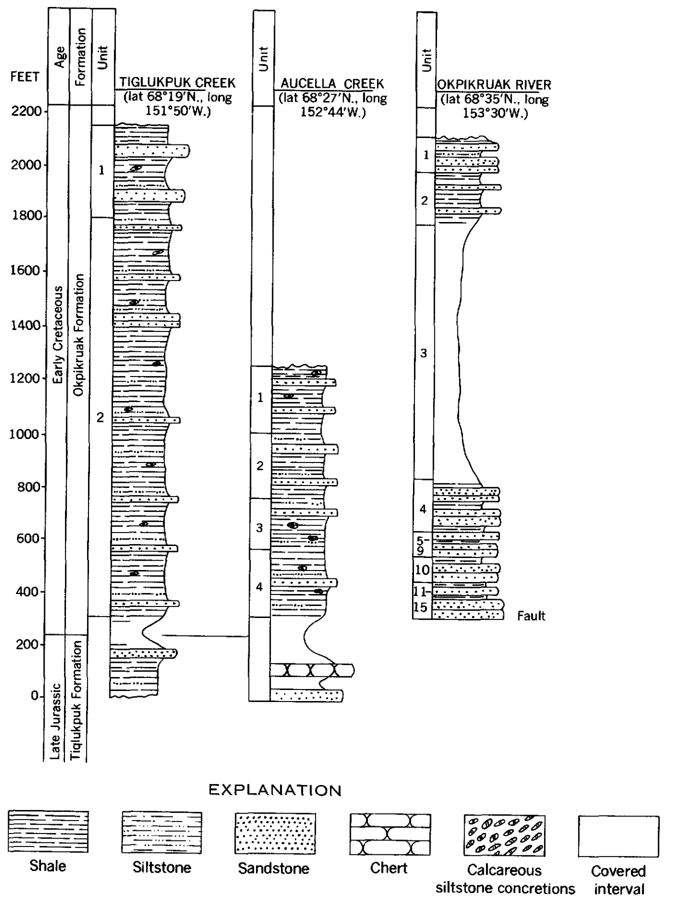

FIGURE 76.—Columnar sections of the Okpikruak Formation.

Several feet of the Okpikruak Formation near the middle of the Tiglukpuk Creek section were measured in detail and are shown in figure 77 to illustrate the characteristic development of rhythmic bedding. A single unit consists of a thin bed of sandstone or siltstone overlain by a thick bed of shale. The sandstone or siltstone bed commonly grades upward into the shale, but it has a sharp contact with the shale bed of the underlying unit. Flow casts and casts of *Buchia* are common at the base of the sandstone or siltstone bed.

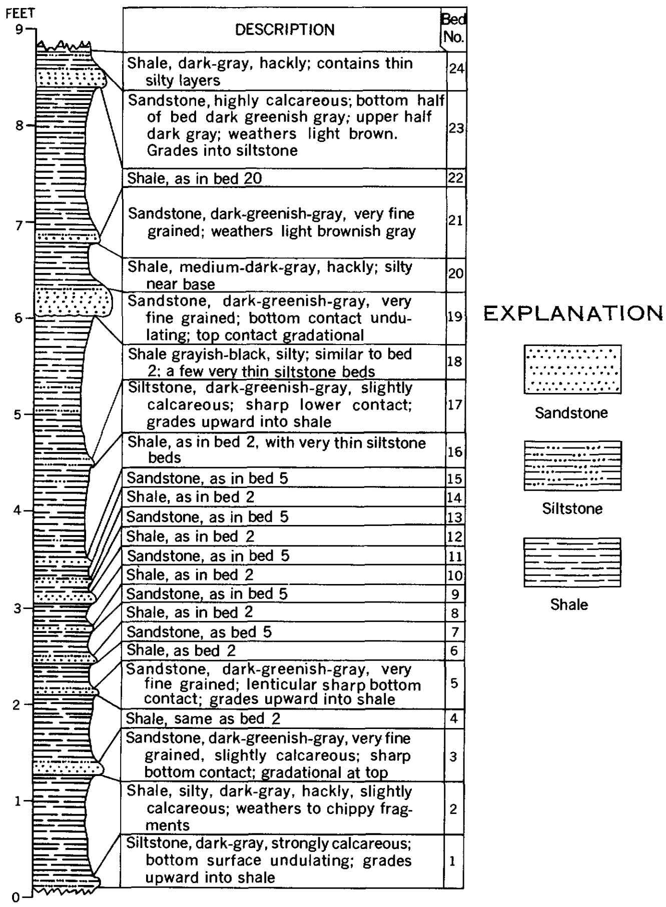

FIGURE 77.—Characteristic development of rhythmic bedding in the Okpikruak Formation; detail of small part of the Tiglukpuk Creek reference section (lat 68° 19′ N., long 151°50′ W.).

Scattered outcrops of conglomerate tentatively assigned to the Okpikruak Formation occur along the northern margin of the complex belt. The conglomerate appears to rest disconformably upon the Tiglukpuk and older formations and presumably is confined to the base of the Okpikruak. The individual exposures are small and are intricately infolded and infaulted with Tiglukpuk strata so that they cannot be delineated separately on plate 50. They do, however, appear to be concentrated in greater thicknesses in certain localities. One such locality is a 30-square-mile area between lower Tiglukpuk Creek and the Siksikpuk River, a few miles south of their confluence. Another locality is between Chert Creek and the Ayiyak River, south of Fortress Mountain.

Typically the conglomerate is massive, poorly consolidated, and devoid of stratification. It is composed of poorly sorted angular to subround lithic fragments ranging from granule to cobble size set in a highly argillaceous matrix. The lithic fragments consist of green and gray vitreous chert and cherty siltstone with subordinate amounts of black shale chips, calcareous siltstone, mafic igneous rock, fossiliferous limestone (from the Lisburne Group and Shublik Formation), asphaltic matter (from the Tiglukpuk Formation), silty "cannonball" concretions (probably from the Tiglukpuk Formation), and carbonized plant debris.

A thin section of grit from the conglomerate exposures along lower Tiglukpuk Creek reveals the following approximate composition: angular to subround grains of quartz, 15 percent; angular to subangular grains of feldspar, chiefly plagioclase, 10 percent; round to subround grains of chert, siltstone, quartzite, shale, and mafic volcanic rock, 25 percent. The grains range from silt size to 2 mm and are set in a matrix of finely divided silt, clay, and chlorite.

THICKNESS

A complete section of the Okpikruak Formation is not exposed at any one locality; so the full thickness of the formation is not known. Both the Tiglukpuk Creek reference section and the type section are about 1,800 feet thick. On Okonagun Creek, 1½ miles south of the type section, another section of the Okpikruak Formation, about 1,900 feet thick, is partly exposed. However, if this Okonagun Creek section is correlated with the type section, it appears that the basal 400 feet of the Okonagun Creek section is missing from the type section, presumably by faulting, and that an additional 200 feet that is not exposed in the Okonagun section is present at the top of the type section. Thus, a total thickness of 2,200 feet is possible and, judging from the structure and dimensions of occurrences of the Okpikruak Formation elsewhere in the mapped area, this would be about the maximum thickness of the formation.

CONTACTS

In most places the Okpikruak Formation overlies the Tiglukpuk Formation, but in several localities it seemingly rests upon older formations. The contact everywhere is disconformable, and in some places appears to be slightly discordant. Gross features that distinguish the Okpikruak Formation from the underlying Tiglukpuk Formation are (1) the rhythmic and orderly interbedded relation of sandstone, siltstone, and shale; (2) the absence of bedded chert, siliceous shale, coquinoid limestone, and variegated shale and siltstone; (3) the dark-greenish-gray color of the coarse clastic strata of the Okpikruak Formation in contrast to the greenish-gray color of the Tiglukpuk strata; and (4) the abundance of nonresistent minerals and lithic fragments in the Okpikruak Formation.

The Okpikruak Formation is overlain by the Fortress Mountain Formation, but because the principal occurrences of the two formations are in different eastward-trending belts, the nature of their contact is not well known. In the few places where they have been found together, the contact is poorly exposed. It appears to be disconformable and probably locally discordant.

STRATIGRAPHIC SECTIONS

Three measured sections of the Okpikruak Formation are shown in figure 76. The most nearly complete section is exposed in a cutbank on the east side of Tiglukpuk Creek at lat 68°19′ N., long 151°50′ W. It occurs on the north flank of a syncline, the axis of which crosses Tiglukpuk Creek near the mouth of Skimo Creek. The lowest exposed beds are separated by a 100-foot covered interval and possible fault from concordantly dipping beds apparently belonging to the tuffaceous graywacke unit. The section is a monotonous sequence of rhythmically alternating beds of sandstone, siltstone, and shale and is so uniform throughout that no attempt was made to log the entire section in detail. The detailed 9-foot column shown in figure 77 is characteristic of the entire section.

Reference section of Okpikruak Formation, in cutbanks on east side of Tiglukpuk Creek at lat 68°19′ N., long 151°50′ W.

[Measured with tape by A. S. Keller, 1950. Graphic section, figs. 76, 77]

	Thickness (feet)
Eroded, center of syncline.	
Cretaceous.	
Okpikruak Formation:	
1. Shale, siltstone, and sandstone. Dark-gray to grayish-black predominantly silty shale. Thin-bedded dark greenish-gray calcareous siltstone. Greenish-gray to dark greenish-gray very fine grained to fine-grained thin- to thick-bedded calcareous sandstone. Lenses and concretions of moderate-yellowish-brown weathering calcareous siltstone	350
2. Shale, siltstone, and sandstone, rhythmically bedded. Shale and siltstone as above. Greenish-gray to dark greenish-gray very fine grained thin-bedded calcareous sandstone. Lenses and concretions of moderate yellowish-brown weathering calcareous siltstone	1, 500
Total exposed thickness of Okpikruak Formation	1, 850
Covered, possible fault	100+
Jurassic.	
Tiglukpuk Formation(?): Tuffaceous graywacke.	

At the type section on the Okpikruak River the Okpikruak Formation, about 1,800 feet thick, is partly exposed in a cutbank on the east side of the river at about lat 68°35′ N., long 153°30′ W. (fig. 76). The base of the section appears to have been cut off by a fault, and a 1,500-foot-wide covered interval obscures 950 feet (computed) of beds in the middle part of the section.

Type section of Okpikruak Formation in cutbank on east side of the Okpikruak River at about lat 68°35′ N., long 153°30′ W.

[Measured with tape by I. L. Tailleur, 1949. Graphic section, fig. 76]

	Thickness (feet)
Covered.	
Cretaceous.	
Okpikruak Formation:	
1. Sandstone, siltstone, and shale. Greenish-gray to dark-greenish-gray very fine-grained to fine-grained medium- to thick-bedded locally calcareous sandstone. Scour casts and *Buchia* on base of sandstone beds. Interbedded dark-gray siltstone and shale in 3-ft sections	140
2. Shale and sandstone. Grayish-black fissile clay shale with subordinate thin-bedded calcareous siltstone. Very fine grained to medium-grained dark-greenish-gray sandstone with scour casts and *Buchia* on base of sandstone beds	185
3. Covered. Computed	950±
4. Sandstone and shale. Dark-greenish-gray very fine grained to fine-grained thick-bedded locally calcareous sandstone in 8-ft sets at base to 2-ft sets at top. Interbedded grayish-black fissile clay shale occurring in 2- to 12-in. sets	200
5. Sandstone, very fine, grained to fine-grained dark-greenish-gray, thick-bedded, locally calcareous	25
6. Sandstone and shale. Very fine-grained to fine-grained dark-greenish-gray sandstone. Grayish-black clay shale in beds as much as 2 ft thick at base and 6 ft thick near top	30
7. Sandstone, very fine-grained to fine-grained, dark-greenish-gray, thick-bedded	10
8. Sandstone and shale. Very fine-grained to fine-grained dark-greenish-gray calcareous thick-bedded sandstone. Grayish-black clay shale in 5-in. sets. *Buchia*	20
9. Sandstone, fine-grained, dark-greenish-gray, thick-bedded, calcareous	15
10. Sandstone and shale. Very fine-grained to fine-grained greenish-gray calcareous thick-bedded sandstone. Wavy laminations in some beds. Subordinate dark-gray shale in 8- to 10-in. units	90
11. Sandstone and shale. Very fine-grained to fine-grained dark-greenish-gray calcareous thin-bedded sandstone. Wavy laminations in some beds. *Buchia*. Dark-gray shale in 3- to 4-in. beds with a few thin calcareous siltstone layers	40
12. Sandstone, very fine-grained to fine-grained, dark-greenish-gray, calcareous, well-indurated, thick-bedded. Dark-gray shale and thin-bedded sandstone in 1-ft units	15
13. Shale, sandstone, and siltstone. Grayish-black fissile clay shale. Dark-greenish-gray calcareous siltstone and dark-greenish-gray very fine-grained calcareous sandstone. Wavy laminations in some beds. *Buchia* on base of sandstone and siltstone beds	20

Type section of Okpikruak Formation in cutbank on east side of the Okpikruak River at about lat 68°35′ N., long 153°30′ W.—Con.

	Thickness (feet)
Cretaceous—Continued	
Okpikruak Formation—Continued	
14. Sandstone and shale. Dark-greenish-gray fine-grained calcareous thick-bedded sandstone. Wavy laminations in some beds. Dark-gray shale in 1-ft sets contain subordinate thin calcareous siltstone beds. *Buchia* on base of sandstone beds	25
15. Sandstone and shale. Argillaceous fine-grained well-indurated thick-bedded dark-greenish-gray sandstone. Dark-gray somewhat fissile shale in 2- to 3-in. units. Several 12-in. units of intercalated thin-bedded sandstone and shale	35
Total thickness of section approximately	1, 800
Fault.	

A section of the Okpikruak Formation, about 950 feet thick, is exposed in cutbanks along the northeast side of Aucella Creek 1 mile upstream from the Kiruktagiak River, at lat 68°27′ N., long 152°44′ W. The top and bottom of the section are obscured by tundra cover, but the Tiglukpuk Formation is indicated not more than 200 feet from the lowest exposed beds by rubble of greenish chert and greenish-gray sandstone.

Section of Okpikruak Formation in cutbanks along northeast side of Aucella Creek at lat 68°27′ N., long 152°44′ W.

[Measured by Brunton compass and pace by W. W. Patton, Jr., 1949. Graphic section, fig. 76]

	Thickness (feet)
Covered.	
Cretaceous.	
Okpikruak Formation:	
1. Shale and sandstone. Dark-gray to grayish-black silty shale and clay shale. Subordinate very fine grained thin-bedded greenish-gray sandstone. *Buchia* on base of sandstone beds. Dark-gray calcareous siltstone concretions that weather light-brown	250
2. Shale, sandstone, and siltstone. Dark-greenish-gray silty shale and siltstone. Subordinate greenish-gray medium bedded very fine-grained to fine-grained sandstone	250
3. Shale and siltstone. Dark-gray clay and silty shale. Subordinate light-gray very fine grained sandstone. Abundant *Buchia* on base of sandstone beds. Dark-gray calcareous siltstone concretions that weather light brown	200
4. Shale and sandstone. Dark-gray to grayish-black clay shale and silty shale. Subordinate thin-bedded very fine grained well-indurated greenish-gray sandstone. A few light-gray to reddish siltstone beds. Dark-gray calcareous concretions that weather light brown	250

Section of Okpikruak Formation in cutbanks along northeast side of Aucella Creek at lat 68°27′ N., long 152°44′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Okpikruak Formation—Continued	
Total thickness of exposed section approximately	950
Covered	200
Jurassic.	
Tiglukpuk Formation: Greenish-gray sandstone and chert.	

AGE AND CORRELATIONS

Three species of *Buchia* characteristic of earliest Cretaceous (Berriasian and Valanginian) have been found in the Okpikruak Formation—*Buchia crassicollis* Keyserling, *Buchia crassa* Pavlow, and *Buchia okensis* Pavlow.[6] The Buchias and, in particular *Buchia crassicollis* Keyserling, occur locally in great profusion, although as a whole the Okpikruak cannot be considered abundantly fossiliferous. Because specimens of *Buchia* were collected from the lowest to the highest beds, the Okpikruak is assigned with confidence to the earliest Cretaceous.

Other fossils found in the Okpikruak include a single long-ranging ammonite, several long-ranging Foraminifera, and various nondiagnostic organic markings.

The following collections from the Okpikruak Formation were identified by R. W. Imlay (1961):

49ATr252, from conglomerate on ridge 1 mile south of Fortress Mountain, lat 68°32′ N., long 152°59′ W.
: Several plump Buchias similar to species in the Okpikruak Formation.

49ATr374, USGS Mesozoic loc. 21553, from sandstone rubble 3,500 ft east of Okpikruak River, lat 68°35′ N., long 153°28′ W.
: *Buchia crassicollis* Keyserling

49ATr388, USGS Mesozoic loc. 21824, from units 1 and 2 of type section of the Okpikruak Formation (p. 448).
: *Buchia?*
: Organic markings

49APa192, USGS Mesozoic loc. 21823, from sandstone on ridge 2,500 ft east of Ayiyak River, lat 68°35′30″ N., long 152°48′ W.
: *Buchia crassa* Pavlow
: *B. crassicollis* Keyserling
: Markings cf. *Taonurus caudagalli* (Vanuxem)

49APa203, USGS Mesozoic loc. 21837, from sandstone on ridge 4,000 ft east of Ayiyak River, lat 68°36′ N., long 152°47′ W.
: *Buchia crassicollis* Keyserling
: *B. crassa* Pavlow

49APa400, USGS Mesozoic loc. 21560, from unit 4 of stratigraphic section of the Okpikruak Formation on Aucella Creek (p. —).
: *Buchia crassicollis* Keyserling
: *B.* cf. *B. crassa* Pavlow

49APa512, USGS Mesozoic loc. 21561, from sandstone on ridge 1,500 ft east of Chandler River, lat 68°35′ N., long 152°22′ W.
: *Buchia crassicollis* Keyserling

50AKe224, USGS Mesozoic loc. 22589, from sandstone in cutbank on Erratic Creek, lat 68°25′ N., long 150°49′ W.
: *Buchia crassicollis* Keyserling

50AKe272, USGS Mesozoic loc. 22592, from unit 2 of reference section of Okpikruak Formation (p. 447).
: *Buchia crassicollis* Keyserling

50AKe273, USGS Mesozoic loc. 22590, from unit 1 of reference section of the Okpikruak Formation (p. 447).
: *Buchia* sp.

50APa285, USGS Mesozoic loc. 22594, from calcareous siltstone lenses in cutbank on west side of Tiglukpuk Creek, lat 68°18′ N., long 151°50′ W.
: *Phylloceras* sp.
: *Buchia* cf. *B. okensis* Pavlow

The Okpikruak Formation was extensively sampled for microfossils, but it proved to be notably barren. The following are the only specimens recovered from the scores of samples that were collected. Identifications are by H. R. Bergquist (written communication, 1953).

49ATr527, from shale in cutbank near head of Castle Creek, lat 68°28′ N., long 152°38′ W.
: *Haplophragmoides topagorukensis* Tappan

49ATr387, from units 1 and 2 of type section of the Okpikruak Formation (p. 448).
: *Haplophragmoides?*

49ATr384, from units 4 to 15 of stratigraphic section of the Okpikruak Formation (p. 448).
: *Haplophragmoides topagorukensis* Tappan

49APa366, from shale in cutbank on west side of Verdant Creek, lat 68°33′ N., long 153°27′ W.
: *Trochammina?*

49APa405, from unit 2 of stratigraphic section of the Okpikruak Formation on Aucella Creek (p. 448).
: *Gaudryina tailleuri* (Tappan)
: *Trochammina?*

Rocks lithologically similar to the Okpikruak Formation and containing several Early Cretaceous (Berriasian and Valanginian) species of *Buchia* have been reported in the foothills eastward as far as the Canning River (A. S. Keller, written communication, 1952) and westward to the Cape Lisburne area (Smith and Mertie, 1930). Shale equivalent in age to the Okpikruak Formation was penetrated in Oumalik test well 1 at the northern edge of the foothills (Payne and others, 1951). South of the Brooks Range rocks of the same age are widespread (Imlay and Reeside, 1954, p. 236).

FORTRESS MOUNTAIN FORMATION

The Fortress Mountain Formation is the name assigned to the thick sequence of conglomerate, graywacke, siltstone, and shale that overlies the Okpikruak Formation (Patton, 1956b). The Fortress Mountain Formation has been mapped over a wide area in the

[6] Restudy of the Buchias from the Okpikruak Formation by D. L. Jones (oral commun., 1964), indicates that all collections are probably Berriasian in age.

southern half of the Arctic Foothills province from the Sagavanirktok River westward to and beyond the Kukpowruk River, a distance of 350 miles. It was named from exposures on Fortress Mountain (lat 68°34′30″ N.; long 152°58′ W.), where it is typically exposed and was first studied in detail. The type section is a composite of several partial sections exposed along the Kiruktagiak River and on Castle Mountain (fig. 78).

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The principal exposures of the Fortress Mountain Formation are along an eastward-trending belt, 4 to 14 miles wide, across the center of the Killik-Itkillik region. In addition, several small disconnected patches of the Fortress Mountain crop out close to the mountain front in the vicinity of Peregrine and Cobblestone Creeks near the eastern end of the mapped area.

Cutbank exposures, particularly of the coarse clastic facies of the formation, are found on almost every stream that crosses the Fortress Mountain belt except along the glaciated valleys of the major rivers. Especially good exposures occur on the Okpikruak River, Fortress Creek, Kiruktagiak River, Siksikpuk River, and Cobblestone Creek.

In the interstream areas the coarse clastic facies form rubble-covered hogback ridges as much as 1,000 feet high and several mesalike synclinal mountains 500 to 2,000 feet high. On the two most prominent synclinal mountains, Castle Mountain and Fortress Mountain, several thousand feet of gently dipping strata are well exposed (fig. 69).

In general, the best exposures are found along the southern margin of the Fortress Mountain belt where the coarse clastic facies occurs.

PREVIOUS WORK

Rocks of the Fortress Mountain Formation have not been previously mapped as a separate stratigraphic unit. Apparently they were included by Schrader (1904) in his Anaktuvuk Series and by Smith and Mertie (1930) in their Lower Cretaceous Series.

In 1951 all strata above the Okpikruak Formation and below the Nanushuk Group were placed in the Torok Formation (Gryc, Patton and Payne, 1951, p.

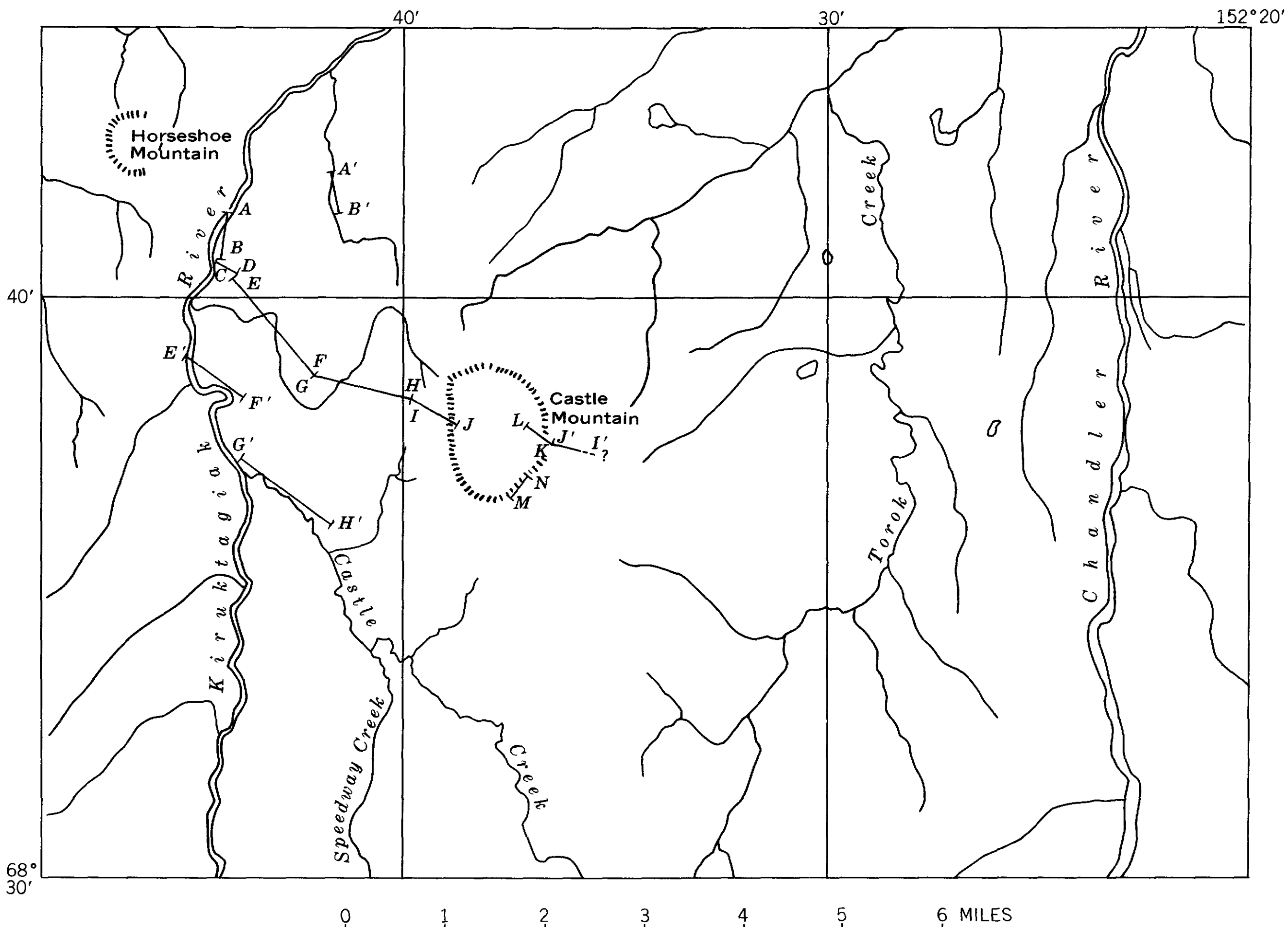

FIGURE 78.—Index map of the Castle Mountain area showing location of the type section (*A–L*) and correlative sections (*A′–B′*, *E′–F′*, *G′–H′*, *I′–J′*, and *M–N*) of the Fortress Mountain Formation.

160–162). However, later work indicated that to describe this part of the stratigraphic column accurately and objectively, two formations were needed (Patton, 1956b). In the Arctic Foothills province two distinctive lithologic units occur in this stratigraphic interval, one generally north of the other. The southern unit consists of shale and a large percentage of coarse sandstone and conglomerate. The northern unit is composed predominantly of shale with very subordinate amounts of coarse clastics. Thus, there is little reason for correlating the two on the basis of lithologic characteristics. Furthermore, over much of the foothills the two units are separated either by a zone of intense thrust faults or by a band in which there are no exposures, and therefore direct tracing of the beds from one unit into the other is virtually impossible. Megafossils indicate that the two units are approximately of the same age, but the microfossils are somewhat different in age. Because the two units differ lithologically and because they cannot be traced from one into the other, the southern unit, which includes coarse clastic rocks, is now called Fortress Mountain Formation and the name Torok Formation is reserved for the northern predominantly shale unit.

LITHOLOGY

Sandstone, conglomerate, shale, and siltstone are the principal components of the Fortress Mountain Formation. Although both the Fortress Mountain and Okpikruak Formations are composed of similar rocks, the characteristic rhythmic alternation of sandstone, siltstone, and shale beds in the Okpikruak Formation is not so common in the Fortress Mountain Formation.

Conglomerate and sandstone.—Conglomerate and sandstone make up about 25 percent of the Fortress Mountain Formation at its type section (fig. 79) but, owing to the marked facies changes—particularly in a northward direction—the ratio of coarse clastics to fine clastics varies considerably from place to place in the mapped area.

The sandstone and conglomerate are typically of graywacke type. They are poorly sorted, highly argillaceous, commonly calcareous, and have low porosity. In color they range from predominantly dark greenish gray west of the Nanushuk River to predominantly medium gray east of the Nanushuk River. Individual beds are from less than 1 inch to more than 50 feet thick and characteristically are highly lenticular. Graded bedding was observed in many places.

