GEOLOGY OF THE UPPER KILLIK-ITKILLIK REGION, ALASKA

by

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

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CONTENTS

CONTENTS (cont'd)

TABLES

ILLUSTRATIONS

Figures

Following page

ILLUSTRATIONS

Figures (cont'd)

Plates

GEOLOGY OF THE UPPER KILLIK-ITKILLIK REGION, ALASKA

Abstract

The upper Killik-Itkillik map area is a 2,500 square mile segment of foothills along the north front of the Brooks Range on the Arctic Slope of Alaska. The rocks exposed in this area include eleven formations of sedimentary rocks, three types of surficial deposits, and one igneous rock unit. The oldest rocks are a 2,500-foot sequence of limestone which belongs to the Lisburne group (Mississippian). The Lisburne is succeeded by the Siksikpuk formation (Permian ?), a 300-foot unit of variegated shale and siltstone. The Shublik formation (Triassic), composed of 200 to 750 feet of fossiliferous dark shale, limestone, and chert, rests upon the Siksikpuk. Next above the Shublik is a sequence, more than 13,000 feet thick, of marine shale and graywacke which is subdivided into four formations: Tiglukpuk (Late Jurassic), Okpikruak (earliest Cretaceous), Fortress Mountain (late Early Cretaceous), and Torok (late Early Cretaceous). The youngest rocks comprise the Nanushuk group (late Early to Late Cretaceous) which consists of 5,000 feet of interfingering marine and non-marine clastic rocks and is subdivided into three formations: Tuktu, Chandler, and Ninuluk.

Small diabase sills, thought to be of latest Jurassic age, intrude the Tiglukpuk and older formations in the western part of the map area.

The rocks of the map area have been deformed by north-south tectonic forces in such a way that the upper part of the crust appears to have moved northward relative to deeper parts. Five east-trending zones of distinctive lithology and structure are recognizable: zone I, at the mountain front--massive strata of the Lisburne group sliced by southward

dipping imbricate faults and locally thrust upon the younger strata of the foothills, zone II--relatively incompetent interfolded late Paleozoic and Mesozoic strata characterized by isoclinal folds and by small, closely spaced high-angle faults, zone III--chiefly rocks of the Fortress Mountain formation which, although folded and faulted, are not as complexly deformed as the rocks of zone II, zone IV--highly crenulated shale of the Torok formation, and zone V, at the northern edge of the map area--gently folded strata of the Nanushuk group.

A seismograph survey across zone IV suggests that, although the incompetent Torok formation is highly crenulated, the subsurface strata lie nearly flat.

The character of the subsurface structure in zones II and III is uncertain. However, it is believed that some of the high-angle faults in these two zones may flatten in the subsurface and merge into large sole faults beneath thrust plates of Paleozoic limestone. Such a fault pattern has been found in the foothills of the Alberta Rockies, where the surface structure, stratigraphy and geologic history are remarkably similar.

The depositional history of the Paleozoic and Mesozoic strata is divided into a shelf phase during late Paleozoic and Triassic and a geosynclinal phase during Late Jurassic and Cretaceous. The shelf sediments were chiefly marine carbonates and fine clastics, apparently derived largely from the north. The geosynclinal sediments consisted of marine graywacke "flysch" deposits overlain by littoral marine and non-marine coal-bearing "molasse" deposits and were derived mainly from the south. Several periods of emergence and erosion interrupted the shelf and geosynclinal deposition; evidently some folding and faulting occurred during deposition of the "flysch". The principal deformation is believed to have coincided with the Laramide orogeny in Late Cretaceous or Tertiary.

In the Pleistocene the Brooks Range was intensively glaciated, and at times of maximum advance, ice tongues along the major river valleys pushed northward into the foothills.

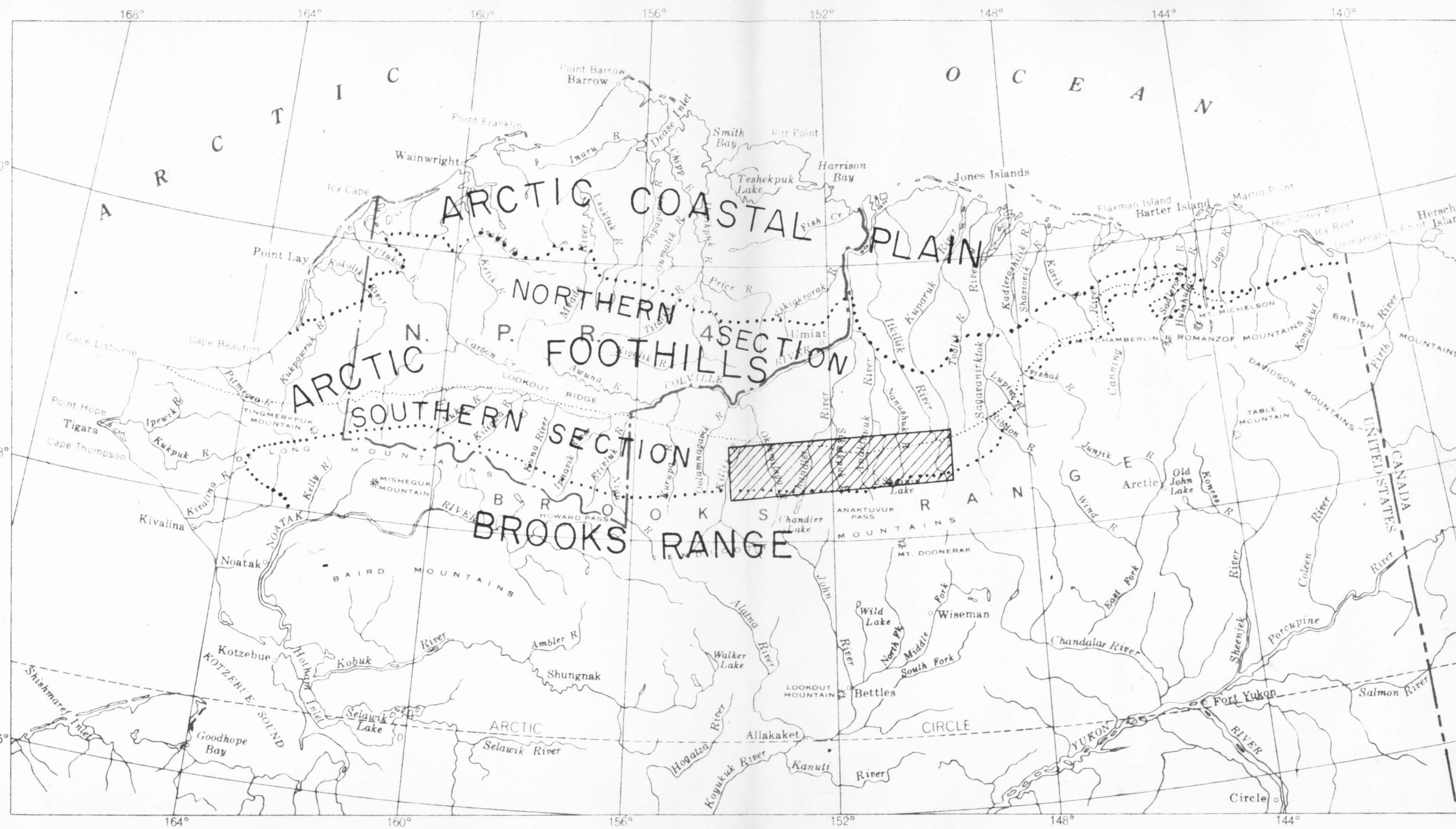

FIG. 1 INDEX MAP SHOWING LOCATION OF UPPER KILLIK-ITKILLIK REGION AND THE PHYSIOGRAPHIC PROVINCES OF NORTHERN ALASKA

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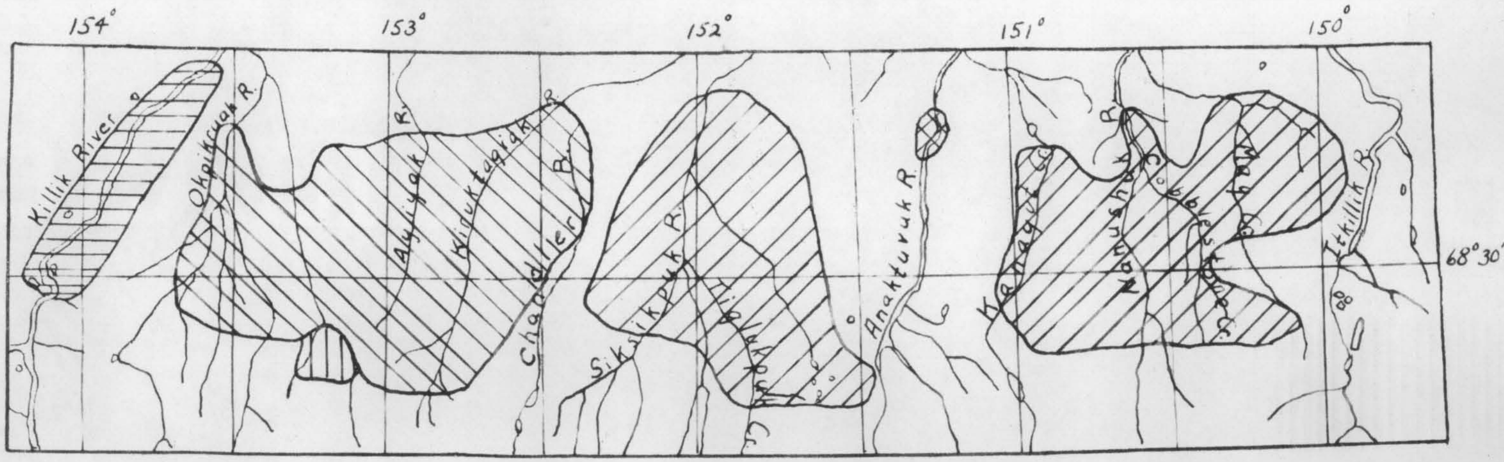


Fig. 2 Source of geologic data on plate 1

Data based principally upon field surveys:

- Patton, Tailleur; 1949
- Patton, Keller; 1950
- Detterman, Bickel; 1953
- Fellows, Chapman, Bressler; 1945
- Patton, Brosge, Mangus, 1951

Rest of data interpreted from 1:20,000 scale vertical aerial photographs

INTRODUCTION

General

This report is based upon field investigations which were carried out in northern Alaska between 1949 and 1953 in conjunction with the recent petroleum exploration of Naval Petroleum Reserve No. 4 and adjoining areas by the U. S. Navy.

The map area, herein designated the upper Killik-Itkillik region, is located on the Arctic Slope of Alaska. It forms a 25-mile wide belt along the north front of the Brooks Range between the Killik and Itkillik Rivers (fig. 1) and covers approximately 2,500 square miles. This is one of the least accessible parts of Alaska. There are no roads or trails of any type and the only practical means of transportation to and from the population centers to the south is by airplane. Transportation within the map area was provided chiefly by small amphibious tractors known as "weasels".

Objectives

The primary objectives of this study are: (1) the subdivisions and description of the pre-middle Cretaceous strata which underlie the foothills of the Brooks Range, (2) the preparation of a reconnaissance geologic map and cross sections to show the structure of the foothills strata, and (3) a structural and stratigraphic analyses of the foothills strata with emphasis on the oil possibilities of the foothills belt.

Mapping Methods

The geologic map (pl. 1) was compiled from field data and supplementary photogeologic data. Fig. 2 shows the parts of the map area that were covered by the field investigations. In the field, time did not permit tracing out all the contacts, faults, and structural axes, so where possible they have been joined or extended by photogeology. Those parts of the map area that were not visited in the field have been mapped entirely by photogeologic methods.

The density of geologic information on plate 1 varies markedly from place to place. This is due in part to the uneven distribution of the rock exposures. However, it also reflects the fact that in order to gather essential stratigraphic data, it was necessary to map certain parts in greater detail than others. Many weeks were spent in detailed mapping and in measuring well-exposed but structurally complex sequences on Tiglukpuk Creek, Cobblestone Creek, the Kiruktagiak River and around Castle Mountain in an attempt to unravel the stratigraphic succession. More data were gathered at these localities than can possibly 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 tracts of gently deformed strata of the Nanushuk group.

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

The elevations used to construct the profiles on plate 2 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.

Early Investigations

Prior to the recent petroleum investigations of the Arctic Slope by the U.S. Navy, only two reports describing the geology of the central foothills were available. Both reports were published by the U.S. Geological Survey and are of a general reconnaissance nature. The earlier report records a traverse across the Brooks Range and Arctic Slope by way of the John, Anaktuvuk and Colville Rivers by F.C. Schrader in 1901. In this report, Schrader subdivided the rocks of the upper Killik-Itkillik region into two mapping units: the Lisburne formation, which he believed to be Devonian in age, and the Anaktuvuk "series" which he assigned to early Cretaceous. The later report also describes a traverse of the Brooks Range and Arctic Slope. This was made by P.S. Smith and J.B. Mertie, Jr., in 1924 along the Alatna and Killik Rivers. Smith and Mertie recognized four mapping units in the upper Killik-Itkillik region, namely, the Lisburne formation (Mississippian); a chert, limestone and shale unit (Triassic); a sandstone and shale unit (Early Cretaceous); and a sandstone and shale unit (Late Cretaceous).

Recent Investigations

Preliminary geological investigations in the upper Killik-Itkillik region during the recent period of petroleum exploration commenced in 1945. That year three separate parties traversed the map area and the adjoining foothills to the north by way of the Killik, Chandler and Anaktuvuk Rivers. The work of the three parties was handicapped by the lack of aerial photographs and adequate base maps. Observations of Early Cretaceous and older strata in the upper Killik-Itkillik region were limited owing to the heavy mantle of glacial drift along the river valleys. However, stratigraphic investigations of mid-Cretaceous and younger strata in the foothills north of the upper Killik-Itkillik region beyond the limit of glaciation were the principal objectives of the three parties and were carried out successfully. The present stratigraphic nomenclature of the post mid-Cretaceous rocks is based in part upon their work.

During the summers of 1947 and 1948, mapping and stratigraphic studies of the post mid-Cretaceous strata in the foothills north of the upper Killik-Itkillik region 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., re-examined the exposures along the lower Chandler River between the Kiruktagiak River and the mouth.

Investigations by the Writer

This report is based principally upon field investigations during the summers of 1949 and 1950, although supplemental field data were collected during parts of the 1951 and 1953 field seasons (fig. 2). In 1949 the writer, assisted by I.L. Tailleur, geologist, and B.H. Kent and D.A. White, field assistants, mapped the area west of the Chandler River. The following year, with the assistance of A.S. Keller, geologist, and J.P. Minard and R.A. Hackman, field assistants, the writer mapped the area east of the Chandler River.

In the 1951 season, during the course of a traverse across the Brooks Range, approximately 25 square miles were mapped along the Okokmilaga River at the south edge of the map area by the writer, W.P. Brosge, and M.D. Mangus (fig. 2). In addition, the area of upper Kiruktagiak River and Monotis Creek was revisited for several days in order to gather additional stratigraphic data and to augment the

Mississippian and Triassic fossil collections.

During the summer of 1953 the area of the upper Kirukagiak River and Monotis Creek was visited again for eight days by the writer and A.L. Bowsher, and ten days were spent on Tiglukpuk Creek by the writer and M.V. Carson. The work at both localities was devoted chiefly to sampling and logging the phosphatic beds in the Lisburne group. However, some additional fossil collections and stratigraphic data were gathered from the Permian, Triassic, and Jurassic strata.

Also, during the summer of 1953, the upper Killik River was traversed by boat by R.L. Detterman and R.S. Bickel. Their mapping has been incorporated in plate 1.

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, 1951) (fig. 1). 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, Richardson, 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 the Arctic Coastal Plain extends southward to the mountain front. The Arctic Foothills province, a westward trending belt varying in width up to 100 miles, is divisible into a Southern section characterized by variously shaped, maturely dissected hills carved out of the complexly deformed late Paleozoic and pre-Late Cretaceous Mesozoic strata, and a Northern section of long parallel ridges and valleys of the "Appalachian" type, which have been carved out of gently deformed Late 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 upper Killik-Itkillik region is located largely within the Southern section of the Arctic Foothills province but at the northern edge it laps into the Northern section and at the southern edge it includes a narrow strip of the Brooks Range (fig. 1).

Upper Killik-Itkillik Region

Except for glaciated areas along the major river valleys, the topography of the map area is to a large extent an expression of the lithologic character and structure of the underlying bedrock. For this reason, and because no contours are shown on plate 1, it is convenient for purposes of physiographic description to subdivide the map area into five eastward-trending physiographic belts that can be referred to five different belts of rock on plate 1. The five belts from south to north are: (1) the Brooks Range belt of Paleozoic strata, (2) the foothills belt of complexly deformed late Paleozoic and Mesozoic strata, (3) the foothills belt of Fortress Mountain formation, (4) the lowland belt of Torok formation, and (5) the foothills belt of Nanushuk group strata.

Brooks Range belt of Paleozoic strata

Although the Brooks Range has a maximum relief of only 5,000 feet, it is exceptionally rugged owing to glacial sculpturing and the lack of vegetative cover. No glaciers are found at the north front of the Brooks Range today, but judging from the freshness of the glacial features the ice must have lingered until recent times. 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; Chandler and Shainin Lakes are the largest of these. The northern mountain front, which is composed of massive Paleozoic limestone and quartzite, forms a bold scarp that rises abruptly 2,000 to 3,000 feet above the maturely dissected foothills of less-resistant Mesozoic strata (fig. 3).

Fig. 3 Looking west from May Creek along front of Brooks Range. South-dipping beds of Lisburne group form mountain front. Foothills composed of complexly deformed late Paleozoic and Mesozoic strata. Thrust faulted outlier of Lisburne group in right background

Foothills belt of complexly deformed Late 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 late 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, there are clusters of irregularly shaped hills separated by broad featureless lowlands (fig. 4). The hills are characterized by discontinuous rubble-covered ridges of Jurassic and Cretaceous sandstone and by small buttes, knobs and pinnacles of mafic volcanic rock, Jurassic chert, and Paleozoic limestone.

The major rivers transect the belt through glacial troughs that have been cut 1,500 feet below the upland surfaces. Broad areas along the rivers are mantled with fresh glacial drift that nearly completely obscures the bedrock. The drift-covered areas have a typical poorly drained knob-and-kettle topography, and are dotted with numerous small lakes.

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 Fortress Mountain formation

The Fortress Mountain belt of foothills, 4 to 10 miles wide, stretches westward across the center of the map 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 mesalike hills,

Fig. 4 View of foothills and north front of Brooks Range, looking southwestward from near junction of Castle Creek and Kiruktagiak River. Shows upland surfaces and dissected hilly areas in belt of highly deformed late Paleozoic and Mesozoic strata

Fortress Mountain and Castle Mountain, dominate the belt between the Okokmilaga and Chandler Rivers (fig. 5). Wide, drift-covered, glacially reduced areas interrupt the foothills along the Killik, Anaktuvuk, and Nanushuk Rivers.

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

The lowland belt of Torok formation

The Torok formation lowland separates the Fortress Mountain foothills belt from the Nanushuk group foothills belt and extends from the northwest corner eastward across the map area 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 outcrops are found. Small cutbank exposures crop out 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 Nanushuk group strata

The belt of foothills along the northern margin of the map area is typified by synclinal mesas and long hogbacks and cuestas which reflect the gently dipping intercalated sandstone, conglomerate and shale of the Nanushuk group. Between the Okokmilaga River and Kanayut Creek the belt is 1 to 3 miles wide and consists of a single south-facing cuesta, the

Fig. 5 Looking eastward along southern margin of Fortress Mountain belt. Shows Fortress Mountain on left and Castle Mountain in center, the name locality and the type locality of the Fortress Mountain formation

Tuktu escarpment, that rises 1,000 to 2,000 feet above the Torok lowland. Eastward from Kanayut Creek the belt widens to eight 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 Kanayut Creek and the Itkillik River, a series of benched mesas of sandstone and conglomerate occur along the axis of the broad Arc Mountain syncline. North of the syncline the sharply creased Arc Mountain anticline is outlined by inward-facing hogbacks and along the core of the anticline a lowland has been carved out of Torok formation.

Drainage

The map area is drained by four large tributaries of the Colville River: the Killik, Chandler, Anaktuvuk and Itkillik. 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 map area are, from west to east: the Okpikruak and Okokmilaga, tributaries of the Killik; the Ayiyak, Kiruktagiak and Siksikpuk, tributaries of the Chandler; and Kanayut Creek and the Nanushuk River, 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 pre-glacial 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 termino-recessional moraines.

The smaller river valleys have not been so extensively glaciated. Most of these rivers head in cirques 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 debouch into the foothills. Across the foothills their courses are heavily alluviated with gravels varying from cobble size near the mountains to pebble size at the north edge of the map area. In places the streambed gravels have spread out across the valleys as much as a mile in width and the streams are diverted into a braided network of channels. These places are commonly the sites of perennial aufeis fields.

