Areal Geology in the Vicinity of the Chariot Site Lisburne Peninsula Northwestern Alaska

By RUSSELL H. CAMPBELL

GEOLOGICAL SURVEY PROFESSIONAL PAPER 395

Prepared on behalf of the
U.S. Atomic Energy Commission

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR
STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY
WILLIAM T. PECORA, *Director*

Library of Congress catalog-card No. GS 66-262

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

AREAL GEOLOGY IN THE VICINITY OF THE CHARIOT SITE, LISBURNE PENINSULA, NORTHWESTERN ALASKA

By RUSSELL H. CAMPBELL

ABSTRACT

Geologic mapping in support of Project Chariot covers about 350 square miles on the southwest side of the Lisburne Peninsula in northwestern Alaska. The area is bounded on the southwest by the Chukchi Sea and on the northeast by a roughly semicircular arc having a radius of about 15 miles from the Chariot site at the mouth of Ogotoruk Creek.

The exposed bedrock ranges in age from Early Mississippian to Cretaceous and crops out in paralled northeast- to north-trending bands in which the rocks are, in general, successively younger from west to east. The rocks are exclusively sedimentary and probably all marine. No angular unconformities have been observed between bedrock units, and, although disconformities may separate several of the units, there is no local evidence of subaerial erosion or other indication of strongly emergent conditions between Early Mississippian and Early Cretaceous times. Limestone and dolomite beds of the Lisburne Group, locally of Mississippian age, predominate in the western part of the area. The underlying mudstone, sandstone, and limestone of Early Mississippian age are exposed chiefly on the extreme western side. The eastern half of the area is underlain by flysch facies mudstone and sandstone of Cretaceous and, possibly, Jurassic age. The presence of younger Cretaceous bedrock units some distance to the north and east of the map area suggests that deposits as young as Late Cretaceous may have been deposited and subsequently completely removed by erosion.

Although the structural relations are complex and westerly dips are common in the surface exposures, the gross distribution of the units indicates a regional dip to the east or southeast. The structure of the western half of the area is dominated by north-trending imbricate thrust faults along which rocks of the Lisburne Group have been thrust eastward over Lisburne and younger strata. The rocks of the eastern half have been intensely folded, and broken by high-angle faults, giving a gross impression of plastic deformation. The structures of both halves of the area appear to be related to a single major deformation of Late Cretaceous or early Tertiary age. Both the thrusting and folding are interpreted to be relatively shallow features that developed as a result of gravity gliding directed down the regional dip to the east.

The Tertiary Period is represented by varied geomorphic features that reflect a long and complex history of erosion and deposition. Most of it was subaerial and fluvial, but marine erosion and deposition are represented by many features at low altitudes along the coast. In about half the area the bedrock is unconformably overlain by a thin veneer of unconsolidated deposits of Quaternary and, perhaps, late Tertiary age. The surficial deposits are chiefly colluvium, fluvial-terrace and flood-plain deposits, gravel and sand of uncertain origin (fluvial or marine) at high altitude, marine-terrace deposits at low altitude near the shoreline, lake and swamp deposits, wind-deposited silt and sand, and sand and gravel of the modern beach.

INTRODUCTION AND ACKNOWLEDGMENTS

In 1959 the U.S. Geological Survey was requested by the U.S. Atomic Energy Commission to provide a geologic map at a scale of 1 inch to 1 mile (1:63,360) of the land area within a radius of 15 miles of the Chariot site as a part of bioenvironmental studies in the vicinity of a proposed nuclear test excavation. Geologic mapping in support of the bioenvironmental studies program was done during the summer field seasons of 1959 and 1960 and was an expansion from the mapping done in 1958 (Kachadoorian and others, 1959; Sainsbury and Campbell, 1959) during preliminary investigations of the site by the Geological Survey in support of technical site-selection studies by the Atomic Energy Commission. The area mapped is roughly semicircular, bounded on the southwest by the Chukchi Sea and on the northeast by the Kukpuk River. It extends along the coast for 15 miles in either direction from the mouth of Ogotoruk Creek: northwest as far as Kemegrak Lagoon and the north side of the Kemegrak Hills and southeast about a mile beyond Pusigrak Lagoon. Along the Kukpuk River it extends from the vicinity of Ogsachak in the northwest (downstream end) to Alolukrak on the southeast (upstream end) (pl. 1). The area included is approximately 350 square miles and includes all the Point Hope A-2 quadrangle as well as adjacent parts of the Point Hope A-1, B-1, and B-2 quadrangles (fig. 1). The general location and accessibility of the area have been described by Kachadoorian (1961, p. 9).

The history of earliest exploration and geologic work in the area has been described by Collier (1906, p. 6), by Kindle (1909, p. 520–521), and by Smith and Mertie (1930, p. 4–9). Kachadoorian (1961, p. 6–8) has summarized the history of Geological Survey operations in the region on behalf of Project Chariot. The area of the geologic map (pl. 1) is included on the small-scale geologic maps of Collier

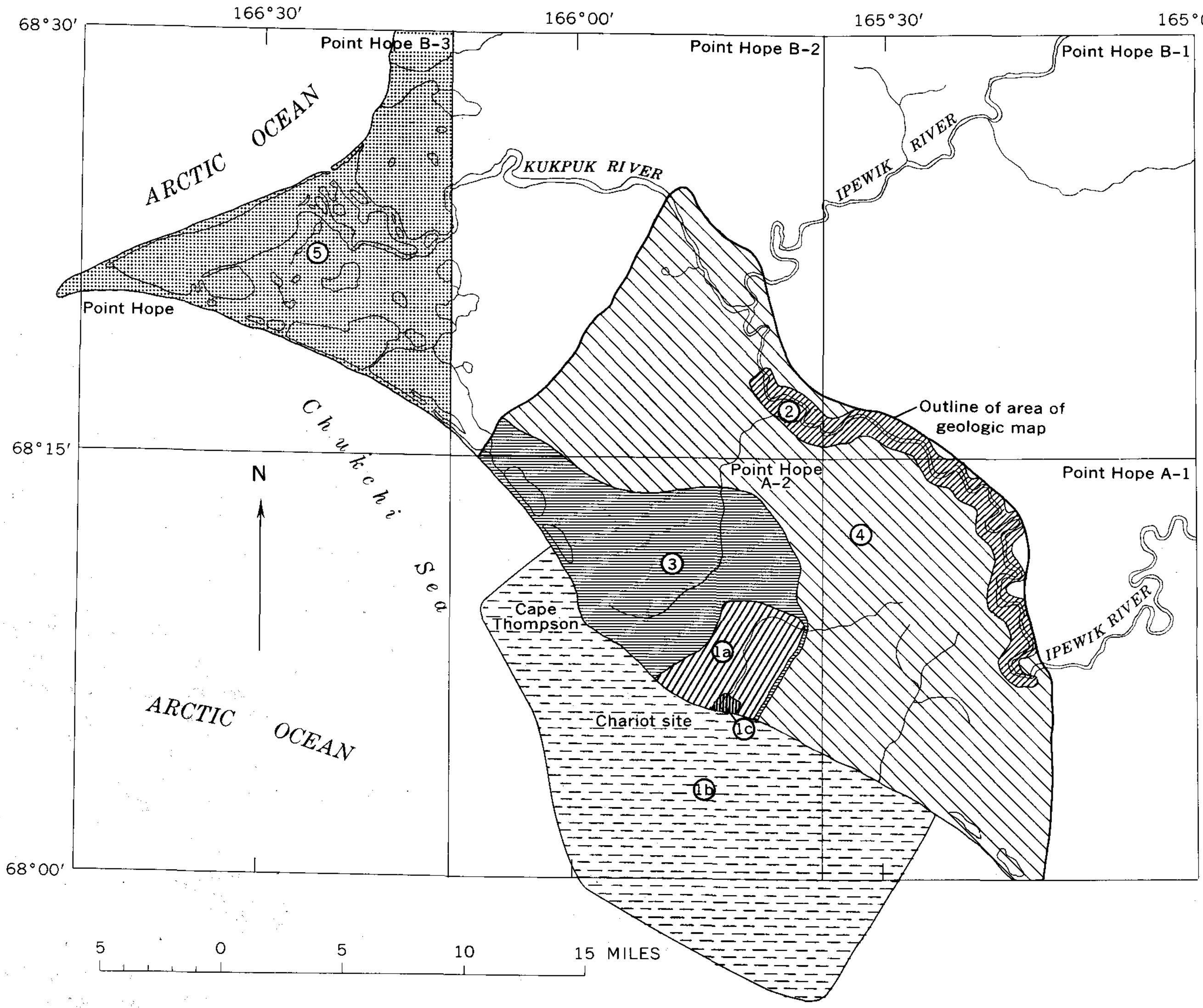


Figure 1.—Index of geologic mapping by U.S. Geological Survey on behalf of Project Chariot.

1. Kachadoorian, Reuben, Campbell, R. H., Sainsbury, C. L., and Scholl, D. W., 1959, Geology of the Ogotoruk Creek area, northwestern Alaska: U.S. Geol. Survey TEM-976, open-file report.
   1a. Plate 1, Geologic map and sections of Ogotoruk Creek area, by Reuben Kachadoorian, R. H. Campbell, C. L. Sainsbury, and D. W. Scholl; scale 1:12,000.
   1b. Plate 2, General bathymetry and marine geology of Ogotoruk Creek area, by D. W. Scholl and C. L. Sainsbury; scale about 1:31,680.
   1c. Plate 3, Engineering geology map of part of Ogotoruk Creek area, by Reuben Kachadoorian and R. H. Campbell; scale 1:4,800.
2. Sainsbury, C. L., and Campbell, R. H., 1959, Geologic strip map of part of the Kukpuk River, northwestern Alaska: U.S. Geol. Survey open-file report; scale about 1:42,000.
3. Campbell, R. H., 1960, Preliminary geologic map and diagrammatic structure sections of part of the Point Hope A-2 quadrangle, northwestern Alaska, *in* Kachadoorian, Reuben, and others, 1960, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI-753, pl. 2, scale 1:48,000.
4. Campbell, R. H., geologic mapping during summer 1960.
5. Moore, G. W., geologic mapping during summer 1960.

(1906) and Smith and Mertie (1930). Data on the rocks exposed to the west of the area of this report have been taken from field notes of and discussions with G. W. Moore and I. L. Tailleur, of the U.S. Geological Survey, who examined those exposures in 1960 and 1961, respectively. Tailleur (oral commun., 1963) also provided additional information about the Mesozoic rocks along the Kukpuk River from his examinations in 1963. J. T. Dutro, Jr., E. G. Sable, and A. L. Bowsher (written commun., 1958) supplied valuable information on paleontology and stratigraphy from a brief reconnaissance of the Cape Thompson area in 1951 and the Cape Lisburne-Corwin Bluff area in 1953. Figure 1 lists the sources of mapping data from which the geological map and sections were compiled. A summary report on the areal geology has been prepared (Campbell, 1966) for the U.S. Atomic Energy Commission volume on bioenvironmental studies of Project Chariot, and much of the text material and several illustrations appear in both this report and the summary.

In July and August, 1958, fieldwork was done in the valley of Ogotoruk Creek by a party consisting of Reuben Kachadoorian, R. H. Campbell, C. L. Sainsbury, and D. W. Scholl, geologists, and Currey Lockett, cook and camp hand. Brief reconnaissance traverses were made along the coast in the company of I. L. Tailleur, who visited the party in early July; in addition, Sainsbury and Campbell examined exposures along the Kukpuk River for a distance of about 20 miles between the mouth of Igilerak Creek and Alolukrak. During the summer seasons of 1959 and 1960 the party engaged in areal mapping consisted of R. H. Campbell, geologist, and D. R. Currey, geologic field assistant.

The fieldwork was done chiefly by weasel and foot traverse except along the sea cliffs between Crowbill Point and Cape Thompson, which were more easily accessible by small outboard motor boat. The field mapping was done on vertical aerial photographs, in 1958 at a scale of about 1:12,000 and in 1959 and 1960 at scales of about 1:46,000 and 1:41,000. Geology was transferred by radial planimetric plotter and by direct tracing (Campbell, 1961a) to topographic base maps. The Point Hope A-2 quadrangle, 1:63,360 scale, was the only sheet published at the time of the field investigations. Topography for the adjacent areas was available only as 1:50,000-scale compilation sheets.

Approximately half the area is covered by a thin veneer of unconsolidated deposits. In addition, nearly all the areas indicated as bedrock on the geologic map (pl. 1) are areas of barren frost-heaved bedrock rubble and therefore do not yield much reliable structural and stratigraphic data. Undisturbed outcrops are generally confined to sea-cliff exposures and stream cutbanks. Many of the unconsolidated deposits display surface features that are easily distinguished on the vertical aerial photographs; for most of the area, the distribution of those deposits was mapped by photointerpretation controlled by spot field examinations of reconnaissance density. By contrast, the photographic expression of the various bedrock units is less distinctive and may locally be deceptive; therefore, their mapped distribution is, necessarily, more closely controlled by field examination of the outcrops. Photointerpretation of the bedrock distribution was used only in a few marginal areas, mostly in the southern part of the drainage basin of Ilyirak Creek. In those areas where the bedrock distribution was mapped by photointerpretation based on field examinations of reconnaissance density, the unit label on the map is followed by a question mark.

Because the work was done as an integral part of investigations of much broader bioenvironmental studies and technical operations in connection with Project Chariot, it is impossible to acknowledge by name all the many persons who contributed materially to the progress of the geologic mapping. Holmes & Narver, Inc., under contract to the U.S. Atomic Energy Commission, and Geological Survey personnel, both in Fairbanks and from parties engaged in other investigations at the Chariot site, provided helpful support without which the fieldwork could not have been effectively done. I particularly wish to acknowledge the geologic work of Donald R. Currey, who served most ably as field assistant for the 1959 and 1960 summer field seasons.

STRATIGRAPHY

The bedrock of the map area consists entirely of sedimentary strata, probably all deposited in marine environments. The oldest strata exposed are mudstone, sandstone, and limestone of an unnamed unit of Early Mississippian age. These are succeeded by the carbonate rocks of the Lisburne Group, locally of Early and Late Mississippian age. The Lisburne Group consists of three formations: the Nasorak Formation, chiefly limestone; the Kogruk(?) Formation, chiefly dolomite; and the Tupik Formation, characterized by thick beds of black chert. The Lisburne Group is overlain by the argillite, chert, and shale of the Siksikpuk Formation of Permian age, which is, in turn, succeeded by the shale, chert, and limestone of the Shublik Formation of Triassic age.

The Shublik is overlain by a very thick section of monotonously similar flysch-facies mudstone and sandstone strata, in which four formations are recognized. They are, from oldest to youngest, the Ogotoruk, Telavirak, Kisimilok, and Fortress Mountain(?) Formations. The Fortress Mountain(?) is the youngest bedrock unit exposed in the map area. The only clearly datable fossils found above the Shublik Formation are pelecypods of Cretaceous age within the Kisimilok Formation, but a thick nonfossiliferous section intervenes between the top of the Shublik and the lowest clearly Cretaceous horizon. The Jurassic Period, therefore, may be represented. Table 1 gives a summary of the stratigraphy.

The bedrock is concealed in more than half the area by a few inches to several tens of feet of unconsolidated sedimentary deposits and vegetation. Peat, sand, silt, and gravel occur as colluvium, windblown deposits, lake and swamp deposits, flood-plain deposits, beach deposits, and terrace deposits at several levels. Most are of Quaternary age, but two deposits of unconsolidated gravel found at high altitudes may be as old as Tertiary.

Of the stratigraphic sections described in detail, all but the Niyiklik Creek section of the Telavirak Formation were measured along the magnificent sea-cliff exposures that extend nearly continuously from Crowbill Point to Cape Thompson (pl. 2). The sections of Mississippian strata and the lower part of the Imikrak Creek section of the Siksikpuk Formation were measured by mapping the sea cliffs on oblique photographs at scales that were generally between 50 and 100 feet to the inch. (The photographs used were taken at sea level and, insofar as possible, perpendicular to the shoreline. The scale for each was computed individually by taping or pacing a reference distance on the beach below the cliff.) The two sections of the Shublik Formation, the upper part of the Imikrak Creek section of the Siksikpuk Formation, and the Niyiklik Creek section of the Telavirak Formation were measured by tape, pace, hand-level, and compass methods. Because of the geographic continuity of most of the

TABLE 1.—*Summary of sedimentary rocks and surficial deposits, Chariot site and vicinity, Alaska*

System	Series	Unit Name	Character	Thickness (feet)
Tertiary(?) and Quaternary		Unconsolidated deposits	Colluvium; windblown sand and silt; fluvial terrace and flood-plain gravel, sand, and silt; marine gravel and sand; and peat.	0–100
		—— Unconformity ——		
Cretaceous	Lower(?) Cretaceous	Fortress Mountain(?) Formation	Rhythmically interbedded silty mudstone and sandstone, with minor conglomerate. Marine turbidites.	3,000+
		—— Unconformity(?) ——		
	Lower Cretaceous	Kisimilok Formation	Chiefly mudstone, with rhythmically interbedded sandstone abundant in basal zone. *Buchia.* Marine; turbidites common.	5,000+
Jurassic or Cretaceous		Telavirak Formation	Rhythmically interbedded sandstone and mudstone, with minor conglomerate. Marine turbidites.	5,000+(1,000?)
		Ogotoruk Formation	Mudstone with interbedded siltstone and sandstone. Marine; turbidites abundant.	5,000±(1,000?)
		—— Disconformity(?) ——		
Triassic	Lower(?), Middle, and Upper Triassic	Shublik Formation	Limestone, shale, and chert. *Monotis* abundant in some limestone beds. Marine.	200
		—— Disconformity(?) ——		
Permian	Lower(?) Permian	Siksikpuk Formation	Argillite, chert, and minor shale. Marine.	400±
		—— Disconformity(?) ——		
Carboniferous: Mississippian	Upper Mississippian	Lisburne Group: Tupik Formation	Chert, mudstone, limestone, and minor argillite.	330+(200?)
		Lisburne Group: Kogruk(?) Formation	Dolomite, limestone, and calcareous sedimentary breccia with minor chert. Marine fossils.	3,670+(500?)
	Lower and Upper Mississippian	Lisburne Group: Nasorak Formation	Chiefly rhythmically interbedded limestone and calcareous shale and minor interbedded silty shale. Marine fossils; limestone turbidites(?).	2,200
		Sedimentary rocks undivided	Mudstone, sandstone, limestone, and minor conglomerate. Marine and possible nonmarine. Base not exposed.	420+(1,500?)

measured sections, all of them have been grouped together in a separate part of this report.

STRATIGRAPHIC AND PETROGRAPHIC METHODS AND TERMINOLOGY

The terminology used to describe the bedding thickness is that recommended by Dunbar and Rodgers (1957, p. 97). The color names conform insofar as possible to those of the National Research Council Rock-Color Chart (Goddard and others, 1948).

Terms designating terrigenous sedimentary-rock types follow the terminology used by Williams, Turner, and Gilbert (1954). The limestones and dolomites have been classified according to the system and nomenclature proposed by Folk (1959) with but two modifications: (1) the traditional 2.00-mm boundary was used to distinguish rudite and arenite, rather than the 1.00-mm boundary suggested by Folk (1959, p. 16); and, (2) calcite grains as much as 0.031 mm in size that could not be determined as to origin—whether recrystallized micrite or dust from the abrasion of coarser allochems—are commonly present in minor amounts as an integral part of some matrix material and as such are included as "micrite" even though, in the strict sense proposed by Folk, the term excludes material coarser than 0.004 mm.

The relative proportions of calcite and dolomite in hand specimens and thin sections of the carbonate rocks were determined by routine staining with Alizarine red S solution (Friedman, 1959), after preliminary optical and X-ray data on a pilot suite of specimens indicated that the rocks were chiefly calcite and dolomite, and that aragonite, gypsum, and high-magnesium calcite were not present in detectable amounts. The solution coats calcite with a deep red stain, whereas dolomite remains uncolored.

MISSISSIPPIAN ROCKS

Four formations of Mississippian age are shown on the geologic map (pl. 1). The lowermost is an unnamed poorly exposed mudstone-sandstone-limestone sequence, the oldest exposed within the map area. It is overlain by the relatively pure limestone and dolomite beds of the Lisburne Group. The succession appears to represent continuous marine deposition from Early to Late Mississippian time.

SEDIMENTARY ROCKS UNDIVIDED

The undivided sequence of mudstone, sandstone, and limestone of Early and Late Mississippian age crops out in the western part of the mapped area. The upper part of the sequence is well exposed in the sea cliffs a few hundred feet east of Cape Thompson (pl. 2*A*), where it is conformably overlain by the Lisburne Group. Strata of the sequence are partly exposed along the back side of the beach between the Cape Thompson cliffs and Agarak Creek, in a few cutbanks along Agarak Creek, in rubble exposures to the west of Akoviknak Mountain, and, farther north, along the upper reaches of Nalakachak Creek.

The upper part of the unit as exposed just east of Cape Thompson (pl. 2*A*, fig. 2) consists of thin-bedded to thin-laminated shaly fine to very fine grained medium-gray sandstone and sandy siltstone interbedded with dark-gray to medium-dark-gray silty shale and mudstone and a few interbeds of medium- to thick-bedded dark-gray limestone. The limestone interbeds are chiefly a medium-grained poorly sorted biogenic calcarenite that has been partly dolomitized and partly silicified. The shales and sandstones appear to be generally noncalcareous. However, a few of the sandstone beds contain dolomite cement, and the mudstone beds are locally fossiliferous. Tiny veinlets of calcite are common in all the beds.

The rocks that crop out along Agarak Creek are very similar to those exposed just east of Cape Thompson, and the fauna from both areas is dominated by abundant small zaphrentoid corals. The rocks exposed on the nearby beach, however, include more abundant thin beds of medium-gray and reddish-brown very fine grained quartz sandstone containing scattered coalified plant fragments and, locally, ferruginous nodules and cement. In addition, the mudstone or shale interbeds are more strongly indurated and a sheen of disseminated very fine grained mica has developed along a few bedding surfaces.

In the exposures east of Akoviknak Mountain a few beds of coarse quartzose sandstone and a polymict fine pebble conglomerate are represented in frost-heaved rubble. The conglomerate pebbles include some quartz, but they appear to be chiefly chert and fragments of other very fine grained rock. The conglomerate is well sorted as to size and contains relatively little matrix, but locally is well cemented with calcite and limonite(?). To the north, the poor outcrops along Angayukuk Creek are chiefly silty mudstone, locally shaly, with subordinate interbedded limestone. Some quartzose sandstone is present in the rubble exposures north of Angayukuk Creek, and the outcrop in Kunuk Creek is a laminated sandy siltstone.

Farther north, along the upper reaches of both major forks of Nalakachak Creek, the rocks are chiefly medium-gray to medium-dark-gray silty mudstone and claystone, generally thin bedded and locally shaly, but in some places occurring in thick and very thick beds. Sandy zones were not found. The mudstones are locally fossiliferous and interbedded with them are a few medium and thick beds of medium-gray fossiliferous limestone.

The precise stratgraphic succession of the various rock types could not be established because of complex structure, poor exposures, and apparently rapid facies changes. Only the upper 420 feet exposed in the cliffs east of Cape Thompson were well established stratigraphically . (See measured sections, p. 33–34.)

The total exposed thickness of the mudstone-sandstone-limestone unit is estimated to be on the order of 2,000 feet. The base of the sequence is not exposed. The contact with the overlying Lisburne Group is gradational and the adjacent strata intertongue. (See pl. 2*A*.)

The collections of marine fossils have been identified by J. T. Dutro, Jr., and Helen M. Duncan, of the Geological Survey, who report (written commun., 1961) that the fauna in collections from near Cape Thompson is Early Mississippian in age. About 12 miles to the north, however, in the upper reaches of Nalakachack Creek, fossil collections from the mudstone-sandstone-limestone sequence (60ACr–129, 60ACr–132, and 60ACr–132A of table 2) are reported to be lower Upper Mississippian (Helen M. Duncan, written commun., 1963; J. T. Dutro, Jr., written commun., 1965). This suggests that the contact between this predominantly terrigenous clastic unit and the relatively pure limestone of the overlying Lisburne Group may transgress time, becoming progressively younger from south to north. It would indicate that something in excess of the 500 feet of fossiliferous carbonate beds assigned to the Lower Mississippian part of the Lisburne Group at Cape Thompson has graded laterally northward into a predominantly mudstone section. This type of gradation is also suggested by Tailleur's observations (oral commun., 1965) that near Cape Dyer, to the northwest of the area of this report, the contact between the lowest thick carbonate sequence and the underlying mudstone unit lies at or very close to the boundary between the Lower and Upper Mississippian.

Fossil collection 50ACr–130, also from the upper reaches of Nalakachak Creek, appears to be anomalous. The fossils have been identified by Duncan (written commun., 1963) as mostly of the genus *Tachylasma*, associated with a few specimens of probable *Ufimia*. Duncan (written commun., 1963) notes that elsewhere *Tachylasma* is recorded only from rocks of Permian age. This age is difficult to reconcile with field observations indicating that the strata from which the fossils were thought to have come are interbedded between Mississippian strata represented by collections 60ACr–129 and 60ACr–132. The fossils of 60ACr–130, however, are mostly silicified horn corals that were found as loose weathered fragments on a frost-heaved rubble surface and may be some sort of lag deposit from an eroded klippe of the Ibrulikorak thrust sheet rather than from the beds on which they lie. Alternatively, if the fossils were from those beds, they may represent tightly infolded or infaulted Permian rocks (though they do not resemble the known strata of the Siksikpuk Formation elsewhere in the map area) in the Ibrulikorak thrust sheet, of which there could remain only a small klippe 5 or 10 feet thick.

The mudstone-sandstone-limestone sequence correlates, at least in part, with the Mississippian coal-bearing formation reported by Collier (1906, p. 18–19) in exposures along the cliffs south of Cape Lisburne. No coal beds have been found within the area of plate 1, but Kindle (1909, p. 523–524) collected plant fragments from this area that were sufficiently large and well preserved to be identified. Dutro suggests (written commun., 1961) that the upper part of the mudstone-sandstone-limestone sequence—as exposed in the vicinity of Cape Thompson—together with some of the lower beds of the overlying Lisburne Group, is probably equivalent to the type Utukok Formation (Early Mississippian) in the western DeLong Mountains (Sable and Dutro, 1961, p. 591, 592) about 90 miles to the east, and that the plant-bearing sandstones of possible nonmarine origin would correlate approximately with the Noatak sandstone (Devonian and Mississippian). The collections from the Nalakachak area were first thought to be faunally equivalent to part or all of the Lower Mississippian part (basal 500 ft) of the Nasorak Formation (Dutro and Duncan, written commun., 1962) and earlier papers (Campbell, 1965a; Campbell, 1966) reported the unit to be Early Mississippian. The collections have subsequently been reported as most likely lower Upper Mississippian (Helen M. Duncan, written commun., 1965; J. T. Dutro, Jr., written commun., 1965) so that the map unit must now be regarded as of Early and Late Mississippian age.

LISBURNE GROUP

The Lisburne Group, here of Early and Late Mississippian age, is about 5,900 feet thick and consists chiefly of limestone and dolomite beds, in part cherty, with variable but minor amounts of interbedded shale. The Lisburne, named by Schrader (1902, p. 241), has been described in recent reports in which five recognizable subdivisions were described as Ml_1, Ml_2, Ml_3, Ml_4, and Ml_5 (Campbell, 1960a, pl. 3; 1960b). The lower three of these units (Ml_1, Ml_2, and Ml_3) have been grouped together and named the Nasorak Formation (Campbell, 1965a). The overlying unit (Ml_4) is designated the Kogruk(?) Formation because of its lithic similarity and partial faunal equivalence to the type Kogruk Formation, named by Sable and Dutro (1961) in the western DeLong Mountains. The topmost unit of the Lisburne Group (Ml_5) is mapped as the Tupik Formation because it is similar in lithology and stratigraphic position to the type Tupik Formation in the western DeLong Mountains (Sable and Dutro, 1961). The formation assignment was not determined for outcrops in a few small areas of poor exposure and complex structural relations; there, the Lisburne Group was mapped as undivided.