The sandstone and conglomerate are intercalated and grade laterally into one another. The sandstone ranges from very fine grained to very coarse grained and from thin to thick bedded. Bedding surfaces of the sandstone are typically rough and uneven owing

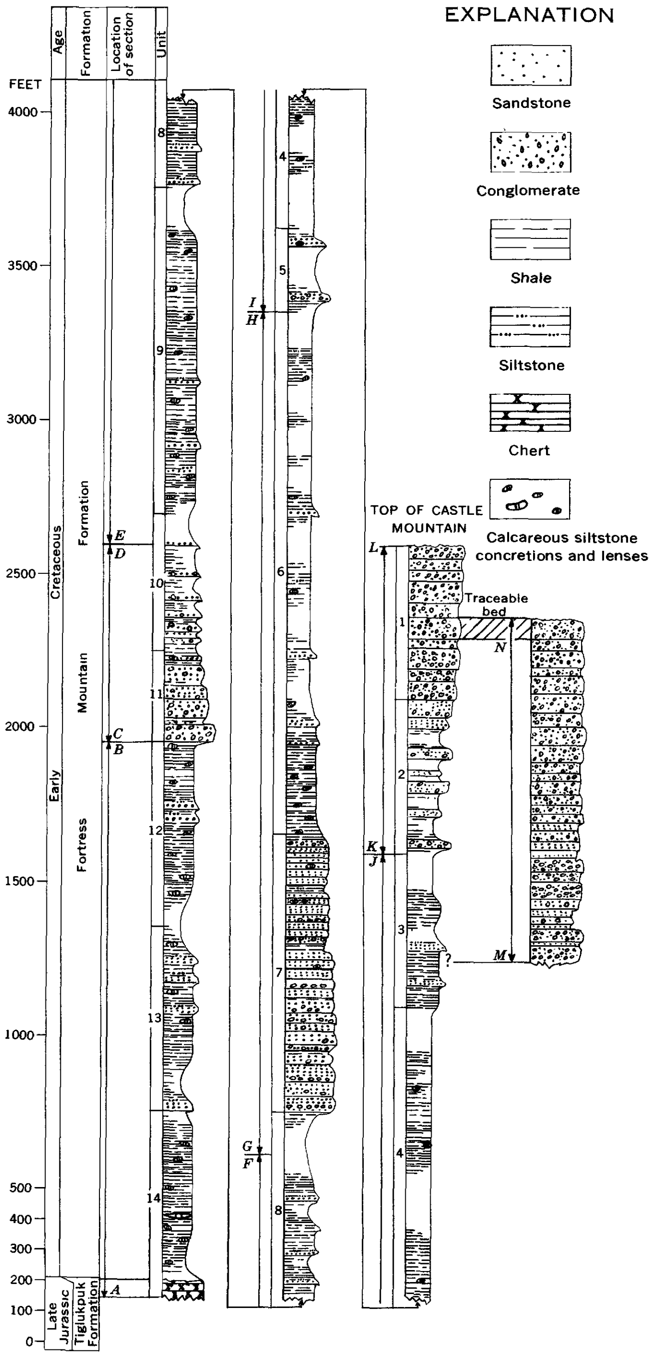

Figure 79.—Type section of the Fortress Mountain Formation (*A–L*). Correlated section (*M–N*) shows northward shaling out of conglomerate on Castle Mountain. Location of sections shown on figure 78.

to the presence of scour- and flow-cast markings. Carbonized plant debris and scattered pebbles and granules of chert and asphaltic shale occur even in the finest grained beds.

The conglomerate is composed of a wide variety of detritus ranging in size from clay and silt to cobbles a foot in diameter. Fragments large enough to be identified megascopically consist chiefly of varicolored chert and greenish mafic volcanic rock. In addition, there are subordinate amounts of light-gray bioclastic limestone (similar to limestone in the Lisburne Group), greenish-gray sandstone (probably from the Tiglukpuk and Okpikruak Formations), dark siliceous limestone (probably from the Shublik Formation), asphaltic shale (from the Tiglukpuk Formation), greenish quartzite, calcareous siltstone, ironstone, pink gneissoid granite, chips and blocks of shale and siltstone, and a variety of carbonized plant material.

Masses of chaotic conglomerate as much as 80 feet thick occur at the base of the formation. Such masses are exposed on Canoe Creek, lat 68°37′ N., long 153°03′ W.. in cutbanks on Pediment Creek at lat 68°36′ N., and on Peregrine Creek at lat 68°26′ N. These masses are virtually unsorted, extremely lenticular, poorly consolidated, and almost devoid of stratification. Angular to rounded pebbles and cobbles, including a high proportion of nonresistant types, are scattered through a mudlike matrix with no suggestion of preferred orientation or segregation. Randomly oriented slabs and blocks of shale and siltstone, presumably derived by penecontemporaneous erosion, were found in several outcrops. Carbonized wood fragments as much as several inches in length are ubiquitous.

Above the base of the formation the conglomerate is better sorted and contains a higher proportion of resistant clasts, notably chert. Stratification is well developed and grading is apparent in many beds.

Several thin sections of sandstone and conglomerate cursorily examined under the microscope have the following approximate composition: 7 to 10 percent quartz; 5 percent feldspar, chiefly sodic plagioclase; 25 to 45 percent chert; 10 to 40 percent mafic volcanic rock; and variable but subordinate amounts of calcite, pyroxenes, siltstone, shale, schist, limestone, sandstone, and quartzite. The matrix constitutes 25 to 50 percent of the rock and consists of finely divided clays, sericite, silt, chlorite, and calcite. The heavily chloritized mafic volcanic detritus and the chlorite in the matrix probably account for the pronounced greenish cast of the sandstone and conglomerate. Samples from east of the Nanushuk River, where the sandstone and conglomerate are gray rather than greenish gray, have much less igneous rock detritus than samples from west of the Nanushuk.

Except for the greater percentage of nonresistant lithic fragments at the base of the formation, there are few obvious differences in the character and composition of the sandstone and conglomerate either from bottom to top or from place to place.

Shale and siltstone.—Soft dark-gray rarely calcareous silty shale and clay shale make up the bulk of the Fortress Mountain Formation. Dark-gray or dark-greenish-gray siltstone in beds several inches thick is intercalated with the shale. Locally, the siltstone is calcareous and weathers light brown.

A variety of siliceous, ferruginous, argillaceous, and calcareous concretions and lenses are embedded in the shale. Ellipsoidal ferruginous and siliceous concretions as much as a foot in diameter are most abundant. Subspheroidal septarian concretions and thin lenses of calcareous siltstone are common, particularly in the lower part of the formation. Scattered fossil-wood fragments, pyrite nodules, and well-rounded and polished chert pebbles are found in the shale.

THICKNESS

The type section the Fortress Mountain Formation totals about 10,000 feet and is the thickest known section of the formation. It is doubtful whether thicknesses of the Fortress Mountain in excess of 5,000 feet are preserved anywhere else in the mapped area. About 4,000 feet was measured in the syncline that crosses the Siksikpuk River at lat 68°32′ N., and about 2,500 feet was measured in the Fortress Mountain syncline.

CONTACTS

The Fortress Mountain Formation rests unconformably, and in some places with apparent angular discordance, upon the Okpikruak Formation and older rocks. The nature of the upper contact is not known, for younger rocks are not preserved in the areas of Fortress Mountain outcrop. The Fortress Mountain and Torok Formations are thought to be at least in part equivalent; however, the precise stratigraphic relationship is uncertain. Between the Itkillik and Kiruktagiak Rivers the two formations are separated by a zone of thrusting that locally has brought slivers of pre-Fortress Mountain rocks to the surface. West of the Kiruktagiak River, exposures are poor and the nature and exact location of the Fortress Mountain-Torok contact are not certainly known.

Features that aid in distinguishing the Fortress Mountain Formation from the underlying Okpikruak Formation are (1) the scarcity of rhythmically alternating sandstone, siltstone, and shale sequences and (2) the presence of massive conglomerate and coarse sandstone units throughout the formation. Features that help to distinguish the Fortress Mountain from the Tiglukpuk Formation are (1) the absence of chert, black siliceous shale, variegated shale and siltstone, and coquinoid limestone, (2) the occurrence of massive conglomerate and coarse sandstone units throughout the formation, (3) the characteristic dark-greenish-gray and medium-gray color of the coarse clastic rock as compared with the characteristic greenish-gray coarse clastic rock of the Tiglukpuk Formation, and (4) the abundance of mafic volcanic detritus.

STRATIGRAPHIC SECTIONS

The type section of the Fortress Mountain is a generalized composite section that has been pieced together from several measured sequences on and around Castle Mountain. The locations of these sequences are shown in figure 78. The Fortress Mountain Formation is folded into a broad eastward-trending syncline that plunges eastward between the Ayiyak River and Castle Mountain (pl. 50). Locally, small faults and folds complicate the broad synclinal structure. Between the lower contact of the Fortress Mountain Formation on the Kiruktagiak River (fig. 78, point *A*) and the center of the syncline at Castle Mountain, discontinuous exposures indicate a regional southeastward dip. A thickness of about 9,000 feet was computed between the lower contact at point *A* (fig. 78) and the base of Castle Mountain at point *J*. The beds cropping out at point *J* were traced around the north flank of Castle Mountain to point *K* on the east side, where an additional 1,000 feet of section was measured to point *L* on top of the mountain. Sections exposed at *A′–B′*, *E′–F′*, *G′–H* , and *I′–J′* are correlative with parts of the type section and were used for additional lithologic and thickness data. Section *M–N* at the southeast end of the mountains was measured to demonstrate the northward facies changes that occur between it and section *K–L* (fig. 79). Sections *K–L* and *M–N* can be correlated by direct tracing of beds along the east side of the mountain.

Because of the wide spacing of the dip and elevation control points, and the possibility of small faults and folds in the covered intervals, the computed thicknesses are only approximate.

Composite type section of Fortress Mountain Formation, Castle Mountain area

[Measured by W. W. Patton, Jr., and I. L. Tailleur, 1949. Thickness computed trigonometrically using measurements from aerial photographs, altimeter, and Brunton compass. Graphic section, fig. 79]

	Thickness (feet)
Eroded, top of Castle Mountain.	
Cretaceous.	
Fortress Mountain Formation:	
1. Conglomerate and sandstone. Dark-greenish-gray thick-bedded pebble- and cobble-conglomerate that weathers moderate yellowish brown. Sixty percent of the pebbles and cobbles is chert, and 40 percent is limestone, sandstone, mafic igneous rock, and pink gneissoid granite. Dark-greenish-gray fine- to coarse-grained lenticular thick-bedded sandstone	500

Composite type section of Fortress Mountain Formation, Castle Mountain area—Continued

	Thickness (feet)
Cretaceous—Continued	
Fortress Mountain Formation—Continued	
2. Sandstone and conglomerate. Dark-greenish-gray fine- to medium-grained medium- to thick-bedded sandstone. Dark-greenish-gray thick-bedded pebble conglomerate. Pebbles similar to above but no gneissoid granite. Minor interbedded dark-gray silty shale and siltstone. Section partly covered	500
3. Shale, sandstone, and siltstone. Dark-gray clay shale and silty shale. Interbedded dark-greenish-gray very fine grained thin- to medium-bedded sandstone. Dark-gray to greenish-black siltstone. Section partly covered	500
4. Shale. Dark-gray clay shale and silty shale. Calcareous siltstone concretions. Section poorly exposed	1,400
5. Conglomerate and sandstone. Dark-greenish-gray thick-bedded lenticular chert-pebble conglomerate. Dark-greenish-gray fine- to coarse-grained sandstone with scattered chert pebbles. Minor interbedded dark-gray shale and siltstone. Section partly covered	250
6. Shale, siltstone, and sandstone. Dark-gray clay shale and silty shale with calcareous ferruginous and siliceous siltstone concretions. Dark-gray very fine grained to fine-grained medium-bedded sandstone. Section poorly exposed	1,700
7. Sandstone and conglomerate. Dark-greenish-gray very fine grained to fine-grained medium- to thick-bedded sandstone with scattered chert pebbles. Lenses 6 in. to 5 ft thick of dark-greenish-gray chert-pebble conglomerate. Minor interbedded dark-gray shale and dark-gray to greenish-black siltstone	900
8. Shale, siltstone, and sandstone. Dark-gray clay and silty shale. Dark-gray siltstone. Dark-greenish-gray very fine grained medium- to thick-bedded calcareous sandstone. Section partly covered	900
9. Shale. Dark-gray clay shale and silty shale with numerous calcareous, siliceous, and ferruginous siltstone concretions. Minor interbedded dark siltstone and greenish-gray very fine grained thin- to medium-bedded calcareous sandstone. Section partly covered	1,050
10. Shale, siltstone, sandstone, and conglomerate. Dark-gray clay shale and silty shale and dark-gray siltstone. Dark-greenish-gray very fine grained to coarse-grained thin- to medium-bedded sandstone, with some chert granules or pebbles. Dark-greenish-gray thin- to medium-bedded lenticular chert-granule and pebble conglomerate. Section partly covered	450

Composite type section of Fortress Mountain Formation, Castle Mountain area—Continued

	Thickness (feet)
Cretaceous—Continued	
Fortress Mountain Formation—Continued	
11. Sandstone and conglomerate. Dark-greenish-gray fine- to coarse-grained medium- to thick-bedded sandstone. Dark-greenish-gray lenticular chert-granule and pebble conglomerate. Minor interbedded dark-gray clay shale and silty shale	300
12. Shale, sandstone, and siltstone. Dark-gray clay shale with numerous septarian calcareous siltstone concretions; 75 ft of dark-greenish-gray thin- to medium-bedded very fine grained sandstone and dark-gray siltstone near middle of section. Section partly covered	600
13. Shale, sandstone, and siltstone. Dark-gray clay shale and silty shale with a few septate calcareous siltstone concretions. Greenish-gray thin-bedded very fine grained sandstone and medium dark-gray siltstone. Section partly covered	600
14. Shale. Dark-gray clay shale with lenses of gray silty limestone and septate calcareous siltstone concretions. Section partly covered	550
Total thickness of Fortress Mountain Formation approximately	10, 000
Jurassic.	
Tiglukpuk Formation: Greenish to grayish glassy bedded chert.	

Two sections of the Fortress Mountain Formation, in addition to the type section, were measured in the mapped area and are shown in figure 80 together with the lower part of the type section. One of the sections, about 4,000 feet thick, is exposed in cutbanks near the confluence of Tiglukpuk Creek and the Siksikpuk River. The upper 2,200 feet was measured on the west side of the Siksikpuk River about half a mile below the mouth of Tiglukpuk Creek, and the lower 1,800 feet was measured along a small tributary that enters Tiglukpuk Creek from the east about 2½ miles above the mouth of the creek.

On figure 80 a possible correlation is suggested between the coarse clastic zone 1,700 feet above the base of this Siksikpuk River section and the coarse clastic zone 1,750 feet above the base of the type section.

Section of Fortress Mountain Formation on the Siksikpuk River, lower 1,800 feet on small tributary at lat 68°29′ N., long 151°58′ W.; upper 2,200 feet in cutbank at lat 68°32′ N., long 152°01′ W.

[Measured by W. W. Patton, Jr., 1950. Thickness computed trigonometrically using measurements from aerial photographs, altimeter, and Brunton compass. Graphic section fig. 80]

	Thickness (feet)
Eroded, center of syncline.	
Cretaceous:	
Fortress Mountain Formation:	
1. Sandstone, shale, and siltstone. Medium-gray medium-bedded very fine grained to fine-grained sandstone. Subordinate coarse-grained sandstone with scattered chert pebbles and shale chips. Dark-gray clay and silty shale and siltstone. Calcareous silty septarian concretions	150
2. Clay shale, dark-gray; contains calcareous silty septarian concretions. A 10-ft lens of dark-greenish-gray chert-granule conglomerate at base	1, 050
3. Shale containing concretions, as above	400
4. Shale and siltstone. Medium-dark-gray silty shale and siltstone. Silty calcareous concretions and lenses	500
5. Sandstone and conglomerate. Greenish-gray medium-bedded very fine grained to fine-grained sandstone containing thin lenses of granule and pebble conglomerate. A massive 20-ft lens of pebble conglomerate at base	150
6. Siltstone, medium-dark-gray, medium-bedded in upper part, thin-bedded in lower part. Silty calcareous lenses near base	600
7. Shale. Dark-gray clay shale and silty shale. Calcareous lenses as in unit 6	800
8. Clay shale, dark-gray. Two lenses as much as 25 ft thick of chert-pebble and granule conglomerate	300
Total thickness of Fortress Mountain Formation approximately	4, 000
Jurassic:	
Tiglukpuk Formation: Bedded chert, chiefly greenish-gray and glassy.	

The other section shown in figure 80 was measured in the cutbanks exposed along Cobblestone Creek between lat 68°25′ N. and lat 68°27½′ N. The Fortress Mountain Formation and older rocks in this area have been sliced into a series of southward-dipping plates by closely spaced reverse faults, and the lower part of the Fortress Mountain Formation is duplicated several

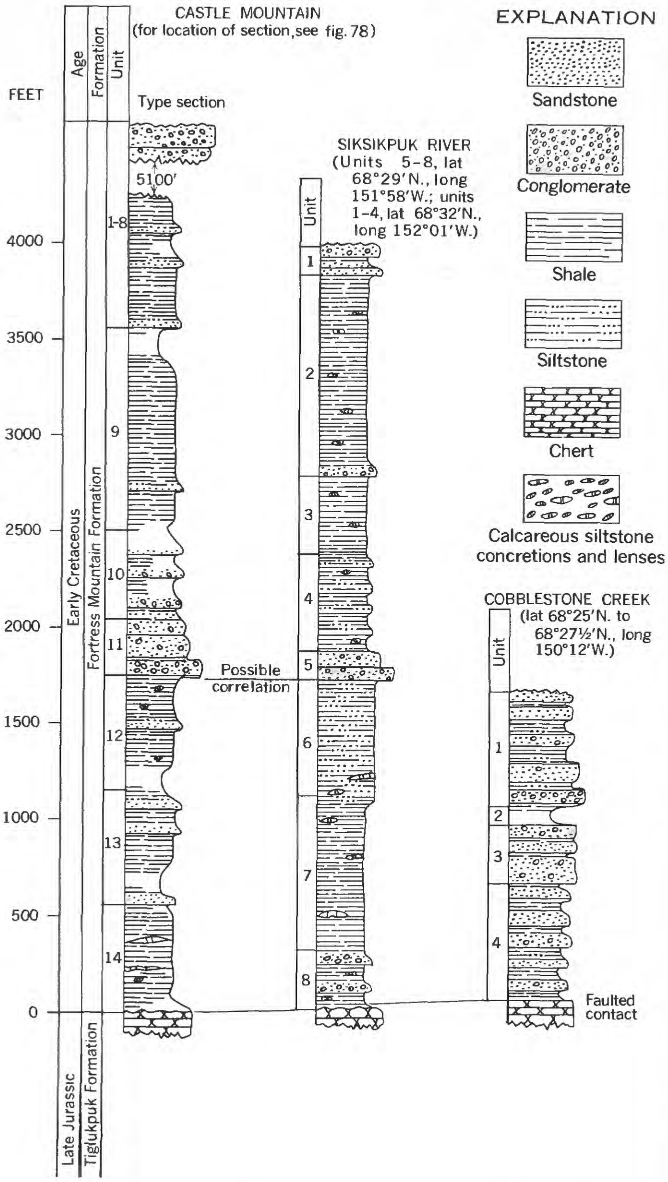

FIGURE 80.—Columnar sections of lower part of the Fortress Mountain Formation.

times. Both the top and the bottom of the section are cut off by faults, but correlation with nearby exposures indicates that not more than 200 feet is missing from the base of the formation.

Section of Fortress Mountain Formation on Cobblestone Creek in cutbanks between lat 68°25′ N. and 68°27½′ N., long 150°12′ W.

[Measured by W. W. Patton, Jr., 1950. Thicknesses computed trigonometrically using measurements from aerial photographs, altimeter and Brunton compass Graphic section, fig. 80]

Fault.

Cretaceous.

	Thickness (feet)
Fortress Mountain Formation:	
1. Sandstone, shale, and siltstone. Medium-gray very fine grained to medium-grained medium- to thick-bedded sandstone with scattered chert granules. Dark-gray clay shale, silty shale, and siltstone. A 6-ft chert-pebble conglomerate lens near base	600
2. Covered	100
3. Sandstone and shale. Medium-gray very fine grained to medium-grained medium- to thick-bedded sandstone. Dark-gray clay shale and silty shale. A few chert-granule conglomerate lenses	300
4. Sandstone and shale. Medium-gray very fine grained to coarse-grained thin- to thick-bedded sandstone; locally contains chert granules. Dark-gray clay shale and silty shale	600
Total thickness of Fortress Mountain Formation approximately	1, 600

Fault.

Jurassic:

Tiglukpuk Formation: Greenish-gray bedded chert.

The coarse clastic rocks of the Fortress Mountain Formation grade rapidly northward into finer clastic rocks. The change of facies is strikingly demonstrated on the east side of Castle Mountain where conglomerate beds at the top of the formation can be traced northward into sandstone, siltstone, and shale. Figure 79 shows that most of the conglomerate that comprises the lower two-thirds of section *M–N* grades into shale, siltstone, and sandstone in the type section, less than a mile to the north. A similar rapid facies change was observed at Fortress Mountain, where in a distance of 2 miles a sequence of conglomerate, 650 feet thick (figs. 81, 82) on the south side of the mountain was traced into sandstone on the north side of the mountain.

Few stratigraphic correlations in the Fortress Mountain Formation can be made across the mapped area,

FIGURE 81.—Several hundred feet of conglomerate of the Fortress Mountain Formation exposed on the south face of Fortress Mountain.

owing to the rapid facies changes and the absence of distinctive and persistent marker beds. Furthermore, considerable thicknesses of the formation apparently are missing locally because of intraformational unconformities. Unconformities, some with slight angluar discordance, were observed where thick sequences of coarse clastics rest upon shale. However, none of these unconformities could be traced far for lack of stratigraphic control and complete exposure. That numerous local unconformities occur throughout the formation is also suggested by the overall decrease in intensity of deformation upward in the formation. Apparently folding occured contemporaneously with deposition.

AGE

Fossils are not abundant in the Fortress Mountain Formation, and most of those collected proved to be long-ranging forms of little significance in determining the age of the enclosing rocks.

Mollusks collected from the Fortress Mountain Formation are listed below. They were identified by R. W. Imlay (1961, p. 31).

49ATr167, USGS Mesozoic loc. 21825, from cutbank on north side of Fortress Creek, lat 68°37′ N., long 152°54′ W. Clay shale and silty shale.
Inoceramus sp. juv.
Fossil wood, undet.

49ATr722, USGS Mesozoic loc. 21556, from cutbank on east side of Kiruktagiak River, lat 68°37′ N., long 152°42′ W. Shale and calcareous concretions.
Aucellina dowlingi McLearn

49APa345, USGS Mesozoic loc. 21558, from cutbank on east side of Okpikruak River, lat 68°38′ N., long 153°30′ W. Calcareous sandstone.
Colvillia crassicostata Imlay
C. kenti Imlay

49APa584, USGS Mesozoic loc. 21562, from cutbank on west side of Kiruktagiak River, lat 68°37′ N., long 152°42′ W. Shale and calcareous concretions.
Aucellina dowlingi McLearn

49APa613, from cutbank on east side of Kiruktagiak River, lat 68°35′ N., long 152°45′ W. Sandstone. From type section, Fortress Mountain Formation, unit 11 (p. 454).
Inoceramus sp.

50AKe291, from cutbank on east side of tributary to Siksikpuk River, lat 68°33′ N., long 152°06′ W. Sandstone.
Pleuromya sp.

FIGURE 82.—View showing west end of Fortress Mountain syncline. The thick sequence of conglomerate that forms the craggy spurs on the south flank of the syncline grades into sandstone and shale on the north flank. Photograph by U.S. Navy.

All six megafossil collections apparently come from the lower 3,000 feet of the formation. According to Imlay, these beds can be dated as early Albian on the basis of the occurrence of *Colvillia crassicostata* Imlay and *Aucellina dowlingi* McLearn.

Imlay (1961, p. 8.) says,

> The age of the *Colvillia crassicostata* zone within the Fortress Mountain Formation and the lower part of the Torok Formation is probably early Albian. Stratigraphic position alone, some thousands of feet below beds containing *Gastropolites* and *Cleoniceras*, indicate that it is early Albian or older. An Aptian age seems unlikely because it lacks such ammonites as *Deshayesites*, *Sanmartinoceras*, *Tropaeum*, and *Crioceras* that occur in late Aptian beds in Greenland. * * * An early Albian rather than an Aptian age is favored also by the characteristics of some of the mollusks in the *Colvillia crassicostata* zone. The resemblance of *Aucellina dowlingi* McLearn to *A. gryphaeoides* (Sowerby) indicates an age not older than Albian if the stratigraphic distribution of the species of *Aucellina* is the same in North America as in Eurasia * * *. The genus *Colvillia* shows considerable resemblance to *Callizoniceras* of late Barremian to early Albian age. Its presence alone is fairly good evidence that the enclosing beds are not younger than early Albian.

Vertebrate remains (colln. 49ATr601) from a shale bank on Torok Creek east of Castle Mountain (lat 68°32′ N., long 152°30′ W.), were examined by David H. Dunkle (written communication, 1949), who identified the collection as parts of a fossil fish skeleton and referred it questionably to the Aspidorhynchidae family, which ranges from Late Jurassic to Late Cretaceous.

Of 377 samples of shale from the Fortress Mountain Formation, that were collected and washed for microfossils, only 161 proved to be fossiliferous. The microfossil collections were examined by Harlan R. Bergquist (written communication, 1953). Twenty-two samples from the type section of the Fortress Mountain Formation yielded the following collections:

Unit 3:
- *Haplophragmoides topagorukensis* Tappan
- *Bathysiphon brosgei* Tappan
- *Pallaimorphina ruckerae* Tappan

Unit 6:
- *Haplophragmoides topagorukensis* Tappan
- *Pallaimorphina ruckerae* Tappan
- *Nanushukella umiatensis* Tappan
- *Marginulina dorsata* Cushman

Units 7 and 8:
- *Haplophragmoides topagorukensis* Tappan
- *Trochamina eilete* Tappan
- *Nanushukella umiatensis* Tappan
- *Pallaimorphina ruckerae* Tappan

Units 12–14:
- *Bathysiphon brosgei* Tappan
- *Bathysiphon vitta* Nauss
- *Haplophragmoides topagorukensis* Tappan
- *Ammodiscus rotalarius* Loeblich and Tappan
- *Saccammina lathrami* Tappan
- *Gaudryina tailleuri* (Tappan)

Units 12–14—Continued
- *Glomospira* cf. *G. gaultina* (Berthelin)
- *Trochamina eilete* Tappan
- *Saracenaria trollopei* Mellon and Wall
- *Globulina* sp.
- *Nodosaria* sp.
- *Lenticulina* sp.
- *Glomospira corona* Cushman and Jarvis

In addition to the forms listed above, the following were identified from collections from the Fortress Mountain Formation elsewhere in the mapped area:

- *Gaudryina* sp.
- *Reophax* fragment
- *Marginulina dorsata* Cushman
- *Zonodiscus* sp.
- *Glomospira corona* Cushman and Jarvis
- *Marginulinopsis jonesei*? (Reuss)
- *Robulus* A
- *Lenticulina* E
- *Rectoglandulina* D
- *Dentalina*? *dettermani* Tappan
- *Marginulina planiuscula* (Reuss)
- *Saracenaria navicula* (d'Orbigny)
- *Valvulineria loetterlei* Tappan
- *Lenticulina polygona* (Perner)
- *Lenticulina macrodisca* (Reuss)
- *Vaginulinopsis* sp.
- *Astacolus strombecki* (Reuss)
- *Ammodiscus rotalarius* Loeblich and Tappan
- *Gaudryina tailleuri* (Tappan)
- *Praebulimina nannina* (Tappan)
- *Gavelinella awunensis* (Tappan)
- *pyritic Lithocampe*? sp
- *Dictyomitra*
- Fragments of *Inoceramus*
- Ostracode

Except for the collections from units 3 and 6 of the type section, all collections are probably from the lower 4,000 feet of the Fortress Mountain Formation. The microfossils have not proved to be significant in determining the age of this formation; however, they are of some value in distinguishing the lower part of the Fortress Mountain from the lower and upper parts of the Torok Formation and the Nanushuk Group. In this regard Bergquist states (written communication, 1957):

> In the lower part of the Torok Formation and in the Fortress Mountain Formation the microfauna is small and in general consists of *Gaudryina tailleuri*, *Haplophragmoides topagorukensis*, *Trochammina eilete*, *Gavelinella awunensis*, *Pallaimorphina ruckerae*, and pyritic casts of *Lithocampe*? sp. *Gaudryina tailleuri* is entirely restricted to the Fortress Mountain Formation and the lower part of the Torok. This foraminifer does not range into the upper part of the Torok Formation, but the other species mentioned are found sparingly in it. *Gavelinella awunensis* was found in more samples in the lower Torok than in samples from other beds, and *Pallaimorphina ruckerae* occurred more often in samples of the Fortress Mountain Formation than in samples from other formations.