ROCKS

General

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

Period	Epoch	Age	Unit name		Character	Approx. Thickness (feet)
Quaternary	Recent		Flood-plain deposits		gravel, sand, and silt	?
	Pleistocene		Glacial deposits		till and outwash gravel	0-50 +
			Upland gravel deposits		outwash gravel	0-50 +
Cretaceous	Late	Cenomanian	Nanushuk group	Ninuluk formation	marine sandstone	1,200 +
	?	?		Chandler formation	sandstone, siltstone, shale, conglomerate, and coal, predominately nonmarine	2,800
	Early	Albian		Tuktu formation	marine sandstone	950-1,350
			Torok formation		shale, siltstone, and subordinate sandstone	6,000+
			?		?	?
			Fortress Mountain formation		sandstone, conglomerate, shale, and siltstone	10,000 ±
		Neocomian	Okpikruak formation		shale, siltstone, and sandstone	2,200 ±

(continued on following page)

Jurassic	Late	Portlandian (?)	tuffaceous graywacke unit / igneous rocks		tuffaceous graywacke, chert, indurated siltstone and shale / mafic intrusive and extrusive (?) rocks	? / ?
		Portlandian-Oxfordian	Tiglukpuk formation		shale, siltstone sandstone, and chert	1,500 +
Triassic	Late	Norian Karnian(?)	Shublik formation	limestone member	dark limestone, chert and shale	175-250
				chert member		
	Middle Early (?)	Anisian Scythian(?)		shale member	dark shale	0-500
Permian(?)			Siksikpuk formation		shale and siltstone	250-350
Mississippian	Late		Lisburne group	Alapah limestone	limestone, and subordinate shale, dolomite, and chert	1,700
	Early			Wachsmuth limestone		530 +

Table 1 Stratigraphic sequence of rocks in the upper Killik-Itkillik Rivers region

Five new formation names are listed in the table: Siksikpuk formation (Permian?), Tiglukpuk formation (Jurassic), Okpikruak formation, Fortress Mountain formation, and Torok formation (Cretaceous). In order to make the new names available to others who are currently preparing reports on various phases of the geology of northern Alaska, a brief description of each of the new formations has already been published (Gryc, Patton and Payne, 1951, pp. 159-162), (Patton, 1956, a, b, pp. 213-223), (Patton, 1957, pp. 41-43). A full description of the five formations, however, is presented for the first time in this report.

In the rock descriptions that follow, a standard terminology has been adapted for color, bedding, and grain size. Color names conform with the National Research Council rock-color chart (Goddard and others, 1949). Stratification units are described as follows: thinly bedded, 1 to 4 inches; medium bedded, 4 to 12 inches; and thickly bedded, more than 12 inches. The grain size and textural terminology is based on the Wentworth scale.

Mississippian Rocks

Lisburne Group

Distributed and topographic expression

The Lisburne group includes the oldest rocks exposed in the upper Killik-Itkillik region. Nowhere in the foothills does it crop out in a complete and continuous sequence, but it is well-exposed along the entire southern margin of the map area, where it forms the north front of the Brooks Range (fig. 3). Time did not permit detailed stratigraphic investigations within the Range.

Most of the Lisburne exposures in the foothills are small fault blocks which are so intensely crumpled that they are of little value for detailed stratigraphic study. However, there are several extensive relatively uncomplicated outcrops of the Lisburne group close to the mountain front. One such exposure is found on the Tiglukpuk Creek anticline between the Siksikpuk River and Natvakruak Lake, about 5 miles north of the Range. Another exposure of Lisburne forms the west-plunging nose of a folded thrust plate near the Nanushuk River, 1 to 2 miles north of the Range. Still another exposure of Lisburne, which is 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 those of 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 so that bedrock is exposed only along the crests. The small fault blocks of Lisburne are usually enclosed by less resistant Mesozoic strata and typically crop out as isolated pinnacles, buttes, or as abrupt wall-like ridges similar to the one shown in fig. 26, which crosses the valley of the Kiruktagiak River at the Notch.

Previous work

The Lisburne "formation" was first described by F. C. Schrader (1902, p. 241; 1904, pp. 62-66). 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, pp. 21-26) in the Cape Lisburne area, by E. deK. Leffingwell (1919, pp. 108-113) in the Canning River region, and by P.S. Smith and J.B. Mertie, Jr., 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 geological investigations of NPR-4, A.L. Bowsher and J.T. Dutro, Jr., systematically examined in considerable detail stratigraphic sections of the Lisburne rocks at Shainin, Nanushuk and Itkillik Lakes in the central Brooks Range. In 1950, 1951, and 1952 these Lisburne studies were continued by W.P. Brosge, 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 limestone has been elevated to the status of a group and subdivided into two formations, the Wachsmuth limestone and the Alapah limestone, which have their type localities at Shainin Lake (Bowsher and Dutro, 1957, p. 6).

Lithology

The Lisburne group in the upper Killik-Itkillik region is dominantly 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 from 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 and includes 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 is produced. Nodules and lenses of dark chert are an important constituent in many horizons where they may make up as much as 80 per cent 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 two formational units, the Wachsmuth limestone and the Alapah limestone (Bowsher and Dutro, 1957). Locally, members of the formational units also can be mapped. In the upper Killik-Itkillik region, however, where the exposures of Lisburne are poor and the rocks are generally badly crumpled, it has not been possible to delineate any of these cartographic subdivisions.

Thickness

The base of the Lisburne group is not exposed in the upper 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 (Brosge and Reiser, personal communication, 1951), this is judged to be nearly the full thickness of the formation.

Contacts

Along the mountain front west of the Anaktuvuk River, where the upper contact is best exposed, the Lisburne group is succeeded disconformably by the Siksikpuk formation. East of the Anaktuvuk, however, the Siksikpuk apparently is missing and the Shublik formation disconformably rests on the Lisburne group. North of the mountains the stratigraphic relationships of the Lisburne and the younger formations of the foothills are obscure as the contact is generally faulted. On Autumn Creek at latitude 68°28' N., and at the Kiruktagiak Notch, the Tiglukpuk formation appears to rest disconformably upon the Lisburne group. However, the exposures at both localities are incomplete, and perhaps some beds are missing because of unseen faults.

Stratigraphic sections

The thickest sequence of Lisburne group north of the mountains in the upper Killik-Itkillik region crops out on the Tiglukpuk Creek anticline at latitude 68°21' N. and longitude 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 part of the detailed stratigraphic investigations of the Lisburne group (Brosge, W.P., and Reiser, H.N., personal communication, 1950). Reiser logged the section in considerable detail and by correlations with other measured sections in the Brooks Range, he was able to draw the Alapah-Wachsmuth contact. The section includes the full thickness of the Alapah limestone, nearly 1,700 feet, and 530 feet of Wachsmuth limestone. Probably not more than a few hundred feet of lowermost Wachsmuth are missing.

Two partial sections of uppermost Lisburne group were measured in the upper Killik-Itkillik region, one in the Monotis Creek-Kiruktagiak River area (latitude 68°22-1/2' N. and longitude 152°54' W.) and the other on Skimo Creek in the Tiglukpuk Creek basin (latitude 68°17' N. and longitude 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 dominantly 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 fig. 6 the two sections are shown graphically and are correlated with the uppermost 450 feet of Reiser's Tiglukpuk Creek anticline section.

The dark limestone-shale-chert facies that characterizes these sections of upper Lisburne group apparently interfingers eastward with the light bioclastic limestone facies and, according to Brosge and Reiser (personal communcation, 1951), pinches out entirely a short distance east of the Anaktuvuk River. Within the dark limestone-shale-chert facies there 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 has been named the chert-shale member by Bowsher and Dutro (1957, p. 6). In the Monotis Creek section the chert-shale member is 67 feet thick and in the Skimo section it is 96 feet thick. However, it must thin northward abruptly, for in Reiser's measured section on the Tiglukpuk Creek anticline it is only 15 feet thick (fig. 6).

In the upper Killik-Itkillik region the chert-shale member has a special significance because the goniatite fauna contains a number of forms, including several new species, that have not been reported elsewhere in the Lisburne. In addition, the exposures on Monotis Creek and Skimo Creek contain the thickest deposits of phosphate rock yet found in northern Alaska (see page 138).

The stratigraphic interval between the chert-shale member and the top of the Lisburne is about 200 feet thick in Monotis Creek section and 525 feet thick in the Skimo Creek section (fig. 6). The difference appears to be due, at least in part, to differential erosion prior to deposition of the Siksikpuk formation.

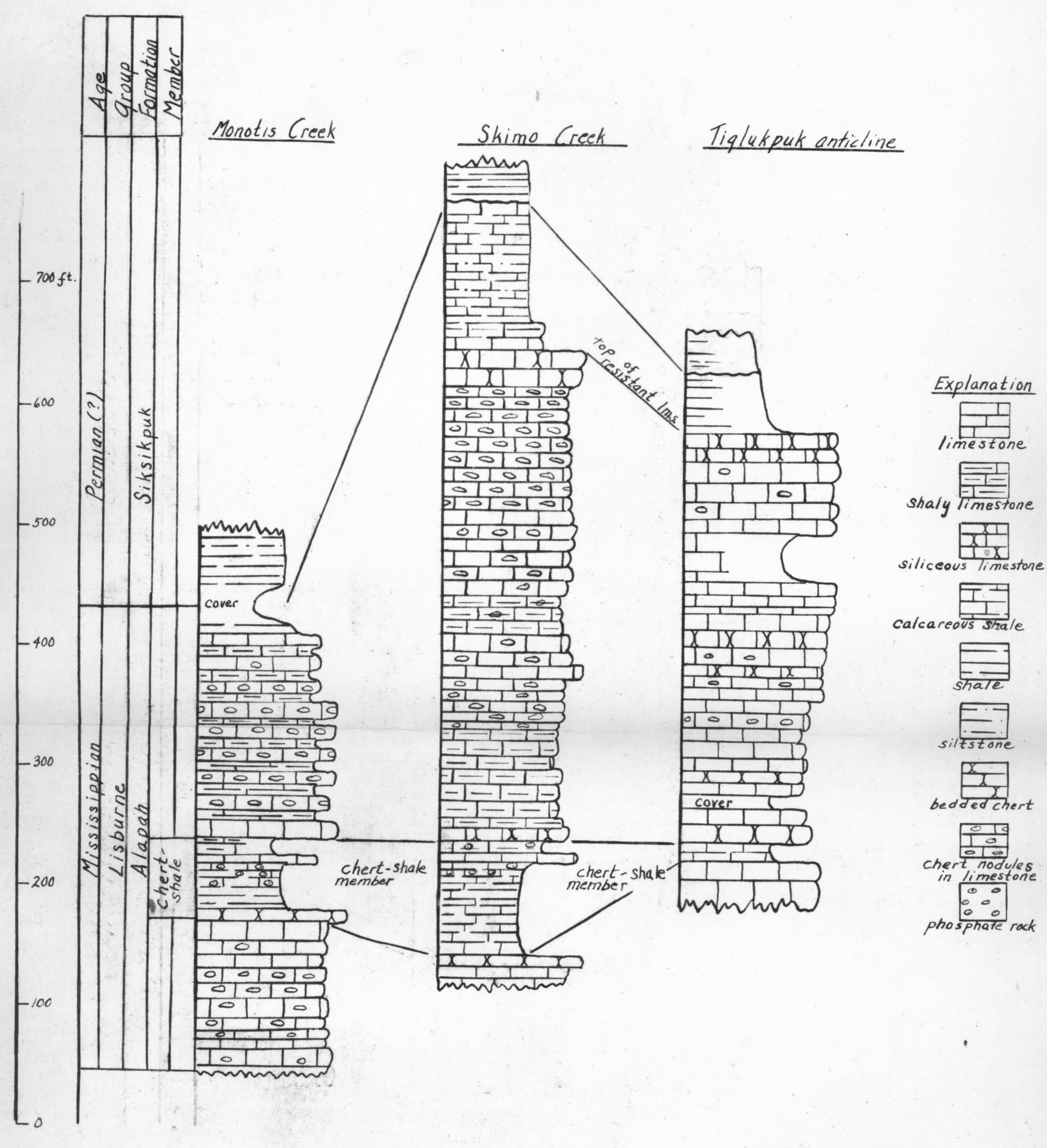


Fig. 6 Correlated columnar sections of uppermost Lisburne group

Another important exposure of upper Lisburne occurs along a narrow belt that crosses the valley of the Kiruktagiak River at the Kiruktagiak Notch (fig. 26). The outcrops of Lisburne at this locality appear to be along the up-thrust edge of a south-dipping fault block and 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 chert-shale member containing a well-preserved goniatite fauna is partially exposed.

Strata of the uppermost 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 to the Okokmilaga. The sequence exposed along these two bands is chiefly the dark limestone-shale-chert facies and is abundantly fossiliferous.

Age

The Lisburne group was originally assigned by Schrader to the Devonian (1904, pp. 62-67). Later, however, Collier established the age as Mississippian, based upon the collections from Cape Lisburne (1906, pp. 21-26). Bowsher and Dutro (1957, p. 6) assign the Wachsmuth limestone an Early Mississippian age and the Alapah limestone a probable Late Mississippian age.

An interesting assemblage of mollusks was found in the exposures of the chert-shale member of the Alapah formation on Monotis Creek, the upper Kiruktagiak River, the Notch, and the Okpikruak River. Of particular significance in the collection are the cephalopods including a number of new species which have been recently described by Gordon (1957); the collections include: Knightoceras pattoni Gordon, Beyrichoceras micronotum Phillips, Goniatites crenistria Phillips, Girtyoceras arcticum Gordon, Entogonites borealis Gordon, Dimorphoceras algens Gordon, Dolothoceras medium Gordon, and Stroboceras crispum Gordon.

Permian Rocks

Siksikpuk Formation

Introduction

The name Siksikpuk formation has been introduced to designate a heretofore undescribed 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 upper Killik-Itkillik region the Siksikpuk formation is exposed west of the Anaktuvuk River principally along a narrow belt at the front of the mountains. Scattered outcrops are also found north of the mountains on the Tiglukpuk Creek anticline and flanking the two bands of Lisburne group that extend eastward from the Okpikruak River to the Okokmilaga River, 10 miles north of the mountain front (plate 1).

The Siksikpuk formation and the overlying Shublik formation have not been differentiated in most places on plate 1. Both formations are structurally incompetent and everywhere are complexly infolded and infaulted.

Since both formations 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.

The only exposures of Siksikpuk formation in the map area occur along steep cutbanks. These are generally slumped so that bedding and structure are not discernible. In the interstream areas, the presence of the Siksikpuk formation is only suggested by a few low ridges of cherty rubble.

The Siksikpuk is sufficiently well exposed to warrant stratigraphic measurements at only two localities, Tiglukpuk Creek and Kiruktagiak River. The Tiglukpuk Creek section is the more complete and has been designated as the type locality.

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 Lisburne group and on the north by irregular foothills composed of Jurassic and Cretaceous sandstone and conglomerate.

Previous work

Prior to the recent geological investigations of Naval Petroleum Reserve No. 4, no rock younger than Lisburne group and older than Shublik formation had been recognized in the central foothills. In the Canning River region of the eastern Brooks Range, Leffingwell (1919, pp. 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 the

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 of variegated green, gray, and dark-red shale and siltstone that locally are notably calcareous, cherty, or ferruginous. All gradation from thin, fissile clay shale to 6-inch beds of silstone occur. Ellipsoidal concretions of barite up to several feet 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 shale 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. At the type locality the contact is marked by several feet of thoroughly oxidized clay and silt. In most places the Siksikpuk formation is overlain disconformably by the Shublik formation, although locally there is a suggestion that it is overlain by younger Mesozoic formations. Basal beds of the Shublik formation rest upon the Siksikpuk formation at the type locality. At the top of the Siksikpuk formation are several feet of heavily oxidized shale underlain by 115 feet

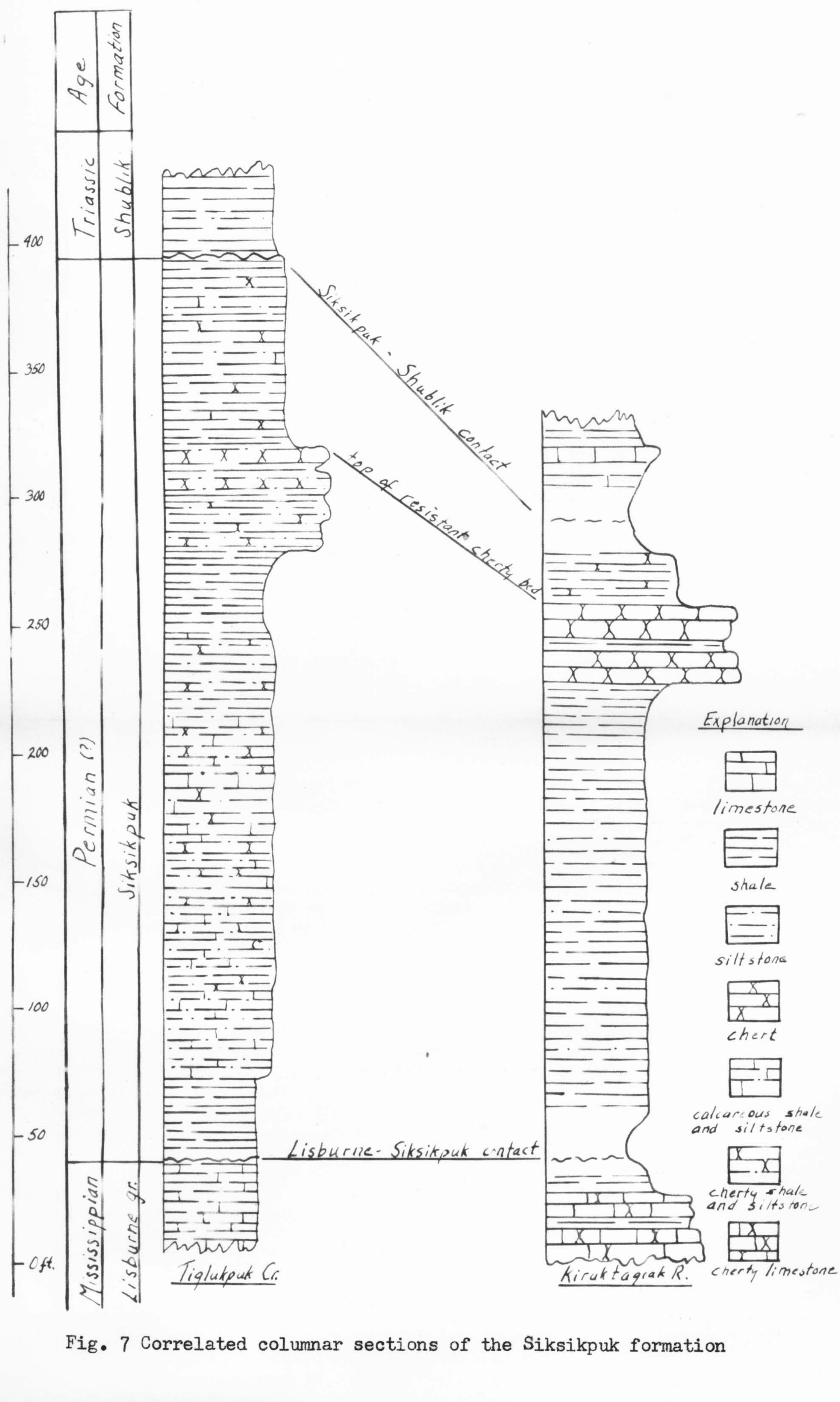


Fig. 7 Correlated columnar sections of the Siksikpuk formation

of silicified (?) shale and siltstone.

Stratigraphic sections

The Siksikpuk formation is not completely exposed at any one locality. The type section is a composite of two separate outcrops, approximately two miles apart, along a narrow belt of Siksikpuk exposures 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 latitude 68°17' N. and longitude 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 latitude 68°17' N. and longitude 151°48' W.

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 underlying Lisburne group appear to be concordant with the Siksikpuk, and there is no indication of faulting between them.

The type section on Tiglukpuk Creek and the Kiruktagiak section are shown graphically in fig. 7. A resistant 40-foot sequence of cherty siltstone 240 feet above the base of the Tiglukpuk Creek section is believed to correlate with a 30-foot sequence of impure chert that occurs near the top of Kiruktagiak section. The difference in thickness of the overlying shale beds at the two localities is attributed to differential erosion prior to deposition of the Shublik formation.

Age

A faunule of corals, brachiopods, and gastropods occurs in the basal

50 feet of the Siksikpuk formation. Collections from the type section have been examined in detail by Ellis Yochelson, J.T. Dutro, Jr., and Helen Duncan (Patton, 1957) who state that although no single species is diagnostic of a specific geological period, the overall aspect of the assemblage, when compared with Permian collections from elsewhere in Alaska, suggests a probable Permian age.

Correlations

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

West of the upper Killik-Itkillik region, the Siksikpuk was identified and mapped as far as the Kiligwa River (Tailleur, personal communication, 1956). At Cape Thompson on the Arctic coast, 350 miles west of the map area, E.M. Kindle (1909, pp. 520-528) described a section believed to be correlative with the Siksikpuk formation. It 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 with 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 formation 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 Shublik crops out at the head of Autumn Creek, and several tiny slivers of Shublik occur close to the thrust faults that bound the east-trending belt of Fortress Mountain formation. The best exposures of Shublik are found near the mountain front in cutbanks on Cobblestone, Peregrine, Welcome, Tiglukpuk and Monotis Creeks.

It was not possible to differentiate Shublik formation from Siksikpuk formation in many places (plate 1) 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.

Previous work

The Shublik formation was named and described by E. de K. Leffingwell (1919, pp. 115-118) from exposures in the Canning River region of northern Alaska, 110 miles northeast of the map 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 is composed of "about 500 feet of dark limestone, shale, and sandstone [overlying] the Pennsylvanian Sadlerochit sandstone and [underlying] 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 upper Killik-Itkillik region. However, they did not believe these rocks should be called Shublik formation because Leffingwell's type section contains no chert. Also, 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 are sufficiently uniform to justify application of the name Shublik thoughout.