NASORAK FORMATION

The Nasorak Formation (Campbell, 1965a) is a limestone sequence named from typical exposures in the sea cliffs near the mouth of Nasorak Creek (pl. 2*B*), where nearly 1,800 feet of the upper part of the formation are nearly continuously exposed with relatively little structural complexity. Most of the formation is also well exposed farther west in sea cliffs in the vicinity of Cape Thompson (fig. 2). (See measured sections, p. 30–33, 44–49.) There the base is exposed in conformable contact with the underlying mudstone-sandstone-limestone sequence. Elsewhere, good exposures are limited chiefly to cutbanks along the Kukpuk and Ipewik Rivers.

The lower member of the Nasorak Formation consists of 165 feet of strata and is best exposed just east of Cape Thompson. It consists of interbedded dark-gray to grayish-black silt clay shale, locally calcareous, and medium-gray to dark-gray cherty limestone. This zone is overlain by the Cape Thompson Member, about 225 feet of massively outcropping very thick bedded light-gray to light-olive-gray limestone. The Cape Thompson Member is resistant to erosion and forms the promontory of Cape Thompson, its type locality, for which it is herein named. It is succeeded by about 50 feet of very thick bedded grayish-black calcareous mudstone containing small pyrite concretions and a few pyritized fossils, the basal part of the upper member of the formation; above this the remaining part of the upper member is remarkably uniform in lithology and bedding characteristics. The upper member is characterized by rhythmically interbedded thin-bedded to medium-bedded dark-gray limestone and by thin-laminated to very thin bedded silty calcareous shale. Shale interbeds generally decrease in both abundance and thickness progressively upward through the member.

The dark limestones of both the upper and lower members of the Nasorak Formation are predominantly medium- to coarse-grained biomicrites. Poorly sorted allochems, nearly all fossil fragments, constitute 20–80 percent of the rock; the remainder is a matrix of microcrystalline calcite and silt-sized detrital calcite (fig. 3*C, D*). There are, however, a few rare interbeds of coarse-grained biosparite (fig. 4*C*) in the upper member. Terrigenous debris is almost entirely lacking. The most abundant recognizable fossil fragments are crinoid columnals, undetermined echinoderm fragments, and fragments of Bryozoa. Foraminifera were seen as sparse constituents of a few beds. Fragments of other shelled organisms, probably chiefly brachiopods, are also common. Incomplete replacement by dolomite is common, though not prevalent (fig. 4*A*). Nodular limestone beds containing variable amounts of dark-gray to black chert are common at some horizons. Dark chert is locally abundant in several zones, chiefly as lenticular nodules and irregular angular masses in limestone beds.

The interbedded calcareous shale is composed chiefly of micrite, fossiliferous micrite, and biomicrite, much of which apparently contains abundant silt-sized detrital calcite grains (fig. 3*A*, *B*). Terrigenous material is generally very rare throughout the formation and is represented chiefly by a small amount of clay (chiefly illite?) in the shale interbeds, and minor amounts of very fine to fine quartz silt. Sand-sized terrigenous debris is almost entirely lacking.

The massive light-gray limestone of the Cape Thompson Member is chiefly a crinoid biosparite, consisting almost exclusively of coarse sand- to fine pebble-sized crinoid stem fragments and columnals (fig. 4*B*); locally it contains very minor amounts of very fine quartz silt and has been partly dolomitized and partly silicified. Bedding is expressed internally in this limestone by crinkly uneven discontinuous laminae at generally regular intervals of half an inch to a foot in spacing.

TABLE 2.—*Fossils collected from the Lisburne Group and the underlying mudstone-sandstone-limestone unit*

[Sample locations: A. Nasorak Creek sea-cliff section; Ad, structurally disturbed part of Nasorak Creek sea-cliff section; B, Cape Thompson sea-cliff section; C, scattered localities, stratigraphic position determined by field-mapping correlations]

	Lisburne Group																	
	Tupik Formation	Kogruk(?) Formation																
Field collection Number	59ACr - 87f	59ACr - 74f	59ACr - 73f	59ACr - 68f	59ACr - 62f	59ACr - 59f	59ACr - 56f	59ACr - 55f	59ACr - 52f	59ACr - 29f	59ACr - 27f	59ACu - 15	59ACr - 171f	59ACr - 147f	59ACr - 85f	59ACr - 133f	59ACr - 78f	58ACr - 35
U.S.G.S. upper Paleozoic locality Number	18991–PC	18990–PC	18989–PC	---------	18988–PC	18987–PC	18986–PC	18985–PC	18984–PC	18983–PC	18982–PC	19060–PC	19059–PC	19058–PC	19057–PC	19056–PC	19055–PC	---------
Brachiopods:																		
Brachiopods, indet. fragment						A						C		C				
Avonia sp.								A										
Brachythyris aff. *B. suborbicularis* (Hall)																		
"*Buxtonia*" sp.																		
Camarotoechid, indet.																		
Chonetes sp.	A																	
aff. *C. oklahomensis* Snider																		
Cleiothyridina? sp.														C				
Cleiothyridina aff. *C. obmaxima* (McChesney)																		
Composita sp.														C				
"*Dictyoclostus*" sp.																		
Dimegelasma? sp.																		
Echinoconchus sp.														C				
Eumetria? sp.								A						C				
Leiorynchus cf. *L. carboniferum* Girty																		
Lingula sp.	A																	
Linoproductus? sp.																		
Martinia? sp.																		
Orbiculoid brachiopod, indet.																		
Orthotetid, indet.																		
Orthotetes? sp.																		
Productoid, indet. fragment			A	A				A										
Punctospirifer sp.																		
Quadratia sp.	A																	
Rynchonelloid, indet. fragment																		
Schizophoria sp.																		
Spiriferoid, indet fragment																		
Spirifer sp.																		
large																		
Spirifer aff. *S. arkansanus* Girty																		
S. keokuk Hall																		
S. increbescens Hall								A										
Syringothris sp.																		
Terebratuloid, indet fragment								A										
Corals:																		
Coral, indet													C					
Amplexizaphrentis sp.															C			
Caninoid coral, indet																		
Caninia sp.										A								
large form																		
Canadaphyllum? sp.																		
Cyathoclisia? sp.																		

	Lisburne Group (continued)													
	Nasorak Formation													
	Upper member													
Field collection Number	59ACr - 24f	59ACr - 23f	59ACr - 22f	59ACr - 1f	59ACr - 8f	59ACr - 8Af	59ACr - 11f	59ACr - 12f	59ACr - 13f	59ACr - 123f	59ACr - 122f	59ACr - 138f	59ACr - 96f	58ACr - 36
U.S.G.S. upper Paleozoic locality Number	18981–PC	18980–PC	18979–PC	18978–PC	18977–PC	18976–PC	18975–PC	18974–PC	18972–PC	18973–PC	18971–PC	19054–PC	19051–PC	---------
Brachiopods:														
Brachiopods, indet. fragment														
Avonia sp.														
Brachythyris aff. *B. suborbicularis* (Hall)										B				
"*Buxtonia*" sp.														
Camarotoechid, indet.														
Chonetes sp.														
aff. *C. oklahomensis* Snider														
Cleiothyridina? sp.														
Cleiothyridina aff. *C. obmaxima* (McChesney)														
Composita sp.														
"*Dictyoclostus*" sp.			A						A	B				
Dimegelasma? sp.										B				
Echinoconchus sp.	A		A											
Eumetria? sp.												C		
Leiorynchus cf. *L. carboniferum* Girty														
Lingula sp.														
Linoproductus? sp.														C
Martinia? sp.			A											
Orbiculoid brachiopod, indet.														
Orthotetid, indet.														
Orthotetes? sp.														
Productoid, indet. fragment											B			
Punctospirifer sp.														
Quadratia sp.														
Rynchonelloid, indet. fragment													C	
Schizophoria sp.														
Spiriferoid, indet fragment				A						B				C
Spirifer sp.												C		
large														
Spirifer aff. *S. arkansanus* Girty														
S. keokuk Hall														
S. increbescens Hall														
Syringothris sp.														
Terebratuloid, indet fragment														
Corals:														
Coral, indet														
Amplexizaphrentis sp.														
Caninoid coral, indet														
Caninia sp.					A	A								
large form														
Canadaphyllum? sp.														
Cyathoclisia? sp.				A										

	Lisburne Group (continued)																	
	Nasorak Formation (continued)								Unnamed mudstone-limestone-sandstone unit									
	Cape Thompson member				Lower member													
Field collection Number	59ACr - 15f	59ACr - 120f	59ACr - 154f	59ACr - 162f	59ACr - 16f	59ACr - 21f	59ACr - 19-20f	59ACr - 119f	59ACr - 116f	59ACr - 117f	59ACr - 129f	59ACu - 30f	59ACr - 128f	60ACr - 78f	60ACr - 129	60ACr - 132	60ACr - 132A	60ACr - 134
U.S.G.S. upper Paleozoic locality Number	18997–PC	---------	18998–PC	18999–PC	18996–PC	19052–PC	19053–PC	18970–PC	18968–PC	18969–PC	18994–PC	18995–PC	---------	20211–PC	20212–PC	20214–PC	20215–PC	20216–PC
Brachiopods:																		
Brachiopods, indet. fragment																		
Avonia sp.																		
Brachythyris aff. *B. suborbicularis* (Hall)				C			Ad	B										
"*Buxtonia*" sp.							Ad											
Camarotoechid, indet.																		C
Chonetes sp.											C							
aff. *C. oklahomensis* Snider																		C
Cleiothyridina? sp.	Ad																	
Cleiothyridina aff. *C. obmaxima* (McChesney)							Ad											
Composita sp.																		
"*Dictyoclostus*" sp.								B										
Dimegelasma? sp.																		
Echinoconchus sp.				C														
Eumetria? sp.																		
Leiorynchus cf. *L. carboniferum* Girty															C	C		
Lingula sp.																		
Linoproductus? sp.																		
Martinia? sp.																		
Orbiculoid brachiopod, indet.																	C	
Orthotetid, indet.																		C
Orthotetes? sp.																	C	
Productoid, indet. fragment											C							C
Punctospirifer sp.							Ad											C
Quadratia sp.																		
Rynchonelloid, indet. fragment																		
Schizophoria sp.	Ad																	
Spiriferoid, indet fragment											C							
Spirifer sp.	Ad			C			Ad											
large								B										
Spirifer aff. *S. arkansanus* Girty																	C	C
S. keokuk Hall								B										
S. increbescens Hall																		
Syringothris sp.							Ad											
Terebratuloid, indet fragment																		
Corals:																		
Coral, indet																		
Amplexizaphrentis sp.																		
Caninoid coral, indet							Ad											
Caninia sp.																		
large form			C															
Canadaphyllum? sp.								B										
Cyathoclisia? sp.																		

Diphyphyllum? sp. indet						A																																												
Diphyphyllum sp																								A																										
Diphyphyllum aff. *D. ingens* Hall																							A																											
Diphystrotion sp										A																																								
Faberophyllum? sp. indet											A																																							
Faberophyllum sp																																				C														
Fasciculophyllum? sp																																										B								
Hexaphyllia sp																						A																												
Horn corals, undet				A	A	A			A																																									C
Liardiphyllum? sp																																											C							
Lithostrotionella sp										A							C					A	A																											
sp. 1																			A																															
sp. 2																			A	A																														
Michelinia sp																																							Ad	B										
Siphonodendron? sp																																									B									
Siphonodendron sp																																								B						C				
Siphonodendron aff. *S. pauciradiale* (McCoy)																							A																											
Syringoporoid, undet						A																																												
Syringopora sp																			A																					B										
Zaphrentoid corals, undet		A	A															C																					Ad			B	C							
Zaphrentites? sp														C												A		B																						
Zaphrentites sp																																									B			C						
very large form																																					Ad													
Zaphriphyllum? sp																																														C				
Bryozoans:																																																		
Bryozoan, indet. fragment											A																																C							C
Archimedes sp								A				C										A																												
Cystodictya? sp. indet																									A	A							Ad																	
Cystodictya sp																															C																			
Fenestellid bryozoans, indet																																			C															C
Fenestrate bryozoan, indet					A	A		A				C										A									C							Ad												
Fenestella sp. indet																									A	A							Ad						Ad											
sp																																														C				
Fistulipora sp																																				C														
Rhabdomeson sp																															C																			
Stenoporoid bryozoan, ramose form																C																	Ad																	
Stenoporoid bryozoans, ramose and incrustings																															C																			
Trepostomatous bryozoans, ramose and lamellar																															C																			
Echinoderms:																																																		
Echinoderm debris, indet				A								C		C				C													C		Ad	B				Ad					C			C			C	C
Pentremites sp								A																						C																				
Crinoid columnals, indet																										A									C															
Gastropods:																																																		
Bembexia? cf. *B.*? *inumbilicata* Yochelson and Dutro	A																																																	
Loxonema sp																																								B										
Platyceras sp																																				C														
Pelecypods:																																																		
Pelecypod, indet. fragment																																							Ad				C							
Other fossil material reported:																																																		
Algal(?) impressions, indet																																										B								
Carbonized plant fragments, indet																																													C					
Fish teeth, indet									A																																									
Foraminifera:																																																		
Endothyroid, undet. (observed in thin sections made for petrographic study).																							A																											

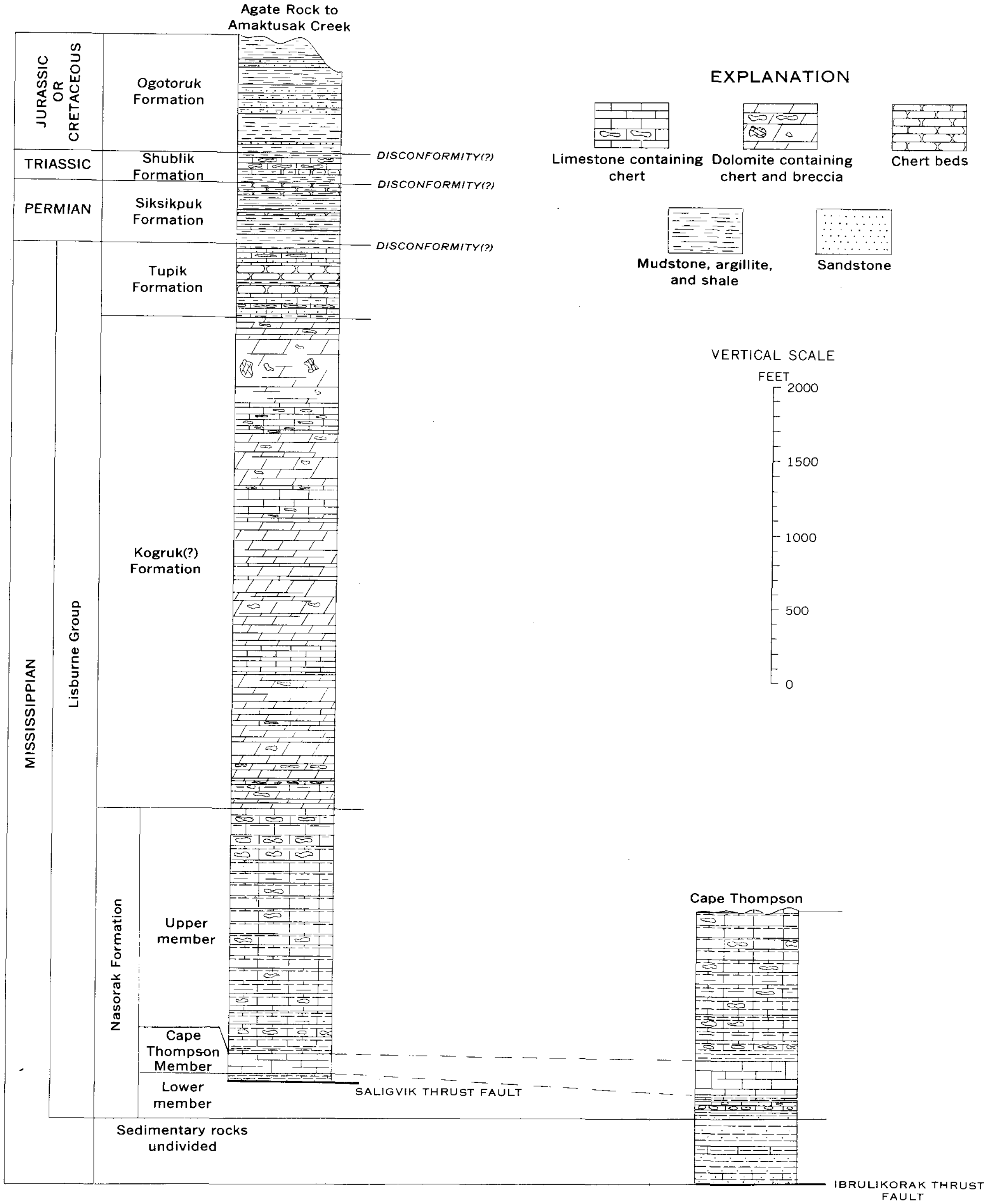


Figure 2.—Generalized columnar sections of strata exposed in sea cliffs.

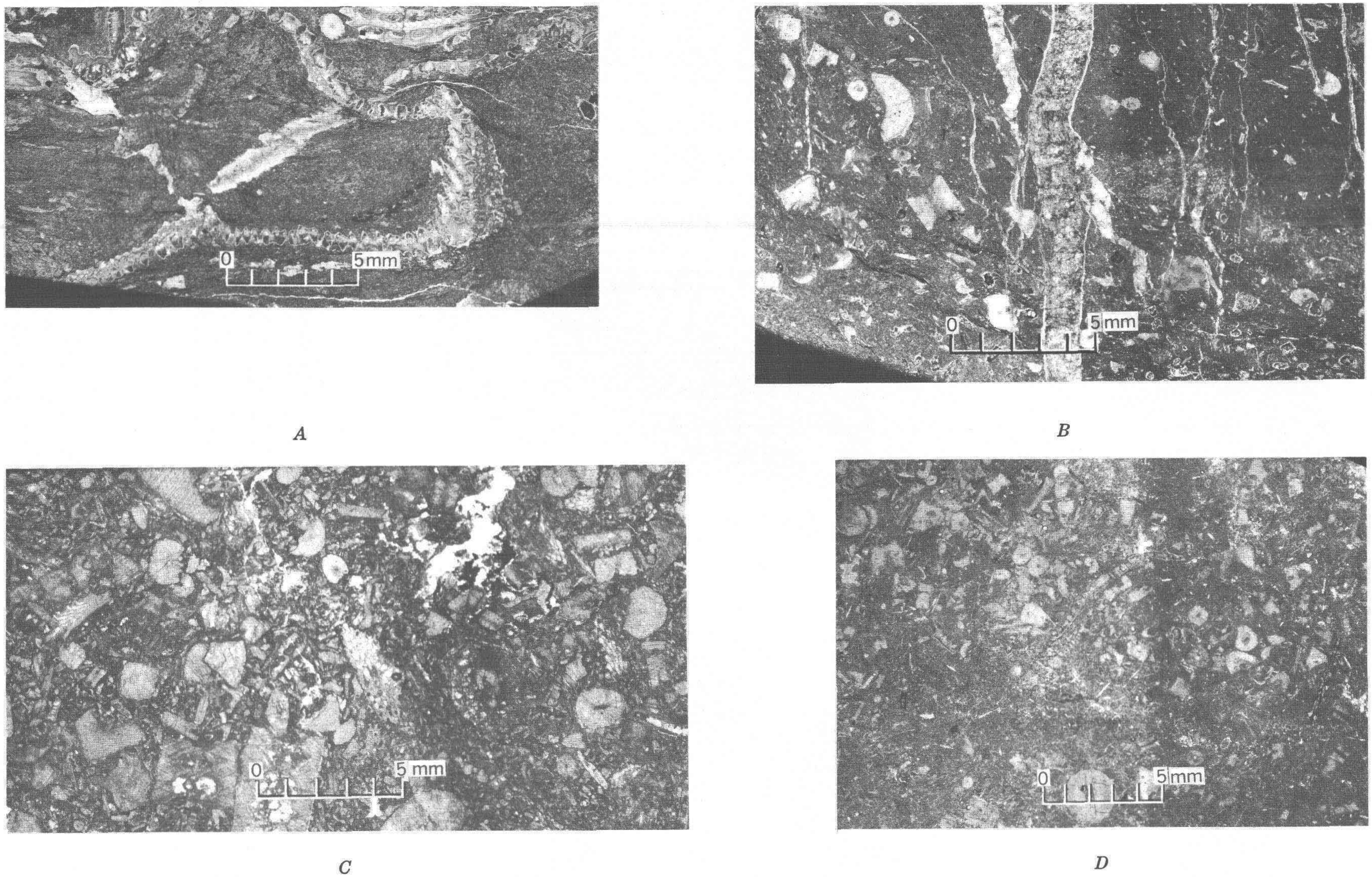


FIGURE 3.—Thin sections showing general range of abundance, size, and kinds of allochems in the most common rock types of the Nasorak Formation. The dark areas on the right side of each section have been stained with Alizarine red S. *A*, A partly dolomitized Bryozoa-bearing laminated micrite. The chief fossil constituent is fragmental Bryozoa. Approximately 25 percent of the rock is dolomitized, chiefly as a very finely crystalline replacement of the matrix. Dolomite also occurs as thin rims around some of the fragmental fossil allochems. (This section is cut very nearly parallel to the bedding.) 59ACr–8a–1/7. *B*, A medium-grained crinoidal biomicrite containing only about 15 percent allochems, nearly all of which are echinoderm fragments, in a micrite matrix; shows a few late calcite veinlets. The prominent veinlike structure that crosses the section near its middle is perhaps best interpreted as the copriolite-filled path of a worm or other burrowing organism. The extremely dark nature of the matrix is due chiefly to its very fine grain size and to an excessive thickness of the thin section; it may also be partly due to a few percent of finely divided inclusions of clay and (or) carbon. A small amount of secondary silica occurs at rims around a few of the calcite fossil fragments. 59ACr–4A. *C*, A medium-grained crinoidal biomicrite. Relatively abundant allochems, nearly exclusively echinoderm and bryozoan debris, poorly sorted as to size, with a matrix of calcite mudstone that perhaps contains a few percent clay. The rock is virtually pure calcite, possibly containing 1 or 2 grains of medium to fine quartz silt; some of the dirty material of the matrix may be inclusions of very fine clay mineral particles. 59ACr–3. *D*, A coarse-grained crinoidal biomicrite containing approximately 30 percent loosely packed fossil allochems in a micrite matrix; may contain a minor amount of clay. Both clasts and matrix are nearly pure calcite.

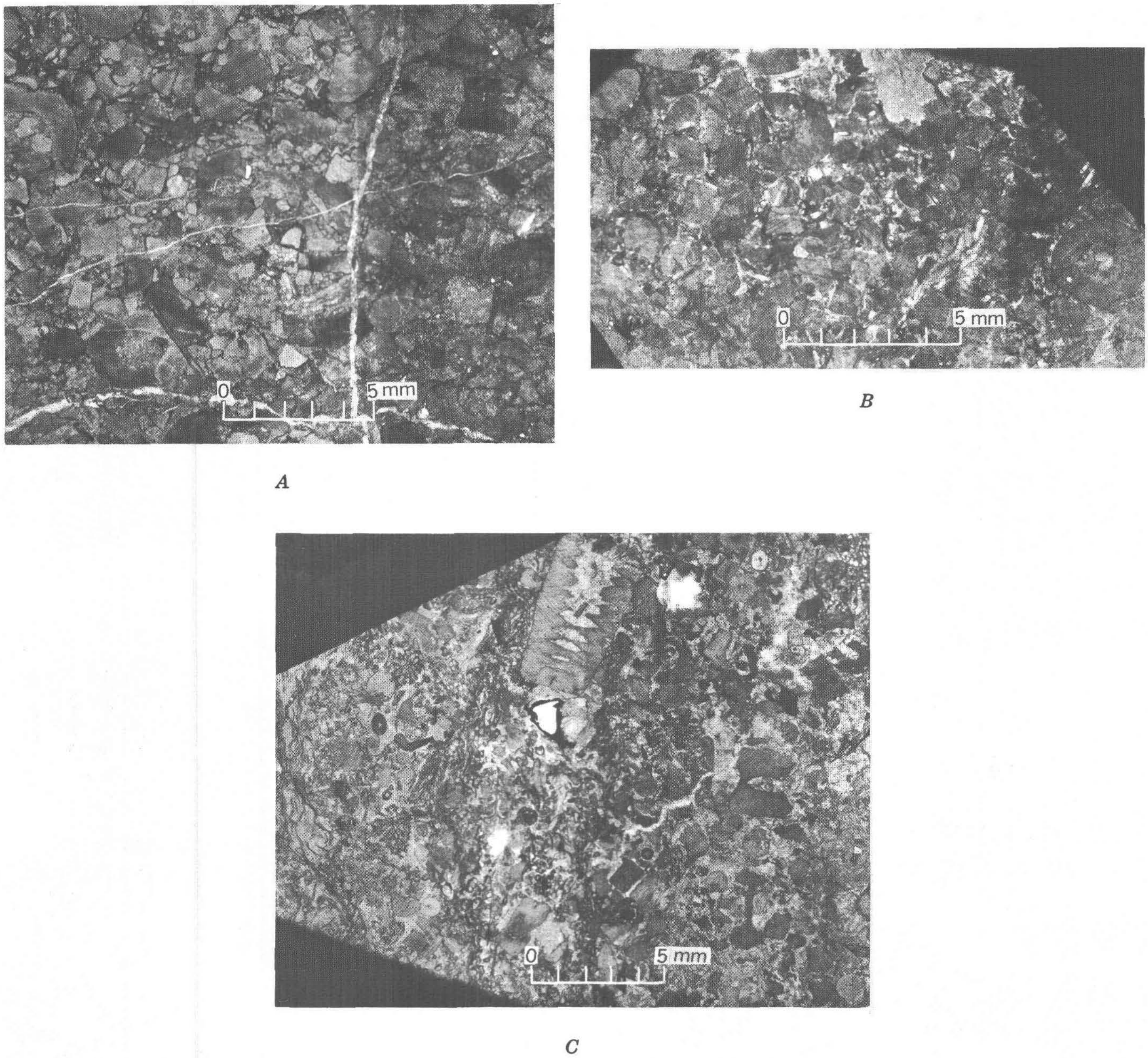


FIGURE 4.—Thin sections showing biosparite and dolomitized biomicrite from the Nasorak Formation. The right side of each section has been stained with Alizarine red S. *A*, A partly dolomitized coarse-grained crinoidal biomicrite from the lower member of the Nasorak. Although the coarse-grained fossil allochems are closely packed, the original intergranular material was probably micrite matrix that is now nearly completely dolomitized. This is indicated by the finely crystalline size of the dolomite and a few small relict patches of micrite. The allochems are only slightly embayed and replaced; most of them remain nearly pure calcite. The late veinlets are calcite. 59ACr–118B. *B*, Coarse-grained crinoidal biosparite of the Cape Thompson Member. Closely packed coarse- and very coarse grained fossil allochems, with clear calcite spar overgrowths and cement; contains a negligible amount of matrix micrite. Virtually no dolomite nor terrigenous material occur in this section. 5ACr–120A. *C*, Coarse-grained biosparite, a rock type that occurs only rarely in the upper member of the Nasorak. The rather poorly sorted fossil allochems contain a relatively small amount of matrix micrite, and most of the intergranular space has been filled with sparry calcite cement. There is no identifiable terrigenous silt and only extremely minor amounts of replacement silica rim a few of the fossil clasts. 59ACr–9b#1.