The upper part of the Fortress Mountain Formation cannot be dated except indirectly, owing to the lack of diagnostic fossils. Furthermore, the stratigraphic relationships of the Fortress Mountain Formation to the Torok Formation and the Nanushuk Group, which lie to the north, are uncertain. It seems unlikely, however, that the Fortress Mountain Formation is as young as the Nanushuk Group (middle Albian to Cenomanian). The paralic coal-bearing deposits which constitute the Nanushuk Group could hardly be contemporaneous with the marine graywacke deposits of the Fortress Mountain Formation, for both sequences appear to have been derived from a southerly source. Presumably, therefore, the top of the Fortress Mountain Formation is no younger than middle Albian.

TOROK FORMATION

The Torok Formation, as redefined (Patton, 1956b, p. 222–223), consists of the predominantly shale sequence that underlies the Nanushuk Group in the Arctic Foothills province of northern Alaska. The base of the shale sequence is not exposed, but presumably it is underlain by the Okpikruak Formation and perhaps, where present, by a part of the intervening Fortress Mountain Formation. The Torok Formation does not include, as originally defined (Gryc, Patton, and Payne, 1951, p. 160–162), the sandstone, conglomerate, and intercalated shale sequence that overlies the Opkikruak Formation and crops out along an eastward-trending belt near the southern margin of the Foothills province. This sequence has been reallocated by Patton (1956b, p. 219–220) to the Fortress Mountain Formation.

The Torok Formation derives its name from Torok Creek, a tributary of the Chandler River. The type locality is designated as Torok Creek and the Chandler River between the mouth of Torok Creek and the mouth of the Kiruktagiak River. The type section is in cutbanks along the Chandler River and Torok Creek between lat 68°40′ N. and lat 68°43′45″ N.

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Torok Formation occurs in the northern part of the mapped area along an eastward-trending belt that extends from the Killik River nearly to the Itkillik River. Between the Killik and Anaktuvuk Rivers the belt ranges in width from 5 to 9 miles, but from the Anaktuvuk eastward it narrows and near May Creek is less than a mile wide. On the north side, the Torok belt is bounded by gently dipping strata of the Nanushuk Group. On the south side between the Itkillik and Kiruktagiak Rivers it is bounded by a zone of faulting along which Fortress Mountain and older rocks have been thrust northward onto Torok strata. Between the Kiruktagiak and Killik Rivers the Torok and Fortress Mountain Formations could not be satisfactorily differentiated for lack of exposures, and the nature and precise location of the contact is not known. The Torok Formation is also exposed north of the main belt along the axis of the May Creek anticline from 2 miles west of the Nanushuk River to the Itkillik River valley.

A broad lowland, bounded on the north by the Tuktu Escarpment and on the south by the ridges and mesas of the Fortress Mountain belt, has been carved from the nonresistant shale that makes up the bulk of the Torok Formation. Scattered low tundra-covered ridges mark the occurrence of lenticular sandstone bodies within the shale. Exposures are confined to small disconnected cutbanks along several of the streams, namely, the Ayiyak River, Kiruktagiak River, Torok Creek, Chandler River, and Autumn Creek. The interstream areas are devoid of outcrops.

PREVIOUS WORK

The Torok Formation was not identified as a separate stratigraphic unit before the present investigations of the Arctic Foothills province. Schrader (1904) probably included the rocks later assigned to the Torok Formation in his Anaktuvuk Series and Smith and Mertie (1930) placed these rocks in their so-called Upper Cretaceous Series.

In 1948 R. L. Detterman (written communication) examined in detail the exposures at the type locality. He described a sequence lying below the Nanushuk Group on the Chandler River, which he estimated to be about 4,700 feet thick. In 1949 this sequence was examined by the authors. More fossils were collected, and an additional section, estimated to be about 1,400 feet thick, was found on the Chandler River and Torok Creek underlying Detterman's 4,700-foot sequence. The complete sequence, about 6,000 feet thick, was included in the original description of the Torok Formation given by Gryc, Patton, and Payne in 1951. However, as then defined, the Torok also included the coarse clastic rocks that were later assigned to the Fortress Mountain Formation. The Torok was redefined in 1956 (Patton, 1956b, p. 222–223) and the 6,000-foot sequence on the Chandler River and Torok Creek was designated as the type section.

LITHOLOGY

The bulk of the Torok Formation is composed of dark-gray and dark-bluish-gray fissle to platy soft silty shale and clay shale. Locally, the shale is brittle and hackly fracturing. Intercalated with the shale in subordinate amounts are thin beds of greenish-gray to dark-gray siltstone and lenses, 2 to 24 inches thick, of dark-gray dense silty limestone that weathers moderate yellowish brown. Subspheroidal ferruginous, calcareous, and siliceous concretions, marcasite nodules and carbonized plant fragments are scattered through the shale and siltstone.

Lenticular bodies of sandstone as much as 800 feet thick occur locally in the shale. Most commonly the sandstone is thin to medium bedded, very fine grained to fine grained, and either light to medium gray or dark greenish gray. All the sandstone is argillaceous and some is calcareous; porosity appears to be negligible. The bedding-plane surfaces of the sandstone are frequently coated with finely comminuted carbonaceous matter, shale chips, and rarely with chert granules. Thin lenses of coarse sandstone and granule conglomerate are scattered through some of the sandstone bodies.

A sample of coarse sandstone from the type section was examined in thin section and found to have the following approximate composition: 10 percent quartz and quartzite; 10 percent feldspar, chiefly plagioclase; 40 percent chert and cherty siltstone; 3 percent mafic igneous rock; 20 percent calcite; and 15 to 20 percent finely divided silt, chlorite and clays. The silt, chlorite, clays, and calcite constitute the matrix or bonding material, and the rest of the mineral and lithic fragments occur as detrital grains as much as 3.0 mm in diameter.

THICKNESS

The base of the Torok is not exposed; therefore the total thickness of the formation cannot be determined. The type section, about 6,000 feet thick, is probably about the thickest section of the Torok Formation exposed in the mapped area.

CONTACTS

The Torok Formation is overlain conformably by the Tuktu Formation, the basal unit of the Nanushuk Group. The contact is marked by sandstone on shale and, where gradational, is arbitrarily placed at the base of the lowest sandstone bed.

STRATIGRAPHIC SECTION

The type section of the Torok Formation (figs. 83, 84) crops out sporadically along the Chandler River and Torok Creek from the base of the Tuktu Formation on the Tuktu Escarpment southward to lat 68°40′ N. On the Chandler River, thicknesses of strata were computed by using the average dip of the strata and horizontal distances measured from vertical aerial photographs. Because of the structural complexity and extensive covered areas, the thicknesses should be considered as only approximations.

Type section of Torok Formation in cutbanks on the Chandler River and Torok Creek, between lat 68°40′ N. and lat 68°43′45″ N.

[Upper 4,700 ft described by R. L. Detterman, 1948; lower 1,400 ft by W. W. Patton, Jr., and I. L. Tailleur, 1949. Thicknesses computed trigonometrically using measurements from aerial photographs and Brunton compass. Graphic section, fig. 84]

	Thickness (feet)
Cretaceous.	
Tuktu Formation:	
Sandstone, medium dark-gray, fine-grained, argillaceous, crossbedded. Four in. of chert granule-pebble conglomerate. Siltstone.	
Torok Formation:	
1. Covered interval; computed thickness approximately	50
2. Clay shale, dark-bluish-gray, hackly fractured, well-indurated; interbedded with numerous layers of calcareous greenish siltstone and silty shale. Small drag folds and faults common; partly covered; computed thickness approximately	350

FIGURE 83.—Lower part of the Torok Formation at its type section along east bank of Chandler River. Shows characteristic crenulations in the incompetent strata of the Torok Formation. Photograph by U.S. Navy.

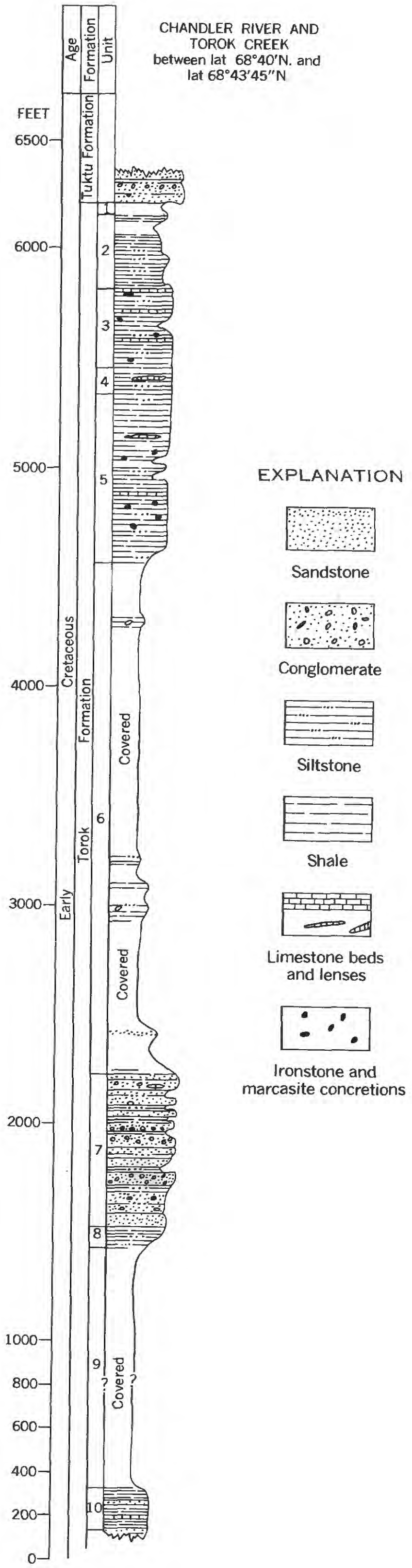

FIGURE 84.—Type section of the Torok Formation.

Type section of Torok Formation in cutbanks on the Chandler River and Torok Creek, between lat 68°40′ N. and lat 68°43′45″ N.—Continued

	Thickness (*feet*)
Cretaceous—Continued	
Torok Formation—Continued	
3. Silty clay shale, bluish-gray, hard, hackly fractured; becomes more silty near base. Numerous interbedded layers of calcareous siltstone, silty shale, and silty moderate yellowish-brown limestone. Marcasite concretions locally abundant; mud lumps and rill markings common. Part of section inaccessible; computed thickness approximately	360
4. Clay shale, paper thin, medium bluish-gray, with irregular fractures, breaking into small flakes; few limestone lenses and nodules. Interbedded with layers of greenish-yellow carbonaceous siltstone that are thinner and less numerous than in section above	120
5. Clay shale, claystone, siltstone, and silty shale. The clay shale is very hard, irregularly fractured, and interbedded with numerous layers of silty shale and siltstone; some thin silty moderate-yellowish-brown weathering limestone. Some white salt efflorescence on the clay shale. Ferruginous zones common with ironstone concretions as much as 2 in. in diameter common in lower part. Scattered fossils 260 ft above base. Some of the unit inaccessible along river; computed thickness approximately	780
6. Mostly covered, with a few rubble patches of clay shale, silty shale, and siltstone; 10 ft of indurated light-brown fine-grained calcareous sandstone (180 ft from base); a few wood fragments and ironstone concretions; computed thickness approximately	2,340
7. Sandstone and granule conglomerate. Dark-greenish-gray very fine grained to coarse-grained thin- to thick-bedded sandstone. Beds are thicker near base. Granule conglomerate in thin lenses. Subordinate interbedded dark-gray shale and siltstone. Dark-gray calcareous siltstone lenses and calcareous silty and sandy concretions as much as 16 in. in diameter; computed thickness approximately	700
8. Shale and siltstone, dark-gray; computed thickness (approx)	100
9. Covered. Exposures at about this stratigraphic position on south side of anticline are chiefly shale; computed thickness approximately	1,100
10. Shale, siltstone, sandstone, and limestone. Light- to dark-gray silty shale and clay shale. Light-gray siltstone and very fine grained thin-bedded sandstone. Medium-gray dense limestone weathering moderate yellowish brown in lenticular beds as much as 2 ft thick; computed thickness approximately	200

Type section of Torok Formation in cutbacks on the Chandler River and Torok Creek, between lat 68°40′ N. and lat 68°43′45″ N.—Continued

	Thickness (feet)
Center of anticline.	
Total thickness of Torok Formation about	6, 000

In addition to small faults and drag folds which may have caused inaccuracies in the measurement of the type section, it is possible that a major fault and an angular unconformity are present. The fault and unconformity have been postulated by E. J. Munns, seismologist, United Geophysical Co., on the basis of a reflection seismograph profile across the belt of the Torok Formation (p. 488 and pl. 51). The fault, according to Munns, intersects the surface between shot points 12 and 13 (pl. 51) and is a steeply northward-dipping reverse fault. If the strike of the fault parallels the regional strike of the strata, the fault would cross Torok Creek and the Chandler River at about lat 68°41′ N. and intersect the type section near the unit 9 covered interval. Unfortunately, the seismic reflections are of such poor quality that it is impossible to estimate the amount of stratigraphic displacement along the fault. The unconformity, which intersects the surface between shot points 4 and 5 (pl. 51), if projected to the type section would occur in the covered interval of unit 6 (fig. 84). No field evidence to support this postulated angular unconformity was found along the belt of the Torok Formation, but in view of the scarcity of Torok exposures the possibility cannot be ruled out.

The presence of an unconformity within the Torok is also suggested indirectly by microfossil evidence. Bergquist (1956, p. 1670) found that throughout northern Alaska beds equivalent to the lower part of the Torok Formation contain a somewhat different microfauna than the beds equivalent to the upper part of the Torok. In the type section the change in faunas apparently occurs between units 5 and 7, thus coinciding with the postulated unconformity. In some well logs from the subsurface of the northern Arctic Foothills and Arctic Coastal Plain the two faunas appear to be separated by an unconformity of slight angular discordance. In other wells, however, there is no evidence of a stratigraphic discontinuity between the two faunas (Robinson and others, 1956, p. 226).

AGE AND CORRELATION

Megafossils were found in the Torok Formation at only four localities. The collections, examined and identified by Ralph W. Imlay (1961, p. 31), are listed below:

48ADt86, USGS Mesozoic loc. 25120, unit 5 of type section of Torok Formation (p. 460).
Inoceramus sp. juv. cf. *I. anglicus* Woods

49ATr641, USGS Mesozoic loc. 21554, unit 7 of type section of Torok Formation (p. 460).
Beudanticeras (*Grantziceras*) *affine* (Whiteaves)
Colvillia crassicostata Imlay
Colvillia cf. *C. crassicostata* Imlay
Puzosia? sp. juv.
Inoceramus sp. juv.

49ATr754, USGS Mesozoic loc. 21557, from siltstone in cutbank on east side of Pediment Creek, lat 68°43′ N., long 153°15′ W.
Subarcthoplites cf. *S. colvillensis* Imlay

50APa201, USGS Mesozoic loc. 22593, from calcareous siltstone in cutbank on east side of tributary to Kanayut River, lat 68°34′ N., long 150°45′ W.
Gastroplites cf. *G. kingi* Mclearn

Imlay (written communication, 1957) recognizes three faunal zones in the Torok: a lower zone of *Colvillia crassicostata*, a middle zone of *Subarcthoplites*, and an upper zone of *Gastroplites kingi* which ranges up into the Tuktu Formation. The middle and upper zones apparently are separated by a stratigraphic interval of the Torok Formation which locally contains *Cleoniceras*. *Cleoniceras*, however, is not restricted to this interval but ranges up into the *Gastroplites kingi* zone. The *Colvillia crassicostata* zone is represented in the mapped area by a collection, 49ATr641, from unit 7 of the type section. According to Imlay, this collection is probably correlative with the only collection, 49APa345, of ammonites found in the Fortress Mountain Formation. Imlay's remarks concerning the age of the lower zone are given on page 457. In regard to *Puzosia*? sp. juv. he states:

> The small ammonites referred to *Puzosia*? sp. juv. are similar to the Greenland "*Puzosia*" *sigmoidalis* Donovan which is associated with *Leymeriella* of early Albian age. *Beudanticeras* (*Grantziceras*) *affine* (Whiteaves) shows some resemblance to certain species of *Beudanticeras* from the Albian of Europe and, also, to the early Albian *Anadesmoceras*.

The *Subarcthoplites* zone is also considered by Imlay to be early Albian in age because of its occurrence below *Cleoniceras*, which in western Europe ranges from late early Albian into middle Albian. The *Subarcthoplites* zone is represented in the mapped area by collection 49ATr754 from an isolated cutbank exposure on Pediment Creek. The stratigraphic position of this collection within the Torok Formation is unknown.

The *Gastroplites kingi* zone is assigned a middle Albian age principally because of the presence of *Cleoniceras* below and within the zone. In the mapped area *Gastroplites kingi* was found in collection 50APa201 in the Kanayut River basin, but again the stratigraphic position of the collection could not be determined, owing to structural complexities and discontinuous exposures.

Of the 125 samples of shale from the Torok that were collected and washed for microfossils, 50 proved to be barren. The samples were examined by H. R. Bergquist (written communication, 1953), and the fossils that were identified are given below:

Ammobaculites fragmentarius Cushman
Bathysiphon brosgei Tappan
Bathysiphon vitta Nauss
Bathysiphon?
Gaudryina tailleuri (Tappan)
Gaudryina?
Gavelinella awunensis Tappan
Glomospira corona Cushman and Jarvis
Glomospirella gaultina (Berthelin)
Haplophragmoides topagorukensis Tappan
Ammodiscus rotalarius Loeblich and Tappan
Miliammina sp.
Pallaimorphina ruckerae Tappan
Psamminopelta bowsheri Tappan
Saccammina lathrami Tappan
Trochammina eilete Tappan
Trochammina rutherfordi Stelck and Wall
Trochammina sp.
Vaginulinopsis sp.
Verneuilinoides borealis Tappan
Verneuilinoides?
Zonodiscus?
"*Spongodiscus*"
Cast *Rectoglandulina*
Fragment of *Reophax*
Pyrite cast *Dentalina?*
Dictyomitra
Pyritic casts of *Lithocampe?* sp.
Ditrupa sp.
Pyritic pelecypod cast
Inoceramus
Fish teeth
Spore

Bergquist comments on the microfossil collections:

Within the Torok Formation are two microfaunas. In the lower part of the formation and in the Fortress Mountain Formation the microfauna is small and in general consists of *Guadryina tailleuri* (Tappan), *Haplophragmoides topagorukensis* Tappan, *Trochammina eilete* Tappan, *Gavelinella awunensis* Tappan, *Pallaimorphina ruckerae* Tappan, and pyritic casts of *Lithocampe?* sp. *Gaudryina tailleuri* is entirely restricted to the Fortress Mountain Formation and the lower part of the Torok and does not range into the upper part of the Torok Formation, but the other species mentioned are found sparingly in it. *Gavelinella awunensis* was found in more samples in the lower Torok than in samples from other beds, and *Pallaimorphina ruckerae* occurred more often in samples of the Fortress Mountain Formation than in samples from other formations.

A very extensive microfauna ranges through the upper part of the Torok Formation and the Tuktu Formation. I have named this the *Verneuilinoides borealis* faunal zone from its most prominent Foraminifera. Associated with this species are about 60 other species of Foraminifera and a few Radiolaria. *Inoceramus* prisms, and tapered curved worm tubes (*Ditrupa* sp.) are common to this zone, particularly in the upper part. The *Verneuilinoides borealis* faunal zone is characterized by such species as *Haplophragmoides topagorukensis* Tappan, species of *Psamminopelta*, species of *Miliammina*, species of *Ammobaculites, Gaudryina canadensis* (Cushman), *Gaudryina nanushukensis, Textularia topagorukensis, Tritaxia manitobensis*, species of *Eurycheilostoma, Gavelinella stictata* (Tappan), etc. Most of these species are absent or very rarely found in the lower part of the Torok and the Fortress Mountain Formation.

According to Imlay (written communication, 1957), the base of the *Gastroplites kingi* megafossil zone coincides with the base of the *Verneuilinoides borealis* microfossil zone.

Both the megafossil and microfossil collections suggest that at least the lower parts of the Torok and Fortress Mountain Formations are lateral equivalents. The fact that the two formations differ lithologically does not preclude the possibility that they are contemporaneous. A rapid facies change in the Fortress Mountain Formation from coarse clastics into shale in a northward direction has already been described. In view of this, it is not unreasonable to assume that most of the coarse clastic beds of the Fortress Mountain belt have graded into shale in the latitude of the Torok belt, especially if the possibility of north-south foreshortening due to thrust faulting along the boundary of the two belts is considered.

NANUSHUK GROUP

The Nanushuk Group overlies the Torok Formation and is exposed in a broad eastward-trending belt across the center of the Arctic Foothills. It consists of a thick sequence of nonmarine and marine strata; the nonmarine strata predominate in the southern part of the belt and interfinger with the marine strata which predominate in the northern part of the belt. The Nanushuk Group was subdivided into several formations and tongues chiefly on the basis of the marine and nonmarine lithologic characteristics (fig. 85).

The Nanushuk Series is the name Schrader (1904) applied to Upper Cretaceous rocks that crop out along the northern edge of the Arctic Foothills. However, the Nanushuk Group, as redefined by Gryc, Patton, and Payne (1951, p. 162–164) is stratigraphically somewhat lower and apparently includes the upper part of Schrader's Anaktuvuk Series (Lower Cretaceous) and the lower part of his Nanushuk Series (Upper Cretaceous). The stratigraphic nomenclature of the Nanushuk Group as defined by Gryc, Patton, and Payne was revised by Detterman (1956).

The subdivisions of the Nanushuk Group that crop out in the Killik-Itkillik region are, in ascending stratigraphic order, the Tuktu, the Chandler, and the Ninuluk Formations (fig. 85.)

TUKTU FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The Tuktu Formation, named for the exposures at Tuktu Bluffs on the Chandler River, occurs at the base of the Nanushuk Group and overlies the Torok Forma-

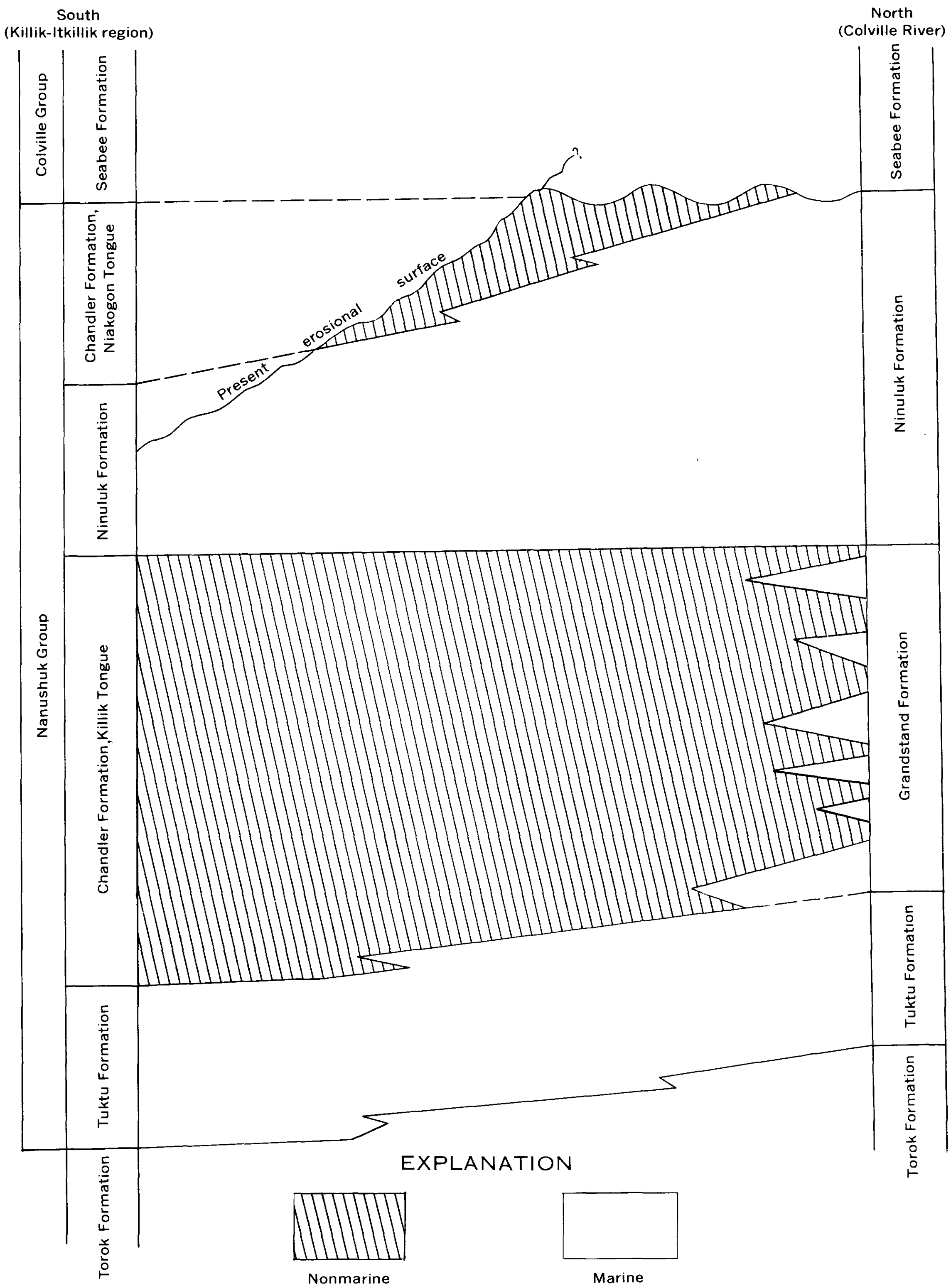

FIGURE 85.—Schematic diagram of the Nanushuk Group in the northern section of the Arctic Foothills. Modified from Gryc and others (1956, fig. 4).

tion. It crops out along a narrow belt extending from the Okpikruak River eastward to the Itkillik River valley. Between the Okpikruak and Siksikpuk Rivers the belt parallels the northern edge of the map and averages a mile in width. From the Siksikpuk River the belt swings southeastward and gradually narrows to a width of 0.3 mile on May Creek. The Tuktu Formation also occurs in the flanks of the Arc Mountain anticline between the Kanayut and Itkillik Rivers.

From the Okpikruak River eastward to May Creek the Tuktu Formation and the basal beds of the Chandler Formation form a prominent south-facing cuesta, the Tuktu Escarpment, which rises as much as 2,000 feet above the lowland that has been carved out of the Torok Formation. The same sequence of strata also forms a hogback that surrounds the core of the Arc Mountain anticline. In the interstream areas both the Tuktu Escarpment and the hogback are largely covered with tundra, except for scattered bedding traces of rubble. However, rocks of the Tuktu Formation are well exposed in cutbanks where these ridges are transected by the major streams.

LITHOLOGY

The Tuktu Formation is composed chiefly of marine sandstone which typically is thin to medium bedded, fine grained, gray to greenish gray, and locally calcareous. The sandstone is better sorted and contains a higher proportion of resistant minerals than sandstone in the Okpikruak and Fortress Mountain Formations; nevertheless, it is highly argillaceous and has a low permeability. Dark-greenish-gray and gray siltstone and medium- to dark-gray clay and silty shale are intercalated with the sandstone in minor amounts. Pyrite nodules, small ironstone concretions, and carbonized plant detritus are locally abundant.

A cursory examination of two thin sections of sandstone samples selected from a typical exposure of the Tuktu on the Nanushuk River revealed the following composition: angular to subround grains of quartz, 30 to 40 percent; chert, 5 percent; feldspar, chiefly plagioclase, 2 percent; and a matrix of fine silt, sericite, clay, and chlorite, 50 to 60 percent.