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, appear to persist across the map area. They are, in ascending stratigraphic order: the shale member, the chert member, and the 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. Golf-ball size, fossiliferous, grayish-black cherty limestone concretions are abundant. The limestone member is composed dominantly of medium light-gray to dark-gray fossiliferous limestone that is rarely cherty and usually weathers a characteristic grayish-orange. The limestone may or may not 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 per cent to 70 per cent 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 per cent to 35 per cent of the sections. The remainder is largely opaque matter, partly fine pyrite dust and partly organic matter. Circular bodies of silica .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 was also examined. It is composed of at least 85 per cent very fine-grained quartz. The rest of the section is chiefly calcite which occurs as fossil fragments. Radiolaria-like siliceous bodies are also present in this section.

Thickness

The only completely exposed sequence of Shublik formation occurs on upper Tiglukpuk Creek where the full thickness of the formation is approximately 750 feet. About 250 feet of this section belongs to the limestone and chert members and the rest to the shale member (fig. 8). 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 is a limestone and chert member and the rest is shale member (fig. 8). The difference in total thickness of the formation in the two sections is accounted for

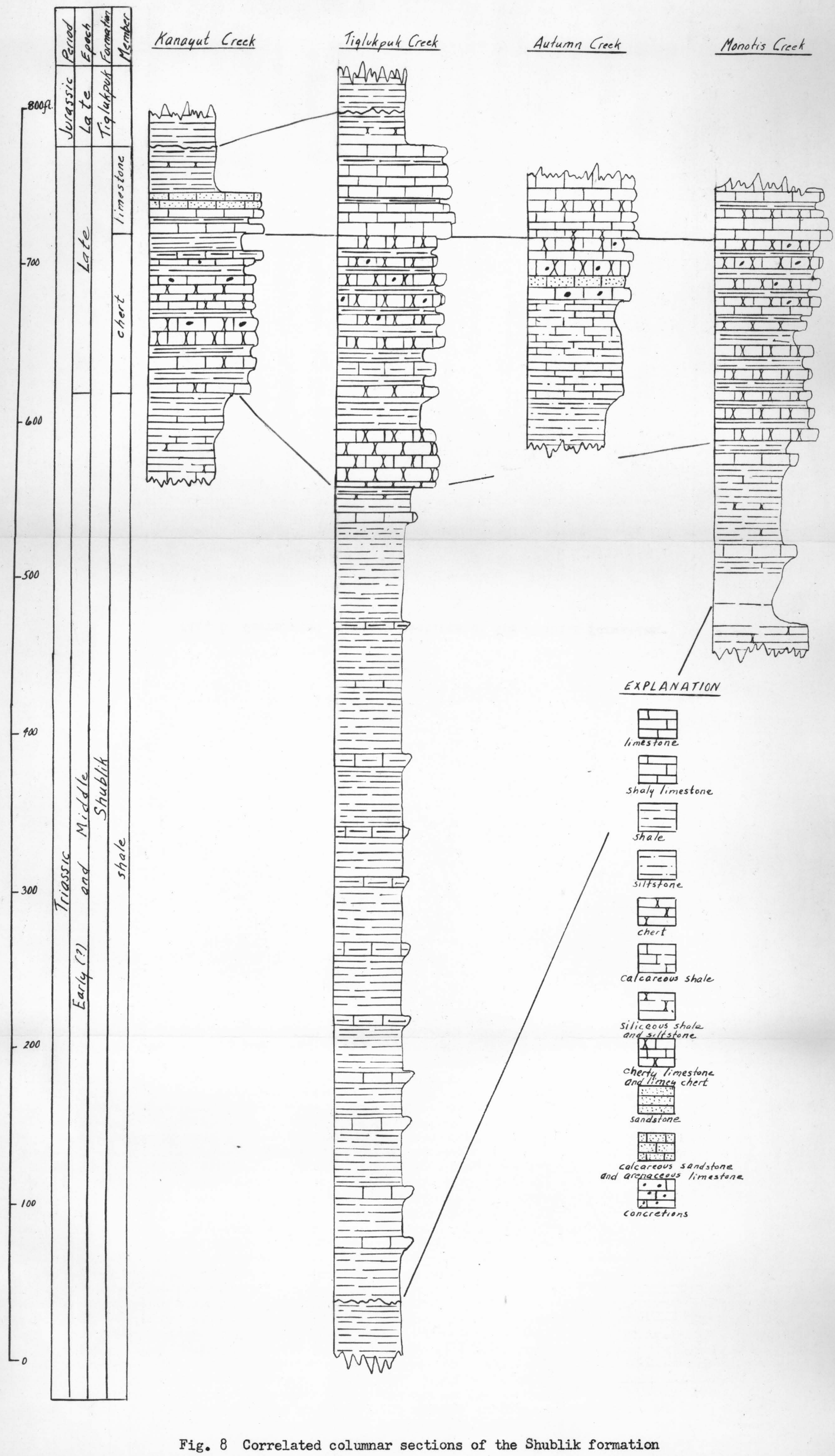


Fig. 8 Correlated columnar sections of the Shublik formation

primarily in the shale member. Unfortunately the shale member is so poorly exposed that little is known about its regional character and extent; and whether the variations in thickness are the result of non-deposition or erosion could not be determined.

Contacts

West of the Anaktuvuk River the Shublik rests disconformably upon Siksikpuk formation, and east of the Anaktuvuk upon Lisburne group. Everywhere that 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 8. The first section was measured on an eastern branch of Kanayut Creek, a mile north of the mountains, at latitude 68°23' N. and longitude 150°47' W. There the upper 200 feet of Shublik and the basal few feet of the overlying Tiglukpuk formation are repeated in four tiny fault slivers (plates 1 and 2). The top of the Shublik is marked by ferruginous-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 the limestone member, 56 feet thick; the chert member, 103 feet thick; and 55 feet of the shale member.

The second section shown in figure 8 is a composite that was compiled from two separate cutbank exposures along upper Tiglukpuk Creek. The section totals 750 feet in thickness and includes approximately 500 feet of shale member, 160 feet of chert member, and 80 feet of limestone member. The upper 400 feet of the section crops out on the south flank of the Tiglukpuk Creek anticline at latitude 68°20' N. and longitude 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 latitude 68°17' N. and longitude 151°53' W. Measurements of the basal 350 feet are approximate, owing to structural complexities at the mountain front. At the top of the section there is an abrupt change from grayish-black shale of the Shublik formation to softer dark-gray shale and siltstone of the Tiglukpuk formation. At the base, several feet of heavily oxidized shale separate grayish-black Shublik shale from variegated Siksikpuk shale.

The third section shown in figure 8 was measured in a small cutbank at the head of Autumn Creek, latitude 68°29' N. and longitude 152° 18' W. The exposed section is 175 feet thick and includes the limestone and chert members. The bottom and top contacts of the Shublik are not exposed. The section occurs 11 miles north of the mountain front and differs from the other three sections, which all lie close to the mountain front, in several respects: (1) the limestone comprising the limestone member is lighter colored, (2) the percentage of chert in the chert member is less and (3) silt- and sand-size clastic rocks occur in the chert member.

The fourth section in figure 8 was measured on Monotis Creek, a small mountain-front tributary of the Kiruktagiak River at latitude 68° 22-1/2' N. and longitude 152°56' W. Gently north-dipping beds of Shublik form a bluff 1-1/2 miles long along the north side of the creek (fig. 9). 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.

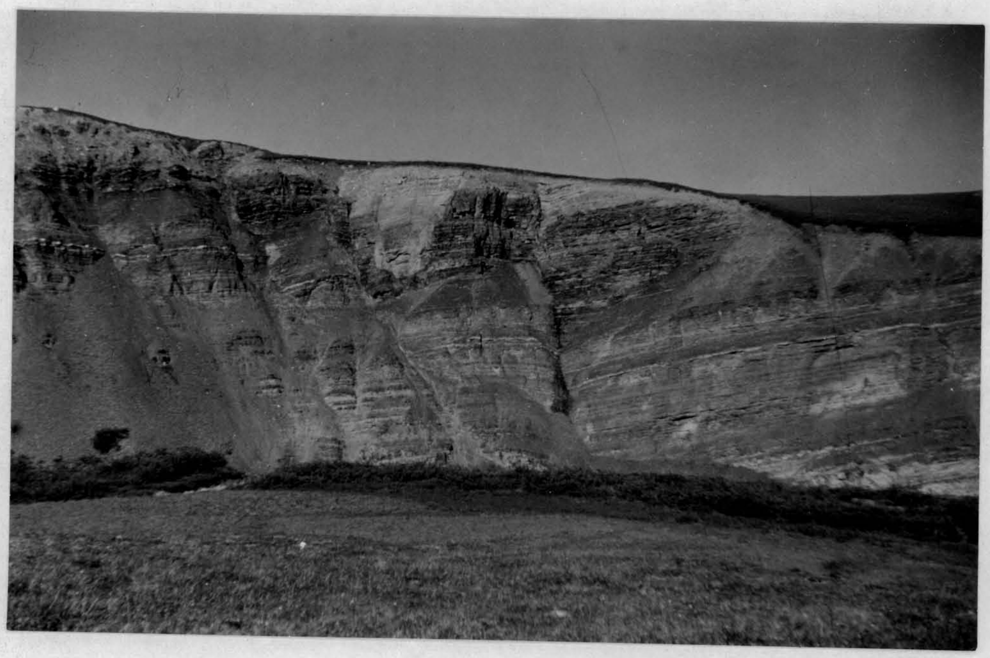


Fig. 9 Exposure of the chert and limestone members of the Shublik formation on Monotis Creek

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

Facies changes

Although the character of the Shublik is remarkably uniform along 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, pp. 115-118), but is an important constituent in the map area west of the Anaktuvuk River and in the foothills west of the map area. Clastic beds occur abundantly in the Shublik east of the map area. On Gilead Creek, 70 miles northeast of the Itkillik River, Keller (personal communication, 1952) reports that below the limestone member of 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 (personal 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 map area as, for example, the arenaceous limestone beds in the limestone member of the Kanayut Creek section (fig. 8). They are also found in the northernmost exposures, as, for example, the silty beds in the chert member of the Autumn Creek section (fig. 8).

Age and correlations

The limestone and chert members of the Shublik are dated as Late Triassic. The limestone member is characterized by *Entomonotis subcircularis* Gabb, and the chert member by a distinctive faunal assemblage that includes Halobia, Arcestes and Trachyceras. Both faunal zones have been recognized in Upper Triassic strata elsewhere in Alaska; the upper zone is dated as Norian on the basis of E. subcircularis Gabb, a worldwide guide fossil, and the lower zone has been regarded as Karnian in age by G.C. Martin and others (1926, pp. 119-131) 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. 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. However, in the Monotis Creek section, E. subcircularis was found about 85 feet below the limestone member and below the lowest occurrence of Halobia in the chert member. This seems to suggest that both the limestone and chert 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 in the black paper shale, cherty limestone or thinly bedded, grayish-black limestone, it is probable that the distribution of the two fossils is ecologically controlled and they may not be of different age.

The shale member of the Shublik is tentatively assigned to Middle Triassic (Anisian) although it may also include some beds of Early Triassic (Scythian) age. In most places the only fossil found in the shale member is Posidonia, a long-ranging pelecypod of little stratigraphic significance. On Monotis Creek, however, Posidonia is associated with a distinctive Middle Triassic fauna that includes Proteusites, Leiophyllites, Pseudaplococeras, and Hungarites (Bernard Kummel, memorandum, April 7, 1952).

The only other reported occurrence of Middle Triassic fossils in Alaska is a collection from Brooks Mountain on the Seward Peninsula. The authenticity of this 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 a number of geologists failed to reveal additional fossils or other evidence of Triassic strata (Martin, 1926, pp. 116-117).

Two collections of vertebrate remains were found in the middle of the measured section of shale member (fig. 8) on Tiglukpuk Creek, and a third collection was found in an isolated exposure of the shale member on the Kiruktagiak River, 2 miles above the confluence of Monotis Creek. The three collections have been examined by D.H. Dunkle, who reports (memorandum, Nov. 4, 1953): (1) a caudal body section from a coelacanthine fish of indeterminate generic and specific identity, (2) a series of post-sacral vertebrae and a portion of a hind leg of a reptile, probably from one of the group of ichthyosaurs that first appeared at the beginning of the Middle Triassic and (3) an incomplete and macerated skeleton of the marine paleoniscoid fish Boreosomus. According to Dunkle, indisputable remains of Boreosomus are restricted to Early Triassic (Otoceratan and Gyronitan). Thus 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 (personal communication, 1954) has found conclusive evidence of Early Triassic strata in the foothills northeast of the Itkillik River.

Jurassic Rocks

Tiglukpuk Formation

Introduction

The Tiglukpuk formation (Patton, 1956a) comprises the sandstone, siltstone, and shale that overlies the Shublik formation and underlies the Okpikruak formation (Cretaceous) in the central and western Arctic Foothills province. It has been mapped from the Lupine River, 50 miles east of the Itkillik River (Keller, A.S., personal communication, 1951) to the Nuka River, 130 miles west of the Killik River (Tailleur, I.L., personal communication, 1953) and is typically exposed in a series of cutbanks 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 map 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 is believed to overlie the bulk of the Tiglukpuk formation. Present information is not sufficient to warrant establishing a new formation for this unit. For mapping purposes it has been included with the Tiglukpuk formation but it is described separately in the text at the conclusion of the discussion of the Tiglukpuk formation.

Distribution and topographic expression

The Tiglukpuk formation underlies about 25 per cent of the upper Killik-Itkillik region and is widely exposed along the belt of complexly deformed late Paleozoic and Mesozoic strata immediately adjacent to the mountain front. Less extensive exposures occur further north within the belt of Foretress Mountain formation chiefly as narrow bands along major thrust faults.

Owing to the fact that both the Tiglukpuk and Okpikruak formations are composed predominantly of nearly identical lithologies and cannot be separated except where extensive exposures occur they are not differentiated over large parts of the map area.

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

Previous work

Schrader (1904), 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 the possibility that the base of his Anaktuvuk "series" (Lower Cretaceous) in the central Arctic Foothills province might extend into the Jurassic. P.S. Smith and J.B. Mertie, Jr., (1930) made no mention of Jurassic rocks along the Killik River. Apparently they included the Tiglukpuk strata partly in the Triassic system and partly in the Lower Cretaceous series.

Lithology

Shale, siltstone and sandstone of the graywacke type (following the terminology of Pettijohn, F.J., 1949, pp. 243-255) are the principal components of the Tiglukpuk formation, but in the basal part it also includes subordinate amounts of bedded chert, siliceous black shale, variegated shale and siltstone, and a coquinoid limestone composed largely of compacted specimens of Aucella.

Sandstone, siltstone, and shale.-- The sandstone is typically a greenish-gray, very fine- 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 it ranges 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 "cannon-ball" concretions of calcareous siltstone are scattered through the sandstone.

Several samples of Tiglukpuk sandstone were examined in thin section and were found to be composed of from 20 per cent to 40 per cent quartz, 10 per cent to 20 per cent feldspar, chiefly sericitized and calcitized plagioclase, and 10 per cent to 20 per cent lithic fragments including chert, slate and siltstone. The rest of the rock is argillaceous matrix composed chiefly of chlorite, clay, and fine silt. Calcite is usually present in variable amounts up to 20 per cent and occurs both as detrital fragments and as a cementing material in the matrix. The sandstone probably owes its characteristic greenish cast to the presence of finely divided chlorite in the matrix. Porosity of the sandstone averages about 5 per cent, but permeability is negligible.

Dark-gray silty shale and siltstone, although less conspicuous than the sandstone, comprise 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 a gun-metal blue. The nodules are discoidal or ellipsoidal and as much as 8 inches in diameter. The lenses range up to a foot thick and several feet long, and usually are concentrated along certain horizons.

Chert.-- Bedded chert occurs in the Tiglukpuk formation everywhere except in the northeastern corner of the map 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 there are scattered lenses of chert that are rarely 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. Extensive cutbank exposures are found where this band is transected by Peregrine Creek, Welcome Creek, Siksikpuk River, and Okokmilaga River. 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 comprise up to 40 per cent of the chert and, where it occurs in large amounts, it gives the chert the texture and appearance of a porcellanite. 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 up to a half-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 a 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 overlying 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 map 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 per cent 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 thick section is exposed on the west side of the Kiruktagiak River a mile north of the mountain front, and a 100-foot thick section crops out on the east side of Tiglukpuk Creek a mile and a half north of the mountains. Small outcrops of the variegated shale and siltstone were noted 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. The siltstone comprises from 30 per cent to 60 per cent of the sections and occurs in lenticular beds from 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 the Kiruktagiak River and Tiglukpuk Creek sections. 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 Early Cretaceous sedimentary formations.

Coquinoid limestone.-- A medium-gray, dusky-red weathering coquinoid limestone, composed almost entirely of mollusk shells, is found in subordinate amounts in the Tiglukpuk formation intercalated with shale. 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 up to 20 feet thick. The shell material is chiefly crushed and fragmented *Aucella* valves, the majority of which appear to be oriented with their convex side upward. Belemnite phragmacones were found with the *Aucellae* in several localities.

Thickness

The total thickness of the Tiglukpuk formation is not known, as a complete section in which both top and bottom contacts are exposed has not been found. The type section, approximately 1,500 feet thick, is the most complete section that crops out in the map area and is believed to represent nearly the full thickness of the formation. From scattered outcrops along the Lupine River, 75 miles east of the map area, A.S. Keller (personal communication, 1951) compiled a composite section totaling approximately 1,800 feet which, although the top of the formation is not exposed, is the thickest sequence of Tiglukpuk formation

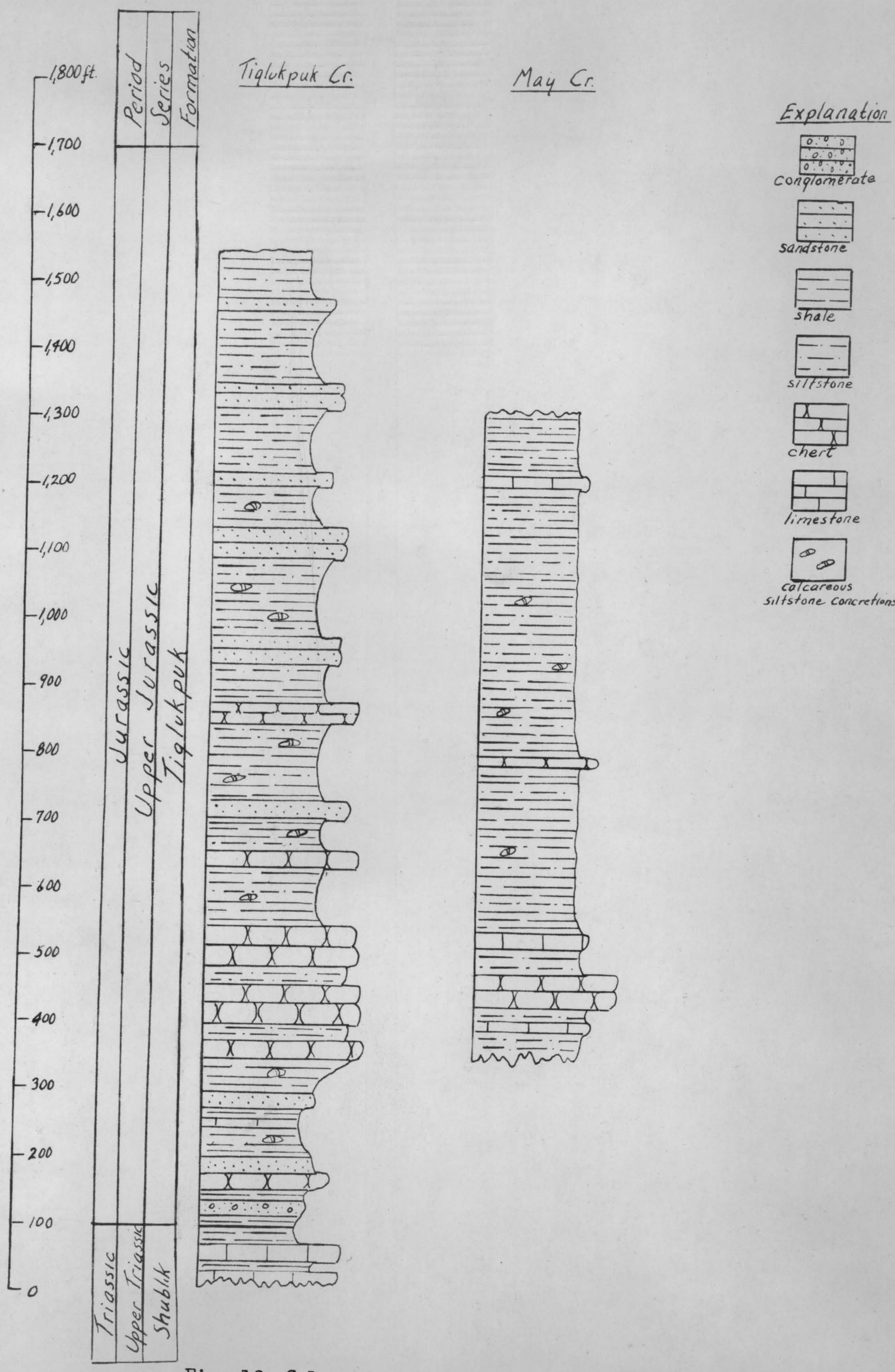


Fig. 10 Columnar sections of the Tiglukpuk formation

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

Stratigraphic sections

Two measured stratigraphic sections of Tiglukpuk formation are shown in figure 10. The more complete section, which is about 1,500 feet thick, has been designated as the type. It crops out in cutbanks on the east side of the Tiglukpuk Creek, 3 miles north of the mountain front, latitude 68°20' N. and longitude 151°50' W. About 20 per cent of the type section is not exposed, but the lithologic character of the covered sequences can be inferred from talus or float. The section occurs on the south flank of the Tiglukpuk Creek anticline and dips 35° to 70° south. The base rests disconformably upon Shublik formation but the top appears to be cut off by a reverse fault. The cherty sequence several hundred feet above the base of the section has been invaded by two diabase sills. The lower sill is about 200 feet thick and the upper one about 75 feet thick. Contact effect is limited to bleaching of the chert at the top of the lower sill.