Many of the dark limestone and shale beds of the upper member occur as rhythmically interbedded pairs that appear to be graded beds (fig. 5). Although there is little obvious gradation of size within the in-

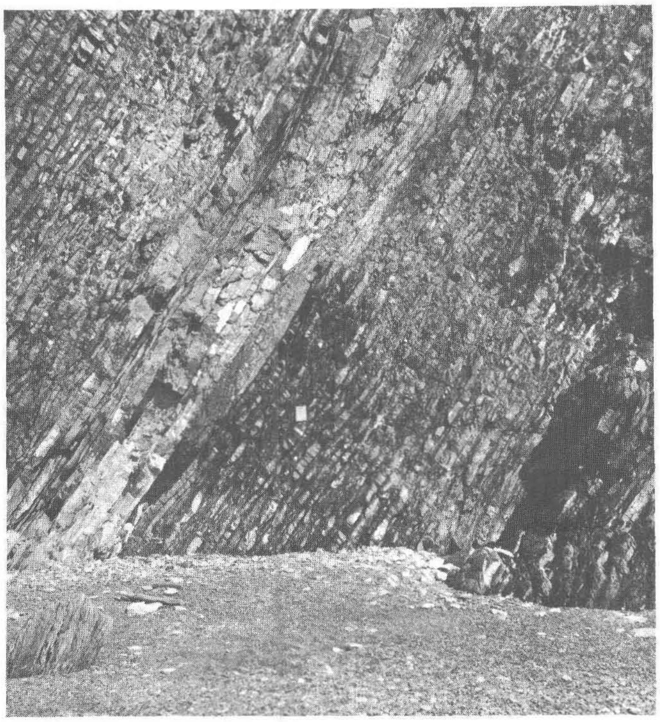


FIGURE 5.—Rhythmically interbedded limestone and shaly limestone of the Nasorak Formation. The upper part of the unit 18 of the section measured near the mouth of Nasorak Creek (see "Measured bedrock sections," p. 48). The thick-bedded zone is the basal part of unit 17. Tops of beds are to the left.

dividual limestone beds, their basal contacts are commonly sharp and continuous, whereas their contacts with the overlying shale are finely intertonguing and gradational. Some of the beds pinch and swell, a few to the extent of being nearly disconnected alined nodules. But the beds are continuous and, at least in gross aspect, parallel, with alternating pinches and swells of successive beds compensating each other. There are also a few zones of even-, continuous-, medium-bedded limestone that have only minor amounts of interbedded shale (fig. 6). The shale interbeds are thinly laminated and many laminae are well expressed by the presence of flat-lying fragments of leafy bryozoan fronds.

The graded bedding, poor sorting of allochems, and continuous and parallel stratification (Haff, 1959) suggest that many beds of the Nasorak were deposited from turbidity currents. Fossils that do not show some indication of fragmentation in transport are rare; only a few small (as much as 2 ft long and

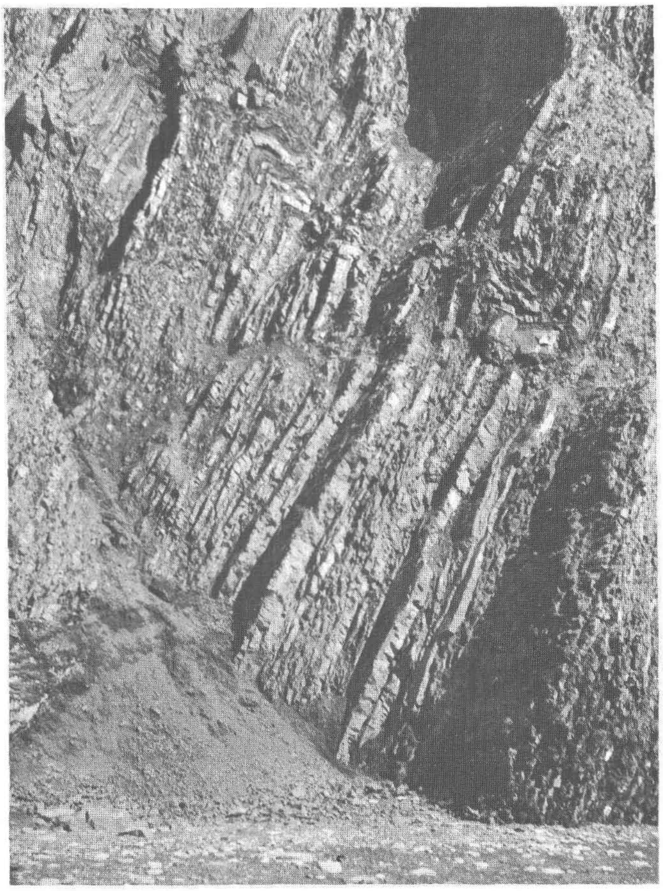


FIGURE 6—Continuous evenly bedded limestone beds of medium thickness, Nasorak Formation. Unit 16 of the section measured in the vicinity of the mouth of Nasorak Creek (see "Measured bedrock sections," p. 48). Note the contact with the underlying unit 17 and the distinctively nodular aspect of unit 17 in section and on bedding surfaces.

8 in. thick) lenticular heads of coral were observed in the section (fig. 7). They probably do not indicate such shallow depth as to preclude their association with turbidity-current deposits. The nodular pinching and swelling of some beds may be due to differential compaction.

The contact with the underlying mudstone-sandstone-limestone sequence is gradational and probably intertonguing. The contact with the overlying rocks designated the Kogruk(?) Formation is gradational. It was arbitrarily drawn at the base of the lowermost thick-bedded dolomite seen in the sea-cliff section west of the mouth of Nasorak Creek. Although the Kogruk(?) Formation is not exposed in the sea cliffs west of Cape Thompson, the middle part of the Nasorak is exposed in both sets of cliffs, and correlations of stratigraphic position may be made on nearly a bed-to-bed basis (fig. 2). The thickness measured from the sea-cliff exposures totals about 2,100 feet. Elsewhere, structural complexities and

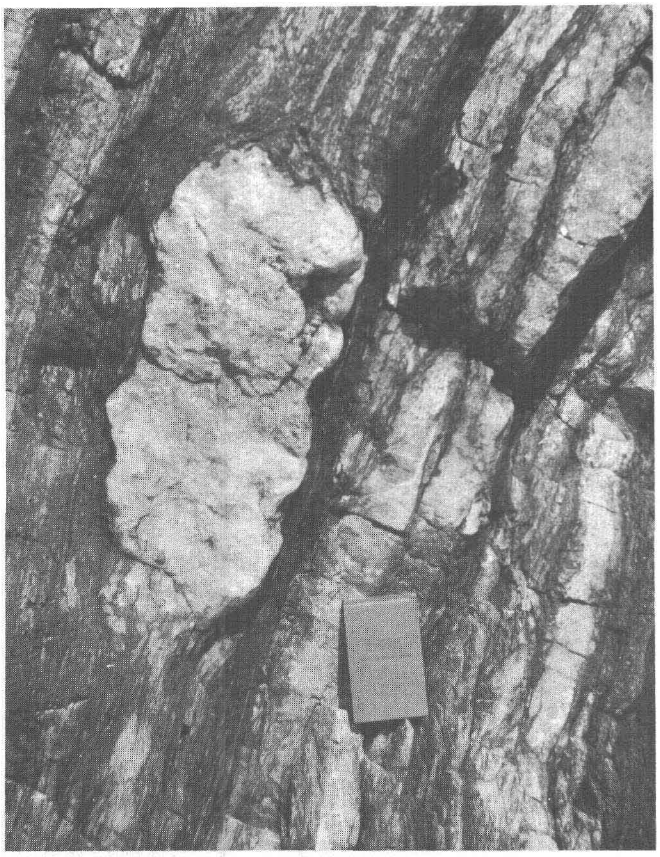


FIGURE 7.—Coral head *(Lithostrotionella)* in upper part of Nasorak Formation. Tops of beds to left. Notebook is 8 by 5 inches.

lack of exposures prevent reliable measurements of thickness.

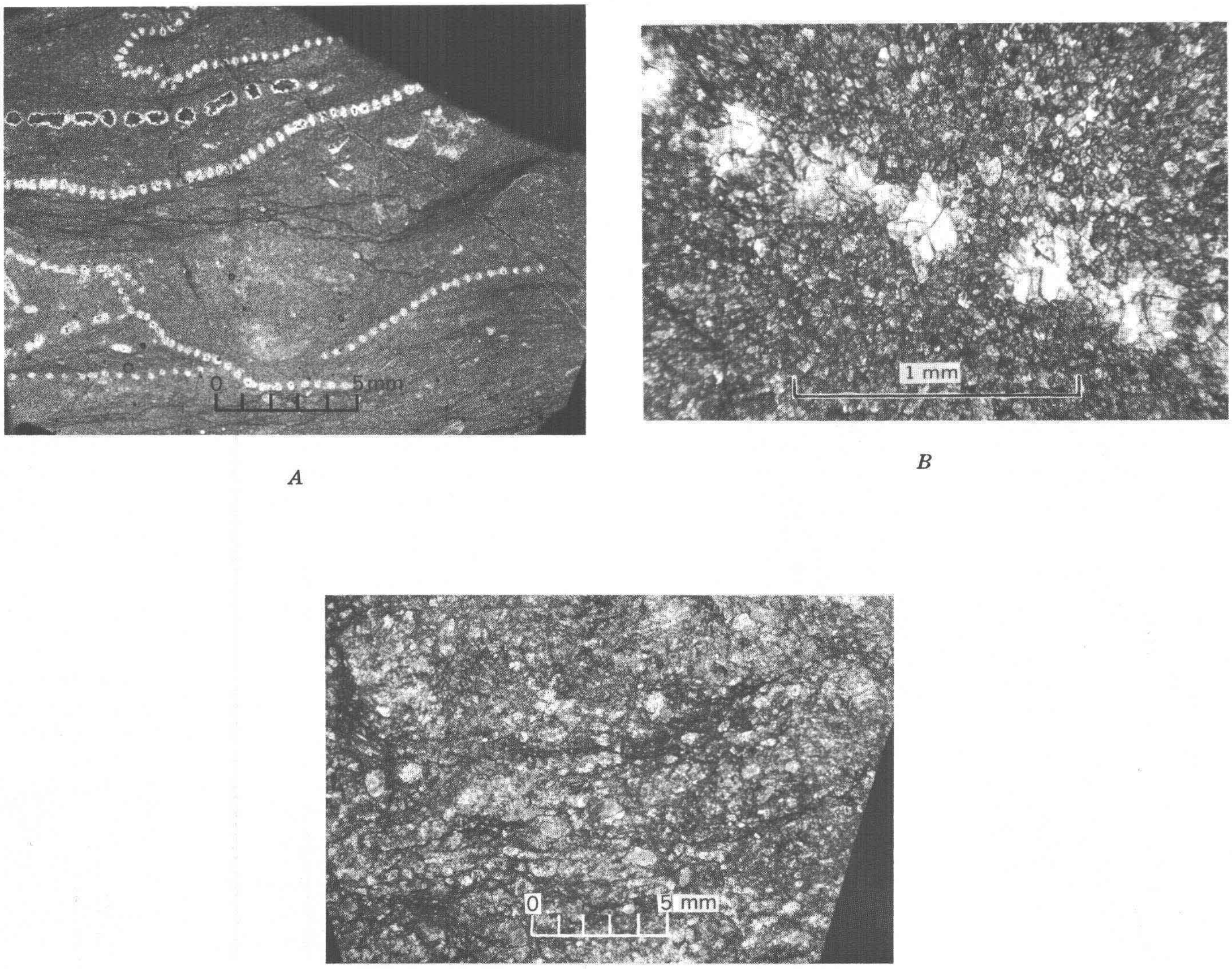
Fossils are relatively abundant. The identifiable forms are chiefly Bryozoa (predominantly fenestrate), brachiopods, horn corals, lithostrotionoid corals, and a few endothyroid Foraminifera. The megafossils were examined by J. T. Dutro, Jr., and Helen M. Duncan, of the Geological Survey, who conclude (written commun., 1961) that collections from the upper 1,500 feet of the Nasorak Formation (table 2) indicate equivalence to the lower part of the Alapah Limestone (Upper Mississippian) of the central and eastern Brooks Range, and those from the lower approximately 500 feet indicate correlation with the upper part of the Wachsmuth Limestone (Lower Mississippian). They also conclude that the basal 165 feet of the Nasorak contains fossils that correlate with those of the Utukok Formation (Lower Mississippian) of the western DeLong Mountains (Sable and Dutro, 1961, p. 591–592) and that the fossils of the remaining 1,935 feet of the Nasorak are equivalent to those in part of the Kogruk Formation (Lower and Upper Mississippian) of the western DeLong Mountains (Sable and Dutro, 1961, p. 592). Apparently, then, the beds of the Nasorak Formation represent continuous deposition from Lower Mississippian at the base to Upper Mississippian at the top. The formation is accordingly assigned an Early and Late Mississippian age; the lower member and Cape Thompson Member are included in the Lower Mississippian part, and the boundary between the Lower and Upper Mississippian lies in the lower part of the upper member.

KOGRUK(?) FORMATION

The name Kogruk(?) Formation is applied to a thick dolomitic sequence (unit Ml_4 of Campbell 1960a, b) in the Lisburne Group of this area because its stratigraphic position is similar to that of the Kogruk Formation described by Sable and Dutro (1961, p. 592) in its type area in the western DeLong Mountains. There seems to be a general similarity of bedding characteristics, rock types, and fauna, although the rocks designated Kogruk(?) in the Lisburne Peninsula contain much more abundant dolomite than the type Kogruk of the DeLong Mountains.

The Kogruk(?) Formation is continuously and almost completely exposed along the sea cliffs west of the mouth of Nasorak Creek; probably only a few hundred feet of beds are missing because of high-angle faulting. It is also exposed in the sea cliffs of Crowbill Point and is intermittently well exposed along the cutbanks of the Kukpuk River. In rubble outcrops the rocks of the Kogruk(?) Formation may be distinguished from the underlying Nasorak Formation by their generally lighter color and the relative abundance of large blocky debris. The Kogruk(?) may be distinguished from the younger overlying units by its generally bolder topographic relief, lighter color, and the general absence of close-spaced bedding traces on rubble ridges.

The Kogruk(?) Formation consists predominantly of light-gray to dark-gray very finely crystalline to medium-crystalline dolomite, interbedded with generally minor amounts of dark-gray partly dolomitized limestone. Most of the rocks are pure carbonate with virtually no terrigenous minerals, but a few beds of carbonate mudstone contain a small amount of fine quartz silt and possibly some clay. Undolomitized calcite allochem remnants are rare in most of the dolomite beds, but many contain some identifiable allochem ghosts (fig. 8). Probably their original composition is best indicated by comparison with the partly dolomitized limestone interbeds. The limestone beds consist chiefly of detrital fossil fragments ranging in size from fine sand to fine pebbles. In



A B C

FIGURE 8.—Dolomitized fossiliferous micrite and biomicrite from the Kogruk(?) Formation. *A*, Finely crystalline biogenic dolomite. The fossil structures are cross sections of leafy bryozoan fragments. The left half of the section has been stained with Alizarine red S and virtually no calcite is present. The rock is nearly pure dolomite. This is a clear example of a completely dolomitized Bryozoa-bearing micrite showing considerable preservation of the original sedimentary fabric, now expressed as variations in the crystal size of the dolomite. 59ACr–54. *B*, Photomicrograph of part of the same section shown in figure 16*A*, showing detail. The fossil allochems have been dolomitized to medium-crystalline subhedral to euhedral dolomite, relatively clear and free of inclusions. The matrix has been dolomitized to a finely crystalline anhedral to subhedral material containing abundant minute inclusions. 59ACr–54. *C*, Fine and coarsely crystalline biogenic dolomite. An excellent example of a completely dolomitized biomicrite. Medium- to coarse-grained fossil allochems (a few of which are readily identifiable as crinoid columnals) have been dolomitized to coarsely crystalline dolomite, whereas the original calcite mudstone matrix has been dolomitized to finely crystalline dolomite. The rock apparently originally contained between 20 and 25 percent fossil allochems. 59ACr–29A.

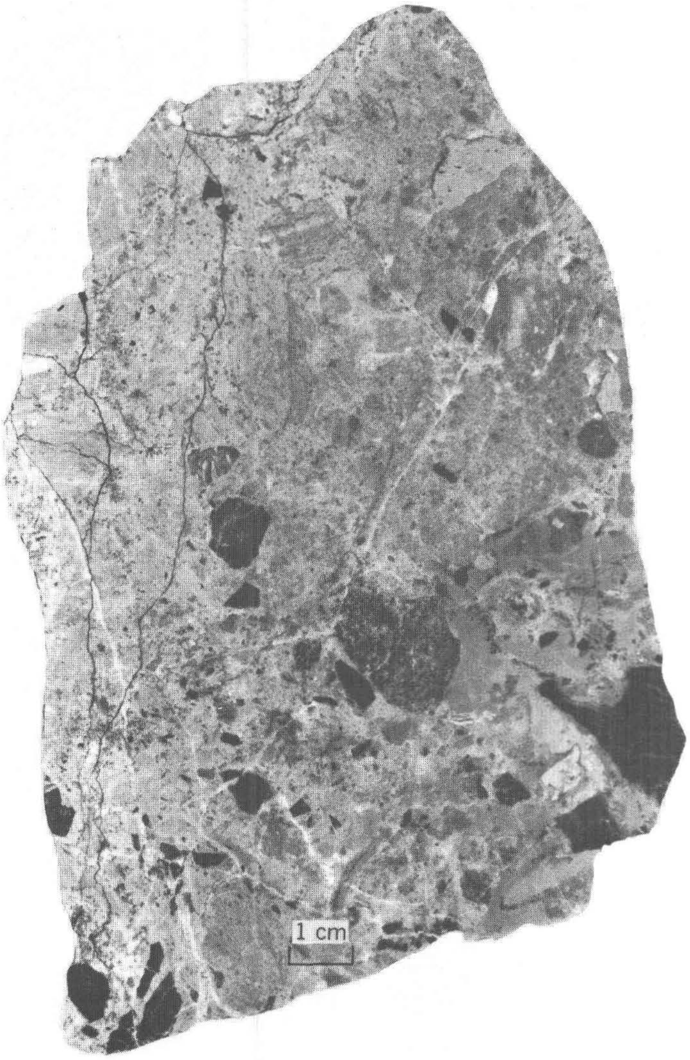


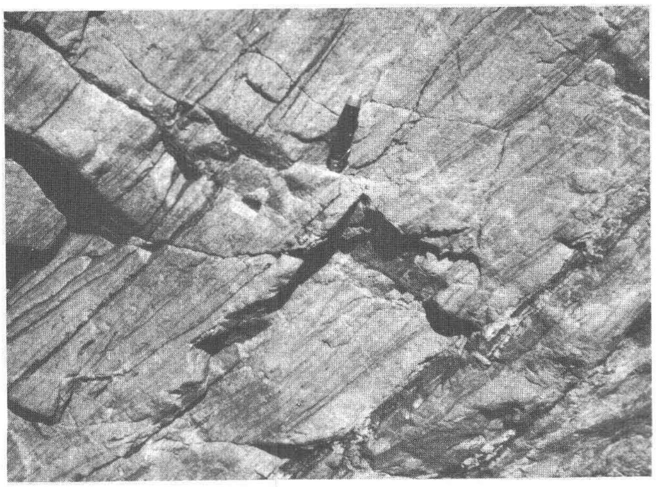
FIGURE 9.—Texture and clast size in dolomitized sedimentary breccia in the Kogruk(?) Formation. The clasts are dark-colored chert and lighter colored dolomite, in a matrix of medium crystalline dolomite and only minor relict(?) calcite micrite.

some, the interstitial material is very finely crystalline dolomite, and dolomite locally rims and replaces irregular patches of the clasts themselves. In other beds the interstitial material consists of a matrix of microcrystalline or very finely crystalline calcite locally with variable amounts of very finely crystalline dolomite. Light-gray and dark-gray chert commonly forms nodules as well as continuous and discontinuous layers in some limestone beds. The chert content varies greatly from bed to bed and also along the strike of individual beds. About 140 feet below the top of the unit is a zone of breccia about 400 feet thick composed of very small to very large fragments of chert and dolomite in a microcrystalline to finely crystalline matrix that is predominantly dolomite (fig. 9). This brecciated unit is bedded within the Kogruk(?) and may be a sedimentary breccia or possibly a cave breccia, though it appears to be too widespread to be entirely cave breccia. There are also several thinner zones in the upper half of the Kogruk(?) that contain intraformational breccia (fig. 10).

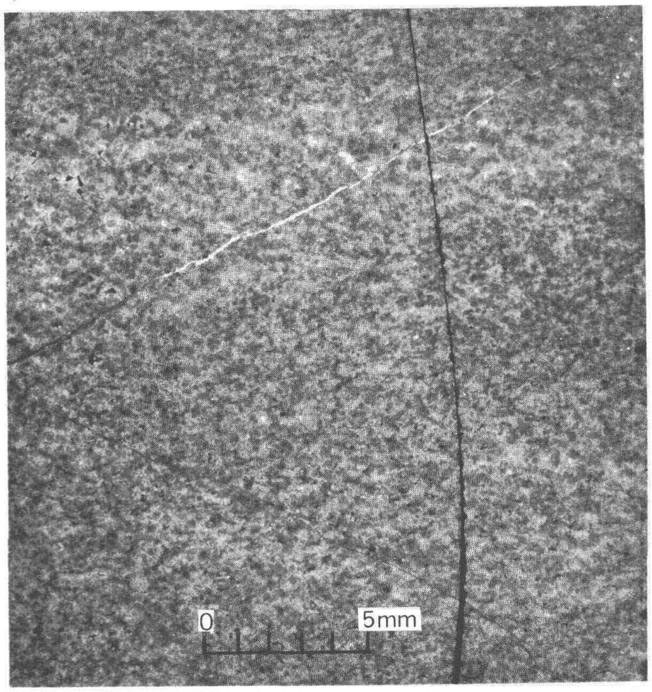
Irregular interbedding of thin, medium, thick, and very thick beds is characteristic of the Kogruk(?) Formation. Very thick beds of crystalline dolomite, one as much as 140 feet, are relatively abundant. The bedding planes are commonly even and are both continuous and discontinuous. Dolomitic rocks commonly show small-scale horizontal and gently cross-stratified internal current lamination that is expressed in exposed rocks as color banding of very low contrast, probably a result of minute impurities (fig. 11). Striking lenticular color mottling was seen in one very thick dolomite bed (fig. 12).

A total thickness of 3,670 feet was measured along the sea cliffs (pl. 2*B*). (See measured section, p. 35–44.) An unknown thickness has been faulted out of the upper part by three high-angle faults, one of which forms the contact with the overlying Tupik Formation of the Lisburne Group. From detailed

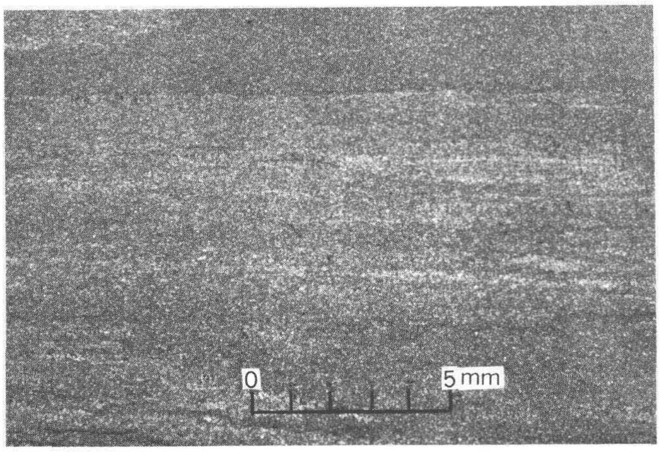
FIGURE 10.—Intraformational breccia in unit 9 of the Kogruk(?) Formation section measured in sea cliffs west of the mouth of Nasorak Creek. Note internal current lamination in light-colored dolomite as well as in the large breccia fragments of dark-colored dolomite.



A



B



C

FIGURE 11.—Relict current lamination in Kogruk(?) dolomite. *A*, Megascopic relict current lamination in dolomite. Unit 9 of the section of the Kogruk(?) Formation measured in sea cliffs west of the mouth of Nasorak Creek. *B*, Thin section of rocks shown in *A*. At this scale the lamination, though still visible nearly perpendicular to the long crack in the thin section, is ghostly and poorly defined. The rock is chiefly an anhedral mosaic (though a few euhedral faces occur) of coarse- to medium-crystalline dolomite. The left edge of the section has been stained with Alizarine red S, which brings out the late calcite veinlet and irregular intergranular patches of late(?) calcite spar. Apparently, an original lamination, formed by the sedimentary alternation of fine and coarser grained calcarenite or carbonate mudstone, was preserved through dolomitization, now being expressed as alternations of dolomite of different crystal size and variations in abundance of inclusions. 59ACr–67a. *C*, Relict current lamination in dolomitized calcilutite. Finely crystalline laminated dolomite, with lamination expressed by the variation in crystal size. From unit 20 of the section of the Kogruk(?) Formation measured in sea cliffs west of the mouth of Nasorak Creek. 59ACr–56a.

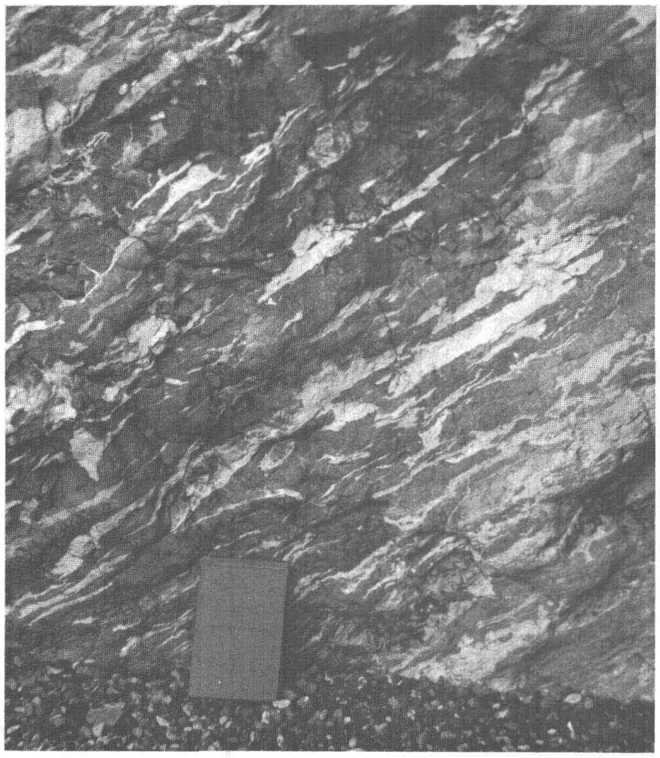


FIGURE 12.—Distinctive lenticular color mottling of unit 16 of the Kogruk(?) Formation in section measured west of the mouth of Nasorak Creek. The notebook is 8 by 5 inches.

structure sections it is estimated that probably not more than 500 feet of beds that should be assigned to the Kogruk(?) Formation are missing at the sea-cliff exposures because of the faulting. The thickness elsewhere could not be reliably determined because of complex structure and poor exposures.

Fossil material consists of abundant crinoid columnals and undetermined echinoderm debris and subordinate Bryozoa, horn corals, small colonial corals (including lithostrotionoid corals, particularly near the base), brachiopods of several species, and at least one blastoid (table 2). The fossil collections were examined by J. T. Dutro, Jr., and Helen M. Duncan, of the Geological Survey, who report (written commun., 1961) that the fossils appear to correlate with those in the upper part of the Alapah Limestone of the central Brooks Range. Several collections represent a Chester-type assemblage of bryozoans, brachiopods, and echinoderms. Dutro and Duncan also note that the collections correlate broadly with the *Gigantoproductus* zone of the central Brooks Range and that *Gigantoproductus* has been found in similar rocks near Cape Lisburne. They further suggest (written commun., 1961) that the Kogruk(?) Formation and most of the underlying Nasorak Formation are faunally equivalent to the type Kogruk of the western DeLong Mountains. The presence of Late Mississippian fossils in the Kogruk(?) and in the upper part of the underlying Nasorak Formation suggests that all the rocks assigned to the Kogruk(?) in this area are of Late Mississippian age, whereas the type Kogruk Formation of the western DeLong Mountains is considered to be of Early and Late Mississippian age (Sable and Dutro, 1961, p. 592).