THICKNESS

The full section of the Tuktu Formation is 1,000 feet thick at the type locality at Tuktu Bluff on the Chandler River, 1,350 feet thick at Gunsight Mountain on the Siksikpuk River, and 940 feet thick on the Nanushuk River.

CONTACTS

The Tuktu Formation conformably overlies the Torok Formation and conformably underlies the Killik Tongue of the Chandler Formation. The basal contact is marked by sandstone on shale and, where gradational, it is arbitrarily placed at the base of the lowest sandstone bed. The upper contact separates marine strata from predominantly nonmarine strata. East of the Anaktuvuk River the upper contact is well defined and nongradational; greenish-gray sandstone of the Tuktu Formation is overlain by a massive ledge of light-gray "salt and pepper" sandstone of the Killik Tongue. However, west of the Anaktuvuk River this contact becomes gradational and is arbitrarily placed at the base of the lowest "salt and pepper" sandstone.

STRATIGRAPHIC SECTIONS

Four stratigraphic sections of the Tuktu are shown on figure 86. The first of these is the type section, which crops out at Tuktu Bluff on the Chandler River a short distance above the mouth of the Kiruktagiak River (fig. 87). The Tuktu strata dip gently northward and are exposed on the face of the Tuktu Escarpment. The section was measured in 1948 by R. L. Detterman (1956, p. 235).

Type section of Tuktu Formation on Chandler River at Tuktu Bluff, lat 68°44′ N., long 152°18′ W.

[Measured by R. L. Detterman, 1948; thicknesses determined in part by tape and in part computed by altimeter and Brunton compass measurements. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue: Conglomeratic sandstone, scattered chert and quartz pebbles in a coarse "salt and pepper" sandstone matrix, well-indurated, ferruginous, crossbedded.	
Tuktu Formation:	
1. Sandstone, siltstone, and silty shale. Sandstone is thin to shaly bedded, very fine grained, medium gray to olive gray, highly argillaceous. Siltstone and silty shale are greenish gray, somewhat sandy. Rubble in part; computed thickness approximately	90
2. Sandstone, medium-bedded, fine- to medium-grained, dark-greenish-gray (weathers to moderate yellowish brown) iron-stained, slightly argillaceous; very friable and fractures into rectangular blocks	50
3. Sandstone, thin to shaly bedded, crossbedded, very fine-grained to fine-grained, medium-dark-gray to dark-greenish-gray, argillaceous, calcareous; in places almost a siltstone. Ironstone concretions locally abundant. Gray silty shale and siltstone are interbedded with the sandstone. In part rubble; computed thickness approximately	430
4. Sandstone, thin- to thick-bedded; more massive than in unit 3; fine-grained, olive-gray, argillaceous; cliff forming; fractures into large rectangular blocks; interbedded with siltstone and silty shale; ironstone concretions. In part rubble; computed thickness approximately	270
5. Sandstone, medium-bedded, medium- to coarse-grained with some chert pebbles; moderate yellowish brown; friable, fractures into large slabs	10

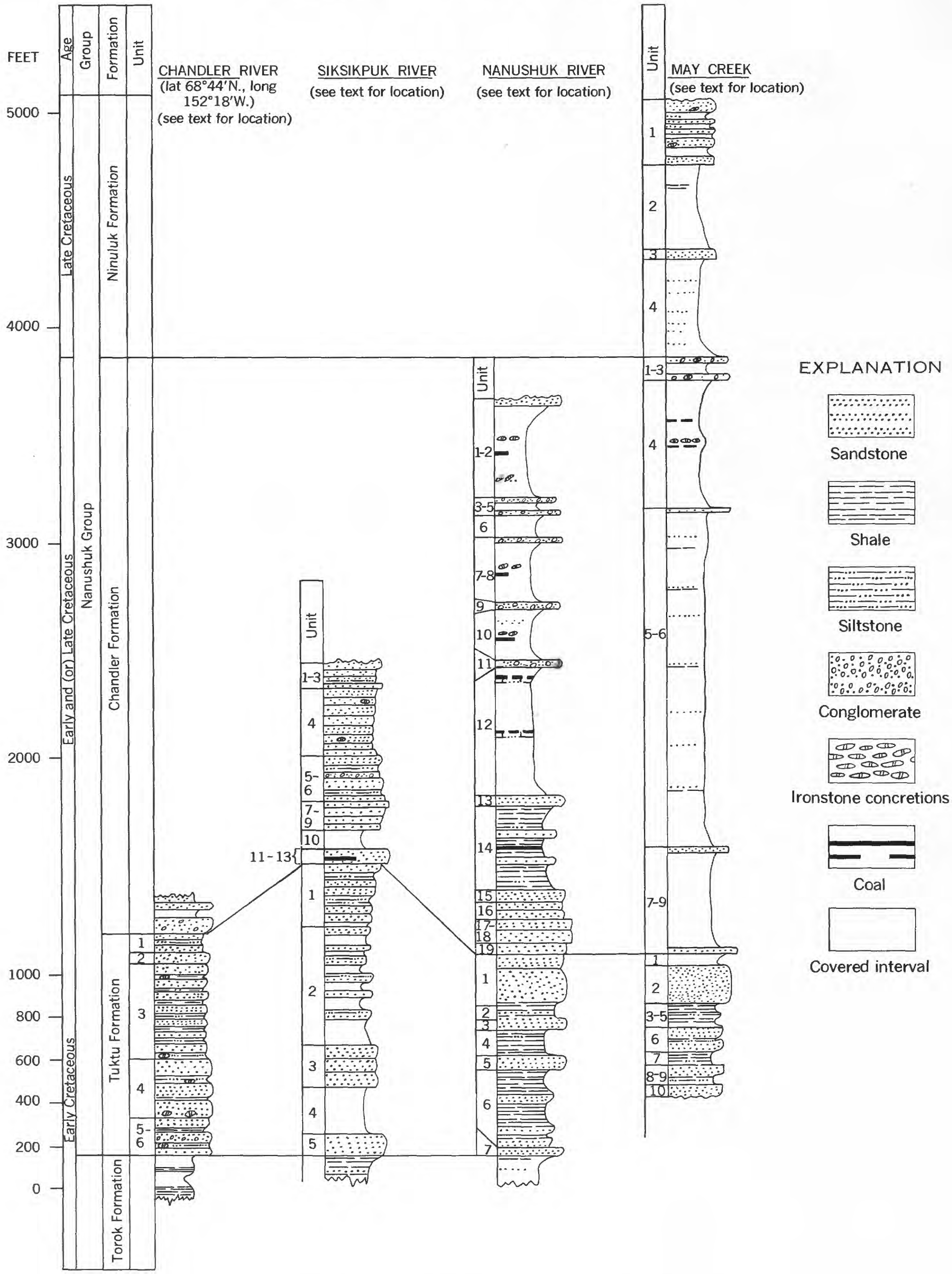

FIGURE 86.—Correlated columnar sections of the Nanushuk Group.

FIGURE 87.—Tuktu Bluff on the Chandler River near the mouth of the Kiruktagiak River. Shows type section of the Tuktu Formation. Photograph by U.S. Navy

Type section of Tuktu Formation on Chandler River at Tuktu Bluff, lat 68°44′ N. long 152°18′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Tuktu Formation—Continued	
6. Sandstone, siltstone, silty shale, clay shale, ironstone concretions. Thin- to medium-bedded fine-grained medium-dark-gray (weathers gray to moderate reddish brown) argillaceous cross-bedded sandstone; a 4-in. seam of pebble-granule conglomerate at about the middle of the section is 90 percent black and gray chert, the remainder mainly well-cemented hard shale fragments. Fossils in the conglomerate. Fossils do not appear to be reworked. Plant fragments common in upper part. The unit is mainly rubble covered; computed thickness approximately	180
Total thickness of Tuktu Formation (approx)	1, 000
Torok Formation: Dark-blue-gray clay shale, partly covered.	

A partly exposed section (fig. 86) of the Tuktu Formation was measured on the south side of Gunsight Mountain, 13 miles east of the type locality.

Section of Tuktu Formation on Gunsight Mountain Siksikpuk River, at lat 68°42′ N., long 151°50′ W.

[Measured by W. W. Patton, Jr., 1950. Thickness computed by plane table and Brunton compass measurements. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue:	
Very fine grained medium-light-gray "salt and pepper" sandstone.	
Tuktu Formation:	
1. Sandstone and siltstone, very fine grained, medium-light-gray to dark-greenish-gray, thin-bedded, crossbedded	300
2. Sandstone and siltstone, thin-bedded, medium-gray, very fine grained. Poorly exposed	550
3. Sandstone, dark-greenish-gray, very fine grained, thin-bedded; locally crossbedded	200
4. Covered	200
5. Sandstone, dark-greenish-gray, very fine grained, thin- to medium-bedded. Pyrite nodules	100
Total thickness of Tuktu Formation approximately	1, 350
Torok Formation: Dark-gray clay and silty shale and very fine grained light-gray sandstone.	

A completely exposed section (fig. 86) of the Tuktu Formation was measured in a cutbank on the east side of the Nanushuk River on the south limb of the Arc Mountain anticline.

Section of Tuktu Formation on Nanushuk River at lat 68°39′ N., long 150°32′ W.

[Measured with tape by W. W. Patton, Jr., 1950. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue: Light-gray very fine- grained to fine-grained thin- to thick-bedded crossbedded "salt and pepper" sandstone; weathers grayish orange.	
Tuktu Formation:	
1. Sandstone, dark-greenish-gray, very fine grained to fine-grained, thin- to thick-bedded. Pyrite nodules. Carbonized plant fragments. Ammonites and pelecypods	235
2. Shale and sandstone. Medium-gray silty shale. Greenish-gray very fine grained thin- to medium-bedded sandstone. Carbonized plant fragments	62
3. Sandstone, greenish-gray, very fine grained, thin- to thick-bedded. Pyrite nodules. Ammonites and pelecypods	56
4. Shale, dark-gray, clayey and silty. Subordinate medium-gray siltstone	122
5. Sandstone, dark-greenish-gray, very fine grained, thin- to medium-bedded. Carbonized plant fragments. Pyrite nodules. Pelecypods	65
6. Shale and sandstone. Dark-gray clay shale with subordinate medium-gray medium-bedded fossiliferous ripple-marked sandstone	360
7. Sandstone, greenish-gray, very fine grained, medium-bedded. Pyrite nodules. Carbonized plant fragments	40
Total thickness of Tuktu Formation	940
Torok Formation: Dark-gray clay and silty shale.	

A section of the upper 660 feet of the Tuktu formation was measured on the north limb of the Arc Mountain anticline on May Creek. The contact between the Torok and Tuktu formations is not exposed at this locality.

Section of Tuktu Formation on May Creek at lat 68°41′ N., long 150°13′ W.

[Measured with tape by A. S. Keller, 1950. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue: Light-gray medium- to coarse-grained carbonaceous "salt and pepper" sandstone that weathers grayish orange.	
Tuktu Formation:	
1. Covered	60
2. Sandstone, medium-gray, very fine grained	170
3. Shale, light- to medium-gray, silty. Poorly exposed	40
4. Siltstone, medium-gray	30
5. Shale, medium-gray, silty. Poorly exposed	40

Section of Tuktu Formation on May Creek at lat 68°41′ N., long 150°13′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Tuktu Formation—Continued	
6. Sandstone, siltstone, and shale. Medium-gray very fine grained sandstone. Medium- to dark-gray shale and siltstone. Ironstone concretions and carbonized plant fragments	110
7. Shale and siltstone, medium- to dark-gray. Pyrite nodules	68
8. Sandstone, medium-gray, very fine grained	42
9. Shale and siltstone, dark-gray	47
10. Sandstone, medium-gray, very fine grained, medium-bedded. Pyrite nodules	53
Covered.	
Total exposed thickness of Tuktu Formation approximately	660

Comparison of the four measured sections shown on figure 86 suggests that there may be a coarsening of the clastics in a westerly direction. The type section on the Chandler River consists largely of sandstone, including some coarse-grained and conglomeratic beds. In contrast, on May Creek and on the Nanushuk River, shale makes up about one-third of the formation and coarse-grained beds are absent.

AGE

The following megafossils were collected from the Tuktu Formation and submitted to R. W. Imlay for identification.

50APa22, from sandstone in a cutbank on small tributary of May Creek at lat 68°35′ N., long 150°07′ W.
Trails or burrows

50APa29, USGS Mesozoic loc. 24425, from sandstone in a cutbank on the east side of May Creek at lat 68°35′ N., long 150°11′ W.
Ditrupa cornu Imlay
Thracia cf. *T. stelcki* McLearn

50APa156, USGS Mesozoic loc. 24426, from calcareous sandstone in a cutbank on north side of Cobblestone Creek at lat 68°35′ N., long 150°24′ W. Near base of Tuktu Formation.
Inoceramus cf. *I. cadottensis* McLearn

50APa180, USGS Mesozoic loc. 24427, from sandstone from unit 7 of stratigraphic section of Tuktu Formation on Nanushuk River.
Pseudopulchellia pattoni Imlay
Solecurtus? *chapmani* Imlay
Panope? *elongatissima* (McLearn)

50APa357, from unit 5 of stratigraphic section of Tuktu Formation on Gunsight Mountain (p. 466).
Arctica sp.
Pleuroma? sp.

50AKe19, USGS Mesozoic loc. 24428, from sandstone from rubble ridge east of May Creek at lat 68°42′ N., long 150°08′ W.
Isognomon? sp.

50AKe25, USGS Mesozoic loc. 24429, from siltstone from unit 9 of stratigraphic section of Tuktu Formation on May Creek (p. 467).
Solecurtus? *chapmani* Imlay
Pleuromya sikanni McLearn
Arctica sp.

50AKe35, USGS Mesozoic loc. 24430, from sandstone from cutbank on west side of May Creek at lat 68°40′ N., long 150°10′ W.
Panope? *elongatissima* (McLearn)
Arctica? sp.
Thracia stelcki McLearn
Dicranodonta dowlingi McLearn
Xenohelix? sp.

49ATr741, USGS Mesozoic loc. 21827, from sandstone from cutbank on west side of the Chandler River at junction with Kiruktagiak River at lat 68°44′ N., long 152°19′ W.
Cleoniceras tailleuri Imlay

48ADt129, USGS Mesozoic loc. 25121, from lower 80 ft of unit 4 of type section of Tuktu Formation at Tuktu Bluff (p. 464).
Entolium utukokense Imlay
Thracia stelcki McLearn
Panope? *elongatissima* (McLearn)

48ADt134, USGS Mesozoic loc. 25122, from near middle of unit 3 of type section of Tuktu Formation at Tuktu Bluff (p. 464).
Ditrupa cornu Imlay
Homomya sp.
Panope? sp.

48ADt147, USGS Mesozoic loc. 25123, from unit 6 of type section of Tuktu Formation at Tuktu Bluff (p. 466).
Arctica? sp.

45AGr31, USGS Mesozoic loc. 20454, from unit 6 of type section of Tuktu Formation at Tuktu Bluff (p. 466).
Inoceramus cf. *I. cadottensis* McLearn
Homomya sp.
Arctica? sp.
Yoldia cf. *Y. kissoumi* McLearn
Astarte ignekensis Imlay
Ditrupa cornu Imlay
Starfish

The Tuktu Formation is dated as middle Albian on the basis of the ammonite *Gastroplites kingi* which, according to Imlay, ranges through the upper third of the Torok Formation and all of the Tuktu Formation. The *Gastroplites kingi* zone includes such species as *Cleoniceras tailleuri* Imlay, *Dicranodonta dowlingi* McLearn, *Inoceramus cadottensis* McLearn, *Solecurtus*? *chapmani* Imlay, *Panope*? *elongatissima* McLearn, *Yoldia kissoumi* McLearn, and *Ditrupa cornu* Imlay.

Concerning the age of the *Gastroplites kingi* zone Imlay states (written communication, 1957):

> The *Gastroplites kingi* zone is correlated with the middle Albian of Europe as defined by Spath. The main evidence consists of the presence of typical *Cleoniceras* throughout most of the zone as well as in beds below the zone. This occurrence below the zone may reasonably be correlated with the first appearance of *Cleoniceras* in Europe at the top of the *Leymeriella tardefurcata* zone. The presence of *Cleoniceras* throughout 2000 to 3000 feet of the *Gastroplites kingi* zone seems ample to account for the occurrences of *Cleoniceras* in the lower part of the middle Albian. The absence of *Cleoniceras* in the upper few hundred feet of the Tuktu Formation suggests that part of the *Gastroplites kingi* zone corresponds to part of the middle Albian above the range of *Cleoniceras*. Such is supported by the presence of *Gastroplites* in England at the very top of the middle Albian. Of course, this does not prove that the top of the *Gastroplites kingi* zone corresponds exactly with the top of the middle Albian of England, but there cannot be much difference in age.

Shale in the measured sections on the Nanushuk River and May Creek were sampled for microfossils. The microfauna has been identified by H. R. Bergquist.

50APa179, from shale from unit 6 of stratigraphic section of Tuktu Formation on Nanushuk River (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Ammobaculites fragmentarius Cushman

50APa182, from shale from unit 4 of stratigraphic section of Tuktu Formation on Nanushuk River (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Ammobaculites fragmentarius Cushman
Gaudryina nanushukensis Tappan
Ditrupa sp.

50APa183, from shale from unit 2 of stratigraphic section of Tuktu Formation on Nanushuk River (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Ammobaculites fragmentarius Cushman
Gaudryina nanushukensis Tappan

50AKe21, from shale from unit 10 of stratigraphic section of Tuktu Formation on May Creek (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Psamminopelta bowsheri Tappan
Ammobaculites fragmentarius Cushman
Gaudryina?

50AKe26, from shale from unit 9 of stratigraphic section of Tuktu Formation on May Creek (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Psamminopelta bowsheri? Tappan
Ammobaculites fragmentarius? Cushman
Gaudryina canadensis Cushman
Gaudryina sp.

50AKe31, from shale from unit 5 of stratigraphic section of Tuktu Formation on May Creek (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Psamminopelta subcircularis? Tappan
Psamminopelta bowsheri Tappan
Ammobaculites fragmentarius Cushman

50AKe33, from shale from unit 3 of stratigraphic section of Tuktu Formation on May Creek (p. 467).
Haplophragmoides topagorukensis Tappan
Verneuilinoides borealis Tappan
Psamminopelta bowsheri Tappan
Ammobaculites fragmentarius Cushman

Bergquist's comments on the microfauna from the upper part of the Torok Formation and the Tuktu Formation are given on page 462.

CHANDLER FORMATION, KILLIK TONGUE

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The predominantly nonmarine Chandler Formation conformably overlies the Tuktu Formation, unconformably underlies the Seabee Formation of the Colville Group, and intertongues northward with the predominantly marine Ninuluk and Grandstand Formations (fig. 85). The Chandler Formation consists of two northward-projecting tongues, the Killik and the Niakogon, separated by a southward-projecting tongue of the Ninuluk Formation. Exposures of the Chandler Formation in the mapped area are confined to the lower of the two tongues, the Killik Tongue.

The Killik Tongue of the Chandler Formation crops out along the northern border of the mapped area from a point 3 miles east of the Okokmilaga River to the valley of the Itkillik River. To the south it is bordered by the Tuktu Formation; to the north it extends beyond the mapped area. It also crops out in a 2- to 5-mile-wide band along the Arc Mountain syncline between the Kanayut River and the Itkillik River valley.

A massive resistant sandstone ledge at the base of the Killik Tongue caps the Tuktu Escarpment and the prominent hogback that surrounds the core of the Arc Mountain anticline. More gently dipping sandstone and conglomerate ledges in the upper part of the tongue form a series of low benched ridges and benched mesas north of the Tuktu Escarpment and also along the axis of the Arc Mountain syncline (fig. 70).

LITHOLOGY

The Killik Tongue comprises intercalated sandstone, conglomerate, siltstone, shale, and coal. In most places only the coarse clastics are exposed; although shale and siltstone are probably the most abundant components, they rarely crop out.

The lower half of the tongue consists chiefly of littoral and nearshore marine and nonmarine deposits and is characterized by light-gray "salt and pepper" fine- to medium-grained crossbedded sandstone interbedded with medium-gray to dark-greenish-gray very fine grained sandstone and siltstone. The upper half of the tongue consists chiefly of nonmarine fine- to coarse-grained moderate-yellowish-orange weathering "salt and pepper" sandstone and conglomerate. The conglomerate occurs in massive beds as much as 60 feet thick and contains pebbles and cobbles of which as much as 70 percent may be dark-gray and green chert and the remainder white quartz. Coal and ironstone float is found throughout the Killik Tongue but is most common in the upper half. The only exposure of coal is a 1-foot seam in unit 14 of the stratigraphic section on the Nanushuk River (p. 470).

Three specimens of typical sandstone from the Killik Tongue were examined in thin section. The sandstone contains 30 to 50 percent angular and subangular quartz grains and 15 to 40 percent angular and subangular chert grains; the remainder is chiefly a fine silt, clay, and sericite matrix.

Megascopically the "salt and pepper" sandstone appears to possess favorable reservoir properties; however, laboratory analyses indicate that although porosity may be as high as 15 percent, permeability is generally low.

THICKNESS

The full thickness of the Killik Tongue is preserved in Arc Mountain syncline east of May Creek, where it measures about 2,800 feet.

CONTACTS

The lower contact separates marine strata of the Tuktu Formation from predominantly nonmarine strata of the Chandler Formation. East of the Anaktuvuk River the lower contact is well defined and nongradational; greenish-gray sandstone of the Tuktu Formation is overlain by a massive ledge of light-gray "salt and pepper" sandstone of the Killik Tongue. West of the Anaktuvuk River the lower contact is gradational and is arbitrarily placed at the base of the lowest "salt and pepper" sandstone.

The upper contact marks the top of the nonmarine coal-bearing beds and in the mapped area it has been placed at the top of the highest ledge of sandstone and quartz-pebble conglomerate.

STRATIGRAPHIC SECTIONS

Three sections of the Killik Tongue of the Chandler Formation are shown on figure 86. None of the three sections in the mapped area is completely exposed. Thicknesses of covered intervals were computed by using the dip of exposed strata and horizontal distances measured on vertical aerial photographs or by plane table.

The 2,800-foot section in the May Creek basin, the only section in which the upper contact is preserved, was measured on the gently dipping north flank of the Arc Mountain syncline east of May Creek.

Section of Killik Tongue of Chandler Formation near May Creek on north flank of Arc Mountain syncline between lat 68°40′ N., long 150°10′ W. and lat 68°38′ N., long 150°08′ W.

[Measured by A. S. Keller, 1950, in part by tape and in part by computations based on aerial photograph, Brunton compass, and altimeter data. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Ninuluk Formation: Sandstone, very fine grained, light-gray, fossiliferous.	
Chandler Formation:	
Killik Tongue:	
1. Sandstone, fine-grained to conglomeratic. White quartz pebbles, ironstone conretions, carbonaceous matter	20
2. Covered	50

Section of Killik Tongue of Chandler Formation near May Creek on north flank of Arc Mountain syncline between lat 68°40′ N., long 150°10′ W. and lat 68°38′ N., long 150°08′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Chandler Formation—Continued	
Killik Tongue—Continued	
3. Sandstone, fine-grained to conglomeratic, light-gray. Ironstone concretions and coaly material	30
4. Covered. Coal float 400 ft above base and coal and ironstone float 300 ft above base	600
5. Sandstone, medium-grained, light-gray to moderate-yellowish-brown	20
6. Covered. Rubble of sandstone and shale	1, 550
7. Sandstone, gray to moderate-yellowish-brown, fine- to medium-grained. Carbonized plant detritus abundant	30
8. Covered	450
9. Sandstone, light-gray (weathers moderate yellowish brown) medium- to coarse-grained; ridgemaker. Carbonized plant detritus abundant	30
Total thickness of Killik Tongue of Chandler Formation approximately	2, 800
Tuktu Formation: Sandstone, medium-gray, fine-grained.	

A 2,600-foot section of the Killik Tongue, nearly the full thickness, is partly exposed east of the Nanushuk River on the north flank of the Arc Mountain syncline. The basal 750 feet of the section crops out in a cutbank on the river.

Section of Chandler Formation on north flank of Arc Mountain syncline on the Nanushuk River between lat 68°39′ N., long 150°31′ W., and lat 68°37′ N., long 150°27′ W.

[Measured by W. W. Patton, Jr., and A. S. Keller, 1950, in part by tape and in part by computations based on aerial photograph, Brunton compass, and altimeter data. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue:	
Center of syncline, eroded.	
1. Sandstone, light-gray, coarse-grained to conglomeratic. Granules and pebbles of black and green chert and white quartz	20
2. Covered. Float of sandstone, coal, and ironstone	425
3. Conglomerate, massive, pebbles and granules of chert and quartz. Coarse-grained "salt and pepper" sandstone	20
4. Covered	50
5. Conglomerate and sandstone as described in unit 3	25
6. Covered	100
7. Conglomerate as in unit 3 capped by 8 ft of medium- to coarse-grained grayish-orange sandstone	25

Section of Chandler Formation on north flank of Arc Mountain syncline on the Nanushuk River between lat 68°39′ N., long 150°31′ W., and lat 68°37′ N., long 150°27′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Chandler Formation—Continued	
Killik Tongue—Continued	
8. Covered. Float of ironstone and coal	275
9. Conglomerate and sandstone. Chert and quartz pebble and cobble conglomerate. Yellowish-gray medium-grained sandstone	30
10. Covered. Float of ironstone, coal, and sandstone	250
11. Sandstone and conglomerate. Yellowish-gray fine-grained medium-bedded sandstone. Chert and quartz-pebble conglomerate	30
12. Covered. Float of coal and medium-gray limy siltstone that weathers dark-yellowish orange	600
13. Sandstone, light-gray, fine-grained, medium- to thick-bedded. Carbonized plant detritus	50
14. Clay shale and silty shale. Subordinate medium- to thick-bedded sandstone and medium-gray calcareous siltstone. A 1-ft coal bed near the middle	400
15. Sandstone, light-gray to yellowish-gray, very fine to fine-grained, thin- to medium-bedded	60
16. Sandstone, medium light-gray, very fine grained, thin- to medium-bedded	80
17. Sandstone, "salt and pepper," fine- to medium-grained, medium-bedded. Strong ledgemaker	20
18. Sandstone, yellowish-gray, very fine grained to fine-grained, thick-bedded, crossbedded. Strong ledgemaker	90
19. Sandstone, light-gray to moderate-yellowish-brown, very fine grained to fine-grained, thin- to medium-bedded. Carbonized plant detritus	50
Total thickness of Killik Tongue of Chandler Formation approximately	2, 600
Tuktu Formation: Very fine grained greenish-gray argillaceous sandstone.	

The lower 925 feet of the Killik Tongue that caps the Tuktu Escarpment was measured at Gunsight Mountain east of the Siksikpuk River.

Section of Killik Tongue of the Chandler Formation on Gunsight Mountain, Siksikpuk River at lat 68°43′ N., long 151°50′ W.

[Measured by W. W. Patton, Jr., 1950, by computations based on plane table and Brunton compass data. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Chandler Formation:	
Killik Tongue:	
Top of mountain.	
1. Sandstone, fine- to medium-grained, light-gray "salt and pepper," medium-bedded	10

Section of Killik Tongue of the Chandler Formation on Gunsight Mountain Siksikpuk River at lat 68°43′ N., long 151°50′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Chandle Formation—Continued	
Killik Tongue—Continued	
2. Sandstone, very fine grained, medium light-gray, muddy; grades into siltstone at base. Plant impressions	100
3. Sandstone, fine-grained, light-gray, "salt and pepper," medium-bedded	15
4. Sandstone, very fine grained, medium-gray to greenish-gray; plant impressions; ironstone concretions	300
5. Sandstone, fine-grained, medium light-gray, "salt and pepper"	10
6. Sandstone, very fine grained, dark-greenish-gray. Ironstone nodules; subordinate interbedded siltstone. Thin lens of white quartz and black chert granules	210
7. Sandstone, fine-grained, crossbedded, medium light-gray, "salt and pepper," medium-bedded	15
8. Sandstone, light-gray, fine-grained, medium-bedded; weathers grayish orange	15
9. Sandstone, dark-greenish-gray, thin- to medium-bedded	100
10. Covered	85
11. Sandstone, very fine grained, light-gray, medium-bedded; weathers grayish orange	5
12. Sandstone, very fine grained, dark-greenish-gray, thin-bedded	30
13. Sandstone, very fine grained to fine-grained, medium light-gray, "salt and pepper," medium- to thick-bedded. Coal float. Plant impressions. Ridgemaker	30
Total thickness of Killik Tongue of Chandler Formation approximately	925
Tuktu Formation: Interbedded very fine grained medium-gray to dark-greenish-gray sandstone and siltstone.	