The other section of Tiglukpuk formation shown in fig. 10 is approximately 965 feet thick and was measured on the east side of May Creek, latitude 68°26'N. and longitude 150°08' W. The top and bottom of this section are cut off by faulting.

Age and correlations

The Tiglukpuk formation is assigned to a Late Jurassic (upper Oxfordian to lower Portlandian) age, principally because of the presence of several species of Aucella.

Although the Tiglukpuk formation appears to be almost entirely of marine origin, fossils are scarce and poorly preserved. Two species of Aucella, A. concentrica (Sowerby) and A. rugosa (Fischer) are by far the most common megafossils. Closely compacted specimens of Aucella comprise the coquinoid limestone, and molds and casts of single specimens occur in sandstone. One ammonite, Lytoceras sp. was found together with A. 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 dominantly of Aucella. In the area east of the Nanushuk River the Aucellas, although most abundant near the base, range upward to within a few feet of the Okpikruak formation-Tiglukpuk formation contact. 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, pp. 73-75), Aucella rugosa (Fischer) and Aucella concentrica (Sowerby) are both indicative of the Late Jurassic but are of slightly different age. A. rugosa ranges from middle

Kimmeridgian to lower Portlandian, and _A. concentrica_ ranges from upper Oxfordian to middle Kimmeridgian. Whether _A. rugosa_ generally occurs at a higher stratigraphic level than _A. concentrica_ in the map area could not be determined owing to the small number of collections and the lack of stratigraphic control with the Tiglukpuk formation.

In the Canning River region near the eastern end of the Arctic Foothills province, Leffingwell (1919, pp. 119-125) described two Jurassic formations, the Kingak shale and the Ignek formation. The Kingak directly overlies the Shublik formation and is succeeded by the Ignek. Subsequent investigations of these two formations in their type area (Keller, personal communication, 1952) has shown that the Kingak ranges in age from Early to Late Jurassic but that the Ignek is of Cretaceous age. Keller has demonstrated that the upper part of the Kingak is probably a fine-grained facies of Tiglukpuk formation.

Tuffaceous Graywacke Unit and Correlative (?) Rocks

Tuffaceous graywacke unit

The tuffaceous graywacke unit consists of an anomalous group of rocks including tuffaceous graywacke, chert, and indurated shale and siltstone which for purposes of mapping have been placed in the Tiglukpuk formation. Owing to cover and structural complexities, the precise stratigraphic position of these strata cannot be determined with certainty but gross relationships suggest that they overlie the Tiglukpuk formation and underlie the Okpikruak formation. They appear to be closely associated with mafic igneous rocks.

The most extensive exposure of the tuffaceous graywacke unit occurs at the head of Fortress Creek between latitude 68°28' N. and latitude 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 latitude 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. A half-mile east of Tiglukpuk Creek the same sequence of rocks is interbedded with mafic volcanic rock.

The tuffaceous graywacke varies 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, .2 mm to .5 mm, set in a highly altered tuffaceous matrix. Plagioclase, chiefly albite and oligoclase with subordinate andesine, comprises 30 per cent of the rock and occurs in individual grains or in lithic fragments. The plagioclase commonly is partially or wholly replaced by sericite, calcite, or in the case of one sample, by zeolite. Quartz is present but always in amounts less than 5 per cent. Augite and less commonly hornblende may aggregate as much as 5 per cent of the rock. Lithic fragments including chert, shale, and mafic volcanics comprise about 10 per cent of the rock. Matrix material accounts for more than 50 per cent 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 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 Creek and Okonagoon Creek and is exposed in cutbanks at several localities along Okonagoon Creek between latitude 68°29' N. and latitude 68°34' N. The contacts of the sequence are covered, but gross relationships suggest that it occurs stratigraphically between the Tiglukpuk formation and the Okpikruak formation. The shale, which comprises approximately 60 per cent 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. Inercalated 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, latitude 68°36' N. and longitude 152°47' W. may also correlate with the tuffaceous graywacke unit. Horseshoe Mountain is composed of a 200- to 300-foot thick succession of layered rocks. In the field the succesion was thought to be entirely mafic sills or flows, but microscopic examination showed that 7 of the 15 samples that were collected from Horseshoe Mountain are clastic rocks. The clastic rocks range from angular breccias of volcanic material through aggregates of slightly rounded volcanic and non-volcanic detritus, to a sandstone of the graywacke type. Apparently they include all variations from tuffs to moderately sorted sedimentary rock.

Age

The tuffaceous graywacke unit is tentatively assigned a latest Jurassic (Portlandian ?) age based upon scanty fossil collections and upon its apparent stratigraphic position above the Tiglukpuk formation and below the Okpikruak formation.

Two fossil collections from the tuffaceous graywacke unit containing fragmentary ammonites and Inoceramus sp. were given to R.W. Imlay for study. On the basis of a preliminary examination of these two collections, Dr. Imlay tentatively assigned the fragmentary ammonites a Middle Jurassic age which would place them below the Tiglukpuk formation (Memorandum, February 12, 1951) (1955, pp. 73-81). Subsequent to his examination, new field data were collected which indicated that the tuffaceous graywacke probably overlies the Tiglukpuk formation and therefore could not be older than Late Jurassic. This information was given to Dr. Imlay who commented as follows (Memorandum, September 6, 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).

A single specimen of Aucella 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 to have come 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 this collection Dr. Imlay states (Memorandum, September 6, 1956):

> The collection consists of a single, well-preserved specimen of Aucella 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 and Oregon. 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 suggests they are probably post-Tiglukpuk formation. The mafic volcanic rocks which locally are intercalated with these strata invade Tiglukpuk and older formations, but have not been found cutting Okpikruak formation or younger strata. Furthermore, lithic and mineral detritus of mafic igneous rock is abundant in the Okpikruak formation and succeeding formations, but 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

Introduction

The name Okpikruak formation has been introduced to designate the sequence of cyclically interbedded sandstone, siltstone, and shale of the graywacke type that overlies the Tiglukpuk formation and underlies the Fortress Mountain formation (Cretaceous). The Okpikruak has been traced along the Arctic Foothills province from the Canning River in the east (Keller, A.S., personal communication, 1952) to beyond the Nuka River in the west (Tailleur, I.L., personal communication, 1953), a distance of over 350 miles.

The Okpikruak formation was described for the first time in 1951 (Gryc, Patton and Payne, pp. 159-160). However, subsequent mapping and stratigraphic studies now permit a closer definition of the limits and composition of the formation. In the original description, the type locality was designated at latitude 68°35' N. and longitude 153°30' W. on the Okpikruak River, but a more complete and typical exposure has been found on Tiglukpuk Creek at latitude 68°19' N. and 151°50' W. Whereas the type section is only about 45 per cent exposed and the lower contact is faulted, the Tiglukpuk Creek sequence is nearly all exposed and appears to rest upon Tiglukpuk formation in normal stratigraphic order.

Distribution and topographic expression

Okpikruak formation is found principally in the belt of complexly deformed late 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 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 local areas where extensive outcrops permit the delineation of the Okpikruak formation are: Cobblestone Creek, upper Tiglukpuk Creek, the Aucella-Speedway Creeks area in the Kiruktagiak River basin, and the Okonagoon-Verdant Creeks area in the Okpikruak River basin.

North of the complex belt two small areas of Okpikruak formation can be outlined within the eastward-trending belt of Fortress Mountain formation: (1) between the Kiruktagiak and Ayiyak Rivers at latitude 68° 36' N. and (2) a short distance east of the Chandler River at latitude 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, which occurs only locally, crops out in low, irregularly shaped knobs and buttes.

Previous work

Judging from his map and description, Schrader (1904) apparently included the Okpikruak formation in his Anaktuvuk "series". He assigned the Anaktuvuk "series" an Early Cretaceous age based upon the occurrence of Aucella crassicolis Keyserling, the characteristic fossil of the Okpikruak formation.

Smith and Mertie (1930) did not use Schrader's Anaktuvuk "series" but placed the Okpikruak formation together with the Tiglukpuk and Fortress Mountain formations in an informally designated time-stratigraphic unit, the Lower Cretaceous series.

Lithology

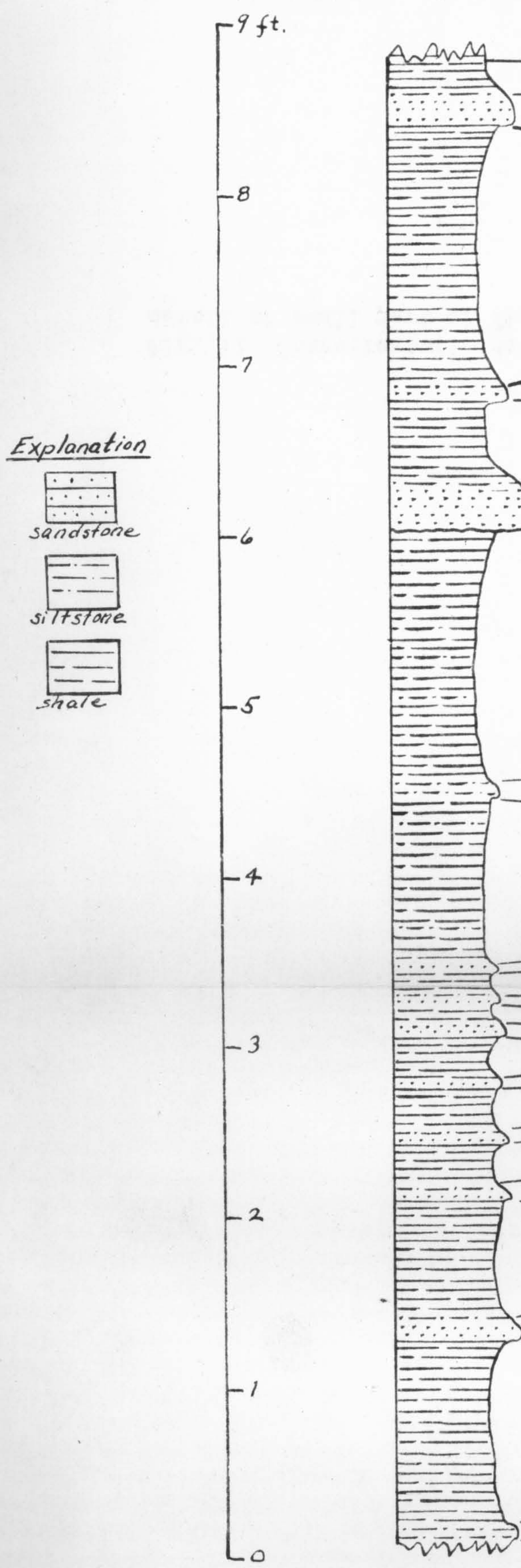
The Okpikruak formation is typified everywhere in the map area by a thick, monotonous, cyclically interbedded succession of shale, siltstone and sandstone of the graywacke type. Conglomerate occurs at the base locally.

The sandstone is greenish-gray to dark greenish-gray, very fine to fine grained and thin 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 per cent to 25 per cent; angular to subangular grains of feldspar, chiefly sericitized sodic plagioclase, 10 per cent to 25 per cent; calcite in irregular masses locally replacing plagioclase, as much as 3 per cent; and finely divided clay, chlorite, and silt, as much as 50 per cent. Fragments of chert, shale, siltstone and mafic volcanic rock comprise from 20 per cent to 40 per cent of the medium- and coarse-grained sandstone.

The siltstone commonly is dark greenish-gray to dark gray, calcareous, and occurs in beds from less than an inch to 6 inches in thickness. Highly calcareous siltstone is notably lenticular or concretionary and weathers a characteristic moderate yellowish-brown.

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

The ratio of sandstone, siltstone, and shale changes from place to place although the cyclic alternation of these rock types is present to



Description	Bed No.
Shale, dark-gray, hackly; contains thin silty layers.	24
Sandstone, bottom half of bed dark greenish-gray; upper half dark-gray, highly calcareous and weathers light brown. Grades into siltstone.	23
Shale, as in bed #20.	22
Sandstone, dark greenish-gray, weathers light brownish gray, very fine grained.	21
Shale, medium dark-gray, hackly, silty near base.	20
Sandstone, dark greenish-gray, very fine-grained, bottom contact undulating, top contact gradational.	19
Shale, grayish-black, silty, similar to bed #2, a few very thin siltstone beds.	18
Siltstone, dark greenish-gray, slightly calcareous, sharp lower contact, grades upward into shale.	17
Shale, as in bed #2 with very thin siltstone beds.	16
Sandstone, as in bed #5	15
Shale, as in bed #2	14
Sandstone as in bed #5	13
Shale, as in bed #2	12
Sandstone, as in bed #5	11
Shale, as in bed #2	10
Sandstone, as in bed #5	9
Shale, as in bed #2	8
Sandstone, as in bed #5	7
Shale, as in bed #2	6
Sandstone, dark greenish-gray, very fine-grained, lenticular, sharp bottom contact, grades upward into shale.	5
Shale, same as in bed #2	4.
Sandstone, dark greenish-gray, very fine-grained, slightly calcareous, sharp bottom contact, gradational at top.	3.
Shale, silty, dark-gray, hackly, weathers to chippy fragments, slightly calcareous.	2.
Siltstone, dark-gray, strongly calcareous, bottom surface undulating, grades upward into shale.	1

Fig. 11 Characteristic development of cyclic bedding in Okpikruak formation; detail of small part of Tiglukpuk Creek section

some extent in every exposure that was examined. In the Tiglukpuk Creek section (fig. 12) sandstone and siltstone comprise 10 per cent to 15 per cent of the lower 1,500 feet and about 25 per cent of the upper 350 feet. In the 950-foot section on Aucella Creek (fig. 12) the lower half is 10 per cent to 15 per cent sandstone and siltstone and the upper half 25 per cent to 30 per cent sandstone and siltstone. In contrast to these two sections, however, the type section on the Okpikruak River (fig. 12) is composed of about 60 per cent sandstone and siltstone. Sections measured in the Cobblestone Creek area (not shown in fig. 12) were also found to contain more than 50 per cent sandstone and siltstone.

Several feet of Okpikruak formation from near the middle of the Tiglukpuk Creek section were measured in detail and are shown in figure 11 to illustrate the characteristic development of the cyclic phenomenon. The cycle consists of a thin bed of sandstone or siltstone overlain by a thick bed of shale. The sandstone or siltstone bed usually grades upward into the shale but rests in sharp contact upon the shale bed of the underlying cycle. Flow casts and casts of Aucella are frequently found in the base of the sandstone or siltstone bed.

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 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 1. 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 varying from granule to cobble size, set in a highly argillaceous matrix. The lithic fragments consist of green and gray vitrous 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 Tiglukpuk formation), silty "cannonball" concretions (probably from 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 per cent; angular to subangular grains of feldspar, chiefly plagioclase, 10 per cent; round to subround grains of chert, siltstone, quartzite, shale, and mafic volcanic, 25 per cent. The grains range from silt size up to 2 mm and are set in a matrix of finely divided silt, clay, and chlorite.

<u>Thickness</u>

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 section and the type section on the Okpikruak River are about 1,800 feet thick. On Okonagoon Creek, 1-1/2 miles south of the type section, another section of Okpikruak formation approximately 1,900 feet thick, is partially exposed. However, if this Okonagoon Creek section is correlated with the type section it appears that the basal 400 feet of the Okonagoon Creek section is missing from the type section, presumably by faulting, and an additional 200 feet that is not exposed in the Okonagoon 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 Okpikruak formation elsewhere in the map area, this would appear to 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 cyclic and orderly interbedded relationships 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 nonresistant mineral and lithic fragments in the Okpikruak formation.

The Okpikruak formation is overlain by Fortress Mountain formation but because the principal occurrence 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 Okpikruak formation are shown in figure 12. The most nearly complete section is exposed in a cutbank on the east

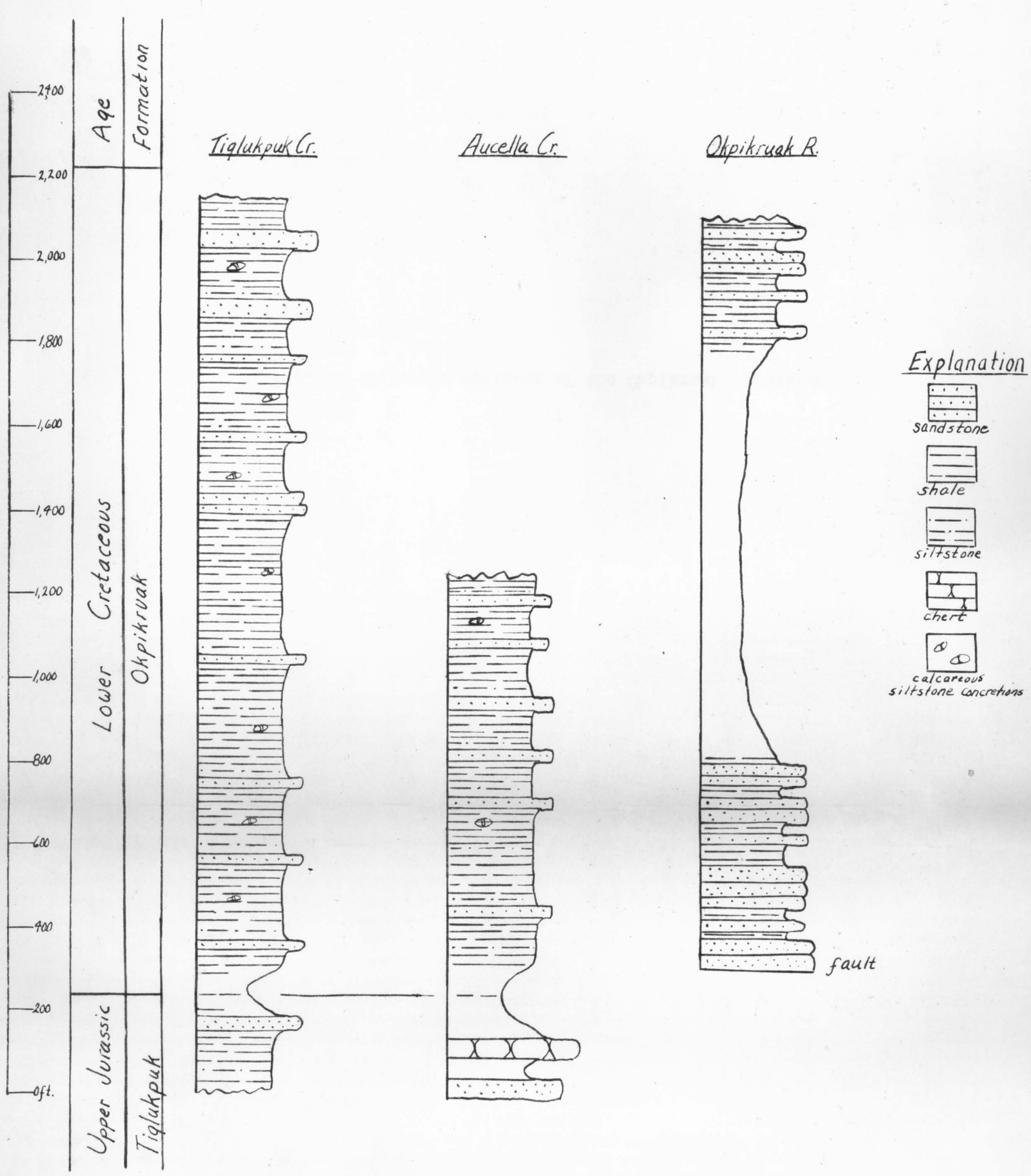


Fig. 12 Columnar sections of the Okpikruak formation

side of Tiglukpuk Creek at latitude 68°19' N. and longitude 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 from concordantly dipping beds apparently belonging to the tuffaceous graywacke unit. The section is a monotonous sequence of cyclically 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 11 is characteristic of the entire section.

The Okpikruk River type section, approximately 1,800 feet thick, is partly exposed in a cutbank on the east side of the river at latitude 68°35' N. and longitude 153°30' W. (fig. 12). The base of the section appears to have been cut off by a fault, and a 1,500-foot-wide covered interval obscures a computed 950 feet of beds in the middle part of the section.

A section of Okpikruak formation, approximately 950 feet thick, is exposed in cutbanks along the northeast side of Aucella Creek a mile upstream from the Kiruktagiak River, latitude 68°27' N. and longitude 152° 44' W. The top and bottom of the section are obscured by tundra cover, but not more than 200 feet from the lowest exposed beds there is rubble of greenish chert and greenish-gray sandstone of the Tiglukpuk formation.

Age and correlations

Three species which are characteristic of earliest Cretaceous (Berriasian and Valanginian) have been found in the Okpikruak formation, *Aucella crassicolis* Keyserling, *Aucella crassa* Pavlow, and *Aucella okensis* Pavlow (Imlay, in press). Specimens of *Aucella crassicolis* Keyserling occur locally in great profusion although as a whole the Okpikruak cannot be considered abundantly fossiliferous. Since the _Aucellae_ were collected from the lowest to the highest beds, the Okpikruak is assigned with confidence to earliest Cretaceous.