TUPIK FORMATION

The Tupik Formation (unit $M1_5$ of Campbell, 1960a, b) is the topmost formation of the Lisburne Group. The Tupik Formation was named after exposures on Tupik Mountain in the western DeLong Mountains area (Sable and Dutro, 1961, p. 592, 593). Although complete equivalence of the type Tupik to the rocks of this area is not clearly demonstrable, the name Tupik is herein used because fossil collections indicate approximate faunal equivalence, because of general similarities in rock type, and because of its stratigraphic position at the top of the Lisburne Group.

The Tupik Formation is best exposed in sea cliffs about 1½ miles west of the mouth of Nasorak Creek (pl. 2*B*). Elsewhere in the map area, it is only locally found at the top of the Lisburne Group, partly because of poor exposures. Where present, the Tupik may be distinguished from the underlying strata by its generally darker colors, more subdued topographic expression of the rubble slopes formed in it, and the relative abundance of black chert. It is distinguished from the overlying Siksikpuk Formation by darker color and slightly greater resistance to erosion.

The Tupik Formation consists chiefly of interbedded grayish-black chert, dark-gray to medium-dark-gray carbonate mudstone including dark-gray to medium-dark-gray very finely crystalline to microcrystalline limestone, and subordinate interbedded greenish-black to dark-greenish-gray chert and very fine to finely crystalline dolomite. The limestone beds contain variable but generally small amounts of nodular chert. The dark-gray to medium-dark-gray carbonate mudstone is locally partly dolomitized; a few beds of the mudstone contain several percent of terrigenous quartz silt, and shaly fissility is common in the beds of the lower half of the section exposed.

Approximately the lower half of the beds exposed in the sea cliffs consist of thin-bedded interbedded limestone and calcareous shale. Thick beds of chert and carbonate mudstone are more common in the upper half. Most of the chert is in beds 0.1 foot to

2 feet thick with slightly uneven but generally continuous bedding surfaces. The carbonate mudstone and very finely crystalline dolomite beds range from less than 1 inch to 3 feet in thickness, but most commonly are 7 inches to 1 foot thick. The beds are generally continuous, parallel, and of even thickness.

About 330 feet of beds are exposed in the sea cliffs just east of the mouth of Imikrak Creek. (See measured section, p. 34–35.) Where well exposed in the sea cliffs, the contacts with both the underlying Kogruk(?) Formation and overlying Siksikpuk Formation are high-angle faults. Farther inland, however, geometric relations of the contacts with the Kogruk(?) and Siksikpuk, although poorly exposed on rubble slopes, indicate accordance, and structure sections suggest that the total thickness of the Tupik probably does not much exceed 500 feet. The sporadic distribution of this unit at the top of the Lisburne may be accounted for by rapid facies changes along the strike, by a disconformity at the top of the Lisburne, or possibly by a combination of both phenomena. Certainly no appreciable angular unconformity occurs at the top of the Lisburne Group in this area.

Fossils are very rare, but a meager fauna was collected (table 2) from one carbonate mudstone bed and detrital fragments are common in some of the microcrystalline limestone beds. The fauna, consisting of gastropods and brachiopods, was examined by J. T. Dutro, Jr., of the Geological Survey, who reports (written commun., 1961) that the age is Late Mississippian.

The absence of a fauna of Pennsylvanian age contributes to the interpretation that the contact between the Lisburne and the Siksikpuk is disconformable. On the other hand, no fossils have been found at a higher stratigraphic position in the Tupik than about 150 feet below the top, and it is possible that the Pennsylvanian Period is represented by a rather thin zone of nonfossiliferous rocks. The relatively thin, though widely distributed, sequences that represent the Permian and Triassic Periods suggest the possibility that the Pennsylvanian too is represented by a thin stratigraphic section. Although an erosion surface underlies the basal Permian rocks in some parts of northern Alaska (Patton, 1957, p. 42), no strong angular discordance has been reported; nor do the Permian rocks contain widespread deposits of clastic material attributable to derivation from the Lisburne Group. It would thus seem fairly certain that the absence of a Pennsylvanian fauna does not reflect major emergence and erosion during that period.

PERMIAN AND TRIASSIC ROCKS

The Siksikpuk Formation of Permian age and the Shublik Formation of Triassic age, widely recognized along the southern foothills of the Brooks Range, are readily recognizable in this area. Here the two units are thin and commonly occur together in tightly folded and complexly faulted relations. The resulting distribution is complex and the units are undifferentiated in many parts of the map (pl. 1) where, because of lithologic similarities of some of the rocks of both units, the two are indistinguishable. The rocks are best exposed in sea cliffs at Agate Rock and near the mouth of Imikrak Creek (pl. 2), where sections were measured. The upper part of the Siksikpuk Formation and all the Shublik Formation are exposed in the sea cliffs at Agate Rock; only the basal few feet (or at most a few tens of feet) of the Siksikpuk is missing from the exposures near the mouth of Imikrak Creek. The formations strike northward from the coast and are intermittently exposed along that trend. Both crop out discontinuously along the east side of Crowbill Point and Saligvik Ridge. They are also exposed along the upper and lower reaches of Ilikrak Creek and in one small area along the Ipewik River about a mile north of its junction with the Kukpuk.

SIKSIKPUK FORMATION (PERMIAN)

The Siksikpuk Formation was named by Patton (1957) from exposures in the central Brooks Range. Overall similarity of lithology, fauna, and stratigraphic position indicates that the name is appropriately used in this area.

Greenish-gray argillite is the predominant rock type of the Siksikpuk Formation. It contains variable but generally very minor amounts of quartz silt and very fine sand. Near the base there is a zone of black gypsiferous(?) shale. Greenish-gray chert is common as interbeds in the argillite at several horizons, the most striking of which is the topmost zone of the formation where argillite is greatly subordinate to chert. Some of the argillite is calcareous in widely ranging proportions, and a few such beds contain marine fossils. Most of the chert appears to be a silicified argillite. Several red-colored zones within the argillite look like interbeds from a distance; in detail, however, the red-green boundary is highly irregular and cuts across bedding. The reddish bands appear to represent oxidized permeable zones within the argillite.

The argillite and chert are commonly medium to thin bedded. The thickness of the topmost cherty zone is variable, suggesting a slight disconformity at the top of the formation; however, no angular discordance with the basal beds of the overlying Shublik Formation was observed and the variable thickness may, alternatively, result from a facies change. The total thickness of beds assigned to the Siksikpuk is about 400 feet.

A meager fauna was collected from two horizons in the lower part of the Siksikpuk Formation. The lowermost, collection 59ACr–88f, comes from a single fossiliferous limestone bed about 4 inches thick, interbedded in argillite that lies beneath a zone of black shale. The locality is about 250 feet east of the mouth of Imikrak Creek, where the rocks are exposed in sea-cliff section. The other collection, 59ACr–89f, consists of calcareous fossils in greenish-gray argillite beds from sea-cliff outcrop exposures just west of the mouth of Imikrak Creek. Both collections have been examined by J. T. Dutro, Jr., of the Geological Survey, who provided the following lists of fossils (written commun., 1961):

Collection 59ACr–88f (18992–PC):
- *Sochkineophyllum*? sp.
- Linoproductoid brachiopod, indet.
- *Martiniopsis*? sp.
- *Squamularia*? sp.
- *Straparollus (Euomphalus)* sp.

Collection 59ACr–89f (18993–PC):
- *Linoproductus*? sp.
- *Cancrinella* sp.
- *Plicatifera*? sp.
- *Martiniopsis*? sp.
- *Spirigerella*? sp.
- *Straparollus (Euomphalus) alaskensis* Yochelson and Dutro
- *Amphiscapha*? sp.

Dutro (written commun., 1961) considers the age of these collections as "probably Early Permian." Thus, the Siksikpuk Formation is herein considered to be of Early(?) Permian age.

SHUBLIK FORMATION (TRIASSIC)

The Shublik Formation was named by Leffingwell (1919) from exposures in the Canning River region, where it was in part redefined by Keller, Morris, and Detterman (1961, p. 187–191). General similarities of lithology, fauna, and stratigraphic position indicate that the name is appropriately applied to the rocks mapped as Shublik in this area.

The Shublik Formation of this area consists of three and, locally, four lithologic zones. At the base there is a zone several feet thick of black shale with a few rare interbeds of dark-gray to black cherty limestone. This grades upward to a zone that consists chiefly of thin-bedded dark-gray to black cherty limestone and interbedded black shale with a few rare interbeds of thin-bedded pale-brown to grayish-orange fossiliferous limestone. Near the top, the most prominent rock type is thin- to medium-bedded pale-brown fossiliferous limestone like that interbedded in the underlying zone. The limestone zone is overlain in places by a thin zone of greenish-gray argillite much like that of the underlying Siksikpuk Formation. About 200 feet of beds are assigned to the Shublik Formation.

The limestone is characteristically a pelecypod coquina with a matrix of variably silicified microcrystalline calcite and perhaps some clay. It crops out distinctively as thin resistant very light colored ridges that are generally easily recognized on aerial photographs.

The fossils appear to be exclusively pelecypods of the genera *Monotis* and *Halobia* that characterize the Shublik Formation over much of northern Alaska. These fossils suggest a Late Triassic age for the upper beds (Keller and others, 1961, p. 190). The Shublik in the Killik-Itkillik area (Patton, 1959), has been assigned to the Early(?), Middle, and Late Triassic, the age designation herein retained.

JURASSIC OR CRETACEOUS ROCKS

Rocks of Jurassic or Cretaceous age include the two lithologic units that make up the lower 10,000 feet of a very thick sequence of flysch-facies mudstone and sandstone that underlies Ogotoruk Valley and the ridges and valleys to the east. The lower unit, in which mudstone predominates with minor amounts of interbedded sandstone, is the Ogotoruk Formation. The upper unit, in which sandstone and mudstone are interbedded in more nearly equal amounts, is the Telavirak Formation (fig. 13). In early reports on the area (Kachadoorian and others, 1959, p. 19; Sainsbury and Campbell, 1959; and Campbell, 1960a, pls. 2, 3) most of these beds were tentatively assigned to the Tiglukpuk Formation of Jurassic(?) age. Although perhaps partly correlative with the type Tiglukpuk Formation of Patton (1956a) in the central Arctic Foothills province of northern Alaska, the lack of faunal evidence, distinctive marker horizons, or physical continuity on which stratigraphic equivalence might be determined suggests that local names for the units are more appropriate. The Ogotoruk and Telavirak Formations were, therefore, named by Campbell (1965b, c). (They correspond respectively with the informal units KJ_1 and KJ_2 of Campbell, 1961b, p. 35.)

OGOTORUK FORMATION

The Ogotoruk Formation is named for exposures along Ogotoruk Creek and its tributaries, its type

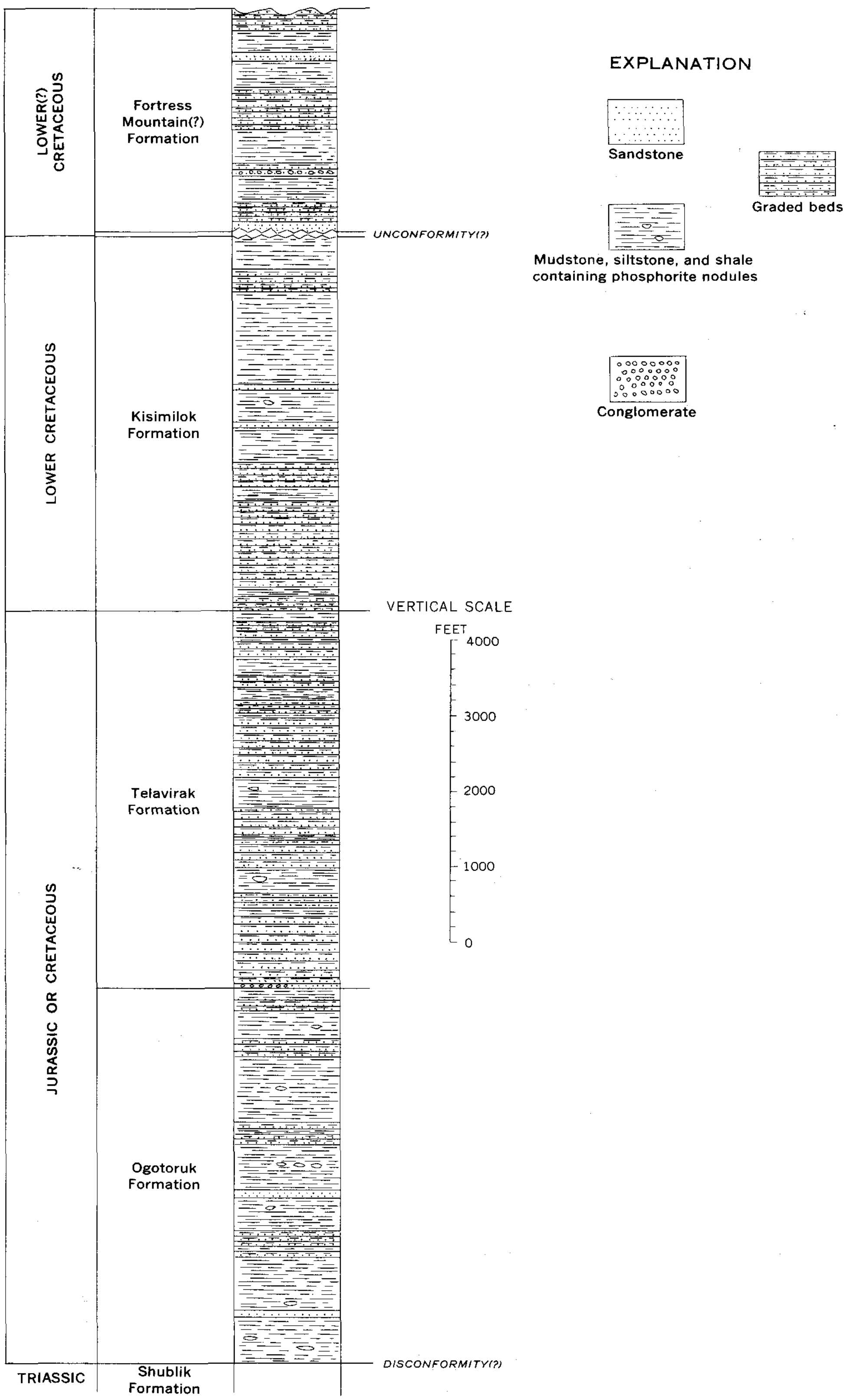


FIGURE 13.—Generalized composite section of the Ogotoruk, Telavirak, Kisimilok, and Fortress Mountain(?) Formations.

locality (Campbell, 1965b). The Ogotoruk Formation is the bedrock of the immediate Chariot test site area, and the proposed test excavation is entirely within this unit and its thin veneer of overlying unconsolidated deposits. Its topographic expression is generally one of low relief, and, indeed, its general extent is rather well defined by the wide, low valley of Ogotoruk Creek (fig. 14) and the continuation of that valley northward to the Kukpuk River. The lowermost 300 feet of the Ogotoruk Formation is also exposed in the low sea cliffs for about a mile east of Agate Rock (pl. 2) and in intermittent exposures extending northward from that coastal area. A thin sliver of rocks assigned to the Ogotoruk Formation is exposed in a faulted zone cut by the Kukpuk River.

The rocks of the Ogotoruk Formation are chiefly dark-gray mudstone interbedded with variable amounts of siltstone and very fine grained to medium-grained dark-gray and brown sandstone. The dark-gray mudstone, sandstone, and siltstone appear to differ only in grain size and relative abundance of clay matrix. The base of the formation, where exposed just east of Agate Rock, consists of several feet of dark-greenish-gray claystone which is commonly highly fractured and sheared roughly parallel to the bedding. A prominent red-weathering layer occurs about 3 feet above the base. Similar claystone beds (generally less intensively sheared) have been noted at several horizons within the Ogotoruk Formation in other areas where the stratigraphic position cannot be well established, but in general these zones appear to be restricted to approximately the lower 1,000 feet of the formation. Phosphorite nodules are locally common, but sparsely distributed, in the dark-greenish-gray claystone and dark-gray mudstone beds of several stratigraphic horizons. They occur chiefly as small oblate spheroids as large as 1 foot in diameter and 6 inches thick (fig. 15).

The rocks may be generally classified as arkosic or feldspathic wackes, as modal analyses generally fall near the boundary between feldspathic wackes and arkosic wackes on the triangular diagram of Williams, Turner, and Gilbert (1954, p. 292). (See fig. 16*A*.) The sand and coarser silt grains are predominately angular to subangular quartz, chert, plagioclase feldspar, and rock fragments. The grains are poorly sorted as to size, and the intergranular space is tightly filled with a matrix of clay and fine silt. Most of the fine silt appears to be finer fragments of the same minerals and rocks as those of the coarser

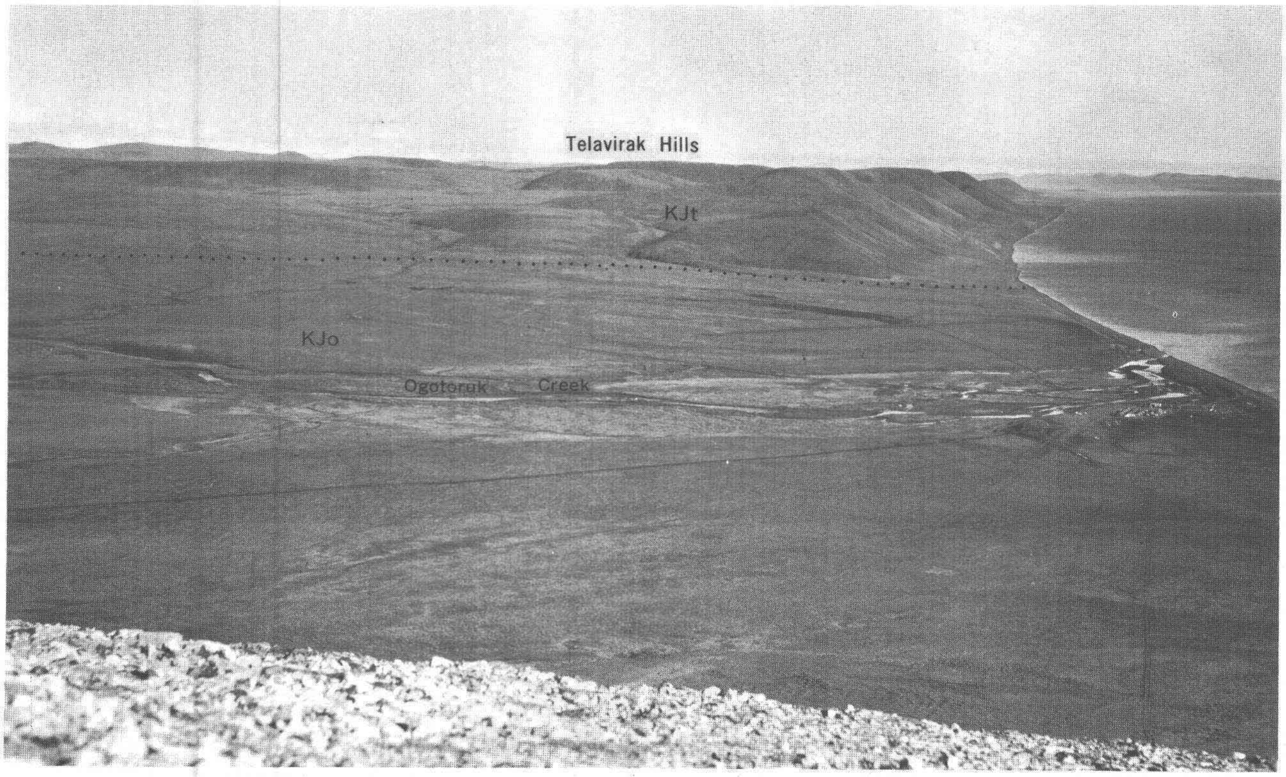


FIGURE 14.—Subdued topography of the valley of Ogotoruk Creek. The valley is cut into the relatively soft rocks of the Ogotoruk Formation (KJo), which is overlain by only a thin veneer of unconsolidated deposits. Across the valley the more resistant rocks of the Telavirak Formation (KJt) are capped by an old surface of low relief into which younger valleys have been cut. View southeastward from above Crowbill Point.

FIGURE 15.—Phosphorite nodule in mudstone of the Ogotoruk Formation. Straight edge of scale case is 2 inches long.

detrital fragments. The quartz grains include both clear quartz—some grains showing shadowy extinction—and quartz with variable amounts of inclusions. The chert grains are almost exclusively microcrystalline anhedral aggregates of quartz. The feldspar is exclusively plagioclase, all of which appears to be within the albite range. For the most part the plagioclase occurs as single clear grains and as granular aggregates of very fine crystalline feldspar; in some grains it occurs as a felty intergrowth of feldspar microlites with chloritic(?) clay minerals. The latter suggest derivation from altered fine-grained mafic igneous rock, but the grain size is generally too small to provide definitive evidence. The rock fragments are chiefly of claystone and siltstone of the same composition as the matrix, and many of them are deformed by adjacent monomineralic grains as if they had been deposited in a plastic condition. A few of the rock fragments consist of quartz-sericite and quartz-albite intergrowths; this suggests possible derivation from a metamorphic terrain.

The composition of the interstitial matrix of the sandstone appears identical to that of the mudstone. X-ray diffraction studies of the clays of the matrix indicate that the clays are almost exclusively chlorite and illite in variable proportions. Common in many rocks is very finely crystalline mica (sericite?), most of which appears to be authigenic. In addition, irregular small patches of authigenic quartz occur in the rocks, and there is also apparently some authigenic albite in the matrix material. The phosphorite nodules are chiefly microcrystalline anhedral aggregates of grains that are too fine to resolve in thin section; they give an apatite X-ray diffraction pattern.

The mudstone is in massive to thin-laminated beds. In many places thin-bedded to thin-laminated mudstone is rhythmically interbedded with thin-bedded and thin-laminated siltstone and sandstone. A few thick beds of sandstone occur at irregular intervals (fig. 17). Mudstone beds commonly have well developed close-spaced fracture cleavage and are locally slaty. The rhythmically interbedded units commonly show graded bedding, and the thinly laminated mudstones commonly show small-scale gentle cross-lamination as well as a size gradation in the relative abundance of silt and fine sand. The base of many of the sandstone and silty sandstone beds show bottom marks which are chiefly casts of scattered small pits and irregular depressions in the underlying mudstone. Flute casts and groove casts are rare and invariably small. Convolute bedding is found in many of the mudstones. Where exposed, the thin individual beds appear to be relatively continuous and parallel. These bedding characteristics, together with the poor sorting of grain sizes, suggest that many of the strata of the Ogotoruk Formation were deposited from turbidity currents.

The Ogotoruk Formation was seen to be in normal contact with the underlying Shublik Formation only along the sea cliff near Agate Rock. The contact relations there are obscured by shearing in the basal strata of the Ogotoruk, but locally the contact appears to be a disconformity of very low relief. East of Saligvik Ridge the main north-trending band of exposures is most commonly bounded on the west by rocks of the Lisburne Group which have been thrust over the Ogotoruk, but in a few places the contact is a high-angle fault with Permian and Triassic strata. The contact with the overlying Telavirak Formation is gradational. The total thickness of the Ogotoruk Formation is not accurately known. Because of the complex structure, lack of exposures, and lack of marker beds or key horizons, repetitions of lithologic types by stratigraphic alternation cannot be discriminated from structural repetition, and only an approximation can be made. A total thickness of about 5,000 feet is estimated from the structure sections (pl. 1).

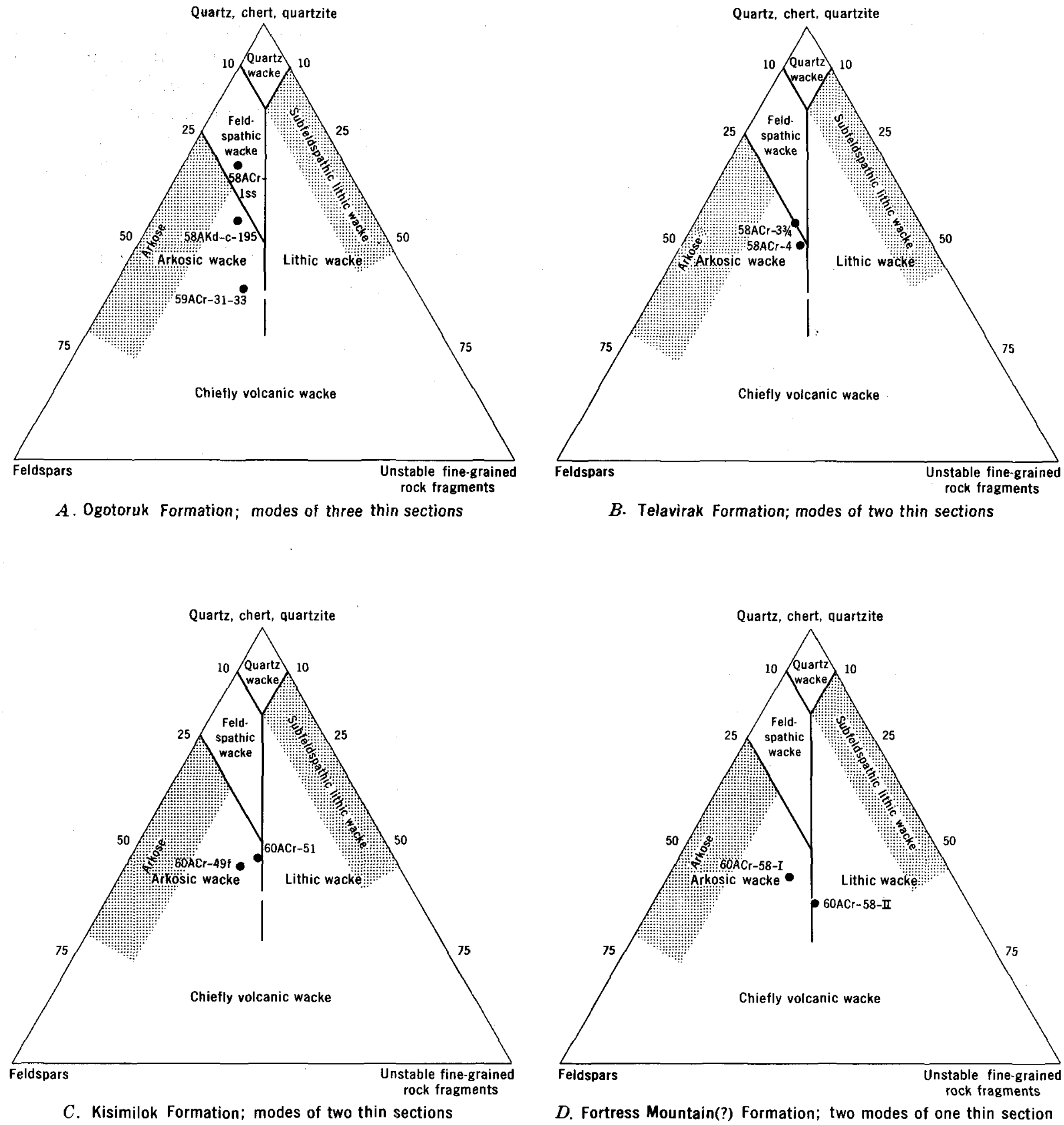


FIGURE 16.—Classification of "impure sandstones" or "wackes," after Williams, Turner, and Gilbert (1954, p. 292), showing plots of modes of thin sections of Cretaceous and Jurassic or Cretaceous rocks. The diagrams indicate only the three major constituents of sand or coarse silt size; the presence of 10 percent or more argillaceous matrix is understood as an essential constituent.
Mode 60ACr-58-I (*D*) was computed with detrital calcite included as matrix and closely resembles modes of sandstones from the underlying Cretaceous and Jurassic or Cretaceous formations. Mode 60ACr-58-II (*D*) was computed with detrital calcite included with the unstable rock fragments.