AGE

Fossils are rare in the Killik Tongue; only two collections of unidentifiable pelecypods were found: collection 50APa189 from unit 14 of the section on the Nanushuk River (p. 470) and collection 50APa359, from unit 4 of the section on Gunsight Mountain.

A single collection (50APa188) of microfossils was made from shale in unit 14 of the Nanushuk River section (p. 470):

Verneuilinoides borealis Tappan
Psamminopelta bowsheri Tappan

The Killik Tongue cannot be dated directly from fossil evidence; however, its stratigraphic position between the Tuktu and the Ninuluk Formations indicates that it represents part or all of the interval between middle Albian and late Cenomanian.

NINULUK FORMATION

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

The youngest bedrock in the mapped area is a poorly exposed sequence of the Ninuluk Formation which occurs along the axis of the Arc Mountain syncline east of May Creek. This Ninuluk sequence apparently belongs to a southward-projecting transgressive marine tongue which separates the Killik Tongue of the Chandler Formation from the Niakogon Tongue of the Chandler Formation (fig. 85).

Beds of the Ninuluk are nearly flat lying and form several low rounded rubble-covered hills along the axis of Arc Mountain syncline.

LITHOLOGY

Exposures of the Ninuluk Formation in the Arc Mountain syncline are confined to rubble of very fine grained to medium-grained light-gray argillaceous thin-bedded fossiliferous sandstone that weathers grayish orange. In the foothills north of the mapped area, where the Ninuluk is better exposed, shale and siltstone were found to constitute much of the formation (Detterman, 1956, p. 241–244) and presumably make up most of the formation in the covered intervals in the Arc Mountain syncline section.

THICKNESS

The maximum thickness of the Ninuluk Formation preserved in the Arc Mountain syncline is about 1,200 feet.

CONTRACTS

The lower contact of the Ninuluk Formation marks the transition from nonmarine coal-bearing beds of the Killik Tongue to marine beds of the Ninuluk. The contact is arbitrarily placed at the top of the highest ledge of sandstone and quartz-pebble conglomerate.

STRATIGRAPHIC SECTIONS

A 1,200-foot section of the Ninuluk Formation was measured on the gently dipping north flank of the Arc Mountain syncline in the May Creek basin.

Section of Ninuluk Formation on north flank of Arc Mountain syncline near May Creek between lat 68°38′ N., long 150°08′ W. and lat 68°37′ N., long 150°06′ W.

[Measured by A. S. Keller, 1950, by computations based on aerial photograph, Brunton compass, and altimeter data. Graphic section, fig. 86]

	Thickness (feet)
Cretaceous.	
Ninuluk Formation:	
Center of syncline, eroded.	
1. Sandstone, very fine grained, argillaceous, light-gray weathers grayish orange, fossiliferous, thin-bedded. Rubble	300
2. Covered	400

Section of Ninuluk Formation on north flank of Arc Mountain syncline near May Creek between lat 68°38′ N., long 150°08′ W. and lat 68°37′ N., long 150°06′ W.—Continued

	Thickness (feet)
Cretaceous—Continued	
Ninuluk Formation—Continued	
3. Same as in unit 1	50
4. Sandstone as in unit 1 becoming fine- to medium-grained near base. Rubble	450
Total thickness of Ninuluk Formation approximately	1, 200
Chandler Formation:	
Killik Tongue: Fine-grained to conglomeratic sandstone.	

AGE

Five collections of pelecypods from the Ninuluk Formation were examined and identified by R. W. Imlay (written communication, 1953).

50APa13, sandstone rubble, lat 68°37′ N., long 150°05′ W.
Volsella sp.

50APa15, sandstone rubble, lat 68°37′ N., long 150°07′ W.
Volsella cf. *V. silentiensis* McLearn
Panope sp.

50AKe2, sandstone rubble, lat 68°39′ N., long 149°53′ W.
Volsella cf. *V. silentiensis* McLearn

50AKe5, sandstone rubble, lat 68°39′ N., long 149°53′ W.
Volsella cf. *V. silentiensis* McLearn
Panope? *dunveganensis* Warren
Corbula? sp.

50AKe7, unit 3 of stratigraphic section
Inoceramus cf. *I. athabaskensis* McLearn
Panope? *dunveganensis* Warren
Arctica sp.
Volsella sp.

Mr. Imlay states that these collections contain the same megafossil assemblage as found elsewhere in northern Alaska in the Ninuluk Formation and that the species are identical with species in the Dunvegan Formation of Canada of Cenomanian age.

HEAVY MINERALS

Studies of the heavy minerals in samples taken from the Jurassic and Cretaceous rocks in the Killik-Itkillik region have been of value in this investigation; these studies suggest that heavy minerals may provide a much-needed index for determining the stratigraphic position of isolated exposures of these lithologically similar rocks. The samples were first studied by Morris and Lathram (1951), but the heavy-mineral zones to which the samples were assigned as a result are stratigraphically ambiguous in this region. A review of the heavy-mineral data after the geologic compilation was completed showed that the average heavy-mineral compositions of samples from different stratigraphic units are distinguishable. This stratification in heavy-mineral contents is uncertain because of inadequate field sampling, but the chances are that it is real. Many useful inferences based on the heavy-mineral association also resulted from the review.

More than 250 samples were studied, of which about 230 were collected west of the Chandler River in 1949 and the remainder east of the Chandler in 1950. Although the stratigraphic identity of the sampled rocks was not always clear, the distribution of the samples derived from Jurassic and Cretaceous rocks is considered to be as follows: 16 from the lower part of the Tiglukpuk Formation, 9 from the tuffaceous graywacke unit and possibly correlative rocks in the upper part of the Tiglukpuk Formation, 8 from the Okpikruak Formation, 23 from rocks in areas mapped as the undifferentiated Tiglukpuk and Okpikruak Formations, 179 from the Fortress Mountain Formation, 12 from the Torok Formation, and 5 from the Tuktu and Chandler Formations.

In spite of a substantial number of samples, shortcomings in the sampling preclude conclusive results. As indicated above, there is uncertainty in the stratigraphic position and disproportion in the geographic and stratigraphic distribution of the samples. Moreover, samples were not collected systematically from typical or thick orderly successions of rocks, or with regard to grain size or weathered state.

The samples were disaggregated in dilute hydrochloric acid, and the heavy minerals were separated from the −80,- +235-mesh sieve fraction in bromoform (sp gr 2.79) and methylene iodide (sp gr 3.0) in the Fairbanks laboratory. Morris studied grain mounts of the concentrates and supplied the writers with his determinations.

The heavy-mineral assemblages determined by Morris, were characterized by varying proportions of andalusite, augite, epidote, garnet, hornblende, mica, picotite tourmaline, and zircon. The opaque minerals were not determined in detail because they were not diagnostic in Morris and Lathram's study. A check of more than 15 concentrates showed that most, at least, of an andalusitelike mineral was apatite; apatite has therefore been substituted for andalusite in Morris' determinations.

The distribution of the heavy minerals that were determined is of interest. Although a listing of the composition of individual samples is not warranted, the distribution of the nonopaque minerals can be summarized in terms of frequency and maximum abundance. Garnet was identified in 90 percent of the samples; tourmaline and zircon in 75 percent; apatite, augite, epidote, hornblende, and mica in 50–60 percent; picotite in 35 percent; chloritoid in less than 5 percent; and anatase, glaucophane, hypersthene, and rutile in less than 1 percent. The highest proportion of nonopaque minerals in a single sample is 99 percent for augite; 70–90 percent for epidote, garnet, mica, or tourmaline; 40 percent for zircon; and 25 percent for hornblende or picotite.

Morris and Lathram's classification (1951) of the nonopaque mineral assemblages into heavy-mineral zones, on the basis of diagnostic mineral(s) or feature(s), could not be utilized in the Killik-Itkillik region. Morris grouped the samples into six zones, of which an epidote zone, an augite zone, and a zoned zircon zone had been identified with the Okpikruak Formation, the Fortress Mountain Formation (Morris and Lathram's Torok Formation), and with part of the Nanushuk Group, respectively. Comparison of the zones with final stratigraphic assignment of the samples showed that the zones included samples from more than one stratigraphic unit, and that more than one zone was represented by the samples from each unit.

A significant variation in the content of opaque minerals was indicated by inspection of the grain mounts. The proportion of opaque grains ranges from about 50 to nearly 100 percent; they are so abundant in some mounts that nonopaque grains are too few to be statistically valid. Where they form lower proportions, the opaque minerals occur as discrete detrital grains; where they form higher proportions, they occur as irregular grains and particles, making the grain mount look dirty. Much of the more abundant opaque material seems to be leucoxene, occurring as detrital grains of altered minerals and, perhaps, as alteration on detrital grains of other minerals.

Heavy-mineral compositions vary to some extent with the stratigraphic position of the samples. Although classification of the samples into heavy-mineral zones obscured this variation, histograms of samples from individual stratigraphic units showed that the average heavy-mineral content of the samples from different units is distinguishable. Partly owing to the lack of definite stratigraphic identity of the samples, the differences between the average compositions are not sharp—single samples may be related more closely to the average composition of samples from units other than their own. However, compositions characteristic of samples from each unit can be described, and the number of units with which a sample may be related can be limited.

The heavy-mineral compositions are distinguishable primarily by the proportion of unstable nonopaque minerals and secondarily by the preponderance of a particular mineral and the proportions and form of the opaque minerals. Samples characteristically are either rich in the unstable nonopaque minerals, epidote, or augite, and hornblende; or rich in stable nonopaque minerals. Although samples intermediate in composition between the two extremes are common, the gradation is incomplete.

The apparent distinctions in the heavy-mineral content of the sampled rocks are described below by formations and parts of formations.

TIGLUKPUK AND OKPIKRUAK FORMATIONS

The 16 samples from the lower part of the Tiglukpuk Formation are distinguished generally by the absence of unstable minerals; they tend to be distinguished from samples of younger rocks similarly rich in stable minerals by moderate proportions of opaque minerals and clean-appearing mounts. Zoned zircons, an index of a heavy-mineral zone within the Nanushuk Group, occur in three of the samples.

A scarcity of nonopaque minerals other than augite and hornblende distinguishes the tuffaceous graywacke unit of the Tiglukpuk Formation from all but one sample from the Okpikruak Formation and a few from the Fortress Mountain and Torok Formations. A diagnostic heavy-mineral content follows the diagnostic lithologic aspect of these rocks. A single sample from the variegated shale-siltstone sequence, possibly correlative in time with the tuffaceous graywacke unit, is rich in epidote rather than augite.

Seven of the eight samples from the Okpikruak Formation are rich in epidote. A content of less than 10 percent stable minerals is lower than that of most epidote-rich samples from the Fortress Mountain Formation. Hornblende is present in proportions equal to augite, in contrast to its general subordinance to augite in other samples. The eighth sample is augite-rich and contains no epidote; no explanation for this has been found.

Both epidote-poor and epidote-rich samples were collected in areas mapped as undifferentiated Tiglukpuk and Okpikruak Formations. However, because many of the samples came from a relatively small area just south of Fortress Mountain, this group of samples may not be generally representative of the rocks mapped as undifferentiated Tiglukpuk and Okpikruak Formations. About three-quarters of the 23 samples contain few or no unstable minerals; they compare reasonably well with the samples from the lower part of the Tiglukpuk Formation. The other quarter are epidote rich, but the proportions of stable minerals are in excess of those in samples from the Okpikruak Formation. As a group, the samples resemble the group of samples from rocks in the basal part of the Fortress Mountain Formation. In view of the uncertain stratigraphic position of many of the samples, this similarity to samples from younger rocks may be significant.

FORTRESS MOUNTAIN FORMATION

Numerous samples and fair stratigraphic control permit description of the heavy minerals in the Fortress Mountain Formation with some assurance. In the formation as a whole, the heavy minerals are chiefly those found in samples of the older formations, but in individual samples, generally, the nonopaque minerals are chiefly those that distinguish only one of the older units. The heavy-mineral contents of gross subdivisions of the formation seem distinguishable.

Most of the samples can be readily classified as rich in epidote, augite-hornblende, or stable minerals; few contain these distinguishing minerals in near-equal proportions. About half the samples are rich in either augite-hornblende or epidote. The proportions of stable minerals in all but a few of these are higher than in the samples of the tuffaceous graywacke unit of the Tiglukpuk Formation or of the Okpikruak Formation. The epidote-rich samples very closely resemble the epidote-rich ones in the group of samples from the undifferentiated Tiglukpuk and Okpikruak Formations. Most of the samples rich in stable minerals can be distinguished from the samples of the Tiglukpuk Formation by higher proportions of unstable minerals; a number resemble some of the samples of the undifferentiated Tiglukpuk and Okpikruak Formations.

An easterly and a northerly decrease in abundance of the unstable minerals is indicated. The easterly change is based on very few samples; it follows the observed decrease in frequency of igneous clasts toward the east (p. 452). The northward decrease in unstable minerals probably reflects attrition over a greater transport distance.

Some distinctions between heavy-mineral assemblages from different stratigraphic intervals are also indicated. Samples from rocks that are probably in the basal part of the Fortress Mountain Formation, in the vicinity of Horseshoe Mountain, are the most distinct. The lack of unstable minerals is clear and the frequency of zoned zircons is moderate. As mentioned above, many of the samples of the undifferentiated Tiglukpuk and Okpikruak Formations that were collected south of Fortress Mountain closely resemble these samples from the basal part of the Fortress Mountain Formation.

Apparent differences between the average content of the lower part, excepting the basal few hundred feet, and the upper part of the Fortress Mountain are not great and may be insignificant or depend on factors other than stratigraphic position. The lower part of the formation yielded about twice as many epidote-rich as augite-rich samples and few stable-rich samples in the vicinity of the Canoe Hills, but about equal numbers of epidote- and augite-rich and about half stable-rich samples in the vicinity of Castle Mountain. The upper, conglomeratic, part of the formation may be disguished from the lower by a higher frequency of samples in which augite and hornblende are very abundant and by stable-rich samples containing glaucophane, zoned zircons, or relatively high proportions of tourmaline.

TOROK FORMATION AND NANUSHUK GROUP

The samples from the Torok Formation are distinguished by the absence of epidote and by the preponderance of stable minerals. Only one of the 12 samples is rich, almost to the exclusion of other nonopaque minerals, in augite and hornblende. Proportions of augite, hornblende, apatite, and garnet are smallest, and the proportions of tourmaline are largest, in the northernmost samples. However, the significance of this variation cannot be tested because the number of samples is insufficient and their stratigraphic positions are not precisely known. Zoned zircons are present in a third of the samples.

Only five samples were collected from the Nanushuk Group. Apatite, garnet, and the unstable minerals are lacking in the two samples from the Tuktu Formation; proportions of tourmaline, zoned zircon, and picotite are consequently high. Hornblende, apatite, garnet, and chloritoid reappear in the samples from the Chandler Formation.

HEAVY MINERALS AS STRATIGRAPHIC INDICES

Although no stratigraphic markers were defined, the study shows that the heavy-mineral content can help identify the stratigraphic position of a rock. The formations, or parts thereof, with which rocks are likely to be noncorrelative are indicated by the heavy minerals in a single sample; the stratigraphic position with which rocks are correlative seems determinable by the average content of heavy minerals in several samples.

The possible stratigraphic indications of the heavy minerals in a single sample are summarized below. Rocks of the Nanushuk Group are not included because in few places are they possible correlatives of rocks of uncertain relationships.

1. If rich in stable minerals, noncorrelative with the tuffaceous graywacke unit of the Tiglukpuk Formation and, probably, with the Okpikruak Formation.
    - a. If nonopaque minerals more than 10 percent unstable, or if proportions of leucoxene are high, noncorrelative with the lower part of the Tiglukpuk Formation.
    - b. If zoned zircons are present, probably noncorrelative with the middle part of the Fortress Mountain Formation.

2. If rich in unstable minerals, noncorrelative with the lower part of the Tiglukpuk Formation and, probably, with the Torok Formation.
   a. If nonopaque minerals more than 15 percent stable, probably noncorrelative with the Okpikruak Formation.
   b. If nonopaque minerals more than 90 percent augite-hornblende, probably noncorrelative with the Okpikruak Formation and all but the upper part of the Fortress Mountain Formation.
   c. If nonopaque minerals largely epidote, less than 15 percent stable, probably correlative only with the Okpikruak Formation.

INTERPRETATIONS

The nature of the heavy minerals that distinguish the various stratigraphic units can be used to speculate on the source rocks of the sediments and on the environment in which the sediments were deposited. The interpretations supplement other evidence and contribute to the synthesis of the geologic history described on pages 493–495.

It is presumed that the Jurassic and Cretaceous rocks formed in an eastward-trending geosynclinal basin that was filled with debris carried northward from a rising landmass in the general area of, or south of the present Brooks Range. Orogenic pulses and at least one volcanic episode took place during the deposition of these Jurassic and Cretaceous rocks. From time to time sedimentary rocks along the southern margin of the geosyncline were uplifted and eroded, supplying detritus to younger sediments being deposited farther north. Some of this history is reflected in the heavy-mineral content of the rocks.

The source rocks for the lower part of the Tiglukpuk Formation obviously contained the stable minerals, but they probably did not contain appreciable proportions of unstable minerals. If they had, greater quantities of unstable minerals would be present because the conditions that produced the graywacke-type sediments of the Tiglukpuk Formation should not have allowed much attrition of the less resistant material. A generally high garnet to zircon ratio in the heavy-mineral assemblages indicates a less intense rate of weathering in the provenance of the Tiglukpuk Formation than exists at present in the Central Piedmont region of the United States (Dryden and Dryden, 1946).

Source rocks for the lower part of the Tiglukpuk Formation must have contributed relatively little sediment to the tuffaceous graywacke unit or to the indurated variegated shale and siltstone sequence. An almost wholly volcanic source is indicated for the tuffaceous beds, and an epidote-rich source for the shale and siltstone sequence is indicated by the single sample. Rapid sedimentation is implied by the abundance of unstable minerals.

Epidote-bearing rocks must have been the principal source of the sediments of the Okpikruak Formation also. The scarcity of stable minerals in the Okpikruak Formation indicates that the bulk of these sediments were not derived from the Tiglukpuk Formation or from the source rocks for the Tiglukpuk Formation. If the epidote-rich ones among the group of samples from the undifferentiated Tiglukpuk and Okpikruak Formations are from the basal part of the Okpikruak Formation, the relatively high proportions of stable minerals may have been eroded locally from the Tiglukpuk Formation. In general, the Tiglukpuk Formation and older rocks appear to have been buried by an epidote-rich rock during deposition of the Okpikruak Formation. This epidote-rich rock was probably the extrusive phase of the volcanic episode reflected in the Killik-Itkillik region by the tuffaceous graywacke unit of the Tiglukpuk Formation and by the mafic intrusive bodies. Rapid sedimentation of the Okpikruak Formation is indicated by the abundance of unstable minerals. The single augite-rich sample from the Okpikruak Formation is anomalous and unaccounted for.

Heavy minerals indicate that older Cretaceous and Jurassic rocks and some pre-Jurassic rocks contributed to the sediments of the Fortress Mountain Formation. The proportion of individual older units in the source area seems to have varied somewhat with time; various individual units seem to have been the predominant source of many of the small parts of the formation that are represented by single samples.

Unlike the rest of the formation, the basal part of the Fortress Mountain may have been derived from rocks no younger than the lower part of the Tiglukpuk Formation. The observed paucity of unstable minerals probably reflects the scarcity of unstable minerals in the source rocks rather than attrition because there appears to have been little difference in depositional conditions between the basal and overlying parts of the formation.

Epidote-rich rocks appear to have predominated slightly over augite-rich rocks in the source area of the lower part of the Fortress Mountain Formation; the converse is indicated for the upper part of the formation. A higher frequency of augite-hornblende and a greater proportion of stable minerals in the upper part may reflect an increased exposure, by deeper erosion, of mafic intrusive rocks and of pre-Tiglukpuk rocks in the source area.

The local, restricted nature of the sources for the small parts represented by single samples is indicated by the lack of mixing, in the samples, of the different heavy-mineral assemblages from the older rocks. Rapid shifting between local sources is suggested by the differences in heavy-mineral content of samples of rocks that are not widely separated spatially.

Little can be interpreted from the heavy minerals in the Torok Formation. The scarcity of unstable minerals is probably due to attrition rather than to absence in the source because an augite source is recorded for one time during deposition. The northward decrease in apatite and garnet may be depletion by longer transport; it could, also, result from differences in stratigraphic positions. Comparisons of the heavy minerals in the Fortress Mountain and Torok Formations contribute nothing to the question of the contemporaneity of the two formations.

With so few samples, interpretation of the heavy minerals in the Nanushuk Group is conjectural and is based on the assumption that the characteristics of the samples are valid. Unstable minerals would be unexpected in the moderately well sorted Tuktu Formation. Intrastratal solution in these somewhat porous rocks could account for the absence of garnet; the interval of intense weathering required to remove garnet at the source is unlikely. Differences in depositional and instrastratal conditions, rather than in sources, could account for the relatively higher proportions of less stable minerals in the Chandler Formation. Rocks somewhat different from source rocks of the Fortress Mountain and older formations could have contributed the greater quantities of chloritoid and hornblende that are found in the Chandler Formation.

SUGGESTIONS FOR ADDITIONAL STUDY

Although the heavy minerals have not furnished the hoped-for keys for correlation, they are not stratigraphically valueless. In view of the limitations of the present study, the heavy-mineral associations described above are encouraging evidence of a differentiation in the heavy minerals that would have considerable stratigraphic value. There is enough promise to warrant additional study in future detailed mapping. Several recommendations for such additional work can be made from the experience gained: (1) establishment of heavy-mineral reference columns by thorough sampling of known sections of rocks, (2) determination and comparison of the weight-percents of the gravity fractions of the samples, (3) determination and comparison of the weight-percents of the opaque minerals, and (4) varietal study of the translucent mineral species.

QUATERNARY DEPOSITS

UPLAND GRAVELS

Large areas of bedrock near the mountain front between the Okokmilaga and Siksikpuk Rivers are obscured by deposits which are designated here as upland gravels (pl. 50). These gravels occur on the interstream divides where they mantle remnants of an erosional surface of probable preglacial age.

The largest continuous area of the upland gravels is at the head of the Ayiyak River. There the gravels blanket a surface that slopes gently northward from an altitude of 3,500 feet at the mountain front to an altitude of 2,300 feet 10 miles north of the mountains. At the northern edge the gravel-covered surface is partly dissected and long fingerlike remnants project northward along the interstream divides. Extensive upland gravel deposits also occur on the margins of the Chandler River valley till sheet along the divides of the Chandler and Kiruktagiak Rivers and the Chandler and Siksikpuk Rivers.

Elsewhere in the mapped area near the mountain front small patches of upland gravels are scattered along the drainage divides, but inasmuch as they do not obscure sizable tracts of bedrock, they have not been mapped.

The gravel-covered upland surfaces are probably remnants of a broad piedmont slope that bordered the north front of the Brooks Range in preglacial time. The remnants of this surface are now much modified, and although at a distance they appear as a gently northward-sloping plane, actually they are made up of numerous slightly different terrace levels. The upland surfaces are typically poorly drained and are covered with a thick mat of tundra vegetation. In aerial photographs they are identifiable by a peculiar very fine rill or "horsetail" drainage pattern, and they can be outlined by the stony patches that occur around the rims of the surfaces where the vegetation cover is thin.

The upland gravels are composed chiefly of boulders, cobbles, and pebbles of quartzite embedded in sand and silt. The quartzite apparently was derived from the belt of Kanayut Conglomerate (Devonian) that crops out on the north flank of the Brooks Range. Boulders of quartzite as much as several feet in diameter occur even at the northernmost extent of the deposits. Where exposed along the dissected margins, the gravel deposits are as much as 50 feet thick and locally show crude stratification.

The upland gravels have not been examined or mapped in sufficient detail to permit the authors to speculate upon their origin. The thickness, stratification, composition, and geographic position of the gravel deposits all suggest a glacial origin, probably outwash. However, it is also possible that they may be in part or entirely preglacial pediment gravels. If they are glacial deposits they must be related to an early ice advance, since they obviously predate the fresh till deposits along the major river valleys. It is thought that the glaciers from which they were derived advanced northward from the mountains across a preglacial piedmont slope which had much less relief than exists in the foothills today. Probably the ice filled the shallow valleys of major rivers like the Chandler and Okokmilaga, and outwash from the margins of the ice sheet was spilled across the low interstream divides into nonglaciated tributaries like the Kiruktagiak and Siksikpuk Rivers. Subsequent glaciation deepened the major river valleys and lowered the local base level so that the outwash deposits on the piedmont slope were dissected, and today only scattered remnants are found along the drainage divides.

GLACIAL DEPOSITS

Deposits of fresh unmodified glacial drift blanket about 20 percent of the mapped area. During field mapping very little time was available to devote to these deposits, and they have been mapped chiefly from aerial photographs. Patches of older modified drift were observed over a much wider area; but since they do not obscure large continuous areas of bedrock, they have not been mapped.

The unmodified glacial deposits occur along the valleys of the major rivers. On the Killik and Itkillik Rivers they extend from the mountain front to and beyond the northern edge of the mapped area. On the Anaktuvuk they could be traced as far as the Tuktu Escarpment, and on the Okokmilaga, Chandler, and Nanushuk Rivers they were found 10 to 15 miles north of the mountains. The deposits extend up the sides of the valleys 800 to 1,200 feet above the present river levels. In places, a coalescence of tributary glaciers with the main glacier formed a piedmont lobe which has left broad bands of drift along the mountain front.

The glacial deposits are made up chiefly of till, although locally they probably contain small areas of stratified drift, including outwash. The till is an unsorted aggregate of boulders, cobbles, pebbles, sand, silt, and clay. The coarse fraction is chiefly quartzite derived principally from strata below the Lisburne Group in the Brooks Range. However, limestone of the Lisburne Group and sandstone of Mesozoic age occur in subordinate amounts. The drift deposits do not appear to be more than 50 feet thick, except locally along morainal ridges where they may be as much as several hundred feet thick.

FLOOD-PLAIN DEPOSITS

Alluvial deposits of gravel, sand, and silt occur on the flood plains of the modern streams and are shown on plate 50. Locally, these deposits cover sizable areas, as, for example, along the lower Okpikruak and Okokmilaga Rivers where the flood plain is more than 3 miles wide, and along parts of the Siksikpuk, Kanayut, and Nanushuk Rivers and May Creek where the gravels spread laterally across the stream valleys to widths of more than half a mile.

The average grain size and composition of the flood-plain deposits vary from place to place, depending upon the local gradient of the stream, the volume of water, and other factors. However, there is an overall decrease in size northward, and whereas Paleozoic limestone and quartzite detritus is most abundant near the mountains, Mesozoic sandstone and chert detritus predominates in the northern part of the mapped area.

Fine-grained brown silt deposits, probably of lacustrine origin, are also included in the flood-plain deposits. They occur in a belt three-fourths of a mile wide along the Okokmilaga River from a point beyond the southern edge of the map to lat 68°27′ N., where they appear to terminate against a recessional moraine. The river is incised about 25 feet and the silt is exposed in cutbanks. Areas along the Okokmilaga flood plain which are underlain by the silt deposits have thermokarst topography characterized by small thaw lakes and polygonal nets.

On aerial photographs similar lacustrine silt deposits were observed along the Killik River extending from the western edge of the map to lat 68°33′ N., where they appear to terminate against a recessional moraine.

The entire mapped area is underlain by permanently frozen ground (permafrost) to an unknown depth. Blocks and wedges of ice are exposed in many cutbanks where unconsolidated deposits are being actively eroded by the streams. Several well-preserved mammoth tusks were recovered from frozen silt banks along the Ayiyak River near lat 68°41′ N. and on Ivory Creek, a small tributary to the lower Kiruktagiak River.