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

Rocks lithologically similar to the Okpikruak formation and containing several species of Early Cretaceous (Berriasian and Valanginian) _Aucella_ have been reported in the foothills eastward as far as the Canning River (personal communication, A.S. Keller, 1952) and westward to the head of the Colville River and the Kivalina River (personal communication, I.L. Tailleur, 1953) (Smith, P.S. and Mertie, J.B., 1930). Shale equivalent in age to the Okpikruak formation was penetrated in Oumalik test well 1 at the northern edge of the foothills (Payne, T.G. and others, 1951). South of the Brooks Range rocks of the same age are widespread (Imlay, R.W. and Reeside, J.B., Jr., 1954, p. 236).

Fortress Mountain Formation

Introduction

The Fortress Mountain formation is the name assigned to the thick sequence of conglomerate, graywacke, siltstone and shale that succeeds the Okpikruak formation (Patton, 1956b). It has been mapped over a wide area in the southern half of the Arctic Foothills province from the Sagavanirktok River west beyond the Kukpowruk River, a distance of 350 miles. The Fortress Mountain formation is named from exposures on Fortress Mountain (latitude 68°35' N., longitude 152°58' W.) where it is typically exposed and where it was studied in detail. The type section is a composite of several partial sections exposed along the Kiruktagiak

River and on Castle Mountain.

Distribution and topographic expression

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

Cutbank exposures, particularly of the coarse clastic facies, are found on almost every stream that crosses the Fortress Mountain belt except for the major glaciated rivers. The most extensive exposures occur on the Okpikruak River, Fortress Creek, Kiruktagiak River, Siksikpuk River, and Cobblestone Creek. Excellent exposures also occur on Peregrine Creek and Cobblestone Creek where they cross the small area of Fortress Mountain formation near the mountain front.

In the interstream areas the coarse clastic facies form rubble-covered hogback ridges as much as 1,000 feet high, and several mesa-like synclinal mountains from 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. 5).

In general the best exposures are found along the southern margin of the Fortress Mountain belt because the coarse clastic facies pinches out into shale northward.

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, pp. 160-162). However, later work indicated that in order to describe this part of the stratigraphic column accurately and objectively two formations are 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 sandstones 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 microfaunas are somewhat different. 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 Torok formation is restricted to 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 generally found in the Fortress Mountain formation.

<u>Conglomerate and sandstone</u>.-- Conglomerate and sandstone comprise about 25 per cent of the type section of the Fortress Mountain formation (fig. 17) 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 map area.

The sandstone and conglomerate are typically of the graywacke type. They are poorly sorted, highly argillaceous, commonly calcareous, and have a low porosity. In color they range from predominately dark greenish-gray west of the Nanushuk River to predominately medium-gray east of the Nanushuk River. Individual beds are from less than one inch to more than 50 feet in thickness 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 varies from very fine- to very coarse-grained and from thin to thick bedded. Bedding surfaces of the sandstone are typically rough and uneven owing 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 from clay and silt size up 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 Tiglukpuk and

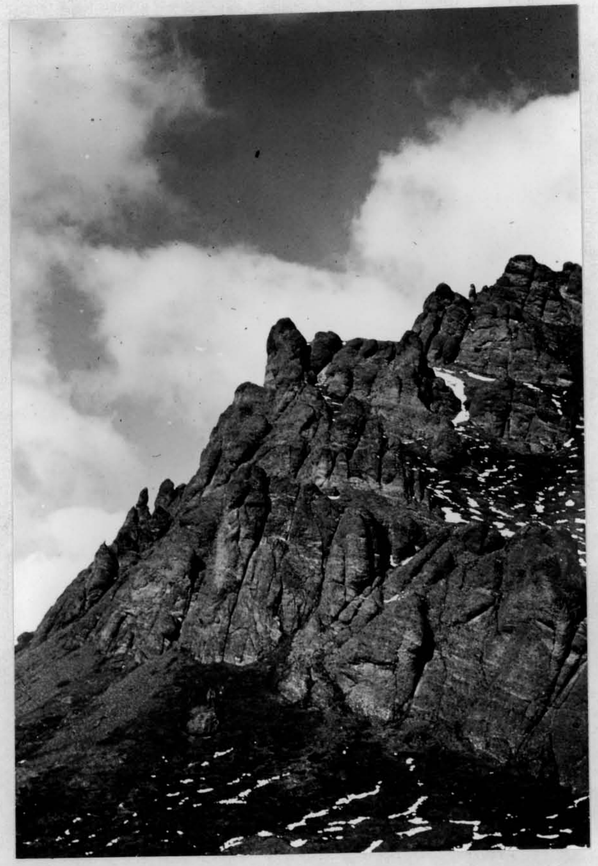


Fig. 13 Massive conglomerate of the Fortress Mountain formation, south flank of Fortress Mountain

Fig. 14 Typical conglomerate of the Fortress Mountain formation

Okpikruak formations), dark siliceous limestone (probably from Shublik 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 in the Canoe Hills, latitude 68°37' N. and longitude 153°03' W., in cutbanks on Pediment Creek at latitude 68°36' N., and on Peregrine Creek at latitude 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 metastable 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 up to 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 were given a cursory examination under the microscope. They have the following approximate composition: 7 per cent to 10 per cent quartz, 5 per cent feldspar, chiefly sodic plagioclase, 25 per cent to 45 per cent chert, 10 per cent to 40 per cent mafic volcanic rock, and variable but subordinate amounts of calcite, pyroxenes, siltstone, shale, schist, limestone, sandstone, and quartzite. The matrix comprises 30 per cent to 50 per cent of the rock and consists of finely divided silt, clays, sericite, 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 were found to 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 comprise the bulk of the Fortress Mountain formation. Beds of dark-gray or dark greenish-gray siltstone, several inches thick, are intercalated with the shale. Locally the siltstone is calcareous and weathers typical light-brown.

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

Thickness

The type section of the Fortress Mountain formation totals approximately 10,000 feet and is the thickest known section of the Fortress Mountain formation. It is doubtful whether thicknesses of Fortress Mountain formation in excess of 5,000 feet are preserved anywhere else in the map

Fig. 15 Exposure of Fortress Mountain formation in Fortress Mountain syncline

area. Approximately 4,000 feet was measured in the syncline that crosses the Siksikpuk River at latitude 68°32' N. and about 2,500 feet was measured in the Fortress Mountain syncline (fig. 15).

Contacts

The Fortress Mountain formation rests unconformably and in some places with apparent angular discordance upon 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 formation and Torok formation are thought to be at least in part equivalent, however the precise stratigraphic relationship is uncertain. Between the Itkillik River and the Kiruktagiak River the two formations are separated by a zone of thrusting that locally has brought slivers of pre-Fortress Mountain formation 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 uncertain.

Features that aid in distinguishing Fortress Mountain formation from Okpikruak formation are: (1) the scarcity of rhythmically alternating sandstone, siltstone and shale sequences and (2) the occurrences of massive conglomerate and coarse sandstone units throughout the formation. Features that help to distinguish Fortress Mountain from 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 of the Tiglukpuk formation coarse clastic rock, 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 16. In the vicinity of Castle Mountain the Fortress Mountain formation is folded into a broad eastward-trending syncline that plunges east between the Ayiyak River and Castle Mountain (pl. 1). Locally small faults and folds complicate the broad synclinal structure. Between the lower contact of the Fortress Mountain formation on the Kiruktagiak River (fig. 16, point A) and the center of the syncline at Castle Mountain, discontinuous exposures indicate a regional southeastward dip. A thickness of approximately 9,000 feet was computed between the lower contact at point A (fig. 16) and the base of Castle Mountain at point J. The beds cropping out at point J were traced around 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 Castle Mountain was measured to demonstrate the northward facies changes that occur between it and section K-L (fig. 17). Sections K-L and M-N can be correlated by direct tracing of beds along the east side of the mountain.

Owing to the wide spacing of the dip and elevation control points, and the possibility of small faults and folds in the covered intervals, the thickness computations are only approximations.

Two sections of Fortress Mountain formation in addition to the type were measured in the map area and are shown in figure 18 along with

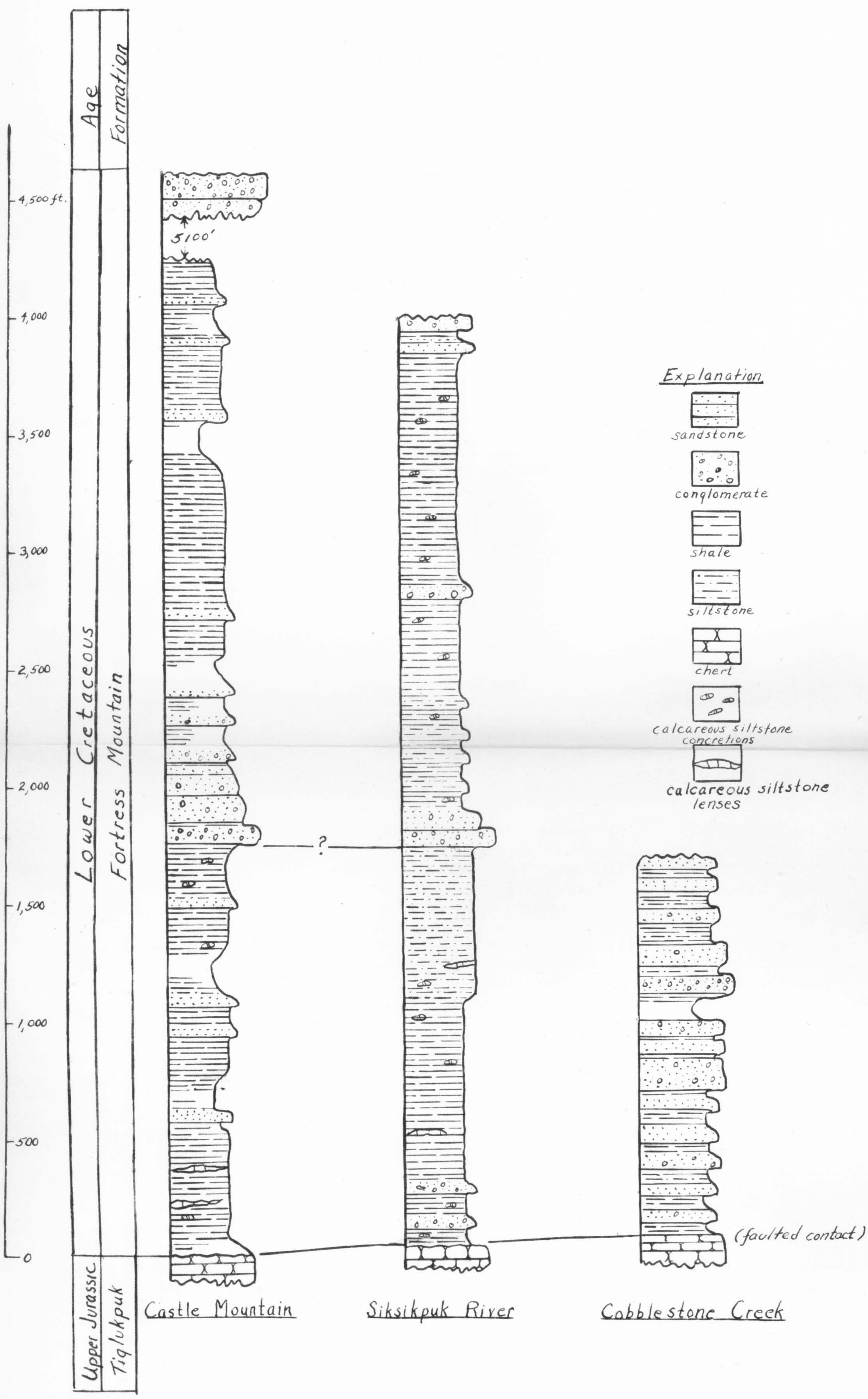


Fig. 18 Columnar sections of the Fortress Mountain formation

the lower part of the type section. One of the sections, approximately 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 a half 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 2-1/2 miles above the mouth of Tiglukpuk Creek.

A possible correlation is suggested in figure 18 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.

The other section shown in figure 18 was measured in the cutbanks exposed along Cobblestone Creek between latitude 68°25' N. and latitude 68°27-1/2' 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 times. Both the top and the bottom of the section are cut off by faults but correlation with nearby exposures indicates that not over 200 feet are missing from the base of the formation.

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 trace northward into sandstone, siltstone, and shale. Figure 17 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, on the south side of the mountain traces into sandstone on the north side of the mountain.

Few stratigraphic correlations in the Fortress Mountain formation can be made across the map area 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 due to intraformational unconformities. Unconformities, some with slight angular discordance, were noted 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 exposures. 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 occurred contemporaneously with deposition.

Age

Fossils are not abundant in the Fortress Mountain formation and the majority of those collected proved to be long ranging forms of little significance in determining the age of the enclosing rocks. However, according to R.W Imlay (in press) the lower part of the Fortress Mountain formation can probably be dated as early Albian based upon two collections, one from the Kiruktagiak River containing Aucellina dowlingi McLearn and the other from the Okpikruak River containing Colvillia crassicostata Imlay and Colvillia kenti Imlay.

Vertebrate remains were collected from the Fortress Mountain formation on Torok Creek east of Castle Mountain and were given to David H. Dunkle for examination (memorandum, October 28, 1949). Dunkle 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.

Out of 377 samples of Fortress Mountain formation shale that were collected and washed for microfossils only 161 proved to be fossiliferous. Although the microfossils are not significant in determining the age of the Fortress Mountain formation, 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 Nanushuk group.

In this regard Bergquist states (memorandum, February 7, 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 almost 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 age of the upper part of Fortress Mountain formation cannot be established directly owing to the lack of diagnostic fossils. Furthermore, the stratigraphic relationship of the Fortress Mountain formation to the Torok formation and Nanushuk group is uncertain. It seems probable that the Fortress Mountain predates the Nanushuk group, inasmuch as the Fortress Mountain marine graywacke sequence and the Nanushuk group paralic coal-bearing sequence could hardly have been deposited in the geosyncline at the same time. Since the Tuktu formation, the basal unit of the Nanushuk group, is dated as middle Albian, the upper part of the Fortress Mountain formation must be no younger than middle Albian.

Torok Formation

Introduction

The Torok formation, as presently defined (Patton, 1956, pp. 222-223), comprises 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 Okpikruak formation and perhaps by a part of the Fortress Mountain formation. The Torok formation does not include, as originally defined (Gryc, Patton, and Payne, 1951, pp. 160-162), the sandstone, conglomerate, and intercalated shale sequence that overlies the Okpikruak formation and crops out along an eastward-trending belt near the southern margin of the Foothills province. This sequence is now called 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 occurs in cutbanks along the Chandler River and Torok Creek between latitude 68°40' N. and latitude 68?44' N. (fig. 27).

Distribution and topographic expression

The Torok formation occurs in the northern part of the map 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 varies from 5 to 9 miles in width, 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 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 comprises the bulk of the Torok formation. Scattered low tundra-covered ridges mark the occurrence of lenticular sandstone bodies within the shale. Exposures in the Torok belt are confined to small disconnected cutbanks along several of the streams, namely, the Ayiyak River, Kiruktagiak River, Torok Creek, Chandler River and Autumn Creek. No outcrops are found in the interstream areas.

<u>Previous work</u>

The Torok formation was not identified as a separate stratigraphic unit prior to the present investigations of the Arctic Foothills province. Probably Schrader (1904) included the Torok strata in his Anaktuvuk "series" and Smith and Mertie (1930) placed it in their "Upper Cretaceous series".

In 1948 R.L. Detterman (personal 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 approximately 4,700 feet thick. In 1949 this sequence was re-examined by the author. More fossils were collected on the Chandler River and Torok Creek, and an additional section, estimated to be about 1,400 feet thick was found underlying Detterman's 4,700-foot sequence. The complete sequence, approximately 6,100 feet thick, was included in the original description of the Torok formation given by Gryc, Patton and Payne in 1951 (pp. 160-162). However, as then defined, the Torok also included the coarse clastic rocks now called the Fortress Mountain formation. The Torok was redefined in 1956 (Patton, pp. 222-223) and this 6,100-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, fissile 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 weather 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- 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 per cent quartz and quartzite, 10 per cent feldspar, chiefly plagioclase, 40 per cent chert and cherty siltstone, 3 per cent mafic igneous rock, 20 per cent calcite, and 15 to 20 per cent finely divided silt, chlorite and clays. The chlorite, clays, and calcite comprise the matrix or bonding material and the rest of the mineral and lithic fragments occur as detrital grains up to 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, approximately 6,000 feet thick, is believed to be about the maximum thickness of the Torok formation exposed in the map area.

Contacts

The Torok formation is overlain conformably by the Tuktu formation of the Nanushuk group. The contact is marked by sandstone on shale and where gradational the contact is arbitrarily placed at the base of the lowest sandstone bed.

Stratigraphic section

The type section of the Torok formation (fig. 19) crops out sporadically along the Chandler River and Torok Creek between the base of the Tuktu formation on the Tuktu Escarpment and the crest of a broad eastward-trending anticline at latitude 68°40' N. On the Chandler, thicknesses of strata were computed using the average dip of the strata and horizontal distances measured from vertical aerial photographs. Because

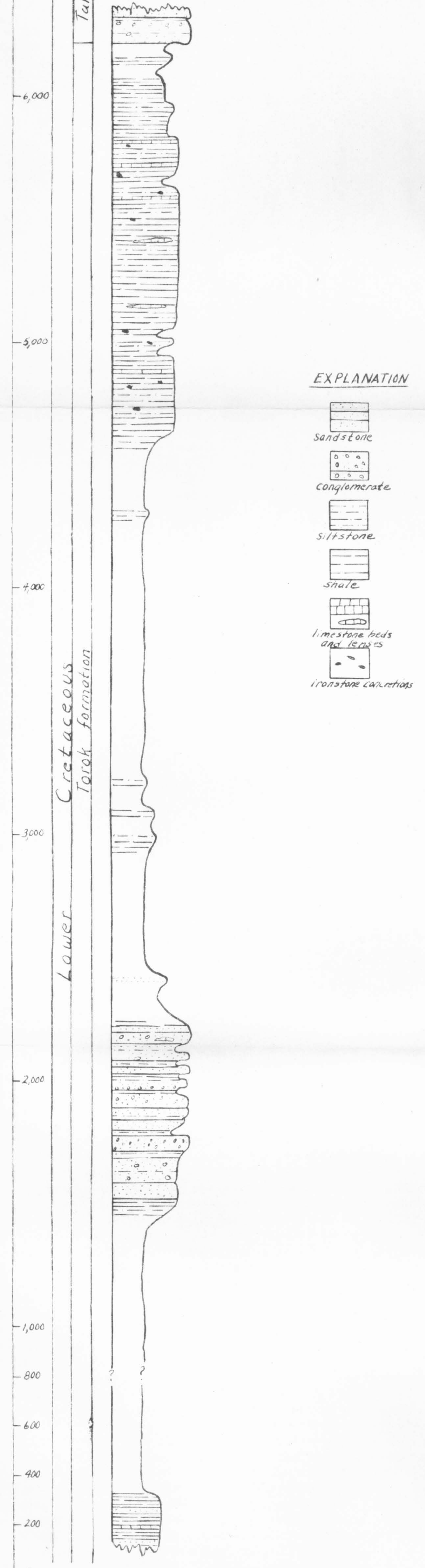


Fig. 19 Type section of the Torok formation

of the structural complexities and extensive covered intervals, the thicknesses should be considered only approximations.

In addition to the inaccuracies of measurements which may be intoduced into the type section because of small faults and drag folds, there is also the possibility of a major fault and an angular unconformity. The fault and unconformity have been postulated by E.J. Munns, seismologist, United Geophysical Company, on the basis of a reflection seismograph profile across the best of Torok formation (see pp. 107-111 and figs. 28, 29 and 30). The fault, according to Munns, surfaces between shot points 12 and 13 (fig. 29) and is steeply northward-dipping with reverse movement. If the strike of the fault parallels the regional strike of the strata, the fault would cross Torok Creek and the Chandler River about latitude 68°41' N. and intersect the type section in the covered interval 4,800 to 5,900 feet stratigraphically below the Tuktu contact (fig. 19). 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 surfaces between shot points 4 and 5 (fig. 29), if projected to the type section would occur in the covered interval 1,600 to 4,000 feet stratigraphically below the Tuktu contact (fig. 19). No field evidence to support this postulated angular unconformity was found along the Torok belt but the possibility cannot be ruled out in view of the scarcity of Torok exposures.

Microfossil evidence also suggests indirectly that an unconformity may occur within the Torok. Bergquist (1956, p. 1670) finds 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 coincides with the postulated unconformity. In some well logs from the subsurface of the northern Foothills and 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, Rucker, and Bergquist, 1956, p. 226).

Age and correlations

Megafossils were found at only four localities in the Torok formation. The collections, which were examined and identified by Ralph W. Imlay (in press), include the following: Inoceramus sp. juv. cf. I. anglicus Woods, Beudanticeras (Grantziceras) affine (Whiteaves), Colvillia crassicostata Imlay, Subarcthoplites cf. S. colvillensis Imlay and Gastroplites cf. G. kingi McLearn.

Imlay 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 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 map area by a collection which was found 4,000 to 4,800 feet below the Tuktu contact in the type section. According to Imlay this collection is probably correlative with the only collection of ammonites found in the Fortress Mountain formation (p. 65). Concerning the age of the lower zone Imlay states (personal communication, 1957):

> 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 Gastroplites 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 species of Aucellina is the same in North America as Eurasia. 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 map area by a collection from an isolated cutbank exposure on Pediment Creek. The stratigraphic position within the Torok of this collection is unknown.