Fossils are extremely rare, and the few found were nondiagnostic as to age. The Ogotoruk, together with the Telavirak Formation, lies between known Upper Triassic and Lower Cretaceous strata. Dutro, Sable, and Bowsher (written commun., 1958) report that microfossils found in one sample near the base of the formation east of Agate Rock are nondiagnostic; but they conclude, from inferred correlation with the Kingak Shale of Jurassic age (Leffingwell, 1919, p. 119–120), that the age is probably Jurassic and possibly Early Cretaceous. The Ogotoruk Formation is therefore assigned a Jurassic or Cretaceous age.

FIGURE 17.—Bedding characteristics in the Ogotoruk Formation. Thick-bedded sandstone and interbedded slaty mudstone. Steel tape is extended about 3½ feet.

TELAVIRAK FORMATION

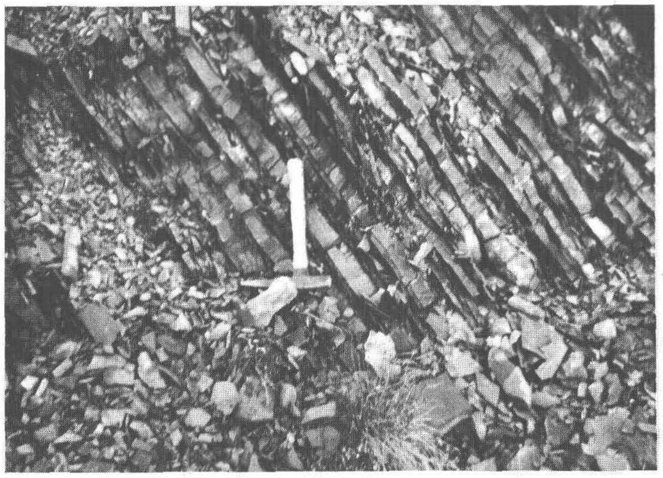
The Telavirak Formation (Campbell, 1965c) is named from the Telavirak Hills, which lie along the coast at the southernmost end of a north-northeast-trending belt of outcrops of this map unit. This belt is bounded on the west by Ogotoruk Valley and on the east by the western flank of Sigrikpak Ridge. The topographic expression of the Telavirak is much bolder than that of the underlying Ogotoruk Formation but is similar to adjacent parts of the overlying Kisimilok Formation. Upland areas of bedrock rubble are abundant, and relatively deep narrow valleys dissect an old upland erosion surface of low relief and cut both along and across the bedrock strike (fig. 14). Fresh outcrops of the formation are limited almost exclusively to stream cutbanks and therefore are small and disconnected.

The rocks of the Telavirak Formation are very similar to those of the Ogotoruk Formation. The Telavirak is distinguished chiefly by more nearly equal proportions of sandstone and mudstone and generally thicker bedding of the sandstone. Although sandstone is abundant, massive and thin-laminated mudstone is probably the dominant rock type. Phosphorite nodules are prominent minor constituents in the mudstone beds of several stratigraphic horizons. A single discontinuous bed of polymict coarse pebble conglomerate, locally containing some material of cobble size, was found near the base of the Telavirak.

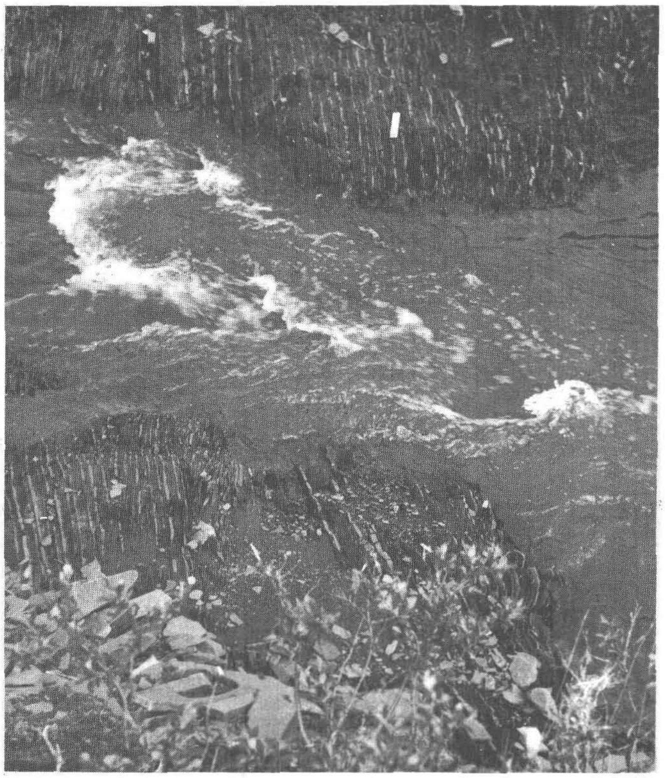
The lithology is nearly identical to that of the rocks of the Ogotoruk Formation. The sandstone is commonly fine- to very fine grained and of feldspathic or arkosic wacke composition (fig. 16*B*). The clays are chiefly chlorite and illite. A few sandstone beds contain relatively abundant coarse sand- and silt-sized fragments of coalified plant debris. The pebbles of the conglomerate bed are chiefly fine-grained graywacke, mudstone, chert, and cherty limestone, but at least one small pebble consists of a felty intergrowth of plagioclase microlites in a chloritic(?) matrix.

Characteristically, the beds of the Telavirak Formation are rhythmically interbedded mudstone and siltstone or very fine grained to medium-grained sandstone (fig. 18). The sandstone beds are generally graded, showing a general decrease in the maximum grain size upward. The graded beds are commonly bounded at the base by sharp contacts with the underlying mudstone, whereas their contacts with the overlying mudstone are commonly gradational and intertonguing on a very fine scale. Low-angle small-scale cross-lamination is moderately common in the sandstone beds. Nonlinear organic bottom marks are common at the base of many of the sandstone beds; groove casts and flute casts are rare (fig. 19). Cycles, consisting of a single sandstone bed at the base grading to mudstone at the top, range from 1 inch to 1½ feet in thickness; sandstone generally makes up from one-half to three-fourths of the thickness of the cycle. Individual graded beds are commonly continuous and parallel through the limits of individual outcrops (distances of as much as 200 ft locally). However, the beds appear to change facies rapidly along the strike, commonly within distances of a mile or less. The poor sorting, parallel stratification, graded bedding, convolute bedding in the laminated mudstones locally, and general absence of shallow-water phenomena suggest that these rocks were deposited from turbidity currents.

Fracture cleavage in the mudstone is common in the Telavirak Formation, as it is in the underlying Ogotoruk Formation. In both formations the fracture cleavage that is developed in the mudstone commonly does not penetrate adjacent sandstone beds. This is best illustrated in the rhythmically interbedded sandstone and mudstone that is found in



A



B

FIGURE 18.—Bedding characteristics in the Telavirak Formation. *A*, Rhythmically interbedded thin- and very thin bedded mudstone and very fine grained sandstone in nearly equal proportions. *B*, Thin-bedded to thinly laminated mudstone with subordinate rhythmically interbedded very thin bedded siltstone or very fine grained sandstone. Scale on opposite bank of stream is 6 inches long.

both formations but that is more abundant in the Telavirak (fig. 28).

The thickness of the Telavirak, like that of the underlying Ogotoruk Formation, is not accurately known because of the scarcity of exposures, lack of known key horizons, and the many structural complexities. However, one partial section of at least 5,000 feet was measured along Niyiklik Creek, a north tributary of Ogotoruk Creek.

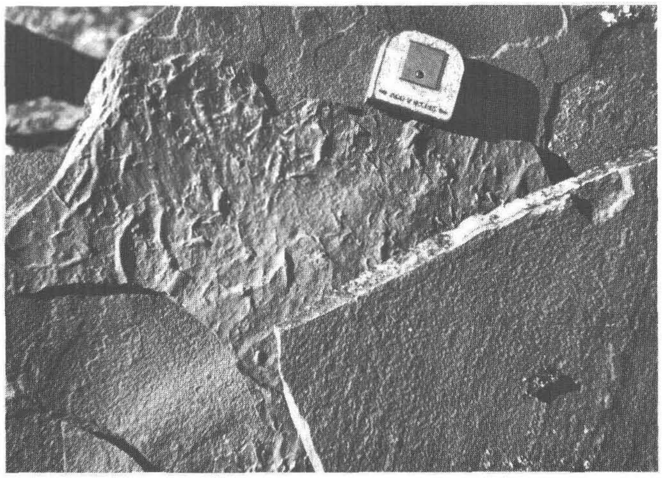


FIGURE 19.—Bottom marks in the Telavirak Formation. Straight edge of tape case is 2 inches long.

The contact relation between the Telavirak and the underlying Ogotoruk Formation is gradational. The contact was drawn at the base of the lowermost thick zone of rhythmically interbedded mudstone and thick-bedded sandstone; because of facies changes at the base of this zone, the contact is probably not everywhere at precisely the same stratigraphic horizon. The contact between the Telavirak and the overlying Kisimilok Formation appears conformable in poor intermittent exposures in the eastern headwaters of Ogotoruk Creek, but north and south of that area structural discordance suggests it lies along high-angle faults.

No diagnostic fossils have been found in the Telavirak Formation. Two collections of *Lebenspuren* were examined by P. E. Cloud, Jr., who concludes that the fossils are long-lived types. He notes (written commun., 1961) the association of similar forms with flysch-facies rocks in other areas and suggests that the fauna may represent deposition at bathyal or even possibly abyssal depths. Two other collections of poorly preserved fragmentary fossil material were examined by David L. Jones, of the Geological Survey, who reports (written commun., 1961):

M 1106. Field No. 60ACr–22f. Indeterminable plant and shell scraps.

M 1112. Field No. 60ACy–46f. *Buchia*? sp.

As the Telavirak Formation is overlain by strata of Early Cretaceous age and, together with the Ogotoruk Formation, lies above Upper Triassic rocks, it is assigned a Jurassic or Cretaceous age.

CRETACEOUS ROCKS

The two youngest bedrock units of the area are the Kisimilok Formation and the overlying unfossiliferous sequence that is questionably assigned to the Fortress Mountain Formation. Fossils of Early Cretaceous age have been found in the Kisimilok, and regional stratigraphic associations indicate that the Fortress Mountain (?) strata also are of Cretaceous age.

KISIMILOK FORMATION

The Kisimilok Formation was named for its exposures in the vicinity of Kisimilok Creek (Campbell, 1965d), whose drainage basin is almost entirely within the rocks of this unit. It is exposed in rubble suboutcrops on low hills along the coastline from a point about a mile west of the mouth of Kisimilok Creek to the east edge of the map area. The exposures along the coast form the base leg of the crude L-shaped outcrop pattern that extends northeastward up the valley of Kisimilok Creek to the Kukpuk River and an unknown distance beyond. The rocks are best exposed in stream cutbanks of southeast- and northwest-flowing tributaries of Kisimilok Creek and along some cutbanks of the Kukpuk River (fig. 20). The topographic expression is variable. A resistant zone containing relatively abundant sandstone beds underlies the high north-trending Sigrikpak Ridge, and a thick zone of softer mudstone underlies the broad valley of Kisimilok Creek. Resistant sandstone-bearing facies are also intermittently exposed in low hills along the coast, to the east of the mouth of Kisimilok Creek.

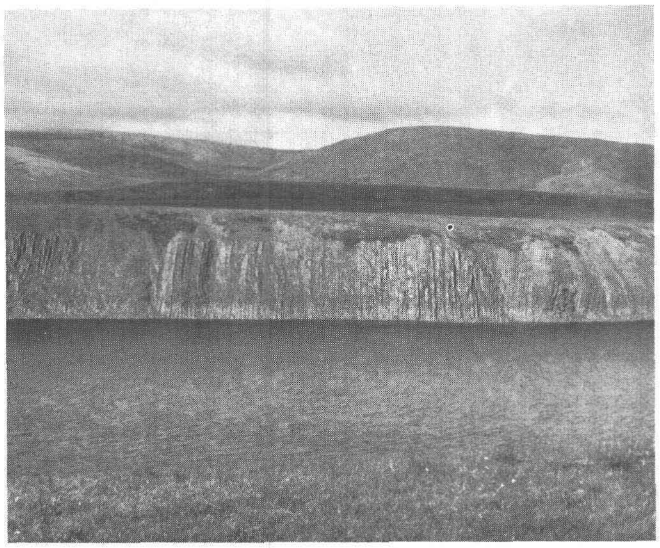


FIGURE 20.—Bedding characteristics and river cutbank outcrop aspect in the Kisimilok Formation on the Kukpuk River. Rhythmically interbedded sandstone and mudstone, standing nearly vertical, truncated by a stream-cut terrace that is overlain by a relatively thin veneer of stream-terrace deposits. View looking eastward to the northeast side of the river. The cutbank is about 40 feet high.

Massive to thinly laminated medium-dark-gray to dark-gray mudstone is the dominant rock type of the Kisimilok Formation. A zone containing relatively abundant interbedded sandstone, possibly as much as 2,000 feet thick, is prominent at the base of the unit. It locally contains abundant fossils. It is overlain by 3,000 feet or more of mudstone containing only rare thick sandstone interbeds. The sandstone-bearing facies exposed along the coast east of Kisimilok Creek are of uncertain stratigraphic position. They may be nonfossiliferous facies of the basal zone, returned to the surface by folding; or reflect rapid facies changes from sandstone to mudstone northward; or represent sandstone-bearing facies in a zone overlying the thick mudstone zone. Only the relative abundance of fossils, the sequence of thick zones of markedly different proportions of sandstone and mudstone, and a few subtle changes in bedding characteristics and lithology serve to distinguish this formation from the older ones beneath it.

In detailed lithology as well as bedding characteristics, the rocks of this formation are very similar to those of the underlying Telavirak and Ogotoruk Formations. The sandstones are graywackes of the feldspathic- or arkosic-wacke type (fig. 16*C*), and the mudstones have about the same composition as the matrix material of the sandstone with chlorite and illite as the predominant clays. Fossils are important distinguishing constituents where present. In the sandstones, detrital calcite sand grains form a very minor but significant accessory. A few percent of K-feldspar was noted in one of the fossiliferous basal sandstones of the Kisimilok Formation, but the bed is discontinuous and K-feldspar was not found in any of the other sandstones of this formation that were sampled and examined. The mudstones, particularly in the thick zone with relatively few sandstone interbeds, are commonly less silty and more argillaceous than those of the underlying formations. Phosphorite is generally less common in the mudstone of the Kisimilok Formation than in that of the underlying Telavirak and Ogotoruk Formations. Indeed, one 1-inch thick lens of material that resembled the phosphorite of the lower units was sampled and found to contain no phosphorite; it was instead about 70 percent siderite, the remainder being fine quartz silt and clay.

Although most of the mudstone is massive or thinly laminated like that found in the older formations, a significant amount of it shows a rhythmic interbedding of thin- to medium-bedded strata in which grading is expressed as a minor color change from medium gray at the base to dark gray at the top. The color gradation represents a gradual decrease upward in the amount of fine sand and silt included in the mudstone. These mudstones commonly lack both bedding-plane and fracture-cleavage fissility and crop out with a conchoidally fractured aspect (fig. 21). Most of the sandstone is rhythmically interbedded with the mudstone in locally continuous and parallel graded beds. As in the Ogotoruk and Telavirak Formations, the bedding characteristics and textures suggest that many of the beds were deposited from turbidity currents.

The contact between the Kisimilok Formation and the overlying Fortress Mountain(?) Formation is exposed only in rubble suboutcrop within the area of plate 1. On the basis of distinctive lithologic differences, the position and configuration of the contact can be drawn fairly accurately; the map shows it as a relatively smooth curve through an arc of nearly 90°, concave to the east. The general structural trends in the Kisimilok Formation locally parallel the contact, but in many places they appear to intersect it at an acute angle. The strikes and axes within the Fortress Mountain(?) Formation locally parallel the contact, particularly in areas immediately adjacent to it, but the dips indicate that those beds immediately adjacent to the contact are not necessarily the lowermost beds of the Fortress Mountain(?) Formation. Owing to the poor exposure, the possibility that this contact is an unconformity cannot be eliminated; however, the generally smooth curvature of the contact and the indications that both units are discordant with the contact suggest that it may be an eastward-dipping thrust fault. The contact between the Kisimilok Formation and the underlying Telavirak Formation is apparently conformable, but for much of its length it is faulted.

FIGURE 21.—Bedding characteristics and outcrop aspect of some of the mudstone of the Kisimilok Formation. Thin- to medium-bedded clayey mudstone in which bedding is expressed chiefly as color banding (of various hues of gray). Note also the lack of distinctively resistant strata and the conchoidal fracture. Straight edge of tape case is 2 inches long.

The total thickness of the Kisimilok Formation here could not be accurately determined because of the complex structure, absence of marker horizons, and poor exposures; but probably at least 5,000 feet of strata are represented, and perhaps several thousand feet more if the contact relations with the overlying Fortress Mountain(?) Formation are correctly interpreted.

Fossils, almost entirely pelecypods of the genus *Buchia* (=*Aucella*), are abundant locally in the lower zone of interbedded mudstone and sandstone and sparsely distributed in the overlying mudstone, but most of the beds of the Kisimilok Formation are relatively barren of fossils. The collections have been examined by David L. Jones, of the Geological Survey, who reports (written commun., 1961, 1963):

M 1107. Field No. 60ACr–49f *Buchia* sp. indet. Not well enough preserved for positive identification but could be *B. crassicolis* or *B. okensis*.
Age: Neocomian.

M 1108. Field No. 60ACr–53f Probably is *B. sublaevis*.

M 1109. Field No. 60ACr–75f *Buchia* sp. indet. Could be *B. okensis* but too poorly preserved to be sure.

M 1110. Field No. 60ACy–11f *B. subokensis*?

M 1111. Field No. 60ACy–12f *Lebenspuren*. Feeding marks? No age significance.

M 1113. Field No. 60ACy–48f Worm tubes, snail, and indeterminable clam fragments.

Jones concludes that the collections containing *B. "sublaevis"* are probably from early Valanginian rocks, and that the probable presence of *B. subokensis* suggests a Berriasian age for some of the section (written commun., 1963). On the basis of the pelecypod fauna, the Kisimilok Formation is assigned an Early Cretaceous age. A correlation with part of the Okpikruak Formation of Early Cretaceous age (Gryc and others, 1951, p. 159–160) is suggested on the basis of the *Buchia* species, following the zonation of Imlay (1959, p. 165).

FORTRESS MOUNTAIN(?) FORMATION

The Fortress Mountain Formation was defined in the Colville River region by Patton (1956b). Several general similarities of lithology and bedding characteristics between the youngest bedrock formation exposed in this area and the rocks called Fortress Mountain Formation a few tens of miles to the north in the Utukok-Corwin region (Chapman and Sable, 1960, p. 71–73) suggest that the unit may be suitably designated the Fortress Mountain(?) Formation. This formation is exposed in only one relatively small region along the east edge of the mapped area. Its outcrops are mainly limited to the cutbanks of the Kukpuk River and tributary stream, although bedding traces composed of the coarser rubble of more resistant rocks are locally common on ridge tops. The topographic expression of the formation is distinctively less subdued than that of the thick mudstone zone of the Kisimilok Formation that underlies it in most places.

Interbedded silty mudstone, siltstone, and sandstone are the dominant rock types with minor amounts of conglomerate. Thinly laminated to medium-bedded dark-gray silty mudstone predominates, but rhythmically interbedded thin- to thick-bedded sandstone is abundant in some zones as much as several hundred feet thick. The sequence differs from the underlying Kisimilok Formation in its generally more abundant sandstone content and in the greater abundance of silt and fine sand in the mudstones. The sandstones of this formation differ from the sandstones of the Kisimilok and Telavirak Formations in the character of the internal lamination, in the size and character of bottom marks, and to a minor degree in lithology and color.

The mudstone commonly is slightly but distinctively micaceous. The sandstone is graywacke of the arkosic- or feldspathic-wacke type (fig. 16*D*), in many respects similar to the graywackes of the older rocks of the area; but it is brownish gray to medium dark gray, and is commonly characterized by minute discontinuous uneven internal laminae of dark-gray mudstone. The sandstone beds differ slightly from those of the underlying units in that detrital calcite sand grains form a characteristic minor accessory. A polymict pebble conglomerate bed exposed along the Kukpuk River contains relatively abundant chert and altered mafic igneous rocks. Many of the sandstone beds contain as much as several percent of interstitial calcite cement, and secondary calcite is relatively abundant as thin veins and veinlets along fracture surfaces, chiefly joints.

As in the underlying units, the rhythmically interbedded sandstone-mudstone sequences display graded bedding, poor sorting, continuous parallel stratification (fig. 22), load casts, convolute internal lamination of mudstones, small-scale slump structures, and a general absence of shallow-water phenomena which strongly suggest deposition from turbidity currents. The internal lamination of the sandstone commonly is cross stratified on a very small scale at low angles, and the angles commonly are distinctively higher than those of the internal cross-lamination of the graywackes in the older formations. These rocks differ slightly from the turbidites of the older units in that current ripple marks were observed in several localities (fig. 23), and linear sole markings were seen, chiefly of the variety described elsewhere by Kuenen (1957, p. 235–242) as flute casts.

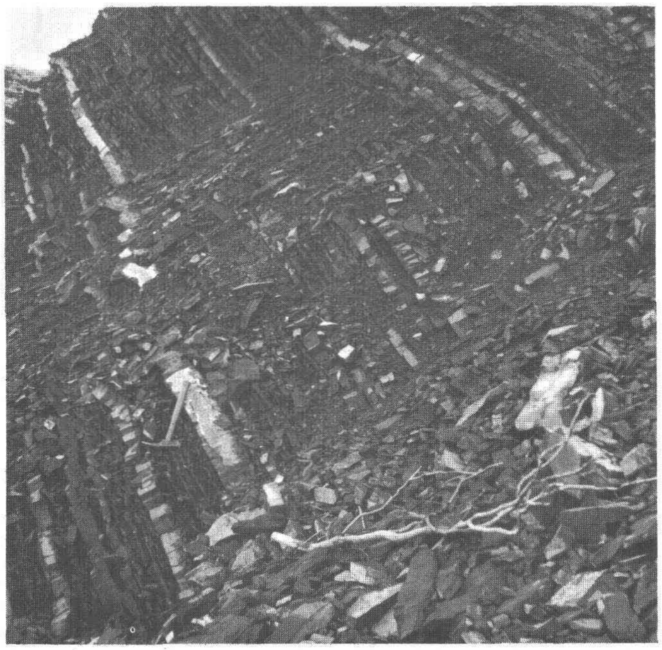


FIGURE 22.—Bedding characteristics in the Fortress Mountain(?) Formation. Rhythmically interbedded thin-bedded to laminated mudstone and somewhat subordinate sandstone. White coatings on some surfaces are calcite veinlets that formed along joints.

The thickness of the Fortress Mountain(?) Formation is not known in this area. A combination of poor exposures and complex structures prevents a reliable measurement of thickness, or even an evaluation of relative stratigraphic position of zones. About 3,000 feet of beds are probably represented, based on interpretations of structure sections (see structure sections, pl. 1). As noted above, the contact between the Fortress Mountain(?) and Kisimilok Formations appears to be a thrust fault. No bedrock formations younger than the Fortress Mountain(?) are exposed in the mapped area. A few tens of miles to the north, in the Utukok-Corwin region, the Fortress Mountain is succeeded by the marine Torok Formation, which is overlain by marine and nonmarine strata of the Nanushuk Group, in turn overlain by

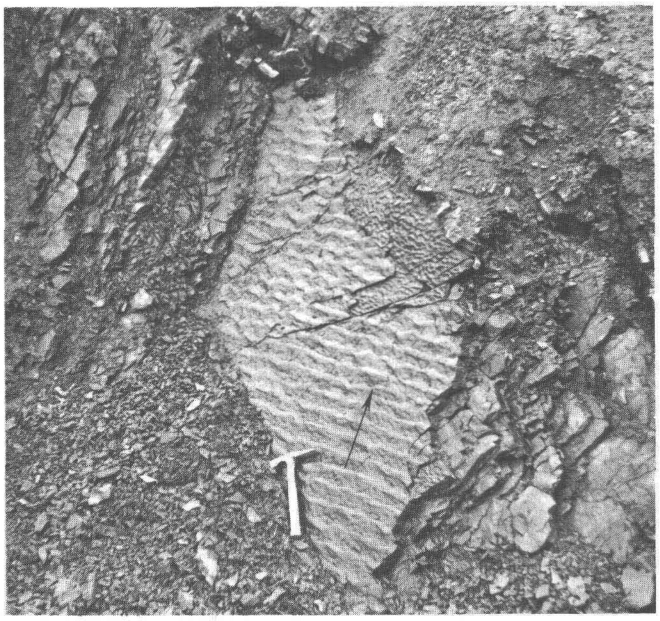


FIGURE 23.—Current ripple marks in the Fortress Mountain(?) Formation. Slight asymmetry of ripples indicates current in direction shown by arrow.

the nonmarine beds of the Colville Group, collectively of Early to Late Cretaceous age (Chapman and Sable, 1960). It seems reasonable to infer that at least some of them originally overlay the Fortress Mountain(?) Formation in the Ogotoruk Creek area but that they have been removed by erosion.

No fossils were found in the rocks of the Fortress Mountain(?) Formation within the mapped area. The rocks appear to be lithologically equivalent to the Fortress Mountain Formation in the Utukok-Corwin area (Chapman and Sable, 1960, p. 71–73); they are therefore tentatively assigned a probable Early Cretaceous age.

MEASURED BEDROCK SECTIONS

MISSISSIPPIAN ROCKS—WEST SECTIONS

[Sections measured at sea-cliff exposures at Cape Thompson and nearby, by R. H. Campbell and D. R. Currey, August 1959]

LISBURNE GROUP

NASORAK FORMATION

Erosion surface, top not exposed.