IGNEOUS ROCK

DISTRIBUTION AND TOPOGRAPHIC EXPRESSION

Numerous small sills, sill-like bodies, and three large masses of diabase and basalt crop out in the foothills west of the Anaktuvuk River within the belt of complexly folded Paleozoic and Mesozoic rocks adjacent to the mountains and within the belt of the Fortress Mountain Formation. The exposures of igneous rock in this area form the eastern end of a belt of diabase that extends westward across the Arctic Slope at least as far as the Utukok River (E. G. Sable, oral communication, 1951).

Nearly 100 separate occurrences of igneous rock have been mapped. More could probably be located by detailed mapping, and many others doubtlessly occur in the covered areas.

As the igneous rock is more resistant than most of the rocks with which it is associated, it generally crops out more strongly or stands above covered surfaces. In the interstream areas, igneous rock usually occurs in isolated knobs or in short knobby or rubble-strewn ridges that rise 25 to 100 feet above the surrounding surfaces; it forms several nearly continuous ridges as much as 1½ miles long. Along valleys igneous rock forms low bluffs or rubble-covered knolls on the valley walls and flats; it is exposed in few cutbanks. The large masses on the Kiruktagiak River at lat 68°30′ N., between Autumn Creek and the Siksikpuk River at lat 68°29′ N., and at Horseshoe Mountain make rounded hills a mile or two across and as much as 700 feet high.

FORM AND RELATIONSHIP TO SURROUNDING ROCKS

Most of the small igneous bodies seem to be sills. They appear to be tabular and concordant with the bedding of the enclosing host rock. Alteration of the host rock was noted in good exposures at many localities, and in several places altered inclusions of the host rock were found within the sills. A few of the small bodies, particularly those near the head of Fortress Creek, have textural features characteristic of extrusive rock. However, field evidence is insufficient to prove them flows rather than shallow sills.

The three large masses previously mentioned may be partly intrusive and partly extrusive. The main mass of Horseshoe Mountain consists of interlayered flows and clastic rocks, but probable intrusive rocks are exposed at two places at the western foot of the mountain. The mass at lat 68°30′ N. on the Kiruktagiak River is intrusive into limestone on the southeast end; large inclusions of sedimentary rocks parallel to the trend of the igneous mass and diabase projections into the sediments parallel to bedding are additional indications of intrusive relationships. However, the textures of some of the igneous rock suggest that part of this mass may be extrusive.

Most tabular bodies range in thickness from a few feet to 100 feet. The lower of two bodies measured on Tiglukpuk Creek near lat 68°20′ N. is 212 feet thick, and the upper is 75 feet thick. The thickest one observed is at The Notch on the Kiruktagiak River and appears to be about 300 feet thick. Most of the tabular bodies crop out along strike no more than a few hundred yards; a few can be traced for 1½ miles. The thickness of the rocks in the three large masses was not measured, but it must be at least a few hundred feet.

LITHOLOGY

MEGASCOPIC

The igneous rock crops out in rounded dark-colored knobs or ledges that are characteristically covered with orange and dark-gray lichen. Rubble fragments present on most exposures are small, rounded, and light brown. A rind of relatively soft rock encloses a hard and tough interior in rubble fragments and on outcrops; the fresh rock generally effervesces with dilute hydrochloric acid. Fresh surfaces of the rocks are generally dark green to dark gray, but some of the aphanitic rocks are light grays and greens. The texture is predominately fine grained and equigranular, but locally is aphanitic, porphyritic, or coarse grained.

Rocks with amygdaloidal or clastic textures occur in subordinate amounts. Amygdaloidal aphanites are present at Horseshoe Mountain, on Fortress Creek, and at several other localities. The amygdules are subspheroidal, 0.5 to 5 mm in diameter, and are composed of carbonates, chloritic minerals, or zeolites which weather out to form a vesicular rock. Fragmental rocks, present in the sequence at Horseshoe Mountain, contain angular fragments, as much as a few centimeters across, of igneous rocks and minerals set in a dense matrix.

Inclusions of chert, limestone, and siltstone are scattered through the igneous rock in some exposures. Many of the inclusions are light colored but are otherwise unaltered; some large inclusions of limestone have been recrystallized, and small amounts of chloritic minerals and sulfides have been added.

Few contacts between the igneous rock and the enclosing rocks are exposed. Along those that were seen, contact effects were limited, even in limestone, to a few inches and seldom consist of more than bleaching. At the lower contact of the 212-foot-thick body on Tiglukpuk Creek, there is no chilled zone and no alteration of the underlying glassy chert; at the upper contact, there is a 1-foot-thick aphanitic zone on the margin of the igneous body, and the bordering interbedded chert and limestone appear to have been baked. The 75-foot-thick body above shows no alteration at either contact. On the footwall contact of the steeply south-dipping sill at The Notch, limestone of the Lisburne Group has been partly recrystallized and somewhat altered; abundant seams and veinlets of coarse-grained carbonate lace the limestone, and some iron-copper sulfide minerals have replaced the limestone within a few inches of the contact.

MICROSCOPIC

Thin sections of 29 specimens of igneous and associated clastic rocks were examined. Of these specimens, 15 are from Horseshoe Mountain, 8 from near the head of Fortress Creek, and 6 from scattered localities between the Okpikruak and Chandler Rivers.

The igneous rocks are microscopically similar in gross aspect but are varied in detail. They are generally composed of about 50 percent feldspar, dominantly albite; about 30 percent pyroxene or other mafic mineral; and the remainder of accessory, deuteric, and secondary minerals. Textures are varied: medium- to fine-grained diabasic, felsitic, microgranular, microporphyritic, and microlithic. Rock types identified are albite diabase (spilite), diabase, and basalt.

The essential minerals are plagioclase and augite; accessory minerals are titaniferous magnetite, apatite, and possibly biotite, chloritic minerals, quartz, and sphene; deuteric or secondary minerals are albite, prehnite, quartz, carbonate, antigorite, chlorites, celadonite, stilpnomelane(?), biotite, magnetite(?), sphene, sericite, kaolinite(?), clinozoisite, and zeolites. The original composition of many of the rocks is difficult to determine because of alteration. In a few sections of the least altered rocks, plagioclase ranges between 50 and 65 percent, mode about 55 percent, and augite makes up most of the remainder.

PLAGIOCLASE

The microtextures of the rocks are determined chiefly by the form in which plagioclase has crystallized because it is the dominant mineral in most of the rocks. A description of the forms of plagioclase closely approaches, therefore, a description of the rock textures. In thin sections, amounts of plagioclase range between 30 and 65 percent with a mode of about 50 percent. Lengths of plagioclase grains range in length from 0.04 to 5.0 mm in the suite of thin sections, and the larger grains in individual sections may be as much as five times as long as the smallest grains. In the diabasic rocks, plagioclase has grown in subhedral laths and in felted or granular aggregates interstitial to the laths. Felts of plagioclase laths or microlites are characteristic of the aphanitic rocks; plagioclase has crystallized as subspherulitic masses in some of them. Many of the phenocrysts in porphyritic rocks are broken and corroded subhedra of plagioclase. Some movement during consolidation is indicated in a few thin sections of the finer grained rocks by curved zones of microlites wrapped around larger grains, by patches of subalined microlites parallel to streaks of opaque minerals or to a crude layering of phenocrysts, and by broken phenocrysts and distorted laths of plagioclase.

Twinning in plagioclase ranges from complex to simple and from sharp to obscure. Although the sharpest and most complex twinning occurs in the rocks that are apparently the least altered, twinning is nearly as prominent in albite as it is in the more calcic plagioclases. This suggests that the development of albite was not part of the alteration process that tends to obscure twinning.

Albite predominates in the thin sections—the refractive indices of plagioclase exceed 1.54 in only three sections. Extinction angles on twins indicate a composition of 90–95 Ab for the plagioclases with the low indices of refraction and a range of 15–70 Ab for the plagioclases with the higher indices.

The preponderance of albite in the thin sections may indicate an extensive alteration of more calcic plagioclases to albite. However, the only evidence of albite originating from other than pyrogenetic crystallization is in one thin section from a rock on Horseshoe Mountain in which albite, indistinguishable from albite in the body of the rock, has grown from walls of veinlets and cavities. In addition, the development of albite may may be mainly a feature of the extrusive and very shallow intrusive rocks, because relatively few thin sections of the thicker sills were studied and albite was absent in about half. A 60-foot-thick sill on Okonagun Creek at lat 68° 31′ N. is an example of the crystallization of more calcic plagioclase in diabase sills. A thin section from the middle of the sill, where external influences during consolidation were probably minimal, consists of small bytownite phenocrysts set in a fine-grained diabasic matrix of labradorite with interstital granular aggregates of andesine(?).

Albite in many of the sections shows subsequent alteration by secondary and surficial processes. Chloritic minerals are widely distributed along grain margins and cleavages of albite, and the centers of many albite grains are clouded by sericite, kaolinite(?), clinozoisite, and carbonate. Minor quartz appears to have been produced in advanced stages of alteration of albite. In a few thin sections albite has been partly to completely replaced by prehnite. Calcite forms interstitial to albite grains and encroaches upon them on incipient weathering of the rocks.

AUGITE

The occurrence of augite is similar to that of plagioclase and has formed in grains about the same size. A subophitic texture is typically developed in diabase by augite anhedra, subhedra, and mosaics that enclose or are interstitial to plagioclase laths. Augite in granular textures and in phenocrysts is common in the finer-grained rocks. A maximum refractive index of approximately 1.72 and an optic angle of approximately 50° indicate a composition for the augite of 25 percent of the iron member and equal parts of the calcium and magnesium members of the pyroxene series (Winchell and Winchell, 1951, fig. 289, p. 410). Although the purple tint of titaniferous augite is lacking, appreciable amounts of titanium seem to be included in the augite because sphene is produced by alteration of augite. Proportions of augite in the sections range from nearly

0 to 40 percent. Part of the variation may reflect differences in the compositions of the melts from which the rocks formed, but most of it results from variable quantities of mafic constituents that occur in other minerals.

Alteration of augite in the suite of thin sections varies from negligible to nearly complete. In some sections, augite is only slightly replaced by chloritic minerals along cleavages and grain borders; in others, replacement has been complete and only augite pseudomorphs are left. A successive replacement of augite by (1) biotite, (2) celadonite, (3) chlorite, and (4) carbonate is preserved in a few sections. Generally, though, biotite is absent, and the augite has been altered to variable proportions of celadonite, chlorite, and carbonate. This alteration is thought to be largely deuteric, although much of the carbonate may be the product of incipient weathering. Abundant sphene has been dispersed into mineral grains surrounding altered augite grains, and small amounts of quartz are byproducts of the alteration of augite to biotite.

The crystallization history of augite and plagioclase can be reconstructed from several thin sections in which consolidation took place at two or more rates: (1) Plagioclase laths began crystallizing first, followed by augite to form ophitic textures. (2) Plagioclase continued crystallizing with augite but in decreasing proportions. (3) Plagioclase continued to form after the augite constituents were exhausted or as temperature-pressure conditions lowered to levels at which the mafic constituents crystallized as chloritic minerals rather than augite.

OTHER PYROGENETIC MINERALS

Hornblende occurs only in a thin section of a sample from the western foot of Horseshoe Mountain. Relics of a low-iron common hornblende are enclosed by secondary minerals in pseudomorphs after amphibole subhedra. The pseudomorphs, 0.3 to 4 mm long, occur interstitial to plagioclase laths of similar size. They indicate an original hornblende content of about 20 percent. Minerals that make up the pseudomorphs are biotite, celadonite, chlorite, carbonate, quartz, skeletal ores, sphene, and pyrite. Rhombic cleavage has been imaged in some celadonite pseudomorphs by sphene concentrated along the traces.

Primary biotite also was recognized only in the hornblende rock mentioned above. Brown grains as large as 0.5 mm have pleochroic patches centered about minute zircon(?) grains. Biotite may have formed more than 10 percent of the rock originally, but it has been progressively altered to celadonite and chlorite.

The only evidence of olivine in the thin sections is in a porphyritic aphanite from Fortress Creek. Hexaggonal masses of antigorite-bastite(?), two to three times larger (0.3–1.5 mm) than the surrounding plagioclase laths, have sagenetic webs(?) of opaque minerals and contain small flakes of iddingsite(?). These masses of secondary minerals may be pseudomorphs after olivine phenocrysts; if so, olivine constituted about 10 percent of the rock.

Plagioclase grains in several of the sections contain small amounts of apatite, and the section from the center of a sill on the Okpikruak River contains about 2.5 percent apatite. In it, apatite rods have grown within plagioclase laths and extend into plagioclase grains from granular masses of minerals interstitial to the laths. Apatite is evidently a late primary constituent of some of the rocks.

OPAQUE MINERALS

Some grains of opaque minerals are about the same size as the essential minerals and have formed interstitial to them in euhedral to anhedral shapes. Other grains of opaque minerals are smaller than the essential mineral grains and are disseminated through the rock. Still others are skeletal. The content of these minerals in the rocks averages about 5 percent, with a range from a trace to 10 percent. Proportions of the opaque minerals that are of primary or secondary origin were not determined. Many of the grains are dusted with leucoxene, and some have been extensively altered to sphene. It is assumed that most of the opaque material is titaniferous magnetite. Opaque minerals in the olivine(?) rock have been oxidized to hematite.

DEUTERIC AND SECONDARY MINERALS

Many of the thin sections, particularly of fine-grained rocks, are composed of large amounts of a micaceous-chloritic mineral series. Minerals in the series appear to have formed largely in a late—deuteric—stage of consolidation of the rocks. Biotite and chlorite can be identified as the end members, but the optical properties of the crystalline material in between grade from those of biotite to those of chlorite. The intermediate minerals as a group have been provisionally identified as celadonite or a celadonitelike mineral. Part of the series in one section resembles stilpnomelane.

This mineral series is best developed in a stage of consolidation that is thought to be deuteric, but it also formed in earlier and later stages. In the deuteric stage, which involves reactions with and within residual fluids, biotite, celadonite(?), and chlorite replaced plagioclase and augite, and crystallized in subordinate quantities in pores between pyrogenetic mineral grains. An earlier formation of these minerals is indicated in a few thin sections in which they constitute a major part of the rock as the matrix for felted or loosely packed aggregates of plagioclase laths or microlites. A postconsolidation formation of the series is shown by celadonite-chlorite fillings of cracks and amygdules. In addition, the presence of celadonite(?) and chlorite in the cementing material as well as in the clasts of some of the fragmental rocks at Horseshoe Mountain indicates that part of the mineral series formed under conditions approaching diagenetic.

Prehnite replacement of plagioclase and as filling of voids was observed in several thin sections of the rocks from Horseshoe Mountain. It was formed in part before fragmentation of the rocks because it is present in clasts in the fragmental rocks, but it is also present in the matrix of the clastic rocks and looks as if it had grown there authigenically. The origin of prehnite was not determined, but it may follow the pattern of the micaceous-chloritic series.

Zeolites are present in only two thin sections. In these sections, minerals with the optical properties of chabazite, stilbite, and thomsonite fill amygdules and form relatively large masses within the rocks.

Quartz, opaque minerals, sphene, and carbonate appear to be byproducts of alteration. Carbonate fragments and matrix in rocks from Horseshoe Mountain suggest that considerable quantities of carbonate were formed in some of the rocks before fragmentation. However, much of the pervasive carbonate in the igneous rocks seems to be a product of weathering.

CLASTIC ROCKS

Clastic rocks, thought to correlate with the tuffaceous graywacke unit (p. 443), are interlayered with flows in the 200- to 300-foot-thick sequence of rocks at Horseshoe Mountain. They are poorly sorted aggregates consisting mainly of fine-grained diabase, plagioclase, augite, chloritic minerals, carbonate, and prehnite, cemented by chloritic minerals, carbonate, and prehnite. Most of the fragments are only slightly rounded. Fragments ranging in size from 0.01 mm to more than 3 mm are visible in thin section, but the outlines of much larger fragments are visible in hand specimens. The clasts are closely packed in some thin sections; they are widely separated and float in the matrix in others. The matrix material has corroded and replaced some of the fragments along their margins. Although part of the material may have been glassy originally, no evidence of original glass was recognized.

AGE

No igneous rock is shown in the area of this report on Smith and Mertie's geologic map (1930, pl. 1), but masses of mafic igneous rock are shown in the areas to the west. Although Smith and Mertie (1930, p. 261–262) observed that all the igneous masses are post-Mississippian, they reasoned that two ages were represented. They correlated the intrusive and extrusive rocks along the canyon of the Noatak River with the gabbro on the Nimiuktuk River. They assigned a Jurassic age to these rocks because the gabbro intruded Upper Triassic strata, and because fragments of igneous rocks like those on the Noatak occur in Lower Cretaceous sedimentary rocks. They believed, however, that lavas on the Kivalina River were more likely to be late Paleozoic or early Mesozoic in age.

The relation of the igneous rocks to the succession of sedimentary rocks can be determined in detail in the area of this report. Although the determination by Smith and Mertie of a Jurassic igneous episode is substantiated and refined, their suggestion of an earlier episode cannot be supported. Igneous rocks have been intruded into the Tiglukpuk Formation and, to a lesser extent, into the older Lisburne Group; no intrusions into the Siksikpuk or Shublik Formations were observed, and none occur in the Okpikruak Formation or younger rocks. Extrusive rocks are associated with sedimentary rocks that may be correlative with the tuffaceous graywacke unit. The abundance of igneous minerals in the heavy minerals in the tuffaceous graywacke unit, the variegated shale siltstone sequence, and the Okpikruak Formation show that igneous material was included in the sediment at the time these rocks were deposited.

Only one igneous episode is indicated and it can be closely dated as latest Jurassic. It is of post-Tiglukpuk age (Oxfordian to Portlandian) because the Tiglukpuk Formation has been intruded, and it is pre-Neocomian because volcanic debris is abundant in the Okpikruak Formation. The variegated shale siltstone sequence contains a Portlandian fossil. The tuffaceous graywacke unit, possibly correlative with the variegated sequence, contains fossils that are Jurassic rather than Cretaceous in age (R. W. Imlay, written communication, 1956).

STRUCTURAL GEOLOGY

GEOLOGIC MAP AND CROSS SECTIONS

The structural features shown on the geologic map (pl. 50) and on the eight generalized north-south cross sections (pl. 50) are necessarily highly interpretive owing to the general scarcity of exposures, the lack of stratigraphic control, particularly among the Jurassic and Cretaceous rocks, and the complexity of the structure. There was not sufficient time in the field to examine all exposures and to trace out the contacts and faults; many of the structural interpretations, therefore, are based upon observations on aerial photographs. In many places, lithologic units and structural features which were observed on stream cutbanks have been extended along the regional strike across poorly exposed interstream areas. This seems justified in view of the apparent persistence of the structural features and lithologic units throughout the best exposed parts of the mapped area.

Only a few of the several hundred strike and dip observations that were used in compiling the map and sections are shown on the finished map.

Most of the faults shown on the map and cross sections are inferred; few faults are actually exposed. North of the mountains most of the faults are interpreted as high angle. This is the nature of the few faults that are exposed and is also indicated by the relatively straight trend of the fault traces even in areas of considerable relief. However, there is reason to believe that some of these faults may flatten at depth and merge into a few large flat sole thrust faults (p. 490–491).

The small-scale folding shown in the cross sections within the belt of complexly deformed late Paleozoic and Mesozoic strata adjacent to the mountains and in the belt of Torok strata is largely diagrammatic. The general shape of these folds and the inclination of their axial planes, however, are based upon field observations.

REGIONAL SETTING

The Killik-Itkillik region falls within two of the major tectonic elements of Alaska, the Brooks Range geanticline, an east-trending positive element composed of highly folded and faulted pre-Mesozoic strata, and the Colville geosyncline, an east-trending negative element in which a great thickness of Mesozoic sedimentary rocks is preserved (Payne, 1955). From the axis of the Brooks Range geanticline near the center of the Brooks Range to the axis of the Colville geosyncline along the Colville River the regional dip is northward, exposing progressively younger rocks.

The mapped area (pl. 50) can be subdivided into five narrow east-trending structural zones which are, from south to north:

Structural zone I: A belt of thrust-faulted and folded strata of the Lisburne Group along the front of the Brooks Range.

Structural zone II: A belt of complexly folded and faulted upper Paleozoic and Mesozoic rocks adjacent to the mountain front.

Structural zone III: A belt of folded and faulted rocks of the Fortress Mountain Formation.

Structural zone IV: A belt of intensely crumpled strata of the Torok Formation.

Structural zone V: A belt of gently folded beds of the Nanushuk Group.

Each of these zones is in effect a discrete structural unit.

STRUCTURAL ZONE I

GENERAL FEATURES

Along the mountain front the Lisburne Group, which occurs in a belt as much as 10 miles wide, generally dips 20° to 40° to the south. To the casual observer the regularly south-dipping succession of strata might suggest a thickness on the order of tens of thousands of feet (fig. 67). However, detailed stratigraphic measurements at several points along the mountain front have shown that the Lisburne Group is only 2,000 to 3,000 feet thick, but it is repeated many times by south-dipping imbricate thrust faults (W. P. Brosgé and H. N. Reiser, written communication, 1951). Many of these imbricate thrust faults parallel or nearly parallel the bedding planes and therefore cannot be recognized except by detailed stratigraphic examination. As no detailed studies of these rocks were undertaken, data are insufficient to permit delineation of the many faults that probably occur within this structural zone.

LOCAL DETAILS

OKPIKRUAK RIVER TO CHANDLER RIVER

Zone I along the mountain front between the Okpikruak and Okokmilaga Rivers was not visited in the field. The distribution of Lisburne rocks and the structural data shown on plate 50 are based on interpretation of aerial photographs. The nature of the upper contact of the Lisburne Group along this part of the mountain front is not known.

On the west side of the Okokmilaga River, Lisburne rocks appear to have been thrust upon the Siksikpuk and younger formations. The thrust sheet of Lisburne, which has been partly removed by erosion, seems to have been folded into an east-trending anticline. At the head of the Kiruktagiak River there is evidence that rocks of the Lisburne Group have overridden the strata of the foothills (pl. 50, section *B–B'*). Two miles south of Monotis Creek this sheet of the Lisburne Group has been removed by erosion, exposing beneath it a small area of complexly folded rocks of the Lisburne Group and Siksikpuk, Shublik, and Tiglukpuk Formations. The trace of the fault plane is shown in figure 88. The fault plane apparently has been folded; north of the eroded area it dips north beneath the foothills, but on the west and south side, it appears to dip gently south. The northward extent of the overriding sheet is not known because the fault plane, if it reappears at all, cannot be recognized among the many faults that have been mapped in the foothills.

FIGURE 88.—Looking westward along mountain front near head of Kiruktagiak River. Dashed line shows approximate trace of thrust fault. Folded limestone of the Lisburne Group (Mississippian) forms the mountains; complexly deformed upper Paleozoic and Mesozoic strata underlie the lowland in the middle and left foreground. Photograph by U.S. Navy.

From the Kiruktagiak River to the Chandler River the contact of the Lisburne Group in the Brooks Range and the younger rocks in the foothills is obscured by a mantle of glacial debris.

CHANDLER RIVER TO ANAKTUVUK RIVER

Zone I at the mountain front between the Chandler River and Tiglukpuk Creek was not visited in the field, but it has been mapped from aerial photographs. Some strikes and dips and fold axes that were observed on the photographs have been plotted on the map. In several places rocks of the Lisburne Group appear to be thrust onto the younger rocks of the foothills.

At the head of Tiglukpuk Creek the Lisburne is folded into an asymmetric anticline whose north limb is nearly vertical and locally overturned. The axial trace of the anticline lies about a mile south of the mountain front and can be traced east-west for a distance of 9 miles. West of Tiglupuk Creek the anticline terminates by plunging westward beneath younger rocks of the foothills. East of Tiglukpuk Creek the anticline appears to be overturned to the north, and two small west-plunging subsidiary anticlines occur on the north flank.

At the mountain front south of Natvakruak Lake, Lisburne strata have overridden younger rocks. The fault plane is exposed in several places and has an average south dip of 16° (fig. 89). A short distance north of the mountain front, three small klippen of Lisburne lie on the Siksikpuk and Shublik Formations. Another much larger outlier of Lisburne which occurs 2 or 3 miles southeast of Natvakruak Lake may also be a klippe, but as it is entirely surrounded by glacial drift, the structural relationships to the underlying strata are unknown.

FIGURE 89.—Overturned anticline of limestone of the Lisburne Group (Ml) that has been thrust faulted upon the Siksikpuk Formation (Ps) at the mountain front a few miles south of Natvakruak Lake. Dashed line indicates trace of fault plane.

ANAKTUVUK RIVER TO ITKILLIK RIVER

Glacial drift covers the foothills strata along the mountain front from the Anaktuvuk River eastward nearly to Erratic Creek. On Erratic Creek the strata of the Lisburne Group are exposed in fault contact with the Shublik Formation (pl. 50, East half, section *E–E′*). Between Erratic and Welcome Creeks, the Lisburne Group is folded into a broad, asymmetrical, west-plunging anticline. On Welcome Creek at the mountain front, the Lisburne Group appears to dip northward normally beneath the Shublik Formation at an angle of about 70°.

At the mountain front on the Nanushuk River, rocks of the Lisburne Group are faulted against the Shublik Formation. A mile north of the mountain front is a wishbone-shaped outlier of the Lisburne Group that appears to be the west-plunging nose of an anticline. The Lisburne outlier is flanked by the Shublik Formation, and this formation also occurs along the axial region of the anticline. Between the Nanushuk River and the Kuhsuman Creek, the Tiglukpuk Formation is also exposed along the axial zone. The outlier is interpreted (pl. 50, East half section *F–F′*) as a thrust plate of the Lisburne Group resting upon a thrust plate of the Shublik Formation, which, in turn, rests upon the Tiglukpuk Formation. Both the Lisburne and the Shublik thrust plates apparently have been folded into an anticline, and erosion has removed both thrust plates except on the west-plunging nose of the anticline.

From Nanushuk Lake to Cobblestone Creek, the mountain front is marked by thin fault slivers of the Lisburne Group and Shublik Formation offset by several north- and northwest-trending cross faults. At Cobblestone Creek, the Lisburne dips normally beneath the Shublik, but from the westernmost fork of May Creek to the valley of the Itkillik River, the Lisburne Group appears to be thrust northward onto the Okpikruak Formation.

STRUCTURAL ZONE II

GENERAL FEATURES

Structural zone II, an east-trending belt of complexly folded and faulted upper Paleozoic and Mesozoic strata, is adjoined by the Lisburne belt at the mountain front (zone I) on the south and by a belt of Fortress Mountain strata (zone III) on the north (pl. 50). West of the Siksikpuk River it is 12 to 14 miles wide, but east of the Nanushuk River it narrows to 5 to 6 miles wide. It is composed predominantly of the interfolded and interfaulted Tiglukpuk and Okpikruak Formations, but it also includes the Lisburne Group, Siksikpuk and Shublik Formations, and mafic volcanic rocks. In addition, there are two large infolded masses of rocks of the Fortress Mountain Formation, one between the Siksikpuk and Chandler Rivers at lat 68°26′ N., and the other between Peregrine Creek and the eastern edge of the mapped area from lat 68°24′ N. to lat 68°29′ N.

Structural zone II is characterized by numerous small tightly appressed folds and closely spaced faults. The folds are generally overturned to the north and are commonly isoclinal. The faults are chiefly south-dipping high-angle reverse faults, but normal faults and transverse strike-slip faults were also noted.

Small folds and faults occur in nearly every outcrop, but they are far too numerous to be plotted on plate 50. Only a few of the more significant faults and fold axes are shown on plate 50.

The large faults shown on plate 50 along the northern margin of the belt are generalized and actually represent a zone of numerous closely spaced faults, each of small individual displacement. On the south these faults are bounded by a band of intensely crumpled rocks containing several small upfaulted slivers of the Lisburne Group and Shublik Formation.

The various formations that crop out in structural zone II are grossly distributed along several east-trending bands, suggesting that broad structural highs and structural lows are superimposed upon the small closely spaced folds. The structural lows are marked by bands of the Okpikruak Formation, the Fortress Mountain Formation, and the undifferentiated Tiglukpuk and Okpikruak Formations; the structural highs are indicated by bands of the Tiglukpuk Formation and scattered exposures of pre-Tiglukpuk strata.