The Gastroplites kingi zone is assigned a middle Albian age principally because of the presence of Cleoniceras below and within this zone. In the map area Gastroplites kingi was found in a single collection from the Kanayut Creek basin, but there 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 formation that were collected and washed for microfossils, 50 proved to be barren. Collections from the rest were examined by Harlan R. Bergquist. Bergquist's comments concerning the microfauna from the lower part of the Torok are given on page 66. In regard to the microfauna from the upper part of the Torok he states (memorandum, February 7, 1957):

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 V. borealis faunal zone is characterized by such species as Haplophragmoides topagorukensis Tappan, species of Psamminopelta, species of Milliammina, species of Ammobaculities, 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 (in press) 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 non-marine and marine strata; the non-marine strata which predominate in the southern part of the belt

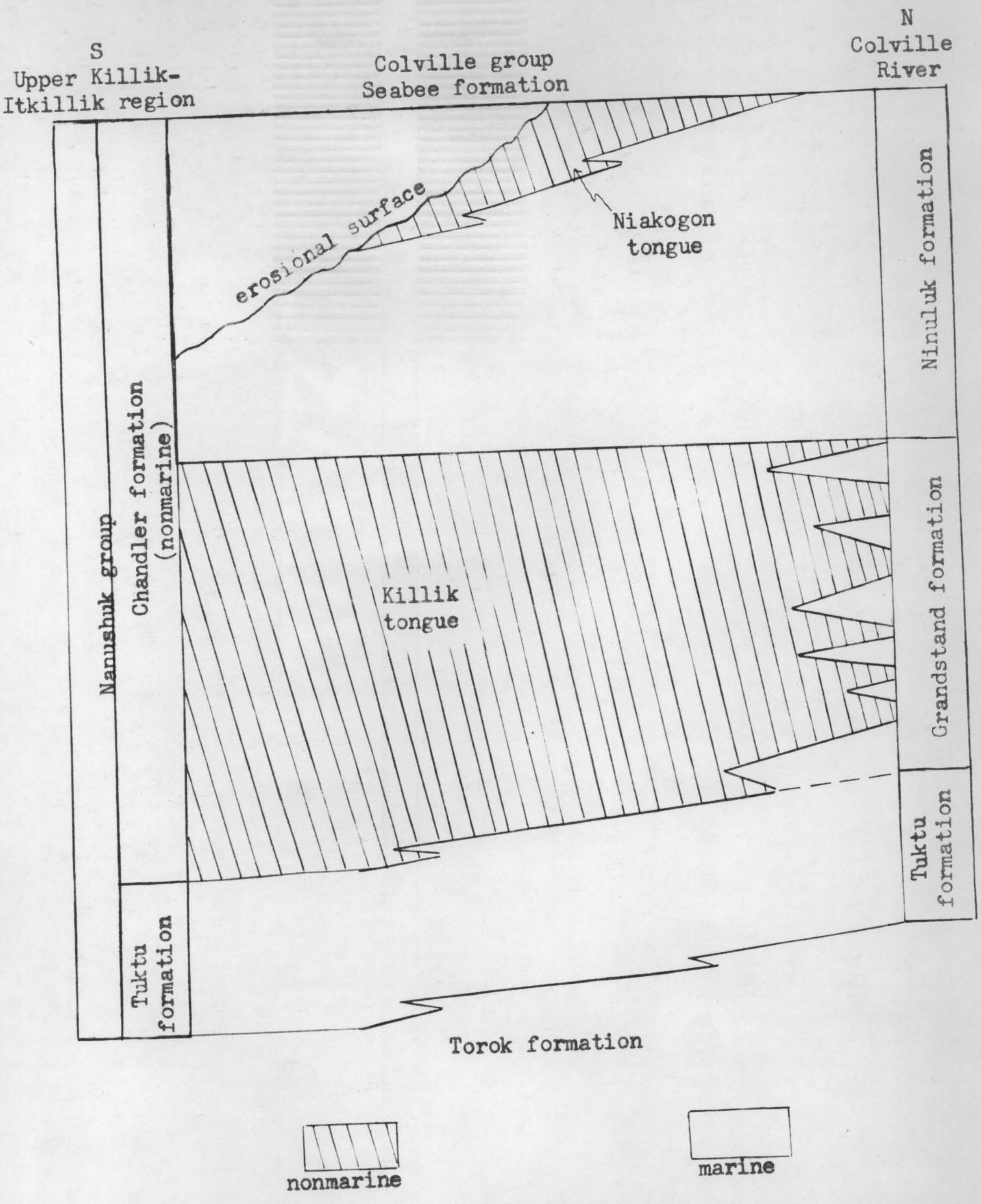


Fig. 20 Schematic diagram of Nanushuk group in northern foothills

interfinger with the marine strata which predominate in the northern part of the belt. The Nanushuk group has been subdivided into several formations and tongues based chiefly upon the marine and non-marine lithologic characteristics (fig. 20).

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 now defined (Gryc, Patton and Payne, 1951, pp. 162-164) is stratigraphically somewhat lower and apparently includes the upper part of Schrader's Lower Cretaceous Anaktuvuk "series" and the lower part of his Upper Cretaceous Nanushuk "series". The stratigraphic nomenclature of the Nanushuk group as originally established by Gryc, Patton and Payne recently has been revised by Detterman (1956, pp. 233-244).

The subdivisions of the Nanushuk group that crop out in the upper Killik-Itkillik region are, in ascending order: the Tuktu formation, the Killik tongue of the Chandler formation, and the Ninuluk formation (fig. 20).

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 formation. 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. Tuktu formation also occurs on the flanks of the Arc Mountain anticline betwen the Kanayut River and the Itkillik River.

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

Lithology

The Tuktu formation is composed chiefly of off-shore 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 Fortress Mountain and Okpikruak formations, but 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 selected from a typical exposure of Tuktu sandstone on the Nanushuk River revealed the following composition: angular to subround grains of quartz, 30 per cent to 40 per cent; chert, 5 per cent; and feldspar, chiefly plagioclase, 2 per cent; and a matrix of sericite, fine silt, clay and chlorite, 50 per cent to 60 per cent.

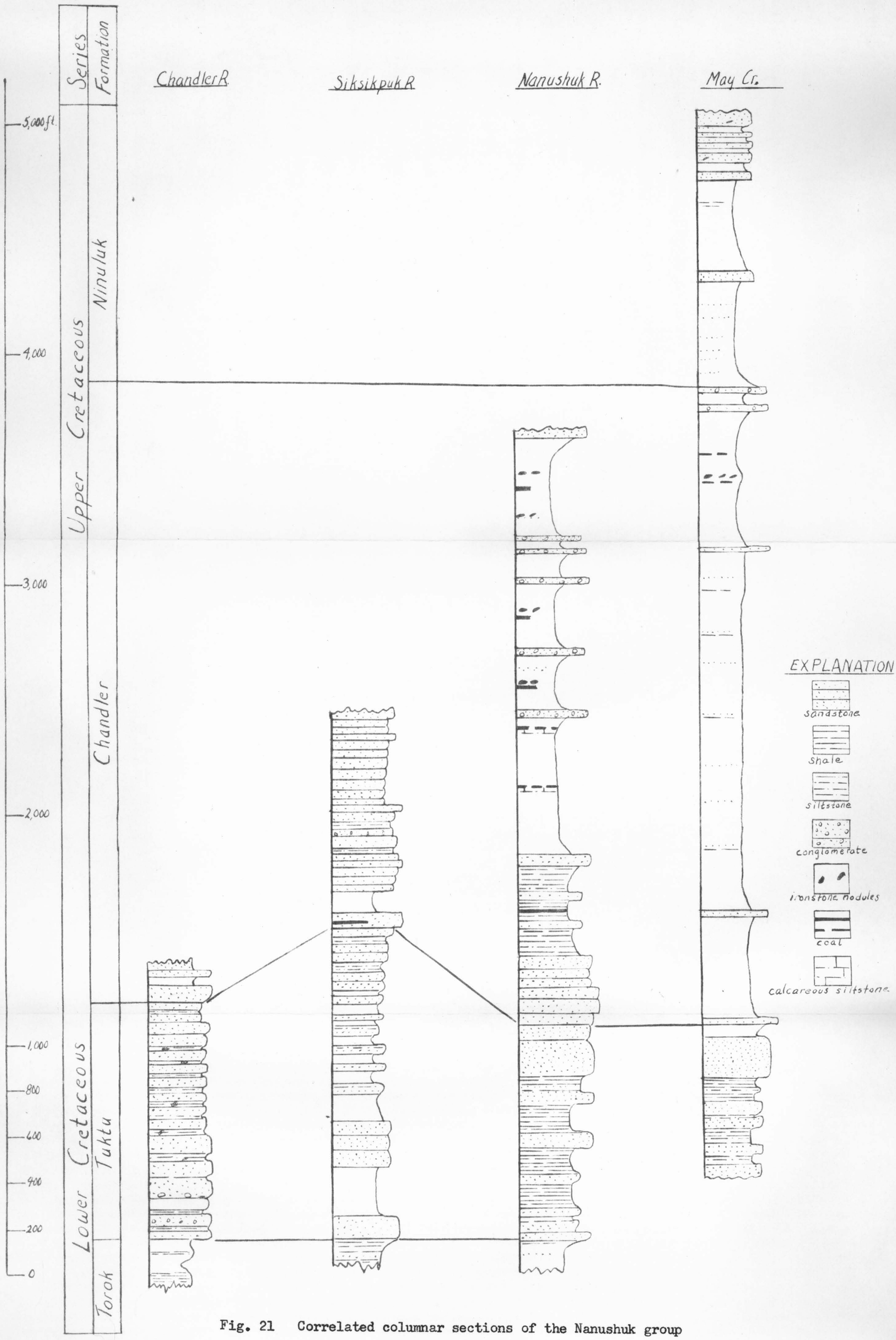


Fig. 21 Correlated columnar sections of the Nanushuk group

Thickness

The full section of Tuktu formation is 1,000 feet thick at the type locality at Tuktu Bluffs, 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 lower 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 predominately non-marine strata. East of the Anaktuvuk River the upper contact is well defined and non-gradational; 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 in figure 21. The first of these is the type section, which crops out at Tuktu Bluffs on the Chandler River a short distance above the mouth of the Kiruktagiak River (fig. 22). The second is a partly exposed sequence which occurs on the south side of Gunsight Mountain, 13 miles east of the type locality. The third is completely exposed and was measured in a cutbank on the east side of the Nanushuk River on the south limb of the Arc Mountain syncline. The fourth is the upper 660 feet of the formation and was logged on the north limb of the Arc Mountain anticline on May Creek.

Fig. 22 Tuktu Bluff, type locality of Tuktu formation

Comparison of the four measured sections shown in figure 21 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 comprises about one-third of the formation and coarse-grained beds are absent.

Age

The Tuktu formation is abundantly fossiliferous, and a number of mollusk collections have been submitted to R.W. Imlay for study. According to Imlay (in press) the Tuktu can be dated as middle Albian on the basis of the ammonite Gastroplites kingi McLearn, which 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:

> 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.

Microfossils collected from the Tuktu belong to the Verneuilinoides *borealis* faunal zone according to H.R. Bergquist (memorandum, February 17, 1957). A discussion of this zone has been given on page 74.

Chandler Formation, Killik Tongue

Distribution and topographic expression

The predominantly non-marine 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. 20). The Chandler formation consists of two northward projecting tongues, the Killik and the Niakogon, which are separated by a southward projecting tongue of Ninuluk formation. Exposures of Chandler formation are confined to the lower of the two tongues, the Killik tongue.

The Killik tongue crops out along the northern border of the map 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 Tuktu formation; to the north it extends beyond the area of mapping. It also crops out in a 2- to 5-mile wide bed along the Arc Mountain syncline between Kanayut Creek and the Itkillik River valley.

Massive, resistant sandstone in the basal part of the Killik tongue caps the Tuktu Escarpment and the hogback that surrounds the core of the Arc Mountain anticline. In the area north of the Tuktu Escarpment and in the Arc Mountain syncline, gently dipping beds of resistant conglomerate and sandstone in the middle and upper parts of the tongue form a series of parallel eastward-trending hogbacks.

Lithology

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

The lower half of the tongue consists chiefly of inshore marine and non-marine 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 non-marine 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 that are composed of up to 70 per cent dark-gray and green chert and up to 40 per cent white quartz. Float of coal and ironstone are found throughout the Killik tongue but is most common in the upper half. The only exposure of coal is a 1-foot seam in the stratigraphic section on the Nanushuk River (fig. 21).

Three specimens of typical sandstone from the Killik tongue were examined in thin section. From 30 per cent to 50 per cent of the sandstone is angular and subangular quartz grains, 15 per cent to 40 per cent is angular and subangular chert grains, and the remainder is chiefly a clay, sericite and fine silt 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 per cent, permeability is generally low.

Thickness

The full thickness of the Killik tongue is preserved in the Arc

Mountain syncline east of May Creek. There it measures approximately 2,800 feet.

Contacts

The lower contact separates marine strata of the Tuktu formation from predominantly non-marine 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 non-marine coal-bearing beds and in the map 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 in figure 21. None of the three sections is completely exposed. Thicknesses of covered intervals were computed using the dip of exposed strata and horizontal distances measured on vertical aerial photographs or by plane table.

The first section, 2,800 feet thick, is the only one in which the upper contact is preserved. It was measured on the gently dipping north flank of the Arc Mountain syncline east of May Creek. The second section, which is 2,600 feet thick and represents nearly the full thickness of the formation, is partially exposed east of the Nanushuk River on the north flank of the Arc Mountain syncline. All of the basal 750 feet of this section crops out in a cutbank on the river. The third section totals 925 feet thick and was measured on Gunsight Mountain on the east side of the Siksikpuk River.

Age

Fossils are rare in the Killik tongue. Only two collections consisting of poorly preserved and non-diagnostic pelecypods were found. The Killik tongue cannot be dated from fossil evidence. However, its stratigraphic position between the Tuktu and 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 map area is a poorly exposed sequence of Ninuluk formation which occurs along the axis of the Arc Mountain syncline west of May Creek. This Ninuluk sequence apparently belongs to a southward-projecting transgressive marine tongue which separates the Killik tongue of Chandler formation from the Niakogon tongue of the Chandler formation (fig. 20).

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

Lithology

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

Thickness

The maximum thickness of the Ninuluk formation that is preserved in the Arc Mountain syncline is approximately 1,200 feet.

Contacts

The lower contact of the Ninuluk formation marks the top of the non-marine coal-bearing beds of the Killik tongue and has been placed at the top of the highest ledge of sandstone and quartz-pebble conglomerate. The nature of the lower contact is not known owing to poor exposures, but the coarsening of the Ninuluk sandstone downward suggests that the contact is gradational.

Stratigraphic sections

The 1,200-foot section of Ninuluk formation, shown in figure 21, was measured on the gently dipping north flank of the Arc Mountain syncline in the May Creek basin.

Age

Five fossil collections of pelecypods from the Ninuluk formation were examined and identified by R.W. Imlay (memorandum, April 29, 1953). Dr. 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. In reference to the age of the Ninuluk formation, Imlay and Reeside (1954, p. 243) say:

"The common species include *I. athabaskensis* McLearn and *I. dunveganensis* McLearn. These have been identified elsewhere in Alaska in the lower part of the Upper Cretaceous sequence in the Kuskokwim region. In northwestern Alberta and northeastern British Columbia they are associated with the ammonite Dunveganoceras in the Dunvegan formation. I. athabaskensis likewise occurs at the base of the La Biche shale on the Athabaska River. All the occurrences in Canada are in beds that underlie the lowest ammonite zone of the Turonian, which zone has been identified in northern Alaska at the base of the Schrader Bluff formation immediately above the Nanushuk group. The stratigraphic position of Dunveganoceras in Montana, Canada, and England is upper Cenomanian, according to present information."

The Ninuluk formation could not be sampled for microfossils inasmuch as rocks suitable for this purpose do not crop out.

Quaternary Unconsolidated Deposits

Upland Gravels

Large areas of bedrock near the mountain front between the Okokmilaga and Siksikpuk Rivers are obscured by gravel deposits which are designated here as upland gravels (plate 1). These gravels occur on the interstream divides where they mantle remnants of an erosional surface of probable pre-glacial 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 partially dissected and long finger-like 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 Chandler-Kiruktagiak divide and the Chandler-Siksikpuk divide.

Elsewhere in the map 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 believed to be remnants of a broad piedmont slope that bordered the north front of the Brooks Range in pre-glacial 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 up to 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 writer to speculate with any degree of certainty 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 pre-glacial pediment gravels. If they are glacial deposits they must be related to an early ice advance, since they obviously pre-date 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 pre-glacial 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 was spilled across the low interstream divides into nonglaciated tributaries like the Kiruktagiak and Siksikpuk Rivers. Then 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 per cent of the map area. During the course of 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, inasmuch as 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 beyond the northern edge of the map 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 from 800 to 1,200 feet above the present river levels. In places a coalescence of tributary glaciers with the main glacier to form a piedmont lobe has left broad bands of drift along the mountain front.

The glacial deposits are comprised 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 course fraction is chiefly quartzite derived principally from the pre-Lisburne group strata in the Brooks Range. However, Lisburne group limestone and Mesozoic sandstone occur in subordinate amounts. The drift deposits do not appear to be over 50 feet thick except locally along morainal ridges where they may be as much as several hundred feet thick.

Floodplain Deposits

Alluvial deposits of gravel, sand, and silt occur on the floodplains of the modern streams and have been mapped on plate 1. Locally these deposits cover sizeable areas, as for example along the lower Okpikruak and Okokmilaga Rivers where the floodplain is more than 3 miles wide, and long parts of the Siksikpuk River, Kanayut Creek, Nanushuk River, and May Creek where the stream bed gravels spread laterally across the stream valleys to widths of over a half mile.

The average grain size and composition of the floodplain 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 diminution 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 map area.

Fine-grained brown silt deposits, probably of lacustrine origin, are also included in the floodplain deposits. They occur in a belt three-fourths of a mile wide along the Okokmilaga River from beyond the southern edge of the map to latitude 68°27' N., where they appear to terminate against a recessional moraine. The river is incised approximately 25 feet and the silt is exposed in cutbanks. Areas along the Okokmilaga floodplain which are underlain by the silt deposits have a thermokarst topography that is 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 latitude 68°33' N., where they appear to terminate against a recessional moraine.

The entire map area is underlain by permanently frozen ground (permafrost) to an unknown depth. Blocks and wedges of ice are found in a number of localities where cutbank exposures of unconsolidated deposits are being actively eroded by the streams. Several well-preserved mastodon tusks were recovered from frozen silt banks along the Ayiyak River and on Ivory Creek, a small western tributary to the lower Kiruktagiak.

Igneous Rocks

Distribution and topographic expression

Nearly 100 small sills and sill-like bodies of diabase and basalt have been mapped in the area west of the Anaktuvuk River (plate 1). They are confined to the Fortress Mountain belt and occur chiefly in the Tiglukpuk formation and the tuffaceous graywacke unit, although a few are known to intrude the Lisburne group (figure 23). Individual sills have been traced along the strike for up to a mile and a half in length, but rarely do they exceed a few hundred feet in width. Since the igneous rock is generally more resistant than the enclosing sedimentary rock, the sills crop out as isolated ridges or as small aligned pinnacles.

In addition to the sills there are three large irregular masses of

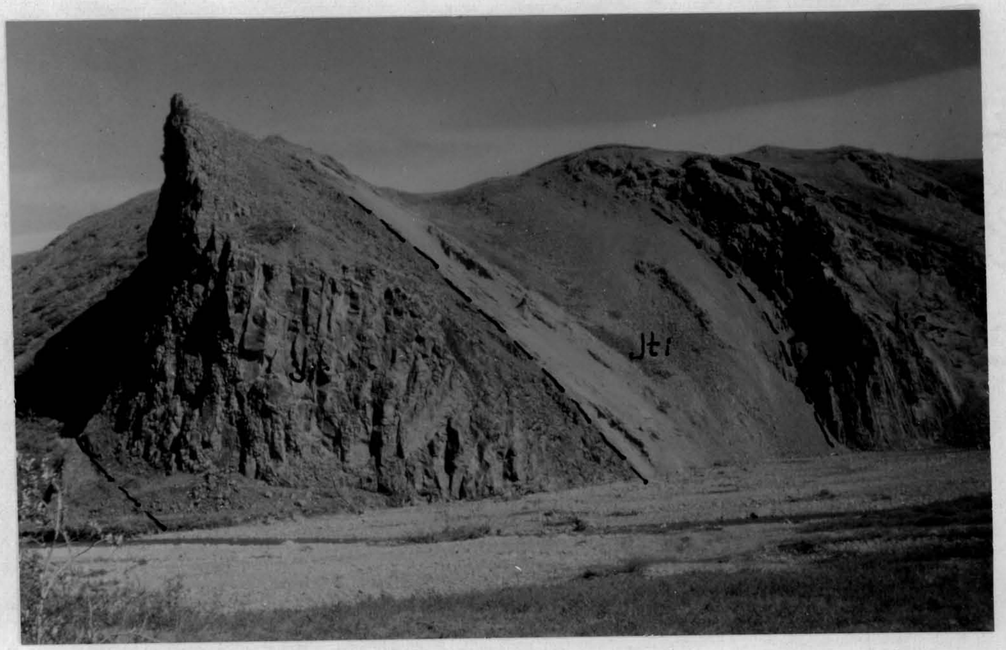


Fig. 23 Sills of mafic igneous rock (Jir) intruding Tiglukpuk formation (Jti) on Tiglukpuk Creek

diabase and basalt. One of these masses forms Horseshoe Mountain, a prominent landmark between the Ayiyak River and the Kiruktagiak River at latitude 68°36' N. Another makes a low rounded hill on the west side of the Kiruktagiak River at latitude 68°30' N. and another forms a small cluster of hills between Autumn Creek and the Siksikpuk River at latitude 68°29' N.