	Thickness (feet) Unit	Thickness (feet) Cumulative
Upper member of the Nasorak Formation (Mlnu):		
1. (Mlnu-g, h of pl. 2*A*) Limestone and calcareous shale or shaly carbonate mudstone. Medium-gray to medium-dark-gray biomicrite (may be dolomitized locally) rhythmically interbedded with variable amounts of dark-gray calcareous shale and (or) shaly micrite. Inaccessible (in upper part of cliff) but very similar to units 1–6 of eastern Nasorak section (pl. 2*B*)	320+(?)	320+(?)
2. (Mlnu-f(?) of pl. 2*A*) Shale and (or) shaly carbonate mudstone; interbedded limestone. Dark-gray shaly micrite or calcareous shale with thin interbeds of medium-dark-gray to dark-gray biomicrite or fossiliferous micrite. May include some chert as one zone contains "nodular" beds closely similar to those of unit 8 of eastern Nasorak section. Unit inaccessible in cliff. Great general resemblance to units 7, 8, and 9 of eastern section	115±30	435±30+(?)
3. (Upper part of Mlnu-b, c, d, e, of pl. 2*A*) Limestone and subordinate shaly carbonate mudstone and (or) calcareous shale. Medium-gray to medium-dark-gray biomicrite and fossiliferous micrite, regularly, and in many zones rhythmically, interbedded with subordinate thin beds and partings of calcareous shale and (or) shaly to thin laminated micrite. Calcareous beds locally partly dolomitized. Only basal beds accessible at beach level in proper stratigraphic position. Although higher beds dip down to beach, strong local folding nearly parallel to shoreline obscure position within unit. Zone near base contains very minor interbedded shale; limestone is coarse-grained crinoid biomicrite that in places shows "crinkly" internal lamination greatly resembling that of unit 16 of eastern Nasorak section. Other bedding characteristics also similar; the principal differences are that the rocks here contain a greater proportion of medium- and fine-grained fragmental fossil allochems. Unit generally resembles and probably correlates with units 10–16 of		

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
eastern Nasorak section. 59ACr–126, 59ACr–127 are chips taken to represent lithology	230	665±30+(?)
4. (Lower part of Mlnu-b, c, d, e, of pl. 2*A*) Limestone, chert and shale. Dark-gray limestone—chiefly fossiliferous internally laminated micrite—in part dolomitized, in part silicified (forming grayish-black chert), in thin to medium (rarely thicker than 1 ft) even and uneven continuous beds. Regularly, and in many zones rhythmically, interbedded with thin- and very thin bedded calcareous shale and (or) shaly, silty clayey micrite. Many of the cherty limestone beds pinch and swell in a "nodular" aspect similar to beds of unit 17 of eastern Nasorak section; probably approximately equivalent to this unit. Echinoderm and leafy bryozoan fragments were only fossils recognized; no fossils collected. 59ACr–125 consists of chips taken to represent lithology	160	825±30+(?)
5. (Upper part of Mlnu-a of pl. 2*A*) Limestone and shale. Medium-dark-gray clayey(?) silty(?) micrite (may include some dismicrite), locally dolomitized, with discontinuous lenticular thin internal lamination, in continuous relatively even surfaced beds commonly 4–6 in. thick. Rhythmically interbedded with shaly calcareous mudstone that makes up about 30 percent of the unit in beds commonly 1–2 in. thick. No fossils recognized, but most of the sparse allochems are probably fragmental fossil material. 59ACr–124 consists of chips taken to represent lithology. Unit similar to, and probably should be correlated with, upper part of unit 18 of eastern Nasorak section	40	865±30+(?)
6. (Middle part of Mlnu-a of pl. 2*A*) Mudstone and minor limestone. Grayish-black calcareous mudstone containing sparse brachiopods and horn corals, in beds as much as 6 ft thick. May have originally been shaly to thin internally laminated, but internal lamination now masked by close-spaced sheared (slickensided) cleavage surfaces. A few thin bends of grayish-black fossil-bearing micrite irregularly interbedded with the mudstone. Many fossil fragments and a few whole brachiopods are pyritized. Unit looks very much like lower part of unit 18 of eastern Nasorak section, with which it should probably be correlated. 59ACr–123f is a fossil collection (table 2). 59ACr–123 consists of chips taken to represent lithology	45	910±30+(?)
7. (Lower part of Mlnu-a of pl. 2*A*) Limestone, in part cherty, and subordinate shale. Grayish-black fossil-bearing (rare) micrite, probably containing some silt and clay and probably locally partly dolomitized, commonly silicified to varying extent and in many places appropriately called chert. Chiefly in moderately continuous relatively even surfaced beds 1–10 in. thick; irregularly interbedded with thin shaly partly calcareous mudstone beds and partings, also grayish black. Fragments of brachiopods only fossils recognized. 59ACr–122f is fossil collection (table 2) of meager material. 59ACr–122 consists of chips taken to represent lithology. Unit should be stratigraphic equivalent of unit 19 of eastern Nasorak section	40	950±30+(?)
Total thickness of partial section of upper member	950±30	

Accordant depositional contact.

Cape Thompson Member of the Nasorak Formation (Mlnc):

8. (Mlnc of pl. 2*A*) Limestone. Medium-light-gray to light-olive-gray (weathering to pale grayish orange) very coarse-grained crinoid-bryozoan biomicrite (in places fine rudite rather than very coarse arenite); commonly contains 60–80 percent fragmental fossil allochems. Parts of some beds

Cape Thompson Member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
appear to have sparry calcite cement rather than matrix micrite, but these seem very local and subordinate. Commonly a minor amount of dolomite (but locally up to nearly 20 percent) replaces matrix and forms rims on fossil structures. Crops out like one massive bed with bedding expressed by internal "crinkly" laminae, some more continuous than others, at 6-in. to 1-ft intervals. Both base and top appear to intertongue with adjacent shaly beds; intertonguing clearly exposed only at base. Unit greatly resembles unit 20 of eastern Nasorak section, it's probable stratigraphic equivalent. 59ACr–120f (table 2) is a chip of highly fossiliferous, but fragmental, limestone. 59ACr–120 consists of chips taken to represent lithology (fig. 9)	225	1,175±30+(?)

Accordant depositional contact.

Lower member of the Nasorak Formation (Mlnl):

	Thickness (feet) Unit	Cumulative
9. (Upper part of Mlnl of pl. 2*A*) Limestone (in some places partly dolomitized), chert, and mudstone. Upper 45 ft of unit is predominantly grayish-black shaly silty (about 30 percent fine quartz silt), clayey(?) partly dolomitized (at least 10 percent locally), ostracode-bearing micrite or calcareous mudstone; in beds from thin partings as much as 5 ft thick. Irregularly interbedded subordinate amount (about 30 percent) of medium-dark-gray partly dolomitized (about 15 percent) coarse- to medium-grained crinoid biomicrite in thin to medium lenticular discontinuous beds. Middle 35 ft is chiefly (about 70 percent) grayish-black to black chert (silicified laminated fossiliferous micrite) in uneven, moderately regular beds, generally 4–6 in. thick. About 15 percent of this cherty zone consists of medium-gray partly dolomitized (locally as much as 30 percent) coarse-grained crinoidal biomicrite in beds as much as 6 in. thick, chiefly near top where zone also includes a few partings of grayish-black calcareous shale as it grades into overlying predominantly mudstone zone. Lower 45 ft chiefly medium-gray partly dolomitized (some common, but generally less than 25 percent) coarse-grained crinoid biomicrite in uneven lenticular beds as much as 1½ ft thick (most commonly about 6 in.) with even internal bedding laminae. Minor interbedded dark-gray to grayish-black shaly micrite or calcareous mudstone. Minor amounts of grayish-black chert occurs as irregular small nodules with indistinct borders within limestone beds; varies in amount from 1 to 10 percent along individual beds. The biomicrite beds of entire unit commonly contain 75–85 percent fragmental fossil allochems. Dolomitization chiefly restricted to the matrix. In a few specimens intergranular material is entirely medium-crystalline dolomite (although most of the dolomite is aphanitic to very fine grained), and classification of the original material as either micrite or spar can only be assumed. Spiriferoid brachiopods are prominent in upper part of central cherty zone. Other brachiopods, colonial and solitary corals, and gastropods also found, along with the abundant echinoderm and bryozoan fragments. 59ACr–119f is a fossil collection (table 2). 59ACr–119 consists of chips taken to represent lithology	125	1,300±30+(?)
10. (Lowermost part of Mlnl of pl. 2*A*) Mudstone and interbedded limestone. Dark-gray fossil-bearing calcareous mudstone, gradational to and interlaminated with clayey fine-grained biomicrite (containing as much as 30 percent		

Lower member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
fragmental fossil material, in which small calcareous spines are locally abundant), in beds a few inches to about 4 ft thick with thin discontinuous internal lamination. Irregularly interbedded medium-gray to medium-dark-gray partly dolomitized (as much as 20 percent locally) medium- to coarse-grained crinoid bryozoan biomicrite in relatively continuous beds, mostly 6–8 in. thick. Looks like a transition zone between the underlying unnamed formation, in which terrigenous clastic material predominates, and Lisburne Group, in which allochemical and orthochemical carbonate predominates. Dominant fossils are echinoderm and bryozoan fragments, but the spinelike structures are common in a thin section of one specimen. No fossils were collected. 59ACr–118 consists of chips taken to represent lithology	40	1,340±30+(?)
Total thickness of lower member	165	
Total exposed thickness of Nasorak Formation	1,340+(?)	

Accordant depositional contact.
Unnamed mudstone-sandstone-limestone unit.

SEDIMENTARY ROCKS UNDIVIDED

Base of lower member of Nasorak Formation.
Conformable, gradational contact.
Unnamed mudstone-sandstone-limestone sequence (Ms):

	Thickness (feet) Unit	Cumulative
1. (Most of unit Ms of pl. 2*A*) Mudstone and sandstone, in large part sufficiently fissile to be called shale or sandy shale, and minor limestone. Sandstone most common in middle third of unit, whereas shaly mudstone predominates in upper and lower thirds. Dark-gray terrigenous mudstone and shaly mudstone occurs in relatively continuous beds from very thin partings to 10 ft thick; commonly contains a few percent disseminated calcite silt or micrite; fossils, chiefly small horn corals, are locally abundant. Olive-gray to light-olive-gray (weathering light brown) very fine and fine-grained quartz sandstone and dark-gray to grayish-black sandy siltstone occur as interbedded paper-thin laminae to beds as much as 1 in. thick. Relative proportions of sandstone, siltstone, and mudstone vary widely. Although sandstone locally makes up as much as 70 percent of the rocks, the thin laminations give beds a shaly aspect. The olive-gray sandstones are fairly well sorted as to size and have a dolomite(?) intergranular cement. Dark-gray muddy micrite and fossiliferous micrite occurs chiefly as thin lenticular discontinuous interbeds as much as 3 in. thick. These limy beds commonly contain several percent of very fine-grained quartz sand, and in places contain sufficient fossil debris to be classed as biomicrite. A few thin lenticular beds, commonly discontinuous over several tens of feet, of both fossiliferous and nonfossiliferous dense mudstone and sandy mudstone, are better indurated (possibly cemented with iron oxide) and crop out as resistant ledges, as much as 1 ft thick, light reddish in color against the generally darker cliff. Fossils include horn corals, brachiopods, and fragmental echinoderm and bryozoan debris. 59ACr–116 and 59ACr–116f (table 2) representative rock chips and a fossil collection from lower part of unit. 59ACr–117 and 59ACr–117f (table 2) representative rock chips and a fossil collection from the sandier middle part of unit	400±20	400±20
2. (Lowermost, contorted part of unit Ms of pl. 2*A*) Mudstone and limestone with minor chert. Dark-gray calcareous mudstone and muddy micrite that locally contains sufficient fossil debris to be classed as biomicrite. Rocks similar to those of lower part of over-		

Unnamed mudstone-sandstone-limestone sequence—Continued

	Thickness (feet) Unit	Cumulative
lying unit 1, but mudstone appears to be more calcareous and limestone is more abundant and contains some dark-gray chert. The rocks occur in thin uneven irregularly interbedded lenticular strata, much contorted by drag folding and minor faulting related to underlying Ibrulikorak thrust fault. The only fossils recognized were a few crinoid columnals. 59ACr–115 consists of chips taken to represent lithology. Thickness of unit estimated. Base not exposed	20(?)	420±20
Total thickness of exposed mudstone-sandstone-limestone unit	420±20	

Ibrulikorak thrust fault, underlain by younger carbonate rocks of Lisburne Group.

MISSISSIPPIAN ROCKS—EAST SECTIONS

[Sections measured at sea-cliff exposures between Amaktusak and Imikrak Creeks, by R. H. Campbell and D. R. Currey, July and August 1959]

LISBURNE GROUP

TUPIK FORMATION

Siksikpuk Formation: High-angle fault contact at cliffs, but configuration farther inland indicates accordant (conformable?) contact.

Tupik Formation (Mlt):

	Thickness (feet) Unit	Cumulative
1. (Uppermost part of Mlt of pl. 2*B*) Interval cut out at cliffs by high-angle fault. (Basal 30 ft is exposed in inaccessible upper part of sea cliffs.) Farther inland it is covered and only frost heaved rubble is found. Generally similar to underlying unit exposed at the cliffs, but more thinly bedded	30+(100?)	30+
2. (Upper part of Mlt of pl. 2*B*) Chert and interbedded carbonate mudstone. Grayish-black chert in beds 0.1 ft to 2 ft thick makes up about 50 percent of unit. Dark-gray to medium-dark-gray internally laminated "carbonate mudstone" of variable composition in beds from less than 0.1 ft to 3 ft thick irregularly interbedded with the chert. Although beds are gently lenticular and many coalesce or wedge out over several tens of feet of exposure, the ratio of length to thickness is so great that most beds appear continuous, parallel, and of even thickness. Fossils rare, generally sparsely disseminated fragments, but one carbonate mudstone bed yielded several gastropods and brachiopods. 59Acr–87f is fossil collection (table 2). 59ACr–87 consists of chips taken to represent lithology	125	155+
3. (Lower part of Mlt of pl. 2*B*) Limestone (partly dolomitized calcite mudstone) containing variable amounts of nodular chert, interbedded chert beds. Dark-gray to medium-gray internally laminated partly dolomitized calcite mudstone (micrite and calcite silt), locally containing sparsely disseminated fossil fragments, in beds from 0.01 ft (locally having shaly fissility) to 2 ft thick, make up 60–70 percent of unit. Black to grayish-black chert occurs as interbeds as much as 1 ft thick and as small irregular nodules and continuous even-to-uneven-surfaced lenses within limestone beds. Chert irregularly distributed; appears to be most abundant (locally as much as 90 percent) in middle third of unit. Beds generally continuous, parallel, and even surfaced, but some shaly partings in upper part change character along the dip into better indurated beds. The interbedding of thick and thin beds, and of beds of different composition, is regular—even appearing rhythmic—in most of unit; some zones of irregular interbedding. Sample 59ACr–77 consists of chips representing the various lithologies	175	330+

Base of unit not exposed.

Thickness of missing part of Tupik Formation, based on apparently normal contact relations with the underlying Kogruk(?) Formation farther

Tupik Formation—Continued

	Thickness (feet) Unit	Cumulative
inland, is on the order of 70–100 ft	(100?)	
Total thickness of Tupik Formation	330+	(200?)

High-angle fault contact.
Kogruk(?) Formation.

KOGRUK(?) FORMATION

Tupik Formation: High-angle fault contact at cliff exposures, but contact configuration farther inland indicates accordant (conformable?) contact within a few tens to a few hundreds of feet stratigraphically above highest Kogruk (?) beds exposed in cliffs.

Kogruk(?) Formation (Mlk):

	Thickness (feet) Unit	Cumulative
1. (Uppermost part of Mlk-h of pl. *2B*) Topmost beds not exposed at beach level, being cut out by fault contact with Tupik Formation; lower part visible in inaccessible parts of sea cliff. Thickness of missing part of Kogruk(?) Formation, based on apparently normal contact relations with the Tupik farther inland, on the order of 100–300 ft. The rocks are probably much like those of underlying unit 2	100+	100+
2. (Lower part of Mlk-h of pl. *2B*) Dolomite and minor dolomitic limestone with variable amounts of chert. Chiefly light-olive-gray to light-gray dolomite and dolomitic limestone in even continuous beds. Unit mostly regularly stratified 1- to 2-ft beds; some beds as much as 15 ft thick in lower part, and a few as much as 6 ft thick in upper part. Medium-gray chert common both as continuous lenticular bands 6–8 in. thick and as small irregular nodules and lenticular nodules as much as a few inches in diameter. No fossils or ghosts of fossils found. Dolomite fine to medium crystalline; commonly shows thin internal lamination. Most probably a dolomitized micrite, or possibly a dolomitized very fine grained calcarenite. Sample 59ACr–76 consists of chips taken to represent lithology	370	470+
3. (Mlk-g of pl. *2B*) Dolomite, dolomitic limestone, and chert. Chiefly medium-gray to medium-dark-gray fine to medium-crystalline biogenic dolomite (dolomitized biomicrite and fossiliferous micrite); about 20 percent medium-light-gray to dark-gray chert in small nodules, irregular patches, and some possible intraclasts; and, locally, about 20 percent light-olive-gray dolomitic limestone (partly dolomitized, 50 percent, fossiliferous micrite). In part a dolomitized coarse intramicrudite (or locally derived sedimentary breccia with carbonate mudstone matrix). Beds generally about 1 ft thick, but range in thickness from 1 in. to 2 ft. Irregular bedding, uneven bedding surfaces, and continuous but indistinct bedding surfaces result in a massively outcropping aspect. Intraclasts generally sparsely disseminated, but locally abundant; chiefly irregularly fragments of carbonate mudstone, some showing internal bedding lamination, and angular pieces of chert that appear to be detrital (though there is also abundant postdepositional chert). Although some clasts are as much as 5 cm across, most are only a few millimeters in diameter. Ratio of dolomite to calcite ranges from about 19:1 to about 1:1. Recognizable ghosts of fossils include horn corals, crinoid columnals, and Bryozoa. 59ACr-74f is a fossil collection (table 2). 59ACr–74 and 59ACr–75 are chips taken to represent lithologic variations. Some tectonic brecciation of unit tends to obscure the nature of sedimentary breccia locally, chiefly along intensely jointed zones that show little observable displacement. Base of unit not exposed; contact with underlying unit is a high-angle fault	270+	740+

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
High-angle fault, unknown thickness missing.		
4. (Mlk-f of pl. 2*B*) Dolomite with minor chert. Massively outcropping medium-gray to olive-gray fine- to medium-crystalline biogenic dolomite; dark-gray to light-gray chert, in nodules generally less than 1 ft in diameter, locally as much as 10 percent of rock. Bedding characteristics and outcrop form much the same as unit 3, but contains less chert; contains no recognizable intraclasts. Breccia abundant in one zone on east side of unit, at its fault contact with unit 5, where it may all be tectonic. Ghosts of fossils include crinoid columnals, Bryozoa, horn corals, and brachiopod fragments. 59ACr–73f (table 2) is fossil collection of the meager, poorly preserved fauna. 59ACr–73 and 59ACr–72 are chips taken of characteristic lithologic types. Unit separated from adjacent rocks on both sides by high-angle faults. Represents a stratigraphic thickness of at least 100 ft, and as the accessible parts not clearly repeated elsewhere in section, it is believed to lie stratigraphically between units 3 and 5, probably with not more than a few hundred feet of beds missing	100+	840+
High-angle fault, unknown thickness missing (probably not more than a few hundred feet).		
5. (Mlk-e of pl. 2*B*) Carbonate-chert breccia, probably sedimentary, but because unit is bounded by high-angle faults, may be largely or completely tectonic. About 30 percent medium gray to medium-dark-gray chert—aphanitic microgranular quartz containing abundant disseminated medium-crystalline euhedral and subhedral dolomite crystals; occurs as 2–15 cm angular fragments. Medium-gray coarsely crystalline to medium-crystalline dolomite occurs as subrounded clasts in same size range. Matrix commonly lighter in color than the dolomite clasts, generally medium light gray to light gray; chiefly fine- to medium-crystalline dolomite with variable but minor amounts of relict(?) calcite micrite and microspar (?). In a few places, coarsely crystalline dolomite appears to occur as an intergranular cement; both clasts and matrix cut by veinlets filled with calcite and dolomite. Bedding characteristics of the massively outcropping unit could not be distinguished. No fossils were seen. 59ACr–71 consists of chips taken to represent lithology. Unit bounded on both sides by high-angle faults; thickness shown is minimum. As lithology is not clearly repeated elsewhere in section, unit is believed to lie stratigraphically between units 4 and 6, probably with not more than a few hundred feet of beds missing	145+	985+
High-angle fault, unknown thickness missing.		
6. (Upper part of Mlk-d of pl. 2*B*) Rocks in inaccessible part of cliff, not exposed at beach level. Looks very similar to, and probably gradational with, unit 7 below. From beach level, only observable difference from unit 7 is that the bedding surfaces of this unit look more even. Top of unit not exposed; thickness shown is therefore a minimum.	*140+*	*1,125+*
7. (Lower part of Mlk-d of pl. 2*B*) Rhythmically interbedded dolomitic limestone and silty calcite mudstone, with about 20 percent chert nodules. Medium-dark-gray dolomitic limestone—dolomitized laminated microsparite or calcite mudstone—in beds averaging 0.5 ft thick (range from 0.1 to 1.0 ft) rhythmically interbedded with shaly partings (generally less than 0.03 ft thick) consisting chiefly of medium-dark-gray silty microsparite. (May contain as much as 18 percent fine		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
quartz silt.) No fossils seen. 59ACr–70 consists of chips taken to represent lithology. Base of unit not exposed, and contact with underlying unit is a high-angle fault. As this lithology is not clearly repeated elsewhere in section, unit is believed to lie stratigraphically between units 6 and 8, probably with not more than a few hundred feet of beds missing	150+	1,275+
High-angle fault, unknown thickness missing.		
8. (Upper one-fourth of Mlk-c of pl. 2*B*) Dolomite with very minor chert. White to yellowish-gray medium-crystalline dolomite with 5–10 percent relict medium-crystalline calcite spar in irregular patches. Patches of finely crystalline dolomite from fine-sand to fine-pebble size look like allochem ghosts of unidentified origin. Unit crops out massively and looks like a single thick bed, but some discontinuous lamination and a few zones of small (less than 1 in.) medium-gray chert nodules express bedding. Chert makes up only about 1 percent of unit. No fossils seen. 59ACr–69 consists of chips taken to represent lithologic types. Top not exposed	140+	1,415+
9. (Lower three-fourths of Mlk-c of pl. 2*B*) Dolomite with minor but distinctive laminated chert. Light-gray to very light gray, medium, coarse, and finely crystalline dolomite commonly showing ghostly internal cross-lamination—probably chiefly dolomitized calcarenite, but includes some clearly recognizable dolomitized fossiliferous micrite—generally with less than 5 percent relict(?) calcite; locally one 3-ft zone contains as much as 50(?) percent calcite. Irregularly bedded massive, thick, and a few thin beds, all discontinuous over several tens of feet, giving unit a massive cliff-forming aspect. Lower part of unit contains about 20 percent dark-gray to light-gray chert in thin lenticular bands along bedding and in irregular small nodules. Upper part of unit contains a few percent more chert, partly as light- to medium-gray lenticular nodules as much as 2½ ft thick and 6 ft long, as well as 3 distinctive zones, each about 10 ft thick, of light-gray and grayish-orange pink chert in very thin (¼ in. and thinner) laminae with minor amounts of interlaminated very finely crystalline dolomite. One prominent zone of intraformational breccia occurs about 60 ft above base of unit (fig. 10.) Fossils are very sparse and consist of dolomitized fragmental material. 59ACr–68f is fossil collection (table 2). 59ACr–68 and 59ACr–67 are chips taken to represent lithology	330	1,745+
10. (Uppermost part of Mlk-b of pl. 2*B*) Dolomite with very minor chert. Chiefly yellowish-gray but partly light-olive-gray and medium-gray medium-crystalline dolomite, locally showing some ghostly internal fine lamination—probably chiefly dolomitized micrite or very fine grained calcarenite. Very thick bedded with discontinuous faint bedding surfaces and a massively outcropping aspect. Light- and dark-gray chert in thin discontinuous zones and bedding-oriented thin lenticular nodules make up 1–5 percent of unit. No fossils found. 59ACr–66 consists of chips taken to represent lithology	57	1,802+
11. (In upper part of Mlk-b of pl. 2*B*) Dolomite and chert. Light-olive-gray and yellowish-gray finely crystalline dolomite—probably chiefly dolomitized micrite or very fine grained allomicrite—with relict(?) intergranular calcite micrite and microspar ranging from 3 to 20 percent. Very fine internal lamination (locally cross laminated) is expressed by alternating color		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
laminae. Megascopic bedding is indistinct, but distribution of chert zones gives basal part of unit a thin-bedded aspect with a gradation upward toward more thickly bedded aspect resembling unit 10. Dark-gray chert occurs in thin (averaging about 1 in. thick) relatively continuous uneven surfaced zones. In lower part of unit, chert zones are regularly interlayered with the dolomite at intervals of about 4 in. In upper half of unit, chert zones are slightly thicker but less continuous, and spacing between them grades upward to 1 ft. Topmost beds contain only a few scattered chert nodules. No fossils found in unit. 59ACr–65 consists of chips taken to represent lithology	60	1,862+
12. (In upper part of Mlk-b of pl. *2B*) Dolomite. Light-olive-gray to light-gray finely crystalline dolomite—including clearly recognizable dolomitized biomicrite, but chiefly probably dolomitized laminated micrite—with minor (but locally as much as 20 percent) relict(?) micrite and local intergranular calcite spar; and dark-gray finely crystalline laminated dolomite—probably a dolomitized micrite—containing as much as 5 percent carbonaceous material(?) interstitial to subhedral dolomite. Light-colored rocks predominate in the lower part of the unit in beds from 1 in. to 3 ft thick. The thick beds show indistinct internal lamination; the thin beds are internally thinly laminated and locally contain abundant small (about 1 in.) grayish-black chert nodules. Dark-colored rocks predominate in upper part of unit in beds as much as 1½ ft thick, containing about 1 percent small dark-gray and grayish-black chert nodules. Bedding is generally lenticular and continuous. Recognizable fossils are exclusively dolomitized ghosts of crinoid columnals. 59ACr–64 consists of chips taken to represent lithology	28	1,890+
13. (In middle part of Mlk-b of pl. *2B*) Dolomite with minor chert. Light-olive-gray fine- to medium-crystalline biogenic dolomite (dolomitized biomicrite and fossiliferous micrite containing from less than 1 percent to as much as 25 percent ghosts of fossils) with generally less than 5 percent relict(?) calcite micrite and intergranular spar. Dark-gray to grayish-black lenticular nodules 1–3 in. thick and from less than 6 in. to about 2 ft long abundant (as much as 30 percent of the rocks) in some stratigraphic zones, where they are oriented along the bedding direction. Light-gray to very light gray irregular small (about 2 in. in diameter) chert nodules randomly distributed. Total chert content of unit is estimated to be 5–10 percent. Unit looks like one massive bed, with bedding expressed by discontinuous internal laminae—chiefly oriented bryozoan leafy fragments—and discontinuous bedding plane partings spaced from 6 in. to 3 ft apart. Recognizable fossils include Bryozoa, crinoid columnals, horn coral, and an indistinct form of colonial coral(?). All fossils consist of dolomitized ghosts; none appeared sufficiently well preserved to warrant collection. 59ACr–63 consists of chips taken to represent lithology	155	2,045+
14. (In middle part of Mlk-b of pl. *2B*) Dolomite. Medium-dark-gray finely crystalline to medium-crystalline biogenic dolomite—dolomitized fossil-bearing micrite and biomicrite containing as much as 50 percent ghosts of fragmental fossils—in 6-in. to 1-ft-thick irregularly bedded discontinuous unevenly surfaced beds, predominates in several zones from 5–20 ft thick; separated by a few continuous beds 2–4 ft thick of light-gray		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
medium-crystalline to coarsely crystalline biogenic(?) dolomite—dolomitized allomicrite containing as much as 30 percent allochem (fossil?) ghosts. Unit is relatively chert free except near top, where some light-gray dolomite beds contain minor amounts (less than 1 percent) of dark-gray to grayish-black chert in thin lenticular nodules. Recognizable fossil material includes Bryozoa, crinoid columnals and other echinoderm fragments, horn corals, and brachiopod(?) shell fragments. 59ACr–62f is a fossil collection (table 2). 59ACr–62 consists of chips taken to represent lithology	82	2,127+
15. (In middle part of Mlk-b of pl. 2*B*) *Dolomite and subordinate chert.* Medium-light-gray to medium-gray medium-crystalline to finely crystalline biogenic(?) dolomite—dolomitized coarse biomicrite or biosparite, containing about 60 percent ghosts of fragmental fossils—in indistinct discontinuous beds from 5 in. to 3 ft thick. Dark-gray chert and minor amounts of light-gray chert make up about 15 percent of unit as irregular nodules arranged in relatively continuous zones within dolomite beds parallel to the bedding. Individual nodules are as much as 1 ft thick but average about 2 in. Dolomitized fossil debris includes chiefly crinoid columnals and other echinoderm fragments and subordinate Bryozoa. None appeared well-enough preserved to warrant collection. 59ACr–61 consists of chips taken to represent lithology	25	2,152+
Unit 16 appears gradational with unit 15 through a transition zone that is about 16 ft thick. These beds are included in the total thickness given for unit 16 below.		
16. (In lower part of Mlk-b of pl. 2*B*) Dolomite. Light-gray, very light gray, and medium-gray finely crystalline to medium-crystalline laminated dolomite—no clear cut ghosts remain, but textures expressed by patches and laminae of coarser crystalline dolomite in finer crystalline matrix and interlaminae suggest the rocks formed by dolomitization of laminated calcite mudstone or fine calcarenite—with distinctive lenticular color mottling that apparently represents variations in abundance of impurities (carbon?). The lighter colored areas possibly represent better "washed" current winnowed calcarenite in which calcite spar cement was deposited instead of interstitial micrite. (Mottling illustrated by photograph, fig. 12). Unit has massively outcropping aspect and is very thick bedded, with individual beds as much as 50 ft thick. Bedding expressed by oriented mottled zones, internal lamination, and a few irregularly spaced indistinct discontinuous bedding-plane partings. Light-medium-gray to light-gray chert occurs as thin lenticular nodules and nodular bands oriented along bedding direction. A few zones may contain as much as 20 percent chert, but total with respect to entire unit is less than 10 percent. No fossils recognized. 59ACr–60 and 59ACr–60a are chips taken to represent lithology	100	2,252+
17. (In lower part of Mlk-b of pl. 2*B*) Dolomite with minor chert. Medium-gray to dark-gray medium-crystalline biogenic dolomite—dolomitized medium-grained biomicrite containing about 20 percent ghosts of fragmental fossils of which leafy Bryozoa, oriented along bedding direction, predominate—with less than 5 percent relict(?) calcite, chiefly as sparry centers of almost wholly dolomitized crinoid columnals(?). Dark-gray to grayish-black chert—silicified biomicrite or fossiliferous micrite in which hollow		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
spines (echinoderm or brachiopod, most likely) predominate—occurs as a few rare irregular nodules, generally about 1 in. in diameter. The unit is thin-bedded, regularly bedded; beds are continuous but have minor undulating unevenness of bedding surfaces. Fossils include Bryozoa, crinoid columnals and unidentified echinoderm debris, horn coral, and brachiopods. 59ACr–59f is fossil collection (table 2). 59ACr–59 consists of chips taken to represent lithology	47	2,299+
18. (Lowermost part of Mlk-b of pl. *2B*) *Dolomite with minor* chert. Medium-light-gray to medium-gray, and dark-gray medium-crystalline dolomite, in large part biogenic—most is probably dolomitized fine- to coarse-grained biomicrite containing from 3 to 30 percent fragmental ghosts of fossils—generally with less than 3 percent relict(?) calcite, chiefly as intergranular patches of spar. Light-gray to dark-gray chert occurs chiefly as small irregular nodules and thin discontinuous zones of nodules within dolomite beds. The light-gray to medium-gray dolomite that makes up most of unit is thick to very thick-bedded (some beds as much as 20 ft thick) with irregularly spaced discontinuous bedding surfaces; has a massively outcropping aspect. The dark-gray dolomite is all in one zone, 10–15 ft thick, of thinly bedded strata near middle of unit. Most beds show some internal lamination at irregularly spaced intervals, most noticeable and closely spaced in thin-bedded central zone. Chert makes up about 10 percent of upper thick-bedded zone, about 5 percent of lower thick-bedded zone, and is very rare in central thin-bedded zone. Recognizable ghosts of fossils include a few crinoid columnals and, rarely, structures that seem to be some form of colonial coral, but none of the material was well-enough preserved to warrant collection. 59ACr–58 consists of chips taken to represent lithology	110	2,409+
19. (Uppermost part of Mlk-a of pl. *2B*) Dolomite. Light-olive-gray to medium-gray very finely crystalline to finely crystalline biogenic dolomite —dolomitized very fine grained to coarse-grained biomicrite, fine biomicrudite, and fossiliferous micrite, containing from 7–60 percent ghosts of fragmental fossils—generally less than 3 percent *relict(?) calcite micrite and* intergranular spar. Medium-light-gray chert makes up a few percent of unit, chiefly in upper part, mostly as thin (as much as 10 in.) irregularly lenticular nodules in discontinuous bedding-oriented zones in and along bedding surfaces. Beds range in thickness from less than 1 in. to as much as 15 ft; bedding surfaces are irregularly spaced (through close spacing is rare), relatively but not perfectly even, and generally continuous for at least 100 ft (though overall aspect is gently lenticular). Cross-joint spacing of about the same range as the bedding thickness combines to give unit a blocky-surfaced massive-outcropping aspect. Recognizable ghosts of fossils include only crinoid columnals and leafy bryozoan fragments, none well-enough preserved to warrant collection. 59ACr–57 consists of chips taken to represent lithology	255	2,664+
20. (In upper part of Mlk-a of pl. *2B*) Dolomite with subordinate chert. Medium-light-gray to light-gray, and light-olive-gray finely crystalline to medium-crystalline dolomite, in part biogenic—dolomitized biomicrite and laminated micrite with as much as 20 percent ghosts of fragmental fossils—generally containing		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
less than 5 percent relict(?) calcite micrite and intergranular spar. Dark-gray and medium-gray chert occurs as lenticular nodules within dolomite beds and as thin long (as much as 20 ft) discontinuous zones along bedding planes. Beds are thin, mostly about 4 in. thick, but ranging from 2 in. to 1½ ft. Bedding surfaces are slightly uneven, but appear relatively continuous. Recognizable ghosts of fossils include crinoid columnals, leafy Bryozoa, colonial corals, and brachiopod fragments. 59ACr–56f is fossil collection (table 2); 59ACr–56 consists of chips taken to represent lithology	120	2,784+
21. (In middle part of Mlk-a of pl. 2*B*) Dolomitic limestone and silty fossiliferous carbonate mudstone. Medium-gray partly dolomitized (as much as 25 percent locally) partly silicified locally as much as 10 percent patchy aphanitic to finely crystalline microgranular chert) fine- to very coarse grained crinoid-bryozoan biomicrite, generally contains 30–85 percent fragmental fossil material and, though micrite matrix predominates, as much as 10 percent intergranular sparry calcite. Chiefly irregularly bedded in thick and thin relatively continuous even beds. With interbedded thin-bedded to thin-laminated dark-gray silty (from less than 1 percent to as much as 25 percent quartz silt) fine-grained biomicrosparite (with 7–30 percent fragmental fossil material), and medium-light-gray finely crystalline biogenic dolomite (probably the dolomitized equivalent of the silty biomicrosparite). Fossils include a blastoid and locally abundant brachiopods, as well as bryozoan and echinoderm debris. 59ACr–55f is fossil collection (table 2); 59ACr–55 consists of chips taken to represent lithology	86	2,870+
22. (In middle part of Mlk-a of pl. 2*B*) Dolomite with subordinate chert. Chiefly light-olive-gray to light-gray, but some medium-dark-gray, finely crystalline biogenic dolomite—dolomitized fossil-bearing micrite, generally containing less than 10 percent fragmental fossil material—generally with less than 1 percent relict(?) calcite micrite. Medium-dark-gray to dark-gray chert makes up about 20 percent of unit, chiefly as small irregularly lenticular nodules within the dolomite beds. Beds are thin (commonly 1–6 in. thick) and have relatively continuous but undulating bedding surfaces, so that beds pinch and swell irregularly along bedding; compensated by alternating pinches and swells in adjacent beds. Ghosts of fossils are chiefly leafy Bryozoa, but brachiopod fragments are locally abundant. No fossil material collected. 59ACr–54 consists of chips taken to represent lithology	25	2,895+
23. (In middle part of Mlk-a of pl. 2*B*) Dolomite. Light-gray to very light gray medium-crystalline partly biogenic dolomite—sparse recognizable ghosts of crinoid columnals and ghostly internal color lamination suggest original rock was a fossiliferous calcarenite. A minor amount of medium-gray chert occurs as small nodules. Bedding irregular; thickness of beds ranges from 6 in. to 12 ft, most commonly 2–4½ ft. Crinoid columnals are the only fossils recognized. 59ACr–53 consists of chips taken to represent lithology. Unit appears very similar to the light-colored dolomite of underlying unit 24, but more thickly bedded (massively outcropping); contains less medium-gray chert and no grayish-black chert. The two units appear gradational	83	2,978+
24. (In middle part of Mlk-a of pl. 2*B*) Dolomite with minor chert. Chiefly light-gray to		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
light-olive-gray coarsely crystalline dolomite—faint lamination suggests a dolomitized calcarenite—in continuous even beds most commonly 8 in. to 1½ ft thick. Irregularly interbedded with medium-gray medium-crystalline(?) laminated dolomite—dolomitized micrite (most laminae are feathery current laminations) —in discontinuous lenticular beds from a few inches to 1 ft thick. Grayish-black chert and medium-gray chert occurs in small (less than 1 ft) irregular nodules in a few long (as much as 30 ft) thin (commonly about 6 in. thick) lenticular zones. Chert totals only about 5 percent of the rocks of unit. Sparse ghosts of fossils include horn coral and brachiopod fragments, as well as more common bryozoan and echinoderm debris. 59ACr-52f (table 2) is collection of sparse ghosts of fossils; 59ACr-52 consists of chips taken to represent lithology	85	3,063+
25. (In middle part of Mlk-a of pl. 2*B*) The following description is from field notes,[1] probable corrections in parentheses: Limestone (probably dolomitic), dolomitic limestone (very possibly a nearly pure dolomite with a few percent relict calcite or late calcite veinlets that may not be obvious in hand specimen), and chert. A 5-ft-thick bed of light-brown coarsely crystalline limestone forms base of unit. It is overlain by a zone about 20 ft thick of thin laminated medium-gray dolomitic limestone in beds a few inches to 3 ft thick, with about 10 percent grayish-black chert in discontinuous irregularly bordered zones locally as much as 1 ft thick. The topmost zone (about 20 ft thick) is medium-gray medium-crystalline limestone in beds 5 in. to 2 ft thick with, very locally, about 1 percent grayish-black chert as discontinuous lenticular zones very locally as much as 2 ft thick	56	3,119+
26. (In lower part of Mlk-a of pl. 2*B*) Dolomite, cherty dolomite, limestone, and chert. Light-gray to medium-light-gray partly cherty largely biogenic very fine to coarsely crystalline dolomite—except for some uniformly coarsely crystalline dolomite in which original textures have been completely masked, rock appears to be a dolomitized (mostly 80–95 percent dolomite) silicified (in many places with 10–20 percent very finely crystalline microgranular quartz, as a porous spongy intergrowth with the carbonate) very fine grained to coarse-grained biogenic calcarenite, in part with a micrite matrix, and in part with intergranular calcite spar cement. Medium-gray to medium-dark-gray limestone —very fine to very coarse grained crinoid-bryozoan biosparite, in places as much as 10 percent dolomitized; generally contains more than 70 percent fragmental fossil material. Light-gray chert (spongy intergrowth in the dolomite) occurs in irregular patches of widely ranging size. Grayish-black chert occurs as irregular discontinuous zones as much as 6 in. thick, commonly oriented along bedding, but locally crosscutting bedding at low angles. Total chert content of unit is probably 5–10 percent. The dolomite is chiefly in beds ranging in thickness from 1 in. to 7 ft, but general aspect dominated by beds 3–4 ft thick. Bedding surfaces generally appear even and continuous. Internal lamination		