LOCAL DETAILS

OKPIKRUAK RIVER TO CHANDLER RIVER

Between the Okpikruak and Chandler Rivers, the northern margin of structural zone II appears to be thrust against the Fortress Mountain Formation. Several small slivers and fault blocks of pre-Tiglukpuk strata are scattered along the south side of the thrust fault. Bordering the fault is a 3-mile-wide band, mostly of undifferentiated Tiglukpuk and Okpikruak strata, which appears to define a structural low. Exposures along this band are poor and the Tiglukpuk and Okpikruak Formations could not be differentiated except locally along the Okpikruak River and east of the Kiruktagiak River. Between the Okpikruak and Okokmilaga Rivers, this band is adjoined on the south by an east-trending structural high along which two narrow faulted strips of rocks older than the Tiglukpuk Formation are exposed. South of the high is another structural low which is marked by an east-plunging syncline of the Okpikruak Formation.

East of the Okokmilaga River the broad structural features in the southern part of structural zone II are obscured by glacial debris and the upland gravels. A large mass of mafic igneous rock and a small exposure of the Lisburne Group may mark a structural high that crosses the Kiruktagiak River at about lat 68°30′ N. The apparent wraparound of the Okpikruak Formation between Speedway and Castle Creeks indicates that this high probably plunges southeastward. Another structural high may cross the Kiruktagiak River at The Notch, lat 68°25′ N., where a thin fault sliver of the Lisburne Group and mafic instruive rock forms a wall-like ridge across the valley of the Kiruktagiak River (fig. 90).

FIGURE 90.—Fault sliver of limestone of the Lisburne Group at The Notch on the Kiruktagiak River.

CHANDLER RIVER TO ANAKTUVUK RIVER

Along the northern margin of structural zone II from the Chandler River eastward to the Siksikpuk River and beyond, the Tiglukpuk Formation seems to be in normal contact with the Fortress Mountain Formation, although the contact is offset nearly 1½ miles by a transverse fault 2 miles east of Autumn Creek.

The northern part of structural zone II between the Chandler and Siksikpuk Rivers is dominated by a structural high along which the Tiglukpuk Formation, mafic intrusive rock, and small slivers of the Lisburne Group and Shublik Formation are exposed. South of this high is a structural low marked by an elliptically shaped synclinal mass of the Fortress Mountain Formation that rests unconformably on older strata.

The southern part of structural zone II between the Chandler River and Confusion Creek was not visited in the field. However, on aerial photographs it has the same texture and grain as contiguous areas to the east and west and therefore probably is also underlain by complexly deformed Tiglukpuk, Okpikruak, and older formations.

From Tiglukpuk Creek eastward to beyond Natvakruak Creek the northern margin of structural zone II seems to be faulted against the belt of Fortress Mountain strata (structural zone III). Several tiny fault slivers of the Lisburne Group occur a short distance to to the south of the fault contact.

The rocks in the northern half of structural zone II between the Siksikpuk and Anaktuvuk Rivers are poorly exposed. They appear to be chiefly interfolded and interfaulted Tiglukpuk and Okpikruak strata and are probably grossly synclinal in structure. In the southern half, the rocks are well exposed. There the structure is dominated by the Tiglukpuk Creek anticline along which is exposed a large mass of the Lisburne Group (pl. 50, West half, section *D–D′*). Near Confusion Creek the main mass of the Lisburne Group plunges abruptly westward beneath younger beds. However, a thin band of the Lisburne Group continues westward from Confusion Creek to beyond Encampment Creek. The structure at the east end of the anticline is complicated by two transverse faults. The structure of the block of the Lisburne Group that lies between the two faults could not be determined, but beyond the easternmost fault the anticline appears to be east plunging. Between the anticline and the mountain front is a belt of post-Lisburne strata which, although complicated by small folds and faults, is grossly synclinal. The axis of the syncline presumably crosses Tiglukpuk Creek near the mouth of Skimo Creek where a thick sequence of the Okpikruak Formation is preserved.

ANAKTUVUK RIVER TO ITKILLIK RIVER

From the Anaktuvuk River eastward to the Iktillik River, the northern edge of structural zone II is bordered by a band, as much as 2 miles wide, consisting of highly deformed strata of the Tiglukpuk Formation. Where exposed in cutbanks, the contact of the Tiglukpuk and Fortress Mountain Formations appears to be faulted. Faulting is also indicated along the northern edge of structural zone II between the Kanayut and Nanushuk Rivers by the divergence in trends of the Fortress Mountain strata and the margin of structural zone II. Strata of the Fortress Mountain Formation have a regional northeasterly strike; the margin of structural zone II has a northwesterly trend.

A structural low along the center of structural zone II is defined by an east-trending band of the undifferentiated Tiglukpuk and Okpikruak Formations between the Kanayut and Nanushuk Rivers and by the infolded mass of the Fortress Mountain Formation east of the Nanushuk River. Exposures are poor west of the Nanushuk River, but east of the Nanushuk the mass of the Fortress Mountain Formation crops out extensively in cutbanks on Cobblestone and May Creeks. The Fortress Mountain Formation is intensely folded and is cut by numerous strike faults which locally bring to the surface thin slices of older rock (pl.

50, East half, section *G–G'*). The northern margin of the Fortress Mountain Formation appears to be thrust upon the Tiglukpuk and Okpikruak Formations.

A band of the Shublik Formation crops out at the southern edge of structural zone II between Kanayut and May Creeks. The Shublik is thrust upon the Tiglukpuk and Okpikruak Formations on the north and is in both fault and normal contact with the Lisburne Group at the mountain front.

STRUCTURAL ZONE III

GENERAL FEATURES

Structural zone III, a belt of folded and faulted rocks of the Fortress Mountain Formation, 4 to 10 miles wide, extends eastward across the center of the mapped area. West of the Nanushuk River the structure along this zone is dominated by several broad open east-trending synclines, such as at Castle and Fortress Mountains, and by smaller asymmetrical anticlines and synclines which generally have steepened north flanks. East of the Nanushuk River, Fortress Mountain strata are more tightly compressed and are characterized by isoclinal folds and numerous high-angle reverse faults.

A fault is inferred along the northern contact of structural zone III from the Kiruktagiak River to the Itkillik River, on the bases of the occurrence of slivers of pre-Fortress Mountain strata and anomalous stratigraphic and structural relationships at scattered exposures along the contact. West of the Kiruktagiak River, exposures along the northern margin of the zone are lacking, and the nature of the Fortress Mountain-Torok contact is uncertain.

LOCAL DETAILS

OKPIKRUAK RIVER TO AYIYAK RIVER

West of Canoe and Fortress Creeks the structure of zone III is obscure for lack of exposures. On the Okpikruak River two folds were observed, an anticline at lat 68°37'30'' N. and a syncline at lat 68°38'30'' N. On the Okokmilaga River an east-plunging syncline is exposed at lat 68°37' N. None of these folds could be traced far from the rivers.

Between Canoe Creek and the Ayiyak River the rocks of structural zone III are better exposed. The noses of two west-plunging synclines form the low hills near the head of Canoe Creek. A thrust fault, inferred from stratigraphic relationships within the Fortress Mountain Formation, appears to extend eastward from Canoe Creek and May Lake to beyond the Ayiyak River. On the north side of this fault a group of hills, named the Canoe Hills, is composed of highly deformed Fortress Mountain strata. Owing to structural complexity and the lack of marker beds, the structural details of these strata could not be delineated except for a single moderately appressed anticline shown on the map (pl. 50) at lat 68°38' N., long 152°55' W. On the south side of the fault is a structural high along which the Tiglukpuk Formation and small fault blocks of the Lisburne Group occur. Between this high and the southern margin of the zone is the Fortress Mountain syncline, a broad east-trending fold in which several thousand feet of strata form a prominent mesa.

East-plunging strata of the Fortress Mountain Formation form the west end of the syncline near Fortress Creek (fig. 82). At the east end near the Ayiyak River, however, the syncline appears to have been overridden by the east-plunging end of the Castle Mountain syncline, and a thrust fault is inferred between Chert Creek and the Ayiyak River. The south limb of the Fortress Mountain syncline near Chert Creek apparently has been buckled and bent from the original east trend to a north trend parallel to the inferred fault and the east-plunging end of the Castle Mountain syncline. This change in trend suggests that the Castle Mountain thrust sheet rode against and crumpled the south limb of the Fortress Mountain syncline.

AYIYAK RIVER TO ANAKTUVUK RIVER

Between the Ayiyak and Chandler Rivers, structural zone III is dominated by a broad synclinal basin in which more than 10,000 feet of the Fortress Mountain Formation is preserved. The axis of this structure passes through Castle Mountain. Near the Ayiyak River, Fortress Mountain beds wrap around and the syncline plunges eastward. East of Castle Mountain the form of the syncline is less obvious; the upper beds of the formation on the east face of Castle Mountain appear to wrap around and plunge westward, but the lower beds exposed along Torok Creek and the Chandler River strike nearly due east. The syncline is bounded by a fault, inferred to be a thrust, and by a thin strip of pre-Fortress Mountain rocks along the north and west margins. The south limb of the syncline appears to be partly faulted out by an overriding thrust sheet of structural zone II. Attitudes of the upper beds of the Fortress Mountain Formation that crop out at the top of Castle Mountain are gentle and regular. By contrast, the lower strata of the formation are more highly deformed, even along the synclinal axis. Locally, some of the lower beds are overturned. It appears, therefore, that perhaps folding was progressive and was in part contemporaneous with deposition.

The thrust fault that bounds the Castle Mountain syncline on the west and north probably continues eastward beyond the Chandler River, as suggested by scattered exposures of pre-Fortress Mountain strata along a narrow east-trending band. Another fault along the north margin of structural zone III is indicated by the structural relations of the Fortress Mountain and Torok Formations and by the presence of scattered exposures of pre-Fortress Mountain strata. The narrow strip of the Fortress Mountain Formation that lies between the two faults appears to dip predominantly southward, although two small reversals in dip were noted on Torok Creek.

The structure of zone III between the Chandler and Anaktuvuk Rivers is not well known because exposures are scarce. Thin slivers of pre-Fortress Mountain strata crop out along the northern margin of the zone, and the two inferred faults north of Castle Mountain probably continue eastward beyond the Siksikpuk River. They may converge east of the Siksikpuk River, for on Desolation Creek the Fortress Mountain and Torok Formations appear to be separated by only a single narrow strip of older rocks. South of the fault within the belt of Fortress Mountain strata only a few structures are exposed. A small doubly plunging syncline occurs on Autumn Creek near the southern margin of the belt. The axis of this syncline is offset 1½ miles by a northwest-trending cross fault. Another small syncline was noted on the Siksikpuk River close to the southern margin of structural zone III, but it could not be traced far from the river for lack of exposures. Two small folds were mapped along the southern margin of the zone between Tiglukpuk Creek and Natvakruak Creek. Pre-Fortress Mountain rocks are exposed along Natvakruak Creek at lat 68°28′30″ N., but owing to cover, their structural relationship to the surrounding Fortress Mountain strata is obscure.

ANAKTUVUK RIVER TO ITKILLIK RIVER

The rocks of structural zone III are not well exposed east of the Anaktuvuk River and are more highly deformed than those to the west. A fault along the northern margin of the zone is indicated by the structural and stratigraphic relationships of the Fortress Mountain and Torok Formations and locally by the presence of pre-Fortress Mountain rocks.

East of the Nanushuk River, strata of the Fortress Mountain Formation form a series of northeast-trending ridges. The exposed beds are tightly compressed and dip between 50° and vertical. Folds are commonly isoclinal and overturned to the north. Reverse faults bring small slices of pre-Fortress Mountain strata to the surface within and along the northern margin of the zone.

STRUCTURAL ZONE IV

Structural zone IV includes the belt of intensely crumpled strata of the Torok Formation which extends from the northwest corner of the mapped area eastward to the Itkillik River valley. It is bounded on the south by the Fortress Mountain Formation (zone III) and on the north by the rocks of the Nanushuk group (zone V). From the Killik River to the Anaktuvuk River, zone IV ranges from 5 to 8 miles in width. East of the Anaktuvuk River it gradually narrows and is 3 miles wide at the Nanushuk River and less than a mile wide at May Creek.

The Torok Formation, composed chiefly of soft shale, has been deeply eroded; exposures are limited to scattered cutbanks along several of the north-flowing streams. No outcrops were found in the interstream areas.

The incompetent strata of the Torok Formation are tightly crenulated and faulted, except along the north margin of the zone where they lie close to or beneath the competent sandstone of the Tuktu Formation. The complexity of structure, absence of stratigraphic marker beds, and scarcity of exposures make it impossible in most places to outline the gross structural features of the zone. The prevailing southward dips on the southern margin of the zone and northward dips on the northern margin suggest that the zone may be broadly anticlinal.

STRUCTURAL ZONE V

The Torok Formation (zone IV) is bordered on the north by structural zone V, a belt of gently folded rocks of the Nanushuk Group, 30 to 40 miles wide, which is characterized by open folds and gentle dips. Only the southern edge of this zone is included in the Killik-Itkillik area.

In the mapped area west of the Anaktuvuk River, structural zone V is dominated by the Tuktu Escarpment, composed of the north-dipping Tuktu and Chandler Formations. The Escarpment occurs on the south flank of a broad regional fold, the Ayiyak Mesa syncline, whose axis lies about 15 miles north of the mapped area.

From the Anaktuvuk River eastward, the Tuktu Escarpment follows the south limb of the Arc Mountain syncline. The dip of strata increases from 25° to 30° N. in the Kanayut and Nanushuk River basins to vertical east of May Creek. The two folds north of the Escarpment, the Arc Mountain syncline and the Arc Mountain anticline, are typical structures of this zone. The anticline is narrow and sharply creased and the syncline is broad and flat bottomed (fig. 70; pl. 50, East half, *G–G′* and *H–H′*). Both folds are overturned to the north. The syncline plunges gently eastward from Kanayut River to beyond May Creek. The anticline plunges westward between the Nanushuk and Kanayut Rivers. However, from 2 miles west of the

Nanushuk River to Kanayut River, the axis of the anticline is broken by a fault that appears to be a thrust. The fault presumably has a maximum stratigraphic displacement of 1,000 to 1,500 feet, because steeply dipping beds of the middle part of the Chandler Formation on the south side of the fault are in juxtaposition with gently dipping beds of the uppermost Tuktu Formation on the north side of the fault. Although the anticline apparently does not terminate by eastward plunge within the mapped area, it may do so beneath the Itkillik valley till sheet. The anticline is not traceable on aerial photographs east of the Itkillik valley. Along the axis of the anticline, shale of the Torok Formation is exposed. The shale, being incompetent, is crenulated and broken, in contrast to the regular strata of the overlying Tuktu Formation.

INTERPRETATION OF SUBSURFACE STRUCTURE

STRUCTURAL ZONE IV

During the spring of 1952 a reflection seismograph survey was conducted across structural zone IV, the belt of the Torok Formation, by the United Geophysical Co. for Arctic Contractors (E. J. Munns, written communication, 1952). The general purpose of the survey was to determine the structure of the Torok belt and specifically to test the possibility of a major structural reversal in the subsurface. Three traverse lines were run across the Torok belt. Their location is shown in figure 91. Line 1 is the only line that completely crosses the Torok structural belt. None of the three lines gives a true cross section of the zone since they deviate as much as 67° from perpendicular to the regional strike of N. 85° W. of the Torok Formation. Results of the seismic survey in general were not satisfactory. According to the seismologist, E. J. Munns (written communication, 1952), this was chiefly because the highly crenulated shale of the Torok Formation at and near the surface tended to absorb much of the seismic energy. So few satisfactory reflections were obtained on line 1 that the profile is of no value in interpreting the subsurface structure. The results obtained along lines 2 and 3 were better, although the bulk of the reflections are classed by the seismologist as poor or questionable, and no continuous horizons could be drawn. Profiles prepared by United Geophysical Co. along lines 2 and 3 are shown on plate 51. For comparison with the surface geology, see cross sections *B–B′* and *C–C′*, plate 50, West half.

North of shot point 12 along the line 2 profile, the subsurface reflectors to a depth of 4,000 feet below sea level dip steeply northward. At 4,000 feet below sea level there is an abrupt discordance below which the reflectors dip gently southward. Munns drew a southward-dipping thrust fault along the line of this discordance. South of shot point 12 there is no discordance, and Munns suggested that the thrust may be a bedding-plane fault. If the fault is projected northward, it presumably would intersect the surface between shot point 1 and the Tuktu Formation contact. If the fault strikes approximately east-west, as do most of the thrust faults in the mapped area, then it should cross the Chandler River. However, it was not recognized in the cutbank exposures of Torok Formation along the northeast bank of the Chandler. Except for local drag folding, Torok strata dip regularly northward without indication of an abrupt change in structure or lithology such as might be expected along a major thrust fault. To explain this, Munns postulated an angular unconformity in the subsurface north of shot point 5 which would postdate the thrust faulting. The unconformity would also account for the anomaly of southward-dipping reflectors in the subsurface and the northward-dipping exposures of the Torok Formation and Nanushuk Group at the surface north of shot point 1. Additional, but also inconclusive, evidence of an unconformity within the Torok Formation comes from microfossil and stratigraphic studies of pre-Nanushuk rocks in the subsurface of the Northern Foothills and Coastal Plain. This has been discussed on page 461.

A second fault drawn by Munns on the profile of line 2 dips steeply northward between the surface near shot point 13 and the aforementioned thrust fault at about 5,000 feet below sea level. The abrupt change in attitude of the reflectors from nearly flat lying south of shot point 13 to steeply northward dipping north of shot point 13 is the basis for postulating this fault.

In the profile along line 3 (pl. 51) the subsurface reflectors indicate several broad folds that persist to a depth of about 12,000 feet below sea level. The folds have been contoured by Munns, using a horizon of noncontinuous reflectors that occurs about 4,800 feet below shot point 29. No steeply dipping reflectors are found along the profile line in the same latitude as the steeply northward-dipping reflectors that occur on line 2 north of shot point 13, and presumably the southward-dipping thrust fault that was postulated on line 2 does not transect line 3.

Perhaps the most striking feature of the seismic data is the prevalence of gently dipping and flat-lying reflectors in the subsurface. These reflectors are in sharp contrast to the surface exposures where high dips and tight folds are the rule (pl. 50, West half, sections *B–B′*, and *C–C′*). On line 2 between shot point 12 and shot point 38, for example, most of the seismic reflectors are flat or dip less than 10°, yet at the surface most of the strata dip more than 40°, and dips of less than 20° are exceptional. In the vicinity of shot points 30 to 38,

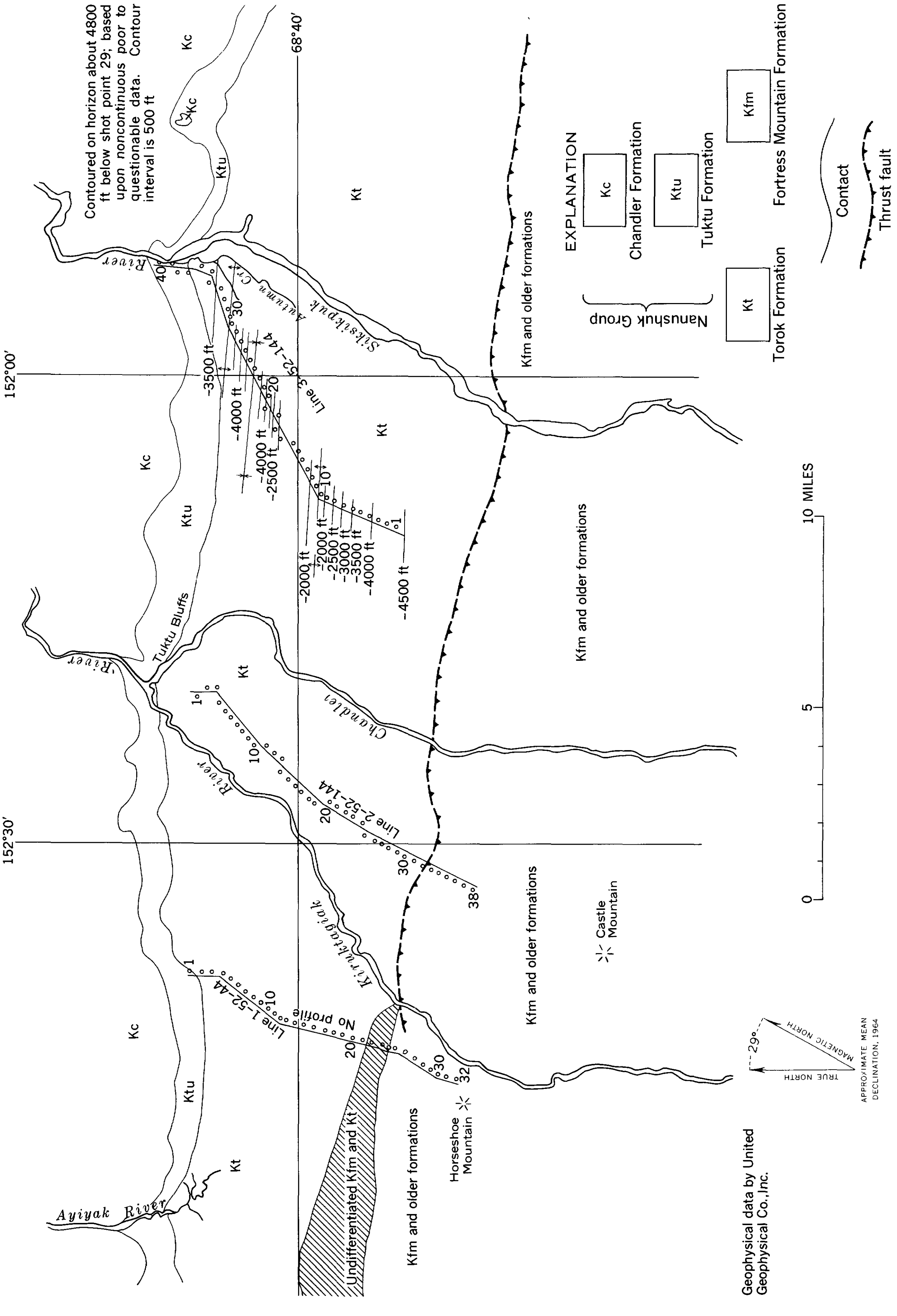

FIGURE 91.—Map showing location of reflection seismic lines across the belt of the Torok Formation (structural zone IV).

Fortress Mountain and pre-Fortress Mountain strata at the surface are thrust faulted and tightly folded, but the bulk of the subsurface seismic reflectors are flat or dip very gently. A possible explanation of the discrepancy may be that the subsurface reflections are from mildly deformed massive competent strata of Paleozoic age. The less competent overlying strata of Mesozoic age, near and at the surface, on the other hand, may be crumpled and broken in the manner of *décollement* structure. Such a structural relationship beween Paleozoic and Mesozoic strata was observed in exposures near the mountain front. There the massive limestone strata of Paleozoic age characteristically are broadly warped and broken by low-angle bedding-plane thrust faults, but the overlying Mesozoic strata, although they reflect the broad structural features of the Paleozoic, are intricately folded and broken by numerous small high-angle faults. Similar structural relationships between massive Paleozoic limestone and less competent Mesozoic strata have been described in the foothills of the Rocky Mountains in Alberta.

The *décollement* interpretation implies that Paleozoic strata are within a few thousand feet of the surface in structural zone IV. However, Munns stated that the character of the reflections suggests that the subsurface sequence has little density contrast and probably does not contain massive and continuous limestone members such as are found in the Paleozoic of the Brooks Range. It is his belief that the subsurface sequence to the maximum depth of the reflection data is probably composed largely of shale.

STRUCTURAL ZONES I-III

Detailed interpretation of the subsurface structure in the area south of structural zone IV is impossible, owing to the lack of seismic and well data and the complexity of the surface geology. No attempt has been made to depict the geology more than a few thousand feet below the surface on the cross sections (pl. 50). However, certain broad generalizations about the subsurface structure of this area may be permitted by analogy with the foothills of the Alberta Rocky Mountains where the subsurface geology has been thoroughly investigated by drilling and geophysical surveys. Both the Alberta and Brooks Range foothills occur along the inner margin of the North American Cordillera and have had a comparable geologic history and structural evolution. Both mountain fronts are composed of a thick sequence of Paleozoic limestone that has been folded and thrust faulted toward the foothills, and both foothills are characterized by a relatively incompetent sequence of Mesozoic shale and sandstone that is tightly crenulated and sliced by numerous small closely spaced high-angle faults, many of which are reverse. The surficial aspects of the faults in the two regions are similar.

The folded overthust sheets of the Lisburne Group at the front of the Brooks Range on the Okokmilaga, Kiruktagiak (fig. 88), and Nanushuk Rivers have their counterpart in the well-known overthrust sheets of Precambrian and Paleozoic strata along the front of the southern Alberta Rockies (McConnell, 1887; Willis, 1902; Daly, 1912; Hume, 1931). The long parallel eastward-trending faults bounding structural zones II and III would appear to be nearly identical to the major faults of the southern Alberta foothills which are described by G. S. Hume (1931, p. 258–259) as follows:

> The foothills are characterized by numerous nearly parallel reverse strike faults, often of great length and mostly of unusual steepness. * * * In the area studied by the writer between the Highwood and Bow Rivers most of the faults dip (westward) 65° to 75° or more at the surface. Consequently, they outcrop in straight lines regardless of topography, in fact this is the main proof of steepness, although a few fault surfaces have been observed.

Parts of the southern Alberta foothills have been explored by geophysical surveys and well drilling in the search for petroleum. Cross sections through the areas of most intensive exploration by Link (1949), Hume (1957), and others show the subsurface Paleozoic strata to be much less intensely deformed than the surface Mesozoic strata. The faults, which are high angle at the surface, flatten at depth and merge into a few large low-angle sole faults. Paleozoic limestone commonly occurs along the sole of the faults and apparently acted as a strut through which the compressional forces from the west were transmitted. Hume (1931, p. 259–261) described the structure in the Turner Valley area of southern Alberta as follows:

> The drilling of wells in the Turner Valley and in the so-called New Black Diamond structure, two miles west of Turner Valley, has indicated at least two faults which, although steep at the surface, become low-angle faults at depth with westerly dips of not more than 20°. One of these faults underlies the Turner Valley and has been penetrated by at least four wells, two of which after passing through a considerable thickness of Paleozoic limestone, cut the fault and the Cretaceous strata beneath. The other fault underlies the New Black Diamond structure and has been cut by two wells. This part of the Foothills, therefore, consists of fault plates or nappes overlying one another, and the Foothills mass is believed to have been thrust eastward onto the relatively flat-lying sediments of the plains. This explains the abrupt change from steeply inclined beds of the Foothills structure to the gently folded strata of the plains. In fact, the fault that underlies the Turner Valley and emerges east of the east flank of this structure is the structural boundary between the Foothills and the plains.

Hume's interpretation of the subsurface structure in this area of Alberta foothills might also apply in the foothills of the Killik-Itkillik region, in view of the remarkable similarity of surface geology in both areas. In fact, there is some field evidence that major thrust faulting has occurred in the Killik-Itkillik region even though most of the faults appear to be high angle at the surface. There is also evidence that Paleozoic limestone occurs along the sole of these thrusts.

EVIDENCE OF THRUST FAULTING IN MAPPED AREA

North-south foreshortening by thrust faulting best explains the occurrence of separate and distinct structural zones in the southern foothills. Zones II, III, and IV each have a characteristic rock assemblage and structure which persist in an east-west belt across the mapped area, but which change abruptly from one zone to another. The rocks along the boundaries between the zones are intensely crushed, and in several places different facies of contemporaneous stratigraphic units apparently have been brought into juxtaposition. East of the Nanushuk River, for example, the chert facies at the base of the Tiglukpuk Formation in zone II is in close proximity to the black siliceous shale facies at the base of the Tiglukpuk in zone III. An abrupt facies change also occurs across the boundary of zones III and IV where the Fortress Mountain Formation adjoins the Torok Formation. The Fortress Mountain and Torok Formations are thought to be the same age, at least in part, yet the coarse clastics which characterize the Fortress Mountain are absent in the adjoining Torok belt. In the Nuka-Etivluk region, 100 miles west of the Killik-Itkillik region, Tailleur found that the coarse clastic facies of the Fortress Mountain and the fine clastic facies of the Torok are separated by a transitional belt, 10 miles wide, of medium-grained clastics. Presumably, this transitional belt has been cut out in the Killik-Itkillik area by northward thrusting of structural zone III.