Detailed mapping in the complex belt and Fortress Mountain belt would unquestionably reveal additional sills to those shown on plate 1. Moreoever, there are probably many sills buried beneath the cover of tundra.

Form and relationship to the 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 at a number of well-exposed localities and in several places large altered inclusions of the host rock were found within the sills. In a few places the very fine-grained vesicular texture of the igneous rock is suggestive of an extrusive. However, the exposures at these localities are poor and the field evidence for extrusives in inconclusive.

The three large irregular masses of igneous rock described above are believed to be partly extrusive and partly intrusive. Definitely intrusive relationships were noted at the margin of the large mass at latitude 68°30' N. on the Kiruktagiak River. Horseshoe Mountain, on the other hand, appears to be composed predominately of the interlayered tuffaceous sandstones, breccias, tuffs, and flows.

Lithology

The igneous rock is classed as diabase and basalt and owing to the abundance of albite might be termed spilitic. Practically all of the rock shows alteration to some extent. The rock is characteristically dark greenish-gray on the fresh surface and dark reddish-brown on the weathered surface. It is predominately fine-grained and equigranular but locally is aphanitic, porphoritic or coarse-grained. Vesicles and amygdules were noted in several places.

A few thin sections of the igneous rock were given a cursory examination. They showed the rock to be composed of about 50 per cent plagioclase and about 30 per cent augite; the rest consists of accessory and secondary minerals. Ophitic and subophitic textures were noted in some sections. The plagioclase is chiefly albite, which may be the alteration product of a more calcic plagioclase. In some specimens the albite itself is partially altered to chlorite, clay, and carbonate minerals and the augite commonly has been partially replaced by chlorite. Other identifiable minerals include magnetite, apatite, quartz, sphene, pyrite and hornblende.

Age

The mafic igneous rocks are probably of latest Jurassic (Portlandian?) age. The youngest rocks that they intrude belong to the Tiglukpuk formation (Oxfordian to Portlandian). Coarse detritus of mafic igneous rock, identical in character to the intrusives, occurs in abundance in the Okpikruak formation (earliest Cretaceous). Sedimentary rocks intercalated with mafic volcanics at Horseshoe Mountain are correlated with the tuffaceous graywacke unit which is believed to be latest Jurassic (Portlandian?) in age.

STRUCTURAL GEOLOGY

Geologic Map and Cross Sections

The structural features which are shown on the geologic map (pl. 1) and on the 8 generalized north-south cross sections (pl. 2) are necessarily highly interpretive owing to the general scarcity of exposures in the map area, the lack of stratigraphic control 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, so many of the structural interpretations are based upon aerial photo observations. In a number of 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 and lithologic features throughout the best exposed parts of the map 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.

The faults shown on the map and sections are rarely exposed in the field and are based largely upon inference. Most of the faults north of the mountains are interpreted as high angle, which is the nature of the few faults that are exposed. A high angle would be consistent with the relatively straight trend of the fault traces even in areas of considerable relief. However, as will be discussed later, there is reason to believe that some of these faults may flatten at depth and merge into a few large flat sole thrust faults.

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

Regional Setting

The upper Killik-Itkillik region falls within two of the major tectonic elements of Alaska, the Brooks Range geanticline, an east-trending linear positive element composed of highly folded and faulted pre-Mesozoic strata, and the Colville geosyncline, an east-trending negative linear element in which a great thickness of Mesozoic sedimentary rocks are preserved (Payne, T. G., 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 map area 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 Mesozoic and late Paleozoic rocks adjacent to the mountain front.

Structural zone III: A belt of folded and faulted 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 a more or less discrete structural unit.

Structural Zone I

General Features

Along the mountain front the Lisburne group, which occurs in a belt up to 10 miles wide, generally dips south from 20° to 40° (fig. 3). To the casual observer the regularly south-dipping succession of strata might suggest a thickness on the order of tens of thousands of feet. 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 is repeated many times by south-dipping imbricate thrust faults (Brosge, W. P. and Reiser, H. N., personal communication, 1951). Many of these imbricate thrust faults are parallel or nearly parallel to 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 the Lisburne belt.

Local Details

Okpikruak River to Chandler River

The belt 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 pl. 1 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 Siksikpuk and younger formations. The upper plate, 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 also evidence that rocks of the Lisburne group have over-ridden (relatively speaking) the foothills belt strata (pl. 2, section

B-B'). Two miles south of Monotis Creek this sheet of Lisburne group has been eroded away, exposing beneath it a small area of complexly folded rocks of the Tiglukpuk, Shublik and Siksikpuk formations and Lisburne group. The trace of the fault plane is shown in figure 24. 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 upper plate is not known because the fault plane, if it reappears at all, cannot be specifically identified among the many faults that have been mapped in the foothills belt.

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

The belt of Lisburne strata at the mountain front between the Chandler River and Tiglukpuk Creek was not visited in the field, but has been mapped from aerial photographs. Some strikes and dips and fold axes that were observed on the photos 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, the north limb of which is nearly vertical and locally overturned. The axial trace of the anticline lies about a mile south of the mountain front and can be followed east-west for a distance of 9 miles. West of Tiglukpuk Creek the anticline terminates by plunging westward beneath younger rock of the foothills. East of Tiglukpuk Creek the anticline appears to be overturned and two small west-plunging

Fig. 24 Approximate trace of folded thrust fault near head of Kiruktagiak River at north front of Brooks Range. The thrust sheet is composed of rocks of the Lisburne group and overlies a structural complex of late Paleozoic and Mesozoic strata.

subsidiary anticlines occur on the north flank.

At the mountain front south of Natvakruak Lake, Lisburne strata have been thrust faulted upon younger rocks. The fault plane is exposed in several places and has an average south dip of 16° (fig. 25). A short distance north of the mountain front, three small klippen of Lisburne rocks lie on Siksikpuk and Shublik strata. Another much larger outlier of Lisburne rocks which occurs 2 or 3 miles southeast of Natvakruak Lake may also be a klippe, but since it is entirely surrounded by glacial drift, the structural relationships to the underlying strata are unknown.

Anaktuvuk River to Itkillik River

Glacial drift covers the foothills strata along the mountain front from the Anaktuvuk River eastward nearly to Erratic Creek. At Erratic Creek the strata of the Lisburne group are exposed in fault contact with the Shublik formation (pl. 2, E-E'). Between Erratic Creek and Welcome Creek, 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 there is a wishbone-shaped outlier of Lisburne group that appears to be the west-plunging nose of an anticline. The Lisburne outlier is flanked by the Shublik formation, and the Shublik formation also occurs along the axial region of the anticline. Between the Nanushuk River and the Kuhsunan Creek the Tiglukpuk formation is also exposed along the axial zone. The outlier is interpreted (section F-F', pl. 2) as a thrust plate of the Lisburne group, which rests upon

Fig. 25 Thrust fault at mountain front south of Natvakruak Lake. Overturned fold (in rocks of Lisburne group) thrust upon Siksikpuk formation

a thrust plate of the Shublik formation, which in turn rests upon the Tiglukpuk formation. Both the Lisburne thrust plate and the Shublik thrust plate 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 Lisburne and Shublik rock units which are offset by several north and northwest-trending cross faults. At Cobblestone Creek the Lisburne strata dip normally beneath the Shublik formation but from the westernmost fork of May Creek to the valley of the Itkillik River, the Lisburne group appears to be thrust northward (relatively speaking) onto the Okpikruak formation.

Structural Zone II

General Features

Structural zone II, an east-trending belt of complexly folded and faulted Mesozoic and late Paleozoic strata, is adjoined by the mountain front Lisburne belt on the south and by a belt of Fortress Mountain strata on the north (plate 1). West of the Siksikpuk River it is 12 to 14 miles wide, but it narrows to a width of five to six miles east of the Nanushuk River. It is comprised predominately of interfolded and interfaulted Okpikruak and Tiglukpuk formations, but also includes Shublik and Siksikpuk formations, the Lisburne group, and mafic volcanic rock. In addition, there are two large infolded masses of 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 map area from lat. 68°24' N. to lat. 68°29' N.

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

The small folds and faults occur in nearly every outcrop but are far too numerous to be plotted on plate 1. Only a few of the more significant faults and fold axes are shown on plate 1.

The large faults shown on plate 1 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 a number of small up-faulted slivers of 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 Okpikruak formation, Fortress Mountain formation, and undifferentiated Okpikruak and Tiglukpuk formations; the structural highs are indicated by bands of 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

Fig. 26 Fault sliver of limestone of the Lisburne group at the Kiruktagiak Notch

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 pre-Tiglukpuk formation are exposed. South of the high there is another structural low which is marked by an east-plunging syncline of 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 about lat. 68°30' N. The apparent wrap-around of Okpikruak formation between Speedway Creek and Castle Creek indicates that this high probably plunges southeastward. Another structural high may cross the Kiruktagiak at the Kiruktagiak Notch, lat. 68°25' N., where a thin fault sliver of Lisburne group and mafic intrusive rock form a wall-like ridge across the valley of the Kiruktagiak River (fig. 26).

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 a mile and a half by a transverse fault two miles east of Autumn Creek.

The northern part of structural zone II between the Chandler River and the Siksikpuk River is dominated by a structural high along which the Tiglukpuk formation, mafic intrusive rock, and small slivers of Shublik formation and Lisburne group are exposed. South of this high there is a structural low marked by an elliptical-shaped 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, in 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. Several tiny fault slivers of the Lisburne group occur a short distance to the south of the fault contact.

The rocks in the northern half of the 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 of the Lisburne group (pl. 2, D-D'). Near Confusion Creek the north limb of the Tiglukpuk Creek anticline apparently plunges westward beneath younger beds, but the south limb seems to pass into a fault sliver that can be traced beyond Encampment Creek. The structure at the east end of the anticline is complicated by two transverse faults. The structure of the Lisburne block 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 Okpikruak formation is preserved.

Anaktuvuk River to Itkillik River

From the Anaktuvuk River eastward to the Itkillik River, the northern edge of structural zone II is bordered by a zone up to 2 miles wide consisting of highly deformed Tiglukpuk strata. Along the creeks where exposed in cutbanks the contact of the Tiglukpuk strata and the Fortress Mountain strata appears to be faulted. Faulting along the northern edge of the complex belt is also indicated in the interstream area between Kanayut Creek and the Nanushuk River by a divergence in trend of the Fortress Mountain strata and the northern margin of the complex belt. The Fortress Mountain strata have a regional northeasterly strike; the margin of the complex belt has a northwesterly trend.

A structural low along the center of the structural zone II is defined by an east-trending band of undifferentiated Tiglukpuk and Okpikruak formations between Kanayut Creek and the Nanushuk River, and by an infolded mass of Fortress Mountain formation east of the Nanushuk River. The rocks in the western part of this belt are poorly exposed. However, on Cobblestone and May Creeks the highly folded and faulted Fortress Mountain and older formations are well exposed in cutbanks (section G-G', pl. 2).

A band of Shublik formation crops out at the southern edge of structural zone II between Kanayut Creek and May Creek. At the north edge the Shublik formation is thrust upon Tiglukpuk and Okpikruak formations, and at the south edge the Shublik formation is in both fault and normal contact with the belt of Lisburne group that forms the mountain front.

Structural Zone III

General Features

The belt of Fortress Mountain strata which comprises structural zone III is 4 to 10 miles wide and extends eastward across the center of the map area. West of the Nanushuk River the structure along this zone is dominated by several broad, open, east-trending synclines, such as at Castle Mountain and Fortress Mountain, and by smaller asymmetrical anticlines and synclines, generally with steepened north flanks. East of the Nanushuk River, the Fortress Mountain strata evidently have been more tightly compressed because they 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, because 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 because of lack of exposures. On the Okpikruak River two folds were observed, an anticline at lat. $68^{\circ}37\frac{1}{2}'$N., and a syncline at lat. 68° $38\frac{1}{2}'$N. On the Okokmilaga River an east-plunging syncline is exposed at lat. $68^{\circ}37'$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 Canoe Hills near the head of Canoe Creek at lat. $68^{\circ}36\frac{1}{2}'$N. A thrust fault, inferred from stratigraphic relationships within the Fortress Mountain strata, is believed to cross Canoe Creek a mile north of the Canoe Hills and extend eastward beyond the Ayiyak River. On the north side of this fault a group of hills, called the Tundra Bowl, are composed of highly deformed Fortress Mountain strata. Owing to the structural complexities and the lack of marker beds, the structural details of these Tundra Bowl strata could not be delineated except for a single moderately appressed anticline, the axis of which is shown on the map (pl. 1) at lat. 68°38'N. and long. 152°53'W. On the south side of the fault there is a structural high along which Tiglukpuk formation and small fault blocks of 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-like mountain. At the west end of the syncline near Fortress Creek, the Fortress Mountain strata wrap around and plunge eastward. However, at the east end near the Ayiyak River, the syncline appears to have been overridden by the east-plunging end of the Castle Mountain syncline and a narrow band of pre-Fortress Mountain strata. A thrust fault bounding the band of pre-Fortress Mountain strata 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 fault and the east-plunging end of the Castle Mountain syncline. This 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 Fortress Mountain formation is preserved. The axis of this structure passes through Castle Mountain. Near the Ayiyak River the 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 which are 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 Fortress Mountain strata are more highly deformed even along the synclinal axis. Locally, some of the lower beds are overturned. It is believed therefore that 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 the structural zone III is indicated by the structural relationships of the Torok and Fortress Mountain formations and by the presence of scattered exposures of pre-Fortress Mountain strata. The narrow strip of Fortress Mountain formation that lies between the two faults appears to dip predominantly southward, although two small reversals were noted on Torok Creek.

The structure of Zone III between the Chandler River and the Anaktuvuk River is not well known because exposures are scarce. Thin slivers of pre-Fortress Mountain strata crop out along the northern margin of the belt, and the two inferred faults north of Castle Mountain are believed to continue eastward beyond the Siksikpuk River. They may converge east of the Siksikpuk, because on Desolation Creek the Torok and Fortress Mountain 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 a mile and a half 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 latitude $68^{\circ}28$-1/2' N., but their structural relationship to the surrounding Fortress Mountain strata is obscure owing to cover.

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 to the west. A fault along the northern margin of the zone is indicated by the structural and stratigraphic relationships of the Torok and Fortress Mountain formations, and locally by the presence of pre-Fortress Mountain rocks.

East of the Nanushuk River strata of the Fortress Mountain formation forms 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 that bring to the surface small slices of pre-Fortress Mountain strata occur within and along the northern margin of the zone.

Structural Zone IV

A belt of Torok formation which comprises structural zone IV, extends from the northwest corner of the map area eastward to the Itkillik River valley. It is bounded on the south by the Fortress Mountain formation and on the north by the rocks of the Nanushuk group. From the Killik River to the Anaktuvuk River, zone IV varies from five to eight miles wide. East of the Anaktuvuk River it gradually narrows, and is three 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 Torok strata 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 broad structural features of the zone. One anticlinal fold is shown on plate 1 extending eastward across the middle of the belt from the Ayiyak River to the Chandler River. The position of the axis has been interpreted on the basis of small crenulations in the shale, believed to be drag folds, which are exposed along the Ayiyak, Kiruktagiak and Chandler Rivers, and Torok Creek (fig. 27). North of the axis most of the crenulations have steep south limbs, and south of the axis most of them have steep north limbs. The axis of the anticline could not be traced west of the Ayiyak River or east of the Chandler River for lack of exposures.

Structural Zone V

The Torok formation is bordered on the north by structural zone V, a belt of Nanushuk group rocks, 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 upper Killik-Itkillik map area.

In the map area west of the Anaktuvuk River, structural zone V is dominated by the Tuktu Escarpment, composed of north-dipping Tuktu and Chandler formations. The Escarpment occurs on the south flank of a broad regional fold, the Ayiyak Mesa syncline, the axis of which lies about 15 miles north of the map 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. to vertical. 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 (sections G-G' and H-H', plate 2). Both folds are asymmetric, with the axial planes inclined to the north. The syncline plunges gently eastward from Kanayut Creek to beyond May Creek. The anticline plunges westward between the Nanushuk River and Kanayut Creek. However, from two miles west of the Nanushuk River to Kanayut Creek, 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 from 1,000 to

Fig. 27 Looking east at cutbank exposures of Torok formation type section on Chandler River near mouth of Torok Creek. Shows characteristic drag folding on north flank of anticline, the axis of which crosses the Chandler River near lat. 68°40' N.

1,500 feet, because steeply dipping beds of middle Chandler formation on the south side of the fault are in juxtaposition with gently dipping beds of uppermost Tuktu formation on the north side of the fault. Although the anticline apparently does not terminate by eastward plunge within the map 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, owing to its incompetent character, 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 Torok formation, by the United Geophysical Company for Arctic Contractors (E. J. Munns, 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 corresponding to the anticline mapped on the surface between the Ayiyak and Chandler Rivers at latitude 68° 40' N. (plate 1). Three separate traverse lines were shot across the Torok belt. Their location is shown in figure 28. Line 1, with an average trend of N. 20°E., lies along the drainage divide between the Ayiyak and Kiruktagiak Rivers. Line 2, with an average trend of N. 35° E., extends from a point four miles north of Castle Mountain to a point one mile south of the confluence of the Kiruktagiak and Chandler Rivers. Line 3, with an average trend of N. 50 $_{o}$E., starts on the drainage divide of the Siksikpuk and Chandler Rivers and terminates at the Siksikpuk River near the mouth of Autumn Creek. Line 1 is the only line that completely crosses the Torok structural belt. None of the 3 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. Results of the seismic survey in general were not satisfactory. According to the seismologist, E. J. Munns (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 Company along lines 2 and 3 are shown in figures 29 and 30. For comparison with the surface geology see cross sections B-B' and C-C', plate 2.

In the profile along line 2 there is no well-defined regional reversal of dip corresponding to the anticline that was mapped at the surface. However, a small fold may occur between S.P. 16 and S.P. 22 from the surface to 7,000 feet below sea level. To agree with the reflections shown on the profile, this anticline would be asymmetrical, with the axial plane dipping south about 55°, and would have a nearly horizontal south limb.

North of S.P. 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 has drawn a southward-dipping thrust fault along the line of this discordance. South of S.P. 12 there is no discordance and Munns suggests that the thrust may be a bedding plane fault. If the fault is projected northward, it presumeably would surface between S.P. 1 and the Tuktu formation contact. If the fault strikes approximately east-west, as do most of the thrust faults in the map 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, the Torok strata dip regularly northward and there is no indication of an abrupt change in structure or lithology such as might be expected along a major thrust fault. To explain this, Munns postulates an angular unconformity is the subsurface north of S.P. 5 which would post-date the thrust faulting. The unconformity would also account for the anomaly of southward-dipping reflectors in the subsurface and the northward-dipping exposures of Torok formation and Nanushuk group at the surface north of S.P. 1. Additional but also inconclusive evidence of an unconformity within the Torok formation comes from microfossil and stratigraphic studies of pre-Nanushuk group rocks in the subsurface of the northern foothills and coastal plain. This has already been discussed in the description of the Torok formation.

A second fault which has been drawn by Munns on the profile of line 2 dips steeply northward between the surface near S.P. 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 S.P. 13 to steeply northward-dipping north of S.P. 13 appears to be the basis for this fault.

In the profile along line 3 (fig. 30) 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 non-continuous reflectors that occurs approximately 4,800 feet below S.P. 29. The contours show two anticlines and a syncline (fig. 28). The more southerly and the larger of the two anticlines crosses line 3 at S.P. 10 and approximately coincides with an eastward projection of the anticline that has been mapped on the surface on the Ayiyak, Kiruktagiak, and Chandler Rivers.

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 S.P. 13, and presumably the southward-dipping thrust fault that has been 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 are in sharp contrast to the surface exposures where high dips and tight folding are the rule (plate 1 and plate 2, sections B-B' and C-C'). On line 2 between S.P. 12 and S.P. 38, for example, most of the seismic reflectors are flat or dip less than 10°, yet at the surface most of the strata dip over 40°, and dips of less than 20° are exceptional. In the vicinity of S.P. 30 to 38, the 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 Paleozoic strata. The less competent overlying Mesozoic strata, near and at the surface, on the other hand, may be crumpled and broken in the manner of <u>decollement</u>

structure. Such a structural reltionship between Paleozoic and Mesozoic strata has been observed in exposures near the mountain front. There the massive Paleozoic limestone strata 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 decollement interpretation implies that Paleozoic strata are within a few thousand feet of the surface in the Torok formation belt. However, Munns states that the character of the reflectors suggests that the subsurface sequence has little density contrast and probably does not contain massive and continuous limestone members such as found in the Paleozoic of the Brooks Range. It is his belief that the subsurface sequence, to the maximum depth of the reflector data, is probably composed largely of shale.