[1] No representative chips from this unit were available; therefore, the field designations could not be checked by staining for calcite or microscopic textural examination in the laboratory. On the basis of comparisons between field and laboratory designations for rocks of other units, the rocks are probably a great deal more dolomitic and more finely crystalline than was believed upon cursory field examination; in addition, the rocks designated as coarsely crystalline in the field commonly owe that crystallinity to the presence of coarse-grained echinoderm debris, which, of course, consists largely of plates, each a single crystal.

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
not commonly well expressed, except in a few beds of dolomitized Bryozoa-bearing micrite near top of unit. In general, lower part of unit has a more massively outcropping aspect and is lighter in color; upward gradation to somewhat darker colored, more ledgy aspect, most noticeable when viewed from a distance. Fossils are rare, but those found include horn coral and colonial coral as well as the ubiquitous fragmental echinoderm and bryozoan debris. 59ACr–29f is a fossil collection (table 2). 59ACr–29 and 59ACr–28f are chips taken to represent lithology	375	3,494+
27. (In lower part of Mlk-a of pl. 2*B*) Dolomitic limestone, dolomite, and chert. Medium-gray to medium-dark-gray partly dolomitized (commonly 15–50 percent dolomite) coarse-grained crinoid biomicrosparite, chiefly with 25–50 percent fragmental fossil material, and clayey(?) microsparite. Subordinate medium-light-gray very finely crystalline biogenic dolomite—dolomitized clayey(?) coarse-grained crinoid biomicrosparite and fossiliferous micrite, with 1–40 percent ghosts and calcite relicts of fragmental fossils, and commonly 60–80 percent dolomite. Grayish-black chert occurs chiefly as relatively continuous nodular zones 1–6 in. thick as well as small lenticular nodules, oriented along the bedding. Chert makes up about 10 percent of the rocks of the unit. The limestone is in beds 1 in. to 2½ ft thick and generally shows some internal lamination. Bedding surfaces generally appear even and continuous. Fossil material includes horn corals—particularly abundant near top of unit—as well as echinoderm and bryozoan debris. 59ACr–27f (table 2) is fossil collection from upper 10 ft of unit. 59ACr–27 consists of chips taken to represent lithology	47	3,541+
28. (In lower part of Mlk-a of pl. 2*B*) Dolomite and dolomitic limestone, with chert. Medium-gray to medium-dark-gray fine- to medium-crystalline dolomite and dolomitic limestone—dolomitized (chiefly from 20–65 percent dolomite) very fine to very coarse grained biosparite and biomicrosparite (commonly with about 60 percent fragmental fossil relicts and ghosts). Pale-yellowish-brown finely crystalline laminated dolomite—dolomitized (to more than 95 percent) current(?) laminated micrite or very fine calcarenite. Carbonate rocks locally include a few percent spongy chert that is discernible only in microscopic examination. The carbonate beds range in thickness from less than 1 in. to about 5 in., averaging about 4 in., and are separated by bedding oriented zones of dark-gray to grayish-black chert averaging about 3 in. thick but ranging from 1 in. to 5 in. in remarkably continuous strata with only minor pinching and swelling. Chert makes up about 30 percent of unit. A few dolomite beds near top of unit are thicker, as much as 2 ft thick, and contain less chert. The only recognized fossil material was crinoid columnals and a few indistinct spiny or spicular structures in some of the chert. 59ACr–26 consists of chips taken to represent lithology	83	3,624+
29. (Lowermost part of Mlk-a of pl. 2*B*) Dolomite, chert, and subordinate limestone. Medium-light-gray medium-crystalline dolomite—probably a dolomitized faintly laminated fossil-bearing micrite, generally containing less than 5 percent allochem ghosts—interbedded with medium-dark-gray but otherwise similar medium-crystalline dolomite and light-gray very coarse-grained crinoid biosparite (which may be partly a biomicrosparite).		

Kogruk(?) Formation—Continued

	Thickness (feet) Unit	Cumulative
The dolomite is in thick beds, generally 2½–7 ft thick, containing abundant (locally as much as 60 percent) thin (about 2 in. thick) continuous zones of grayish-black chert. Grayish-black and light-medium-gray chert also occurs as irregular nodules. Recognizable fossil material is chiefly crinoid columnals as relict calcite in chert and as ghosts in dolomite and ghosts of Bryozoa along lamination in dolomite. 59ACr–25 consists of chips taken to represent lithology	46	3,670+
Total thickness of Kogruk(?) Formation		3,670+ (500?)

Nasorak Formation, conformable contact (actually, the basal four units of the Kogruk(?) Formation together with the top unit of the underlying Nasorak Formation, appear to be a transition zone representing the gradual, alternating change of depositional environments represented by the two formations).

NASORAK FORMATION

Kogruk(?) Formation.

Conformable contact.

Upper member of the Nasorak Formation (Mlnu):

	Thickness (feet) Unit	Cumulative
1. (Mlnu-h of pl. *2B*) Dolomite, dolomitic limestone, calcareous shale, and chert. Dark-gray finely crystalline biogenic dolomite and dolomitic limestone—dolomitized and partly dolomitized crinoid-bryozoan coarse- to very coarse grained biomicrite, containing from 20–60 percent fragmental fossil material, and with replacement dolomite ranging from 20 to 80 percent; rhythmically interbedded with dark-gray thin laminated carbonate mudstone or calcareous shale—partly dolomitized micrite and fossiliferous micrite. Several beds of medium-gray partly dolomitized bryozoan-crinoid coarse biosparite interbedded at widely spaced irregular intervals in lower half of unit. Grayish-black chert forms from 5–15 percent of most of the limy beds, chiefly as irregular nodules of widely ranging size (as much as 1½ ft in diameter, but commonly smaller) in the limestone, with which they commonly have indistinct gradational borders. The limestone beds range in thickness from less than 1 in. to about 2 ft; but thick beds are rare and found only in upper part of unit. More generally, a gradational increase in thickness upward from an average of about 6 in. in the lower part to about 1 ft in upper part. The interbedded carbonate mudstone forms partings as much as 3 in. in thickness; gradual decrease in thickness and abundance of these partings from lower part of unit to top. Fossils include colonial corals and brachiopods as well as echinoderm and bryozoan debris. Colonial coral heads locally stand out as white lenses as much as 1 ft thick and 1½ ft long in the limestone beds (fig. 7). 59ACr–22f, 59ACf–23f, and 59ACr–24f (table 2) are fossil collections. 59Acr–22, 59Acr–23, and a split from 59ACr–24f consist of chips taken to represent lithology	586	586
2. Covered interval. Rocks probably similar to unit 1 but may be gradational to rock types of unit 3 below. Possibility of faulting cannot be completely ruled out, but no major displacement could be found along probable projection of the zone. Stratigraphic thickness represented	85	671
3. (Upper two-thirds of Mlnu-g of pl. *2B*) Limestone, partly dolomitic, and calcareous shale, with subordinate chert, rhythmically interbedded biomicrite and carbonate mudstone or calcareous shale. Medium-gray (weathers to light gray and pale grayish orange) coarse-grained crinoid-bryozoan biomicrite locally with irregular small		

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
patches and laminae where intergranular material is sparry calcite cement) with 40–50 percent fragmental fossil allochems, in continuous but unevenly undulating beds averaging about 3 in. thick, but as much as 1 ft thick. Rhythmically interbedded with dark-gray thin-laminated clayey micrite and fossiliferous micrite in beds commonly less than 1 in. thick. Both are commonly partly dolomitized, and may contain as much as 15 percent dolomite locally, chiefly as dolomitized micrite matrix and as rims around fossil allochems. Grayish-black chert—silicified biomicrite and micrite—makes up less than 10 percent of the unit, chiefly as irregular zones of nodules within and oriented with the limestone beds. Many paired sets of biomicrite and fossiliferous micrite beds may be graded beds, with sharp bedding surfaces at base of calcarenite bed and a gradual decrease upward in maximum size and abundance of allochems through an indistinct commonly intertonguing contact with the overlying carbonate mudstone, whose top is marked by a sharply defined surface at base of next overlying calcarenite bed. The laminated micrite (carbonate mudstone) commonly makes up about 5–10 percent of unit; in central part of unit, where beds increase in thickness to as much as 6 in., it makes up a proportionately much greater part of unit (locally as much as 30 percent). Fossils include horn corals, colonial coral, brachiopod fragments, Bryozoa (including *Archimedes*), and echinoderm debris. 59ACr–1f (table 2) is a fossil collection. 59ACr–1 and 59ACr–1a consist of chips taken to represent lithology	375	1,046
4. (Upper part of lower one-third of Mlnu-g of pl. 2*B*) Limestone, partly dolomitic, and calcareous shale, with subordinate chert. Rhythmically interbedded biomicrite and fossiliferous clayey micrite similar to unit 3 above, but with an abrupt increase in proportion of thin laminated micrite and fossiliferous micrite to about 40 percent of unit. 59ACr–2 consists of chips taken to represent lithology	34	1,080
5. (Middle part of lower one-third of Mlnu-g of pl. 2*B*) Limestone, partly dolomitic, and calcareous shale, with subordinate chert. Rhythmically interbedded biomicrite and laminated clayey micrite similar to units 3 and 4 above, but with abrupt decrease in proportion of interbedded laminated micrite to 5–10 percent. 59ACr–3 consists of chips taken to represent lithology	25	1,105
6. (Lower part of lower one-third of Mlnu-g of pl. 2*B*) Limestone, partly dolomitic, and calcareous shale, with subordinate chert. Rhythmically interbedded biomicrite and laminated clayey micrite similar to units 3–5 above, but with about 40 percent laminated micrite interbeds. Also different in that some fossiliferous micrite is locally dolomitized to a rock containing about 80 percent finely crystalline dolomite with relict calcite allochems making up most of remainder. 59ACr–4 consists of chips taken to represent lithology	64	1,169
7. (Upper part of Mlnu-f of pl. 2*B*) Calcareous shale and limestone, partly dolomitic, with minor chert. Rhythmically interbedded biomicrite and laminated clayey micrite, locally as much as 60 percent dolomitized to finely crystalline dolomite. Very similar to unit 6 above, but with abrupt change at contact to about 60 percent laminated micrite and fossiliferous micrite. 59ACr–5		

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
consists of chips taken to represent lithology	26	1,195
8. (Middle part of Mlnu-f of pl. 2*B*) Limestone and chert. Distinctive unevenly bedded unit. Medium-gray and dark-gray partly dolomitized partly silicified fossil-bearing micrite; and grayish-black chert (silicified fossil-bearing micrite) chiefly as irregularly lenticular nodules in the limestone, commonly having indistinct gradational contacts with the limestone. Beds appear relatively continuous and average about 9 in. in thickness, but pinch and swell from about 3 in. to about 1½ ft in thickness, giving rise to a nodular aspect of the beds; adjacent beds appear to compensate one another. One dip-slope exposure shows that the nodular features are roughly circular in plan and average about 1 ft in diameter. Chert is commonly in the central parts of the "nodules," but does not seem to be requisite for their formation. They are probably differential compaction features. 59ACr–6 consists of chips taken to represent lithology	49	1,244
9. (Lower part of Mlnu-f of pl. 2*B*) Shale and subordinate limestone. Grayish-black calcareous clay shale with abundant close-spaced sheared bedding surfaces, many showing small slickenslides; with 20–30 percent interbedded medium-dark-gray to dark-gray clayey micrite, locally containing as much as 30 percent unidentified calcite allochems, but commonly 5 percent or less. The limestone (clayey micrite) occurs in lenses as much as 4 in. thick and about 3 ft long and appears to follow specific horizons, so that some resemble boudinage structures. 59ACr–7 consists of chips taken to represent lithology	41	1,285
10. (Mlnu-e of pl. 2*B*) Limestone and calcareous shale. Chiefly medium-gray partly dolomitized (ranging from 10 to 40 percent replacement dolomite) laminated Bryozoa-bearing micrite, probably containing some clay, with fragmental fossil material commonly making up 7–10 percent of the rock; but locally the rock is a coarse crinoid biomicrite with fragmental fossil material ranging from 50 to 90 percent and including a few foraminifera. The limestone is chiefly in beds about 1 ft thick or less, rhythmically interbedded with shaly clayey carbonaceous micrite in beds as much as 4 in. thick that makes up about 30 percent of unit. Sets consisting of a limestone bed and a shaly interbed in many places resemble graded beds; such sets commonly range in thickness from 1 to 2 ft. Recognizable fossils include horn corals and colonial corals (most heads making discrete small lenses within limestone beds) as well as fragmental echinoderm and leafy bryozoan debris. 59ACr–8f (table 2) is a fossil collection. 59Acr–8 consists of chips taken to represent lithology (Bedding plant fault within unit 10 rocks makes total thickness of unit uncertain.)	50(?)	1,335
11. (Upper one-fourth of Mlnu-d of pl. 2*B*) Limestone and calcareous shale. Very similar to unit 10 above, but includes about 40 percent shaly micrite, probably containing some clay; the limestone beds are more generally medium dark gray to dark gray and contain a generally higher proportion (commonly 30–40 percent) of fragmental fossil debris and may locally contain as much as 20 percent fine quartz silt. In addition, the thickness of sets of limestone and interbedded mudstone is more nearly uniform and generally about 1½ ft thick. Recognizable fossils include horn corals, colonial corals (chiefly as lenticular heads made up of single colonies		

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Thickness (feet) Cumulative
from 1 in. to 1 ft thick and from 6 in. to 5 ft long), as well as fragmental echinoderm and leafy bryozoan debris. 59ACr–8Af (table 2) is a fossil collection. 59ACr–8a consists of chips taken to represent lithology	66	1,401
12. (Lower part of upper one-half of Mlnu-d of pl. *2B*) Limestone, with minor chert and dolomite. Chiefly medium-gray to medium-dark-gray laminated fossiliferous micrite and medium-grained to very coarse grained crinoid bryozoan biomicrite (containing as much as 70 percent fragmental fossil debris), locally dolomitized (as much as but generally less than 50 percent dolomitized, and locally silicified to grayish-black chert) (cherts commonly contain as much as 30 percent euhedral very finely crystalline dolomite, and may contain as much as 60 percent relict calcite). Chert and dolomite form irregular patches and zones in and along the thin limestone beds and make up about 5 percent and 20 percent of the unit volume, respectively. A few distinctive interbeds of very coarse grained crinoid biosparite that are also dolomitized in irregular patches, locally contain as much as 50 percent dolomite, chiefly as replacement of intergranular cement. Individual limestone beds range from less than 1 in. to about 1 ft in thickness, generally averaging about 10 in. thick. Thin shaly partings, averaging about ½ in. thick, commonly separate the limestone beds, but all together make up only about 1–5 percent of unit. Except for fragmental echinoderm and leafy bryozoan debris, no fossils were recognized, and none were collected. 59ACr–9 consists of chips taken to represent lithology	85	1,486
13. (Topmost part of lower one-half of Mlnu-d of pl. *2B*) Limestone. Medium-gray very coarse grained biosparite, locally partly dolomitized, containing local coral fragments. Individual beds as much as 3½ ft thick, and unit stands out as a thick-bedded zone between the thinner bedded units above and below. 59ACr–9a consists of chips taken to represent lithology	14	1,500
14. (Lower one-half of Mlnu-d of pl. *2B*) Limestone, with minor chert and dolomite. Virtually the same lithology and bedding characteristics as unit 12. A few of the chert specimens show possible ghosts of spicules in thin section (fig. 24). 59ACr–9b consists of chips taken to represent lithology	127	1,627
15. (Upper one-third of Mlnu-c of pl. *2B*) Shale and limestone. Grayish-black silty calcareous shale or shaly micrite (probably dolomitized in places), in beds ½–6 in. thick averaging about 3 in.; interbedded dark-gray dolomitized (as much as		

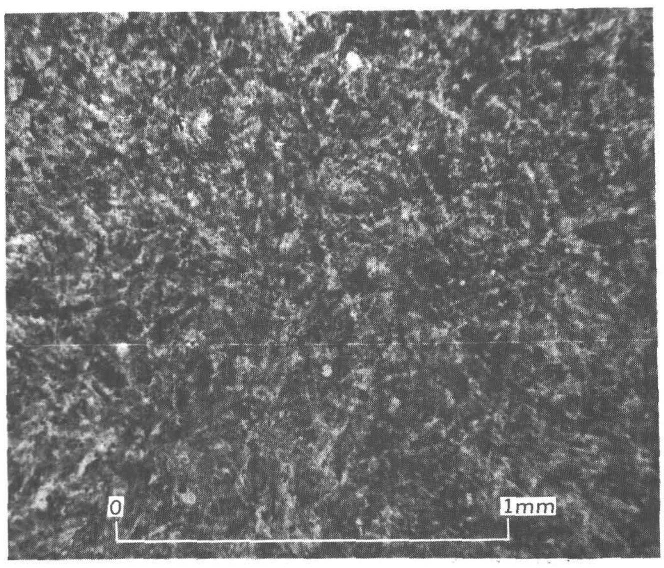


FIGURE 24.—Texture of spicular(?) chert in the Nasorak Formation. Most of the light-gray material is very finely crystalline to aphanitic microgranular quartz. A few percent dolomite is also present in the light-colored fraction, as disseminated very finely crystalline euhedral rhombs. The dark material is chiefly disseminated fine carbon and tiny crystals of disseminated pyrite, but it also includes a few percent of very finely crystalline calcite. 59ACr–9b#2.