Northward thrusting of structural zone III may also account for the obvious narrowing of structural zone IV in an easterly direction. West of the Anaktuvuk River structural zone IV is 5 to 8 miles wide; east of the Anaktuvuk it gradually narrows, and it is less than a mile wide east of May Creek. In the May Creek basin highly deformed Fortress Mountain strata are close to strata of the gently folded Nanushuk Group (pl. 50, East half, section *G–G′*), a situation analogous to that described by Hume (1931, p. 261) at the eastern edge of the Alberta foothills, where steeply dipping foothills strata are faulted against the gently deformed sedimentary rocks of the Great Plains.

Although most of the faults along the boundaries of the structural zone appear to be high-angle reverse faults, divergent structural trends on either side of the fault are difficult to explain except by low-angle thrust movement. This is exemplified along the fault that bounds the southern margin of structural zone III between Fortress Creek and the Chandler River. Some of the structural trends north of the fault are nearly at right angles to the fault and apparently are cut off by it. Structural trends south of the fault parallel it for the most part and do not match the trends on the north side. Between the Ayiyak and Kiruktagiak Rivers along this fault, structural zone II appears to have overridden the southwest limb of the eastward-plunging Castle Mountain syncline in structural zone III.

A similar structural anomaly suggests thrust movement along the contact of structural zone II and structural zone III between the Kanayut and Nanushuk Rivers. There, northeast-trending ridges of structural zone III are cut off by a northwest-trending fault along the contact.

LISBURNE GROUP ALONG SOLE OF THRUST FAULTS

The Mesozoic sequence which underlies the foothills does not appear sufficiently competent to transmit the forces necessary for large-scale thrusting. More likely, massive limestone of the Lisburne Group served as a rigid supporting member along the sole of the thrust plates. Folded thrust sheets of Lisburne at the mountain front on the Okokmilaga, Kiruktagiak, and Nanushuk Rivers attest to the competency of the limestone. The many small allochthonous blocks and slivers of limestone which are scattered along the large faults in structural zones II and III suggest that the Lisburne is involved in the foothills thrusting. Although the Lisburne crops out widely in the foothills, older rocks have not been identified north of the mountain front. This suggests that the Lisburne is the oldest rock included in the thrust plates.

In the thrusts of the Alberta foothills, limestone of Paleozoic age, which crops out along the front of the Rockies, plays a role similar to that of the Lisburne.

GEOLOGIC HISTORY

MISSISSIPPIAN TO TRIASSIC

During the late Paleozoic and Triassic, most of the Arctic Slope appears to have been a broad shelf which was bordered on the south by a geosyncline that covered most of central and southern Alaska, and on the north by a landmass of unknown extent (Payne and others, 1951). From time to time the geosynclinal sea appears to have flooded northward across the shelf, and detritus derived from the northern source accumulated as marine sediments. These sediments, which were chiefly fine-grained clastics and carbonates, occur in relatively thin but persistent well-sorted easily defined lithologic units and are in sharp contrast to the thick graywacke and volcanic geosynclinal assemblages of the same age in central and southern Alaska.

SIGNIFICANT DETAILS

MISSISSIPPIAN

During the Mississippian period sediments of the Lisburne Group were deposited in the area of the Brooks Range, but it is not known at present whether these deposits extended northward into the area of the foothills and coastal plain. Preliminary investigations in the mountains south of the mapped area (W. P. Brosgé and H. N. Reiser, written communication, 1951) indicate that the Wachsmuth Limestone thins northward at a rate of 50 feet per mile and the Alapah Limestone thins northward at a rate of 75 to 125 feet per mile. In the foothills of the mapped area exposures are found as much as 20 miles north of the mountains. However, with the possible exception of the exposures on the Tiglukpuk Creek anticline, all appear to be allochthonous fault blocks. Whether autochthonous Lisburne is present beneath the foothills is problematical. In the coastal plain no Lisburne was encountered in the deep test wells which penetrated pre-Mississippian strata at Barrow, Simpson, and Topagoruk (Payne and others, 1951).

PENNSYLVANIAN

Rocks of unquestionable Pennsylvanian age have not been identified anywhere in northern Alaska, and in the mapped area the Lisburne Group of Mississippian age is succeeded disconformably by the Siksikpuk Formation of Permian(?) age. Differential erosion of the upper strata of the Lisburne Group indicates that the foothills area must have been emergent during at least part of the Mississippian to Permian sedimentary hiatus.

PERMIAN(?)

The Siksikpuk Formation, which has been tentatively assigned to the Permian, can be traced from the Anaktuvuk River for 200 miles westward along the mountain front. No Permian rocks have been found between the Anaktuvuk and Itkillik Rivers, but east of the Itkillik the Permian is represented by the Sadlerochit Formation (Leffingwell, 1919). The stratigraphic relationship of the Sadlerochit and the Siksikpuk Formations has not been established.

The extent of Permian deposition north and south of the mapped area is uncertain. No Permian strata were encountered in the deep test wells at Barrow and Simpson on the Arctic coast (Payne and others, 1951). However, beds of probable Permian age were found about 40 miles to the south in a test well at Topagoruk (Collins, 1958). South of the mapped area near the divide of the Brooks Range, the Shublik Formation of Triassic age rests disconformably on the Lisburne Group; but whether Permian strata are missing as a result of nondeposition or as a result of pre-Shublik erosion has not been determined (Brosgé and others, 1960).

PERMIAN TO TRIASSIC

Following the deposition of Siksikpuk strata the sea apparently withdrew from the Arctic Slope. The uppermost beds of the Siksikpuk Formation appear to have been oxidized and silicified during this period of emergence.

TRIASSIC

Strata of Early Triassic age that compose the upper part of the Permian-Triassic Sadlerochit Formation are reported in the foothills east of the Itkillik River (Keller and others, 1961). However, Lower Triassic strata have not been reported in the foothills west of the Itkillik River, although it is possible that the shale member of the Shublik Formation may include some Lower Triassic beds, as evinced by the poorly preserved collection of vertebrate remains from Tiglukpuk Creek (53APa118, p. 437).

The shale member of the Shublik Formation is the only Middle Triassic unit reported thus far in northern Alaska. It varies considerably in thickness, and is absent in many exposures of the Shublik Formation; but whether this is the result of nondeposition or erosion cannot be determined, owing to the lack of stratigraphic control. Nondeposition would appear to be the most probable explanation in view of the abundance of phosphatized vertebrate remains and phosphatic nodules along certain horizons.

The shale member of Middle Triassic age (Anisian) is succeeded by the chert and limestone members of Late Triassic age (Karnian(?) and Norian). The contained fossils indicate a lengthy time lapse between deposition of the shale and chert members, but no disconformity or other marked break was found at the contact of the two members.

The chert and limestone members of the Shublik have been traced along the mountain front from Cape Lisburne to the Canadian border. Although both of these members are thin, they are remarkably persistent and uniform. Clastic material increases gradually eastward along the foothills at the expense of chert, but otherwise the same distinctive fauna and lithofacies characterize every exposure of these members. North of the foothills Upper Triassic strata have been identified in deep test wells along the Arctic coast (Payne and others, 1951); to the south they were found along the Brooks Range divide by Patton and Brosgé in 1951.

An episode of unusually stable marine conditions in the northern Alaska shelf is indicated by the Shublik Formation. Sedimentation apparently proceeded at a very slow rate, and probably was interrupted by extended periods of nondeposition.

TRIASSIC TO JURASSIC

The record of events in the mapped area between deposition of the Shublik Formation in the Late Triassic and of the Tiglukpuk Formation in the Late Jurassic is unclear. Lower and Middle Jurassic strata are present in the eastern foothills and in the coastal plain, but they have not been found in the foothills west of the Itkillik River (Payne and others, 1951; A. S. Keller, written communication, 1952). The mapped area was probably emergent at this time, but the stratigraphic evidence for this is not entirely convincing. The base of the Tiglukpuk Formation is well exposed at numerous places along the mountain front, and everywhere it rests upon the limestone member of the Shublik Formation with little or no indication of differential erosion. At a few localities north of the mountains, such as on Autumn Creek at lat 68°28′ N., and at The Notch, on the Kiruktagiak River, the Tiglukpuk Formation apparently rests disconformably upon the Lisburne Group. However, exposures at these localities are poor, and it cannot be stated definitely that the missing beds are not the result of faulting.

The absence of middle and late Bajocian, Bathonian, and late Callovian fossils in northern Alaska may indicate, according to R. W. Imlay (1955), that the Arctic Slope was emergent at these times and may, he suggests, be related to major retreats of the Jurassic seas during Bathonian and Callovian elsewhere in Alaska and in the western interior of Canada and the United States.

JURASSIC AND CRETACEOUS

The character of the Jurassic and Cretaceous rocks suggests that a marked change occurred in the pattern of sedimentation on the Arctic Slope between Late Triassic and Late Jurassic time. The Triassic and older rocks are primarily shelf deposits and were derived chiefly from a northerly source. The Jurassic and Cretaceous rocks, on the other hand, are geosynclinal deposits and were derived mainly from the south.

From Late Jurassic until Late Cretaceous time recurrent tectonic activity in the region of the Brooks Range provided a rising landmass which shed vast quantities of detritus northward into a subsiding eastward-trending trough, the Colville geosyncline, that lay across the area of the Arctic foothills and coastal plain. The sedimentation of the Colville geosyncline appears to have occurred in two separate and distinct phases to which the terms "flysch" and "molasse," as used by Pettijohn (1957, p. 588–647), can be applied. The flysch phase occurred in Late Jurassic and Early Cretaceous time and was marked by the accumulation of an enormous thickness of marine sediments of graywacke type. The molasse phase extended from Early to Late Cretaceous and is represented by a thick sequence of interfingering shallow-water marine and nonmarine coal-bearing deposits. The flysch-phase sediments in the mapped area include the Tiglukpuk, Okpikruak, Fortress Mountain, and Torok Formations. The Tiglukpuk, Okpikruak, and Fortress Mountain Formations comprise the marginal facies that accumulated along the southern edge of the geosyncline adjacent to the source area. The Torok Formation is characteristic of the fine-grained facies of the flysch that was deposited in the axial and distal parts of the geosyncline.

The flysch sediments apparently were eroded from a rapidly rising landmass and dumped into an actively sinking geosyncline, as indicated by their tremendous thickness, poor sorting, and the abundance of nonresistant rock and mineral fragments. The scarcity of neritic fossils, ripple marks, and crossbedding suggests that most, if not all, of the flysch was deposited in deep water. Submarine landslides or turbidity currents must have been operative along the southern margin of the geosyncline, at least locally, to account for the chaotic conglomerate masses in the Fortress Mountain Formation.

The high content of plagioclase feldspar, mafic volcanic fragments, and mafic minerals suggests that the flysch sediments were derived mainly from a volcanic and graywacke terrane. The older flysch probably had as its principal source early Mesozoic volcanic and graywacke sequences in the Brooks Range area. The younger flysch probably had the same source; but it was also in part "cannibalistic," for it contains recognizable detrital lithic fragments from the older flysch. Apparently as deposition progressed, the older flysch was uplifted along the southern margin of the geosyncline and added to the source area.

Molasse-phase sediments comprise the Nanushuk Group. They are better sorted and contain a greater preponderance of resistant and stable rock and mineral detritus than the flysch. This is probably the result of less relief in the source area, greater distance of transport of the detritus, and winnowing action along the strand line. It may also indicate that by Nanushuk time the Mesozoic volcanics and graywackes had been stripped from the Brooks Range source area and that the principal source for the geosynclinal sediments was the Paleozoic limestones and orthoquartzites and deep-seated intrusive rocks. White quartz pebbles occur in abundance in the coarse clastics of the molasse, but they are rare in the coarse clastics of the flysch. This may also point to a change in the character of the source rock. In this regard it has been noted that both detrital and vein quartz are common in the Paleozoic strata of the Brooks Range.

Both the southern margin and the axis of the Colville geosyncline appear to have migrated northward during flysch and molasse sedimentation. This migration is suggested by the northward progression of the coarse clastic marginal facies from the southern foothills area during the flysch phase to the northern foothills during the molasse phase.

Deposition, at least along the southern margin of the geosyncline, was not continuous from Late Jurassic to Late Cretaceous, but was interrupted by two or more periods of emergence and erosion during which the geosynclinal deposits may have been folded and faulted. There is also evidence (p. 456) that folding accompanied deposition of the Fortress Mountain formation at the climax of the flysch phase.

SIGNIFICANT DETAILS

LATE JURASSIC (OXFORDIAN-KIMMERIDGIAN-PORTLANDIAN)

Late Jurassic flysch deposition apparently was widespread. The Tiglukpuk Formation has been traced along the mountain front at least as far west as the Nuka River and as far east as the Sagavanirktok River (Patton, 1956a, p. 215). East of the Sagavanirktok River Upper Jurassic strata are reported in the Kingak Shale (A. S. Keller, written communication, 1951). North of the mapped area Upper Jurassic beds were found in the Topagoruk well on the Arctic Coastal Plain (Payne, 1951) and possibly also in the Oumalik well at the northern edge of the Arctic Foothills (Robinson, 1956). Rocks of Jurassic age have not been definitely identified as yet along the south side of the Brooks Range.

The intercalated shale and sandstone that comprise the bulk of the Tiglukpuk Formation are characteristic of marginal flysch deposits. The beds of chert, black siliceous shale, variegated shale, and coquinoid limestone at the base of the Tiglukpuk, however, are not typical flysch and perhaps accumulated in local basins during the initial phases of subsidence of the geosyncline before the heavy influx of clastic detritus from the south.

LATEST JURASSIC (PORTLANDIAN)

The tuffaceous graywacke unit and correlative(?) rocks, tentatively assigned to the latest Jurassic (Portlandian), have been found at only a few localities in the mapped area and have not as yet been identified elsewhere in northern Alaska. These strata record an episode of volcanism and marine deposition in the Colville geosyncline following the deposition of the Tiglukpuk Formation. Inasmuch as the contact between the Tiglukpuk Formation and the tuffaceous graywacke unit is poorly exposed, it is not known whether an intervening period of emergence and erosion occurred.

The mafic intrusive rock may have been emplaced during this volcanic episode for the intrusives invade the Tiglukpuk and older formations, and detrital lithic fragments of the intrusive rock are found in the Okpikruak and Fortress Mountain Formations.

LATE JURASSIC TO EARLY CRETACEOUS

Following the volcanism in latest Jurassic time, the mapped area was uplifted and subjected to erosion, as evinced by differential erosion noted along the Tiglukpuk-Okpikruak contact. That local folding or faulting may have accompanied the uplift is suggested by the massive bodies of chaotic conglomerate in the base of the Okpikruak Formation(?) along the northern edge of structural zone II. The detritus that composes the conglomerate ranges from silt to cobble size, is completely unsorted and unstratified, shows little evidence of having been transported, and contains recognizable lithic fragments of the Lisburne Group, Shublik and Tiglugpuk Formations, and the mafic intrusive and extrusive rocks. Similar conglomerate masses were not found elsewhere in the base of the Okpikruak; it is probable, therefore, that these conglomerate masses were derived from a nearby upfaulted or upfolded ridge.

EARLY CRETACEOUS (NEOCOMIAN)

A widespread marine invasion of the Colville geosyncline occurred in earliest Cretaceous (Neocomian). Coarse clastic sediments comprising the Okpikruak Formation were deposited in the southern foothills, and fine clastics were deposited in the northern foothills and coastal plain. At the same time volcanic and sedimentary rocks were being deposited south of the Brooks Range (Schrader, 1904). The area of the Brooks Range was emergent and undoubtedly served as the principal source for the geosynclinal sediments. The fact that the sandstone in the Okpikruak Formation contains a greater percentage of nonresistant rock and mineral detritus than the sandstone in the Tiglukpuk Formation suggests that the source area may have moved somewhat closer to the Killik-Itkillik region in Okpikruak time.

EARLY CRETACEOUS (NEOCOMIAN TO ALBIAN)

The mapped area apparently was emergent and was subjected to erosion during late Neocomian and Aptian, because the Fortress Mountain Formation of early Albian age rests disconformably upon the Okpikruak and older formations. According to R. W. Imlay and J. B. Reeside, Jr. (1954), there is no fossil evidence of late Neocomian (Hauterivian and Barremian) or Aptian rocks anywhere in Alaska. Payne (1955) believes that the Brooks Range and the area south of the Brooks Range was strongly deformed during this interval. The rocks of the mapped area may have been broadly warped, but there is no evidence at the contact of Fortress Mountain with older formations that intense deformation occurred.

EARLY CRETACEOUS (EARLY ALBIAN)

Flysch sedimentation in the Colville geosyncline and concurrent uplift of the Brooks Range apparently reached a climax in early and early middle Albian, for during this relatively short span of time as much as 10,000 feet of detritus accumulated along the southern margin of the geosyncline. The coarse clastic marginal facies comprises the Fortress Mountain Formation, and the fine clastic facies is represented in the subsurface of the northern foothills by the Torok Formation.

The ratio of coarse clastics to shale in the Fortress Mountain Formation appears to increase markedly at three separate areas along the Fortress Mountain belt: one area includes Fortress Mountain and the Canoe Hills; a second area is in the immediate vicinity of Castle Mountain; and a third area includes the upper Cobblestone Creek basin. At each of these localities the conglomerate and sandstone members occur in great thickness and collectively form huge lenses that pinch out into finer clastics eastward and westward as well as northward. These localities may mark the points where large rivers entered the geosynclinal sea. The long dimensions of the lenses at Castle and Fortress Mountains appear to trend northwest-southeast rather than east-west parallel to the strike of the Fortress Mountain belt. Possibly this reflects a northwest trend along this segment of the old shoreline.

Some folding occurred along the southern margin of the geosyncline concurrent with early Albian sedimentation. Many unconformities of local extent and varying angular discordance were observed in the Fortress Mountain sequence, and, in general, the basal beds of the Fortress Mountain Formation are more intensely deformed than the topmost beds.

EARLY CRETACEOUS (EARLY ALBIAN TO MIDDLE ALBIAN)

The angular unconformity between the lower and upper parts of the Torok Formation that has been postulated on the basis of seismic and microfossil data (Bergquist, 1956) would necessitate a period of emergence, folding, and erosion along the southern margin of the Colville geosyncline. This period presumably would have occurred between early and middle Albian and probably marked the end of the deep-water graywacke flysch phase of geosynclinal filling and the beginning of the shallow-water paralic molasse phase of geosynclinal filling.

EARLY AND LATE CRETACEOUS (MIDDLE ALBIAN TO LATE CENOMANIAN)

The Tuktu Formation of middle Albian age at the base of the Nanushuk Group marks a period of widespread shallow marine conditions along the southern margin of the geosyncline. This was followed, between middle Albian and late Cenomanian time, by transgressions and regressions across the northern edge of the mapped area that resulted in the deposition of nearly 3,000 feet of inshore, bar, beach, lagoonal, flood-plain, and channel deposits of the Chandler Formation. During a major marine invasion in late Cenomanian time, the 1,200 feet of shallow marine deposits comprising the Ninuluk Formation were laid down. The shoreline in late Cenomanian time must have had a northwesterly trend, for the Ninuluk marine deposits pinch out rapidly westward along the southern margin of the northern foothills (R. L. Detterman, written communication, 1956).

LATE CRETACEOUS (POST-LATE CENOMANIAN)

A short distance north of the mapped area the Seabee Formation (Turonian) at the base of the Colville Group rests with angular discordance upon the Chandler Formation, indicating an episode of folding and erosion at the conclusion of Nanushuk Group deposition (R. L. Detterman, written communication, 1956). The transgressive sea marked by deposition of the Seabee Formation withdrew in middle Turonian and the mapped area was probably emergent for the rest of the Cretaceous.

TERTIARY

A Late Cretaceous or Tertiary orogeny subjected the Brooks Range and southern foothills to intense folding and faulting, and the northern foothills to gentle folding. The time of the orogeny is uncertain, but presumably it was roughly correlative with Laramide diastrophism. Events in the mapped area subsequent to the orogeny are obscure, but by the end of the Tertiary the Brooks Range had been reduced to a maturely dissected chain of hills with 3,000 to 4,000 feet of relief, and the foothills were reduced to a gently sloping piedmont surface. Remnants of this preglacial topography are preserved today as benches along the walls of the glacial valleys in the Brooks Range and as upland surfaces along the interstream divides in the foothills.

QUATERNARY

Glaciation in the Brooks Range in the Pleistocene Epoch transformed the maturely dissected preglacial hills into the rugged alpine chain of today. Cirques and arrete ridges were sculptured from the upland, and the major river courses were deepened and scoured into glacial troughs 1,000 to 2,000 feet below their original levels. During times of maximum accumulation tongues of ice pushed north of the mountains across the piedmont slope along the shallow valleys of the Killik, Okokmilaga, Chandler, Anaktuvuk, Nanushuk, and Itkillik Rivers. Outwash gravels from the margins of these valley glaciers were spread across unglaciated parts of the piedmont slopes; remnants of these gravel-covered preglacial surfaces still exist along the interstream divides in the foothills. As glaciation of the foothills continued, deep troughs 1,000 feet below the piedmont slope were cut along the major river valleys. Evidently during the later stages of glaciation ice blocked these troughs, because the tributary streams appear to have captured a large share of the drainage area along the mountain front. The drainage pattern on plate 50 shows that the glaciated major rivers directly drain only a small part of the foothills along the mountain front. The tributaries, such as the Kiruktagiak, Siksikpuk, and Kanayut Rivers and Cobblestone Creek, on the other hand, drain the bulk of the foothills area along the mountain front.

The glaciers evidently disappeared only recently from the Brooks Range and Arctic Foothills, and as yet many of the drift deposits are unmodified by weathering and erosion.

ECONOMIC GEOLOGY

PETROLEUM

SOURCE ROCKS

No oil or gas seeps have been found in the mapped area, but seams and beds of asphaltic matter and highly organic sedimentary rocks occur at several different stratigraphic levels.

Podlike masses of black asphaltic shale as much as a foot thick are intercalated with chert in the base of the Tiglukpuk Formation. The asphaltic shale can be ignited with a match and burns vigorously, giving off a strong oily odor.

Asphaltic matter also occurs as seams along the bedding planes and in crosscutting fractures in the Okpikruak, Fortress Mountain, and Torok Formations. On Torok Creek a short distance above its mouth, a vertical fracture several feet wide that cuts across the Torok Formation is filled with asphalt. On the south face of Fortress Mountain there is a thin grit bed in which chert granules are bonded together by soft gummy asphaltic matter.

Thick sections of dark highly organic shale and limestone occur in the upper part of the Lisburne Group and throughout the Shublik Formation. Nearly all the limestone of the Lisburne Group is organic to some extent and gives off a strong fetid odor when freshly broken. Some black shale in the chert member of the Shublik Formation yields a strong petroliferous odor when heated.

RESERVOIR CHARACTERISTICS

The Lisburne Group is considered the most promising reservoir in strata older than the Nanushuk Group and was the primary target in the petroleum investigations of the southern foothills.

A preliminary porosity study of 87 samples of the Lisburne from the Shainin, Nanushuk, and Itkillik Lakes area by P. D. Krynine and A. L. Bowsher (written communication, 1950) showed that the most favorable zone is a limestone and dolomite sequence between 200 and 750 feet above the base of the Wachsmuth Limestone. A few samples from this zone had as much as 11 percent effective porosity, and many were in excess of 5 percent effective porosity. Krynine and Bowsher also observed that, in addition to this primary pore space, closely spaced fractures and joints were found on every outcrop of limestone and dolomite.

None of the post-Lisburne strata that crop out in the mapped area appears to have favorable reservoir characteristics. The limestone in the Shublik Formation is dense and hard and appears to have little, if any, primary pore space. The sandstone in the Tiglukpuk, Okpikruak, and Fortress Mountain Formations is of graywacke type, and the intergranular spaces are plugged tightly with clay and silt. Specimens of the "salt and pepper" sandstone of the Chandler Formation, which is better sorted and cleaner than the pre-Nanushuk graywacke, were tested for porosity and permeability. Although porosities are between 5 and 12 percent, permeabilities proved to be negligible.

STRUCTURE

STRUCTURAL ZONE V

Within the belt of the Nanushuk Group the only structure suitable for a test of the Lisburne Group is the Arc Mountain anticline. This anticline appears to plunge west, but west of the Nanushuk River the nose is complicated by faulting. East plunge, if it occurs, is obscured by glacial till along the Itkillik River valley. If the lower Torok and pre-Torok strata along the axis of the anticline occur in the same order of thickness that was measured in the outcrop, then the Lisburne Group presumably would be at a depth of more than 10,000 feet.

STRUCTURAL ZONE IV

The scarcity of good exposures, the lack of marker beds, and the tight crenulations of the Torok Formation preclude the possibility of accurately delineating the gross structural features of structural zone IV.

A broad anticlinal reversal along structural zone IV is suggested by the persistent south dips along the south edge of the zone and north dips along the north edge of the zone. This structure was checked in the subsurface by a seismic survey, the results of which have already been described. The seismic profiles show gently dipping and flat-lying strata in the subsurface with no major anticlinal reversal.

The depth to the Lisburne in structural zone IV is uncertain because the base of the Torok is not exposed and because of unconformities and facies changes known to occur in the pre-Torok and post-Lisburne sequence. The absence of persistent and continuous reflection horizons in the subsurface (pl. 50) suggests to the seismologist that the subsurface sequence has low density contrast and probably is shale with no intercalated sandstone or limestone members (E. J. Munns, written communication, 1952). However, the fact that the surface strata, largely shale, are intensely folded in contrast to the subsurface strata, which apparently are very gently deformed, argues for a more competent rock than shale at depth. It is conceivable that all the reflections are from Paleozoic strata.

STRUCTURAL ZONES I–III

Owing to their structural complexity, zones II and III have not been as interesting in the search for petroleum as zones IV and V. It should be pointed out, however, that oil and gas are being produced in areas of comparable structural complexity in the Alberta foothills. In the Alberta foothills well drilling and seismic data have revealed that the highly deformed Mesozoic strata at the surface are underlain by less deformed Paleozoic limestone. The limestone commonly lies along the sole of thrust plates which have ridden eastward over Mesozoic strata. The oil and gas occurs in the buried eastern edge of the limestone thrust plates where drag folding provided a local trap.

The petroleum possibilities of structural zone I have been given little consideration in the past because the limestone of the Lisburne Group, the most promising reservoir rock, crops out at the surface. But mapping in the Killik-Itkillik region now has demonstrated that at least some of the Lisburne that forms the mountain front is allochthonous. Therefore, in future exploration programs one might consider the possibility of exploring beneath the surficial thrust plates of Lisburne for additional thrust plates or perhaps autochthonous Lisburne.

PHOSPHATE ROCK

Deposits of sedimentary phosphate rock occur in the Alapah Limestone of the Lisburne Group. The deposits have been examined in detail and systematically sampled at Tiglukpuk Creek and upper Kiruktagiak River near the mountain front. As the results of these studies are fully described elsewhere (Patton and Matzko, 1959), only a brief summary will be given here.

In the Tiglukpuk Creek area the phosphatic zone in the Alapah Limestone is 36 feet thick and averages 8 percent P_2O_5. A 43-inch sequence of rock 16 feet below the top of the zone averages 21 percent P_2O_5. In the upper 20 feet of the zone 6 beds, from 1 to 5.5 inches thick, contain 30 percent P_2O_5. In the upper Kiruktagiak River area the phosphate zone is 38 feet thick and averages 12 percent P_2O_5. The upper 19 feet averages 19 percent P_2O_5; one 27-inch sequence of rock 16 feet below the top contains 27 percent P_2O_5.

Random samples of phosphate rock were collected from the Lisburne Group eastward as far as the Anaktuvuk River. At Shainin Lake, 10 miles east of the Anaktuvuk, thin beds referred to as phosphorite(?) were reported by Bowsher and Dutro (1957, p. 31). No phosphate rock has been reported east of Shainin Lake, although the Lisburne Group has been studied in detail at several localities. From the Kiruktagiak River westward to the Killik River no phosphate rock was found, but the Lisburne along the part of the mountain front has not been closely examined.

Because of the marked lateral variation in lithology and phosphate content in the Lisburne Group and because of the complex structure along the mountain front, much work remains to be done before the phosphate deposits can be fully evaluated.

COAL

Coal occurs throughout the Chandler Formation of the Nanushuk Group but is most abundant in the upper half. In the Killik-Itkillik region it is exposed only as float, except a 1-foot seam on the Nanushuk River (see stratigraphic section on p. 470).

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