Structural Zones I-III

Detailed interpretation of the subsurface structure on the belts south of structural zone IV is impossible owing to the lack of seismic and well data, and the complexity of the surface geology; therefore no attempt has been made to depict the geology more than a few thousand feet below the surface on the cross sections (plate 2). However, certain broad generalizations can be made by analogy with the foothills of the Rocky Mountains in Alberta, Canada, a region of comparable structure, stratigraphy and geologic history where the subsurface geology has been thoroughly investigated by well drilling and seismic surveys. There is ample justification for comparing the Brooks Range and adjoining foothills with the Alberta Rockies and foothills. Both regions occur along the inner margin of the North American Cordillera. The Brooks Range is generally regarded as the tectonic counterpart of the Rocky Mountains and both regions have had a comparable geologic history and structural evolution. There are also some similarities in specific details of the geology. For example, the mountain fronts in both regions are composed of a thick sequence of Paleozoic limestone that has been folded and thrust faulted toward the foothills (relatively speaking), and the foothills are characterized by relatively incompetent sections of Mesozoic shale and sandstone that are tightly crenulated and sliced by numerous, small, closely-spaced, high-angle faults, many of which are reverse. The stratigraphic successions in both regions are markedly similar in thickness and composition. A table of a typical stratigraphic sequence along the front of the Rockies in southern Alberta is shown in table 2. A comparison of this sequence with the stratigraphic sequence in the upper Killik-Itkillik region as summarized in table 1, shows that both the Alberta foothills and the Brooks Range foothills are composed of over 10,000 feet of intercalated sandstone, shale, and conglomerate of Triassic, Jurassic, and Cretaceous age, which are underlain by several thousand feet of Mississippian limestone.

System	Series	Formation	Character	Thickness (feet)
Cretaceous	Upper Cretaceous	Belly River	Sandstone and shale, non-marine	1,500 ±
		Wapiabi	Shale, black, silty to sandy, marine	1,700 ±
		Cardium	Quartzose sandstone and sandy shale, marine	300 ±
		Blackstone	Black, silty shale, marine	800 ±
	Lower Cret.	Blairmore	Greenish gray sandstone and green and maroon shale, some coal and conglomerate, non-marine	2,500 ±
		unconformity?		
	Lower Cret.?-Jurassic	Kootenay	Sandstone, carbonaceous shale and coal, non-marine	2,000-3,500
		unconformity		
Jurassic		Fernie	Black shale and some fine sandstone, marine	1,100 ±
		unconformity		
Triassic		Spray River	Dark brown, shaly siltstone and dark brown silty shale, marine	1,000 ±
		unconformity		
Pennsylvanian and Permian		Rocky Mountain	Quartzite, siliceous and dolomitic fine sandstone and sandy dolomite, marine	275 ±
Mississippian		Rundle	Upper. Limestone, dolomite, black calcareous shale, red and green shale, argillaceous limestone, minor chert, marine	600 ±
			Lower. Limestone and dolomitic limestone, partly cherty, massive and cliff-forming, marine	1,100-1,300
		Banff	Black calcareous shale and argillaceous cherty limestone, marine	950-1,350

Table 2 Formations near Bow River, Alberta (after L. M. Clark, 1954)

The surficial aspects of the faults in the two regions are similar. The folded thrust sheets of Lisburne group at the front of the Brooks Range on the Okokmilaga River, Kiruktagiak River (fig. 24), and the Nanushuk River have their counterpart in the well-known thrust sheets of Paleozoic and Precambrian strata along the front of the southern Alberta Rockies (McConnell, 1887; Willis, 1902; Daly, 1912; Hume, 1933). 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, pp. 258-262) 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 part 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 seismic surveys and well drilling in the search for petroleum. Cross sections through the areas of most intensive exploration by Link (1954), Webb (1945), Hume (1940), 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, commonly flatten at depth and merge into a few large, low-angle sole faults. Along the sole of the faults Paleozoic limestone commonly occurs, which apparently acted as a strut through which the compressional forces from the west were transmitted. Hume (1931, pp. 258-262) describes 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."

The subsurface structural picture described by Hume might well be applicable to the foothills of the upper Killik-Itkillik region in view of the similarity of the surface geology of this region to the southern Alberta foothills region. Moreover, there are indirect indications in the upper Killik-Itkillik region that major thrust faulting has occurred in the foothills even though most of the faults at the surface appear to be high angle. There are also indirect indications that Paleozoic limestone occurs along the sole of these thrust faults.

Evidence of thrust faulting in map area

North-south foreshortening by thrust faulting best explains the occurrence in the upper Killik-Itkillik Rivers region of structural zones II, III and IV. Each of these zones has a different but characteristic rock assemblage and structure which persist in an east-west belt across the map area. The change in geology from one zone to another in most places is abrupt and usually is marked by a narrow band of faulting. In several places abrupt facies changes were noted from one zone to another. An example of this occurs in the Nanushuk River and Cobblestone Creek basins where the chert facies in the base of the Tiglukpuk formation in structural zone II has been brought into juxtaposition with the siliceous black shale facies in the base of the Tiglukpuk formation in structural zone III. An abrupt change of facies also occurs from structural zone III to structural zone IV. As previously explained the Fortress Mountain and Torok formations are probably at least in part equivalent. However, except for a few thin lenses of grit and coarse sandstone, the coarse clastics which characterize the Fortress Mountain formation are absent in the Torok formation.

In the Nuka-Etivluk Rivers region, 100 miles west of the Killik River, the coarse clastic Fortress Mountain facies and the fine clastic Torok formation facies are separated by a 10-mile-wide belt of siltstone and fine-grained sandstone that apparently is a transitional facies (Tailleur, I. L., personal communication, 1951). In the upper Killik-Itkillik region, however, this transitional facies is missing, presumably as a result of the northward thrusting of the Fortress Mountain strata in structural zone III. Northward thrusting may also account for the obvious narrowing of structural zone IV in an eastward direction across the map area. West of the Anaktuvuk River structural zone IV is five to eight 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 lie in close proximity to the gently folded Nanushuk group strata (plate 2, section G-G'), an analogous situation 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.

Some local structural anomalies along the faulted boundaries of these structural belts are difficult to explain except by thrust-fault movement. One example of this occurs along the fault that bounds the southern margin of structural zone III between Fortress Creek and the Chandler River. In several places along the north side of this fault structural trends strike at nearly right angles to the fault and apparently are cut off by the fault. Matching trends are not found on the south side of the fault in rocks of structural zone II which for the most part appear to parallel the trend of the fault. East of the Ayiyak River the divergent trends along the north side of the fault suggest that structural zone II has overridden the southwest limb of the eastward-plunging Castle Mountain syncline in structural zone III.

A similar structural anomaly suggesting a thrust fault occurs along the contact of structural zone II and structural zone III between Kanayut Creek and the Nanushuk River. There northeastward-trending ridges of structural zone II are cut off by a northwestward-trending fault zone along the contact.

Evidence of Paleozoic limestone along the sole of the thrust faults

It seems probable that, if large sole faults do occur in the subsurface of the Brooks Range foothills, then Paleozoic limestone serves as the rigid supporting member along the base of the thrust plates as in the case in the Alberta foothills. The folded thrust sheets of Lisburne group resting upon younger strata along the mountain front on the Okokmilaga, Kiruktagiak, and Nanushuk Rivers are evidence of this. Another indication is the widespread occurrence of small fault slivers and blocks of Lisburne group near and along the large faults in structural zones II and III.

INTERPRETATION OF THE GEOLOGIC RECORD

In the following pages the broad framework of the geologic history of the Arctic Slope between the Mississippian and the Quaternary is briefly outlined. In addition there is given a number of specific deductions and interpretations pertaining to the historical significance of the various stratigraphic units that crop out in the map area.

Mississippian to Triassic

General

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 which occupied the present Arctic Ocean basin (Payne, 1951) (Eardley, 1951, pp. 526-540). 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 are chiefly fine 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 Mississipppan sediments of the Lisburne group were deposited in the area of the Brooks Range, but it is uncertain if they ever were deposited in the area of the foothills and coastal plain. Preliminary stratigraphic investigations of the Lisburne south of the map area in the Brooks Range by Brosge and Reiser (personal 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 map area, Lisburne exposures occur as much as 20 miles north of the mountain; however, with the possible exception of the Tiglukpuk Creek anticline, all exposures north of the mountains appear to have been thrust faulted into their present position. Lisburne strata were not encountered in the deep test wells which penetrated pre-Mississippian strata at Barrow, Simpson, and Topogoruk (Payne, 1951) on the coastal plain.

The fossiliferous bioclastic limestone and dolomite facies that comprises the bulk of the Lisburne group probably was deposited in a sea of warm, shallow, well-circulated waters in which a diverse and abundant biota flourished. Environmental conditions such as these evidently prevailed throughout Early Mississippian. In Late Mississippian, however, the dark shale, limestone, chert, and phosphate facies which intertongues from the west with the normal bioclastic facies seems to mark the encroachment of deeper, partially stagnated, marine conditions in which a more specialized fauna existed.

Pennsylvanian

Rocks of Pennsylvanian age have not been identified anywhere in northern Alaska, and in the map area the Lisburne group is succeeded disconformably by the Permian(?) Siksikpuk formation. Differential erosion of the upper Lisburne group strata indicates that emergent conditions must have occurred during part of the Mississippian to Permian sedimentary hiatus at least.

Permian(?)

The Siksikpuk formation, which has been tentatively assigned to the Permian, can be traced from the Anaktuvuk River 200 miles westward along the mountain front. No Permian rocks have been found between the Anaktuvuk and Itkillik River, but east of the Itkillik the Permian is represented by the Salerochit formation (Leffingwell, 1919). As yet the stratigraphic relationship of the Sadlerochit and the Siksikpuk formations has not been established.

The extent of Permian deposition north and south of the map area is uncertain. No Permian strata were encountered in the deep test wells at Barrow and Simpson, and the coastal plain area is thought to have been emergent (Payne, 1951). South of the map area near the divide of the Brooks Range, the Shublik formation of Triassic age rests disconformably on the Lisburne group (Patton, W. W., Jr., unpublished notes, 1951), but whether Permian strata are missing as a result of nondeposition or as a result of pre-Shublik erosion is not known.

The general character of the Siksikpuk formation in the map area, and in particular the alternating red, green, and gray coloration suggest that these strata were deposited in an estuary, tidal flat, coastal swamp, or similar environment in which alternating terrestrial and marine conditions prevailed.

Permian to Triassic

Following the deposition of the Siksikpuk strata the sea apparently withdrew from the Arctic Slope. It is probable that the oxidized and silicified zones that characterize the top of the Siksikpuk formation had their origin during this period of emergence.

Triassic

Strata of Early Triassic age comprising the upper part of the Permo-Triassic Sadlerochit formation are reported in the foothills east of the Itkillik River (Keller, A. S., personal communication, 1954). However, Early 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 Early Triassic beds, as evidenced by the poorly preserved collection of vertebrate remains from Tiglukpuk Creek.

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 of the 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 sizeable time lapse between the 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 International Boundary. Although both of these members are thin they are remarkably persistant and uniform. A gradual increase in clastic material at the expense of chert occurs eastward along the foothills, but otherwise the same distinctive fauna and lithofacies characterize every exposure of these members. North of the foothills, Late Triassic strata have been identified in deep test wells along the Arctic Coast (Payne, 1951), and to the south they have been found along the Brooks Range divide (Patton, W. W., Jr., unpublished notes, 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 that transpired in the map area between deposition of the Late Triassic Shublik formation and the Late Jurassic Tiglukpuk formation is unclear. Early and Middle Jurassic strata are present in the eastern foothills and in the coastal plain, but have not been found in the foothills west of the Itkillik River (Payne, 1951) (Keller, A. S., personal communication, 1952). The map 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 sign of differential erosion. At a few localities north of the mountain, such as on Autumn Creek at latitude 68° 28'N., and at Kiruktagiak Notch, the Tiglukpuk beds apparently rest disconformably upon 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 the 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

General

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. The Triassic and older rocks are primarily shelf deposits and were derived chiefly from a northern 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, 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 geosynclinal sedimentation in Late Jurassic and Early Cretaceous is marked by the accumulation of an enormous thickness of marine sediments of the graywacke type and represent, in the terminology of Alpine geologists, the "flysch" phase. The "flysch" phase was followed in middle and Late Cretaceous by deposition of a thick sequence of interfingering marine and nonmarine coal-bearing deposits of the subgraywacke type which mark the closing or "molasse"* phase of geosynclinal filling. The "flysch" phase sediments in the map area are represented by the Tiglukpuk, Okpikruak, Fortress Mountain and Torok formations. The

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* The terms "flysch" and "molasse" are used in this report as F. J. Pettijohn (1949, pp. 435-475) uses them, that is, to distinguish between two different suites of sediments which are manifestations of two separate phases in the characteristic development of a geosyncline.

Tiglukpuk, Okpikruak and Fortress Mountain 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" which 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 non-resistant rock and mineral fragments. The scarcity of neritic fossils, ripple marks, and cross bedding 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 lithic fragments, and mafic minerals suggest 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 was also in part "cannabalistic" as 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.

The "molasse" phase sediments comprise the Nanushuk and Colville groups, but only the former is found in the map area. The sediments of the "molasse" 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 group 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 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 white quartz and white quartz veins are common in the Paleozoic strata of the Brooks Range (Patton, W. W., Jr., unpublished field notes, 1951).

Both the southern margin and the axis of the Colville geosyncline appear to have migrated northward during "flysch" and "molasse" sedimentation. This 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 folding and faulting of the geosynclinal deposits may have occurred. There is also evidence, as previously mentioned, 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. East of the Sagavanirktok River Late Jurassic strata are reported in the Kingak shale (Keller, A. S., personal communication, 1951). North of the map area Late Jurassic beds were found in the Topagoruk well on the coastal plain and possibly also in the Oumalik well at the northern edge of the foothills (Payne, 1951; Robinson, 1956). Rocks of Jurassic age have not been definitely identified as yet along the south side of the Brooks Range.

The Tiglukpuk formation is composed chiefly of intercalated shale and sandstone, the characteristic marginal facies of the "flysch". However, locally the base of the Tiglukpuk contains a variety of lithofacies other than the normal "flysch" deposits. In the map area these include chert, black siliceous shale, variegated shale and coquinoid limestone. The fact that these lithofacies occur at the base of the "flysch" suggests that they probably accumulated in various local basins during the initial phases of subsidence of the geosyncline and prior to 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 map 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 igneous intrusive rock may have been emplaced during this volcanic episode, because the intrusives invade Tiglukpuk and older formations, and detrital lithic fragments of the intrusive rock are found in the Okpikruak and Fortress Mountain formation.

Late Jurassic to Early Cretaceous

Following the volcanism in latest Jurassic time, the map area was uplifted and subjected to erosion, as evidenced by the differential erosion noted along the Tiglukpuk-Okpikruak contact. Local folding or faulting may have accompanied the uplift. This is suggested by the occurrence of massive bodies of chaotic conglomerate believed to be in the base of the Okpikruak formation along the northern edge of structural zone II. The detritus that composes the conglomerate ranges up to cobble size, is completely unsorted and unstratified, shows little evidence of having been transported, and contains recognizable lithic fragments of the Tiglukpuk and Shublik formations, the Lisburne group, and the mafic intrusive and extrusive rocks. Similar conglomerate masses were not found elsewhere in the base of the Okpikruak, and it seems 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). However, the

Brooks Range probably was emergent and served as the principal source for the geosynclinal sediments. The coarse clastics in the Okpikruak formation on the whole contain less quartz and more nonresistant rock and mineral detritus than that in the Tiglukpuk formation, suggesting that the source area may have moved somewhat closer to the upper Killik-Itkillik region.

Early Cretaceous (Neocomian to Albian)

The map 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 map area may have been broadly warped, but there is no evidence at the contact of Fortress Mountain and 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 and coastal plain 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, the Canoe Hills and the Tundra Bowl Hills between Canoe Creek and the Ayiyak River; 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 Mountain and Fortress Mountain 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. Numerous 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 evidence (Bergquist, 1956) would necessitate a period of emergence, folding and erosion along the southern margin of the Colville geosyncline. This presumeably 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 Cretaceous 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 transgressive and regressive oscillations across the northern edge of the map area that resulted in the deposition of nearly 3,000 feet of inshore, bar, beach, lagoonal, floodplain, and channel deposits of the Chandler formation. A major marine invasion occurred in late Cenomanian, during which the 1,200 feet of shallow marine deposits comprising the Ninuluk formation were laid down. The shore line in late Cenomanian must have trended northwesterly, as the Ninuluk marine deposits pinch out rapidly westward along the southern margin of the northern foothills (Detterman, R. S., personal communication, 1956).

Late Cretaceous (post-late Cenomanian)

A short distance north of the map area the Seabee formation of Turonian age 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 (Detterman, R. S., personal communication, 1956). The transgressive sea marked by deposition of the Seabee formation withdrew in middle Turonian and the map area was probably emergent for the remainder 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 map 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 pre-glacial 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 pre-glacial hills into the rugged alpine chain of today. Cirques and arrete ridges were sculptured from the uplands, 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 slope; today remnants of these gravel-covered pre-glacial surfaces occur 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 1 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, Kanayut, and Cobblestone, 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

Possible Source Beds

No oil or gas seeps have been found in the map 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 cross-cutting fractures in the Okpikruak, Fortress Mountain, and Torok formations. On Torok Creek a short distance above the mouth, a vertical fracture several feet wide that cuts across Torok strata 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 are found throughout the Shublik formation and in the upper part of the Lisburne group. Nearly all of the Lisburne group limestone 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 ultimate target in the petroleum investigations of the southern foothills.

A preliminary porosity study of 87 samples of Lisburne from the Kanayut, Nanushuk and Itkillik Lakes area by Krynine and Bowsher (personal 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. Samples from this zone have as much as 11 per cent effective porosity, and many are in excess of five per cent 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 map area appears to have favorable reservoir characteristics. The sandstone in the Tiglukpuk, Okpikruak and Fortress Mountain formations is entirely of the graywacke type and the intergranular spaces are plugged tightly with clay and silt. The limestone in the Shublik formation is dense and hard and appears to have little, if any, primary pore space. Specimens of the Chandler formation "salt and pepper" sandstone, which is better sorted and cleaner than the pre-Nanushuk graywacke, were tested for porosity and permeability. Although porosities were between five and 12 per cent, permeabilities proved to be negligable.

Structure

The mapping of the upper Killik-Itkillik Rivers region was conducted primarily for the purpose of delineating structures favorable for testing the Lisburne group in the subsurface. It should be pointed out, however, that it has not yet been established that the Lisburne extends northward beneath the foothills. The Lisburne group was not found in any of the deep test wells on the coastal plain that bottomed in pre-Mississippian strata.

Structural Zone V

Within the Nanushuk group belt the only structure suitable for a test of the Lisburne is the Arc Mountain anticline. This anticline appears to plunge west, but the nose west of the Nanushuk River 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 thicknesses that were measured in the outcrop, then the Lisburne group would be at a depth of over 10,000 feet.

Structural Zone IV

The scarcity of good exposures, the lack of marker beds, and the tight crenulations of the strata preclude the possibility of accurately delineating the broad structural features of the structural zone IV.

A major anticlinal reversal extending from the Chandler River to the Ayiyak River (plate 1) has been postulated on the basis of drag folding. 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 significant anticlinal reversal to correspond with the postulated reversal at the surface (figs. 28, 29, 30).

The depth to the Lisburne group 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 post-Lisburne sequence. The absence of persistant and continuous reflection horizons in the subsurface (figs. 29, 30) suggests to the seismologist that the subsurface sequence has low density contrast and probably is shale with no intercalated sandstone or limestone members (Munns, E. J., personal communication). However, the fact that the surface strata, which are 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 structural zones II and III have not been as interesting as the Torok and Nanushuk belts in the search for petroleum. However, these belts should not be eliminated from future exploration on this account, since oil and gas have been discovered in an area of comparable structural complexity in the foothills of the Alberta Rockies. 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 strata. The Paleozoic limestone commonly occurs along the sole of a thrust sheet which has ridden (relatively speaking) eastward over Mesozoic strata. Oil and gas have been found in the buried eastern edge of the Paleozoic limestone thrust plate where drag folding provided a local trap.

Structural zone I at the north front of the Brooks Range has not been considered favorable for petroleum chiefly because the most promising reservoir rock, the Lisburne group, is exposed at the surface. However, in several places the mapping shows conclusively that the Lisburne rocks of the mountain front have been thrust faulted northward (relatively speaking) onto Mesozoic strata and subsequently subjected to folding. It is believed that mapping in greater detail will reveal more folded thrusts of this nature along the mountain front. Therefore the possibility of drilling through the thrust sheets and penetrating additional thrust plates of Lisburne and perhaps autochthonous Lisburne strata should be considered in future exploration.

Phosphate Rock

Deposits of sedimentary phosphate rock occur in the chert-shale member of the Alapah limestone, Lisburne group. They have been examined in detail and systematically sampled at Tiglukpuk Creek and upper Kiruktagiak River near the mountain front. In the Tiglukpuk Creek area the phosphatic zone in the Alapah limestone is 36 feet thick and averages 8 per cent P_2O_5. A 43-inch sequence of rock 16 feet below the top of the zone averages 21 per cent P_2O_5. In the upper 20 feet of the zone six beds, from 1 to 5.5 inches thick, contain 30 per cent P_2O_5. In the upper Kiruktagiak River area the phosphate zone is 38 feet thick and averages 12 per cent P_2O_5. The upper 19 feet averages 19 per cent P_2O_5; one 27-inch sequence of rock 16 feet below the top, contains 27 per cent P_2O_5.

Random samples of phosphate rock were collected from the Lisburne group eastward as far as the Anaktuvuk River. At Shainin Lake, ten miles east of the Anaktuvuk, thin beds of "phosphorite" are reported by Bowsher and Dutro (1956, in preparation). 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 this part of the mountain front has not been closely examined.

Because of the marked lateral variation in lithology and phosphate content in the Lisburne strata, and because of 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 River formation of the Nanushuk group, but is most abundant in the upper half. In the upper Killik-Itkillik region it is exposed only as float except for a one-foot seam on the Nanushuk River (fig. 21). No analyses of the coal deposit are available.

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