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
40 percent) silty (about 10 percent quartz silt) fine-grained biomicrite containing as much as 50 percent fragmental fossil material, now chiefly ghosts, in discontinuous uneven beds ½–6 in. thick. The calcareous shale or shaly micrite makes up about 50 percent of the unit. 59ACr–10 consists of chips taken to represent lithology	12	1,639
16. (Lower two-thirds of Mlnu-c of pl. 2*B*) Limestone, partly silicified and partly dolomitized. Chiefly medium-gray very coarse grained crinoid biomicrite containing as much as 60 percent fragmental fossil material, locally with as much as 40 percent replacement chert and 15 percent replacement dolomite as matrix and rimming cell structures in and around calcite allochems; in even continuous beds ranging in thickness from 2 in. to 1½ ft (fig. 6). Dark-gray thinly laminated dolomite—dolomitized micrite—makes up 5–10 percent of unit as very thin interbeds, and laminae within the limestone beds. Dark-gray chert occurs as thin (½ to 3 in. thick) discontinuous irregularly surfaced zones along bedding planes and a few small irregular nodules within limestone beds. The thin internal lamination of much of the limestone has a distinctive "crinkly" uneven aspect, perhaps as a result of differential compaction over the coarse echinoderm debris. 59ACr–11f (table 2) is a fossil collection. 59ACr–11 consists of chips taken to represent lithology	26	1,665
17. (Mlnu-b of pl. 2*B*) Chert, limestone (partly dolomitized), and calcareous shale. Grayish-black chert—silicified (60–75 percent) carbonaceous (about 15 percent black opaque films) micrite; and medium-dark-gray dolomitized (commonly from 10–50 percent replacement dolomite in apparently irregular patchy zones) silt-bearing (generally less than 5 percent quartz silt) carbonaceous shaly micrite that may contain a few percent clay locally. The chert occurs as indistinctly bordered lenticular nodules within the limestone beds and makes up about 50 percent of the unit. The chert-limestone beds appear relatively continuous and are rhythmically interbedded with thin (commonly less than ½ in. thick) calcareous shale partings, but have very uneven undulating bedding surfaces such that individual beds pinch and swell in thickness from about 1 in. to as much as 8 in. in distances of 1–2 ft. This gives the chert-limestone beds the general aspects of zones of nearly disconnected lenticular nodules alined along bedding. Thinning of one bed is generally compensated by thickening of adjacent beds, suggesting a compaction origin for the nodular aspect. In lower 25 ft of unit, chert content decreases slightly—to about 35 percent—shaly interbeds increase in thickness to as much as 1 in.—making up as much as 10 percent of the rocks—and some thin zones are not so prominently "nodular" in bed aspect. Basal 6 ft of unit is a zone containing a few thick beds (as much as 4 ft thick) of coarse-grained crinoid biomicrite from which a few horn corals and Bryozoa were collected (fig. 5). 59ACr–12f (table 2) is a fossil collection. 59ACr–12 consists of chips taken to represent lithology	75	1,740
18. (Upper part of Mlnu-a of pl. 2*B*) Mudstone and limestone. Grayish-black calcareous silt clay mudstone and interbedded dark-gray silty clayey(?) partly dolomitized fossil-bearing micrite. In upper 25 ft of unit the mudstone is in thin, locally shaly, beds 1–4 in. Thick, rhythmically interbedded with silty micrite beds of similar thickness (fig. 5).		

Upper member of the Nasorak Formation—Continued

	Thickness (feet) Unit	Cumulative
In lower 33 ft of unit limestone is virtually absent; the mudstone is in beds as much at 1 ft thick and contains minor but distinctive small patches of pyrites and pyritized brachiopod shells and other shell fragments. Bedding is masked in places by close-spaced fracture cleavage that gives the outcrop a shaly aspect but only locally follows direction of bedding. 59ACr–13f (table 2) is a fossil collection. 59ACr–13 consists of chips taken to represent lithology	58	1,798
19. (Lower part of Mlnu-a of pl. *2B*) Limestone. Medium-dark-gray coarse-grained crinoid biomicrite, locally partly dolomitized in irregularly bedded strata ranging in thickness from less than 1 in. to as much as 4 ft. Dark-gray silty(?) micrite in thin discontinuous laminae and partings as much as 1 in. thick are subordinate interbeds. Echinoderm debris and subordinate bryozoan fragments are the only fossils recognized. 59ACr.14 consists of chips taken to represent lithology	13+(20)	1,811+(20)
Total thickness of upper member of the Nasorak Formation	1,811+(20)	
Cape Thompson Member of the Nasorak Formation (Mlnc):		
20. (Mlnc of pl. *2B*) Limestone. Medium-gray (weathers to pale grayish orange) partly dolomitized (locally as much as 15 percent dolomitized micrite matrix and rims on fossil fragments) very coarse grained crinoid-bryozoan biomicrosparite (in places a fine rudite rather than a very coarse arenite) generally containing about 75 percent fragmental fossil allochems. Irregularly bedded discontinuous(?) relatively even surfaced beds range in thickness from a few inches to about 1½ ft. "Crinkly" uneven discontinuous internal lamination is common, very similar to that in unit 16. Fossils ininclude several brachiopods and, in thin section, a few possible Foraminifera as well as echinoderm and bryozoan debris. 59Acr–15f (table 2) is a fossil collection, of which a split serves to represent the lithology	110±(15)	1,920+(20?)
Lower member of the Nasorak Formation (Mlnl):		
21. (Mlnl of pl. *2B*) Mudstone and limestone. Very similar to unit 18, but no pyritized fossils were noted. Base not exposed	50±(20?)	1,970+(20?)
In a structurally very disturbed zone about 700 ft farther east, rocks thought to be appropriately assigned to unit 21 are associated with limestone beds, chiefly coarse-grained medium-dark-gray biomicrite, that includes a brachiopod fauna closely similar to that collected from lower member of Nasorak Formation in sea cliff section at Cape Thompson, pl. *2A*. 59ACr–19–20f and 59ACr–21f are fossil collections (table 2). 59ACr–19–20 and 59ACr–21 consists of chips taken to represent lithology. Probably several tens of feet of beds are represented	(50?)	1,970+(70?)
Base not exposed.		
Total thickness of lower member	50+(70?)	
Total thickness of Nasorak Formation	1,970+(70?)	

Saligvik thrust fault zone.

Kogruk(?) Formation (younger than Nasorak Formation).

PERMIAN AND TRIASSIC ROCKS—WEST SECTIONS

[Sections of Permian and Triassic rocks measured in sea-cliff exposures at Agate Rock, by Reuben Kachadoorian and I. L. Tailleur, July 1958]

SHUBLIK FORMATION (TRIASSIC)

Ogotoruk Formation (greenish-black claystone and grayish-black siltstone, sheared near contact).

Probable disconformity. (Although beds are generally accordant and relations are somewhat obscured by shearing of basal beds of overlying Ogotoruk, there is a few feet of relief on the contact that may be attributable to pre-Ogotoruk erosion of uppermost beds of the Shublik.)

Shublik Formation ( ):

	Thickness (feet) Unit	Cumulative
1. Shale and minor chert. Dark-gray shale, generally thinly bedded in lower half of unit (beds ½–1 in. thick), but with some thicker beds (as much as 1 ft thick) in upper half. Top 5 ft of unit contains a few chert beds, 2–4 in. thick, interbedded with shale in beds about 1 ft thick	23	23
2. Shale. Dark-gray thin-bedded hard (siliceous?) shale	1.5	24.5
3. Chert. Dark-medium-gray chert in beds averaging 5 in. thick; beds in upper half 5–10 in. thick, and beds in lower half 2–5 in. thick	13	37.5
4. Chert and interbedded shale. Chert in beds 2–4 in. thick, interbedded with shale in beds 1–2 in. thick	6	43.5
5. Limestone. Medium-gray limestone in beds 1–4 in. thick	6	49.5
6. Shear zone	1.5	51
7. Cherty limestone with abundant *Monotis* fossils. Cherty limestone in beds 1–8 in. thick, commonly medium gray in the central part of a bed grading to light gray at the margins, with a few interbeds of shale. Shear zone 1 ft thick 6 ft below top of unit. *Monotis* abundant throughout the unit	23.5	74.5
8. Chert and shale. Black chert in beds ¾–2 in. thick, interbedded with black calcareous shale, most commonly as paper-thin laminae but locally as much as 1 in. thick	9	83.5
9. Chert and shale. Black chert in beds 1–6 in. thick, with slightly undulating bedding surfaces; interbedded calcareous shale in beds as much as 2 in. thick. Basal part of this unit is gradational with top of underlying unit 10	15	98.5
10. Calcareous siltstone and shale. Thinly bedded limy siltstone with interbedded shale. Includes one marcasite-rich zone about 9 in. thick in a shaly bed that grades into limy siltstone	6	104.5
11. Interval inaccessible in cliff. Rocks weather dark gray to black with yellow stain	4	108.5
12. Chert and shale. Medium-gray chert with a dull to glassy luster in thin slightly uneven nodular beds 1–8 in. thick. A zone of shale in beds generally less than 2 in. thick forms the basal 3 ft of the unit	17	125.5
13. Chert and shale. Interbedded chert and shale in approximately equal amounts in beds 3–6 in. thick; contains some concretions as much as 3 in. in diameter	6	131.5
14. Shale. Thinly bedded shale with concretions as much as 1 in. in diameter	2	133.5
15. Shale with some chert. Predominantly shale but including several chert beds about 3 in. thick. Sparse concretions as much as 3 in. in diameter	4	137.5
16. Massive chert; locally silty	18	155.5
17. Chert. Interbedded chert and silty chert; locally weathers yellow to dark yellow orange	2	157.5
18. Shale and chert. Predominantly shale with a few chert beds 2–3 in. thick	3	160.5
19. Cherty silt	.8	161.3
20. Shale, mudstone, and chert. Black shale with interbedded mudstone and silty shale in zones ½–2 in. thick. Top half of unit contains a few dark-gray to black layers of chert about 1 in. thick	2.5	163.8
21. Chert. Dark-gray slightly silty in beds ranging in thickness from 1 or 2 in. in lower part of unit to 6 in. in upper part. Zones 1/16–2 in. thick that weather to dark yellow give the unit an interbedded aspect	5	168.8
22. Shale. Black shaly mudstone interbedded with silty shale in layers ½–2 in. thick. Upper half of unit contains a few dark-gray to black chert layers about 1 in. thick	3	171.8
23. Chert. Dark-gray earthy chert that weathers to a dark yellow in beds that grade in thickness from 1 or 2 in. at base to about 6 in. at top	3	174.8
24. Shale. Black shaly mudstone and silty shale in beds ½–3 in. thick. A few chert interbeds about 1 in. thick occur in upper 2 ft of unit	6	180.8

Shublik Formation—Continued

	Thickness (feet)	
	Unit	Cumulative
25. Chert. Dark-gray earthy chert beds ranging in thickness from 1 or 2 in. at base to 6 in. at top. Locally, zones from 1⁄16–2 in. thick selectively weathered to dark-yellow	4	184.8
26. Shale. Black shaly mudstone and silty shale interbedded in layers from ½ to 3 in. thick. Top 1½ ft of unit contains a few chert interbeds about 1 in. thick	3	187.8
27. Shale. Medium-dark-gray finely laminated muddy shale that weathers to yellowish orange	2	189.8
28. Shale. Soft black shale in beds commonly ranging in thickness from 1⁄16 to 2 in. and averaging about 1½ in. Upper 10 ft of unit has a relatively massive aspect. Basal 3 ft is a clay shale with a probable high-iron content, as it weathers to dark yellow	13	202.8

Possible unconformity (beds may be very slightly discordant).

Siksikpuk Formation.

SIKSIKPUK FORMATION (PERMIAN)

Shublik Formation.

Possible unconformity (beds may be very slightly discordant).

Siksikpuk Formation (Ps):

	Thickness (feet)	
	Unit	Cumulative
1. Chert and argillite, nodular. Greenish-gray to greenish-black chert in thin (as much as 6 in. thick) lenticular nodules that make up relatively continuous uneven beds that average 3–4 in. thick. Interbedded with greenish-gray argillite beds of similar thickness	43	43
2. Chert and argillite, evenly bedded. Interbedded chert and argillite similar to the rocks of unit 1, but in relatively continuous even-surfaced (rather than nodular) beds that commonly are 2–4 in. thick, although a few are as thin as 1 in.	60	103
3. Argillite, with only minor chert. Greenish-gray argillite predominates in beds as much as 8 in. thick, averaging 4 in. One 4-in.-thick greenish-gray chert layer occurs 4 ft below top of unit; 13 ft below top of unit is a distorted nodular red jasperoid zone about 8 ft thick. In lower part of unit some dark streaking, about 2 in. thick, that expresses stratification. Base of unit not exposed	28+?	131+?

Unit 3 is oldest stratigraphic unit exposed at the surface in core of a minor anticline, whose banded aspect in outcrop gave Agate Rock its name.

PERMIAN AND TRIASSIC ROCKS—EAST SECTIONS

[Sections of Permian and Triassic rocks in sea-cliff exposures at the mouth of Imikrak Creek and nearby to the west. Shublik Formation measured by C. L. Sainsbury, R. H. Campbell, Reuben Kachadoorian, and D. W. Scholl, August 1958; the lower part of the Siksikpuk Formation added by R. H. Campbell and D. R. Currey, August 1959]

SHUBLIK FORMATION (TRIASSIC)

Ogotoruk Formation: Grayish-black thin-bedded to shaly argillite, with interbedded mudstone and siltstone in beds 1⁄16–¼ in. thick; persistent but discontinuous zone of red alteration within a few feet of the underlying contact. The Ogotoruk beds are intensely sheared and slickensided—much more so than the more competent beds of the underlying Shublik. The basal Ogotoruk beds are covered, as is the contact, in the immediate vicinity of the measured Shublik section. They are, however, exposed in the sea cliffs in a minor anticline about ⅓ mile west of the exposures where the section was measured.

Accordant contact: The contact appears to be an accordant depositional contact, even though the overlying beds are intensely sheared. The shearing is interpreted as the natural response of the relatively incompetent Ogotoruk rocks to the folding of the more competent Shublik beds, together with the effects of subsequent drag from above by the overriding Ibrulikorak-Agate Rock thrust sheet. Again, the contact zone is covered in the immediate vicinity of the measured Shublik section, and the relations are described from an outcrop to the west—the same outcrop as that from which the above description of the basal Ogotoruk beds was made.

	Thickness (feet)	
	Unit	Cumulative
Shublik Formation ( ):		
1. Mostly covered. Float indicates the topmost beds are greenish-gray to black siltstone or argillite, underlain by a zone of shaly *Monotis*-bearing limestone, underlain in turn by shale(?). (Thickness estimates subject to error due to poor exposure and to the geometry — gently-dipping beds intersecting gentle topographic slopes.)	30	30
2. Chert, interval mostly covered (thickness estimated). Grayish-black to medium-gray chert in beds averaging about 4 in. thick	10	40

Shublik Formation—Continued

	Thickness (feet) Unit	Cumulative
3. Limestone and chert. Medium-olive-gray to medium-gray (weathers to grayish orange) *Monotis*-rich limestone, locally cherty (including some irregular small patches of dark-reddish-brown chert), in beds generally from 2 in. to 1 ft thick; some interbedded dark-gray to greenish-gray chert. Unit crops out as a relatively continuous series of ledges with gentler more generally vegetated slopes above and below	20	60
4. Covered interval. Subdued slope-forming unit, may be shaly here, but to the west limestone and chert similar to unit 3 above, with some interbedded black shale, crop out at what appears to be the same stratigraphic horizon as this covered interval (thickness estimated)	35	95
5. Chert and shale, with some limestone. Grayish-black to greenish-gray chert in beds 1–4 in. thick; interbedded with black to greenish-black shale and subordinate interbedded *Monotis*-bearing limestone. The black chert and shale locally contain thin laminae in which *Halobia* fossils are abundant	20	115
6. Shale. Predominantly thin-bedded black shale, with a distinct sulfurous smell when freshly broken; irregularly interbedded with minor amounts of thin-bedded dark gray chert. In places the shale near the base weathers to reddish colors. A few feet above the base, a continuous thin (1–2 in. thick) layer of very light gray bentonitic(?) clay. Considerable lateral gradation of the unit is indicated by the presence, a short distance to the west, of a 12-ft-thick zone containing abundant thin- to medium-bedded greenish-gray argillite and limy argillite in which *Monotis* and *Halobia* fossils are locally abundant; this zone lies at about upper middle of unit, which, where measured, is predominantly shale	85	200

Accordant contact.
Siksikpuk Formation.

SIKSIKPUK FORMATION (PERMIAN)

Shublik Formation.
Accordant contact.
Siksikpuk Formation (Ps):

	Thickness (feet) Unit	Cumulative
1. Argillite. Greenish-gray argillite in a single relatively continuous bed 1–2 ft thick. Internally laminated, with relatively sparse thin discontinuous lenticular laminae of slightly darker color	2	2
2. Chert and subordinate interbedded argillite. Greenish-gray chert—apparently a silicified argillite, as it displays the same internally laminated structure as the argillite—predominates as continuous beds averaging about 3 in. thick. The chert is regularly interbedded with greenish-gray argillite beds that average about 1 in. thick	15	17
3. Argillite, variegated red and green. Greenish-gray argillite in zones commonly 1–3 ft thick, regularly interlayered with moderate-red argillite in relatively continuous stratigraphic zones commonly about 1 ft thick. The interlayering of red and green generally follows bedding and from a distance looks like true interbedding; in detail, however, edges of red layers are very uneven in many places, and crosscutting irregular to veinlike apophyses of red into green indicate that the zones of red argillite formed by alteration of green argillite. Red zones appear to reflect permeable horizons, and many of the crosscutting apophyses follow joints	15	32
4. Argillite, containing sparse calcareous fossils near base, and minor interbedded chert. Chiefly greenish-gray to dark-greenish-gray argillite, commonly weathering to olive gray and locally to various reddish browns. Most commonly beds are 1–3 ft thick, with faint internal laminae		

Siksikpuk Formation—Continued

	Thickness (feet) Unit	Thickness (feet) Cumulative
best expressed as color banding on weathered surfaces. Greenish-gray chert in continuous even layers, most commonly 1–2 in. thick, interbedded in argillite at irregular intervals. Chert makes up very minor part of unit. Carbonate veinlets heal fractures in both argillite and chert in some places. Near base of unit, two argillite beds contain sparsely scattered carbonate fossils that include only brachiopods and gastropods. 59ACr–89f is a collection of fossils. 59ACr–89 consists of chips taken to represent lithology. A zone of fracturing and high-angle faulting intersects the sea coast at the mouth of Imikrak Creek; thickness exposed is therefore minimum, and a stratigraphic thickness of 20 ft or more may be missing	210+20?	232+20?
5. Black shale, argillite, and chert, partly covered. Predominantly grayish-black gypsiferous (?) limonitic(?) shale that weathers to variegated shades of red, orange, yellow, red brown, and white against the blackish slope. In upper 10–15 ft of unit there are some thin (⅛–3 in. thick) interbeds of dark-greenish-gray argillite and greenish-gray chert	45	277+20?
6. Argillite and minor limestone. Dark-gray to dark-greenish-gray argillite, commonly calcareous, and in places silty, predominates in beds as much as 5 ft thick; internal lamination expressed as uneven discontinuous thin (commonly about ⅛ in. thick), greenish-gray zones in predominantly darker rock. One interbed, 4 in. thick, of medium-dark-gray silty limestone contains a few calcareous fossils: a horn coral, brachiopods, and a gastropod. 59ACr–88f is a fossil collection. 59ACr–88 consists of chips taken to represent lithology. Base of unit not exposed	20+?	297+20?+?
High-angle fault contact. (Farther inland, the map configuration of the Siksikpuk-Tupik contact indicates that units are accordant; total thickness of Siksikpuk, as estimated from structure sections, probably no greater than 400 ft. Consequently, it is estimated that no more than 100 ft of lower part of Siksikpuk Formation is missing from these sea-cliff exposures.)		
Tupik Formation of the Lisburne Group.		

JURASSIC OR CRETACEOUS ROCKS

The Ogotoruk and Telavirak Formations, as well as many parts of the Kisimilok and Fortress Mountain(?) Formations, are made up of a monotonous sequence of similar lithologic types in variable proportions and in beds of variable thickness. The following classification was devised for field use in these rocks to serve as an abbreviated description of the general lithology and bedding characteristics of an outcrop, to which distinguishing characteristics, if any, could be added. The classification is arbitrary, and all gradations between the various types may be found. It has, however, proved to be a convenient field notation and for brevity is retained in describing the measured section below.

M. Massive to thick-bedded medium-dark-gray to dark-gray mudstone having little or no internal bedding expression. In many places close-spaced fracture cleavage—most commonly axial plane cleavage, but, locally, pencil slates have formed at some fold crests and troughs. Rarely fissile enough to be called a shale.

Mg. A dark-greenish-gray subtype of *M*, commonly sheared. May superficially resemble some of the greenish argillites of the Siksikpuk and Shublik Formations. Generally more argillaceous than most of the type-*M* rocks. Common at, but not restricted to, the base of the Ogotoruk Formation.

Mt. Resembles *M* but commonly has recognizable internal bedding expressed as thin laminae of alternating dark-gray and slightly lighter colored layers containing slightly more abundant quartz silt.

MS. Mudstone of type *M* or *Mt* with very thin interbeds of medium-dark-gray fine-grained sandy siltstone (graywacke), generally rhythmically interbedded in cycles less than 2 in. thick. Sandstone beds locally have small bottom marks, most of which appear to be casts of small pellets (fecal?). Low-angle internal cross-lamination is locally visible in sandy siltstone. Cycles are graded beds.

Sm. Zone predominantly *M* or *Mt* with prominent irregularly interbedded lenses of thick-bedded to massive fine- to medium-grained muddy sandstone (graywacke). Individual beds are apparently discontinuous, but some zones may be traced a mile or two along the strike.

SM. Interbedded mudstone of type *M* or *Mt* and muddy very fine-grained to medium-grained graywacke sandstone in nearly equal amounts. Generally rhythmically interbedded in cycles from a few inches to 1½ ft thick. The cycles are graded beds. Bottom marks are common and some are large. Carbonaceous trash is abundant in some sandstones, particularly in the Telavirak Formation. Low-angle cross-lamination is moderately common in sandstone beds. The sandstone-mudstone ratio is generally less than 60/40.

S. Massive to thick-bedded silty very fine grained to medium-grained graywacke sandstone with little or no mudstone interbedded. Sandstone commonly shows little or no internal bedding laminae, but, locally, a few beds split fairly easily along internal bedding planes on which some oriented mica may be seen. Bottom marks are rare, perhaps because shale interbeds are rare.

SMt. Similar to *SM* but intermediate with *S* in that cycles and beds are as much as 2 ft thick and sandstone-mudstone ratios are greater than 60/40. Bottom marks are common and may be large.

TELAVIRAK FORMATION, PARTIAL SECTION, NIYIKLIK CREEK

[Section measured by R. H. Campbell and D. R. Currey, July 22, 1960. Thicknesses measured by pacing the outcrop width of the steeply dipping beds and estimating the correction for local dips]

Top not exposed. Beds younger than unit 1 are covered and lie in structurally complex terrain.

	Thickness (feet) Unit	Cumulative
1. Covered. Judging from float, the rocks are chiefly of type *SM*, similar to unit 2 below. (thickness estimated)	100	100
2. Largely covered. Chiefly *SM* with interbedded *MS*, and *MS* becomes predominant near the base	250	350
3. Mostly *MS* with interbedded *Mt*. Grades from *Mt* at top, through a central thick zone of *MS* with abundant carbonaceous debris and subordinate interbedded *Mt* to *Mt* again at base	350	700
4. Predominantly *MS* with interbedded *SM*. Grades from chiefly *MS* at top; through interbedded *MS* and *SM* that, near base, includes a prominent zone of *SM* with abundant carbonaceous debris; to *MS* at base	200	900
5. Chiefly *MS* and some interbedded *SM*, with minor amounts of *Mt* interbedded in some zones. Sandstones locally carry some carbonaceous debris. (The thickness indicated allows a correction for the double repetition of about 15 ft of the beds in one large drag fold exposed in the cutbank of the stream.)	180	1,080
6. Chiefly *Sm* with abundant carbonaceous debris. Basal 300 ft is largely covered, but appears to contain subordinate interbedded *MS*, and probably grades to predominantly *MS* at the base	450	1,530
7. Chiefly *SM* with only minor interbedded *MS* near base. Well exposed; one small drag fold was seen, and thickness was corrected to allow for repetition	150	1,680
8. Partly covered. Chiefly *Mt* with minor interbedded *SM*, base gradational with underlying unit 9. Locally folded, apparent thickness may be too large by a factor of 2 because of drag folds having high amplitudes and wave lengths of 3–20 ft	150	1,830
9. Rhythmically interbedded strata ranging from *Ms* to *Sm* in cycle thickness, with subordinate interbedded *Mt*	170	2,000
10. Chiefly *Mt* with minor amounts of irregularly interbedded phosphorite in lenses as much as 1 in. thick. Locally some structural contortion, but no appreciable repetition	60	2,060
11. Contorted *M* with minor *Mt* and some *Mg* interbeds; contains a few phosphorite nodules locally associated with *Mg*. Contortion does not appear to represent significant repetition	200	2,260
12. Largely covered. Appears from float to be largely *M* or *Mt* grading to *MS* at base	200	2,460
13. Chiefly *SM* with well-developed bottom marks including good load casts and organic(?) bottom marks. Locally a thin phosphorite(?) lens is present in a mudstone interbed. Top 25 ft of unit is gradational into rocks of *MS*-cycle thickness	100	2,560
14. Largely covered. Mostly contorted *M* mudstone	300	2,860
15. Partly covered. Chiefly *MS* but upper 10 ft of unit is gradational zone to mudstone of overlying unit 14	280	3,140
16. Chiefly *SMt* with a few interbeds of *M*. The sandstone beds are as much as 5 ft thick and locally have a slabby internal parting	200	3,340
17. Unit grades from *Mt* with locally abundant phosphorite lenses at base to *MS* at top	125	3,465
18. Partly covered. Chiefly *M*, with upper 100 ft of beds grading to *Mt*, and lower 120 ft of beds have slaty to shaly aspect. Minor amounts of phosphorite found as nodules in lower middle part of unit, where beds are somewhat contorted	525	3,990
19. Covered interval	70	4,060
20. Chiefly *MS* but grades to *Mt* at top. Lower 150 ft is largely covered	250	4,310
21. Thick unit of *M* mudstone	150	4,460
22. Thin zone of *MS* having relatively uniform structure	15	4,475
23. Sheared, contorted *M*	25	4,500

Unit	Thickness (feet)	Cumulative
24. Thick unit of *MS*, partly covered near base. Some drag folding is evident, chiefly with wave lengths of 1–3 ft, and apparent thickness may be too large by as much as one-fourth	450	4,950
25. Interbedded strata of *S*- and *SMt*-cycle thickness	135	5,085
26. *MS*, base not exposed	50+	5,135

Ogotoruk Formation (largely mudstones of *Mt* and *M* types).

Probably not more than 100 ft of strata represented by covered interval at contact between the Ogotoruk and Telavirak Formations in Niyiklik Creek.

UNCONSOLIDATED DEPOSITS

Unconsolidated deposits cover at least half of the area of plate 1. They generally range in thickness from a few feet to a few tens of feet and in only a few places exceed a hundred feet. The various types of deposits are: colluvium; fluvial gravel, sand, and silt (both terrace and modern flood-plain deposits); water-laid gravel and sand of uncertain origin (fluvial or marine at high altitudes; marine deposits of the modern shoreline and at low altitude along older shorelines nearby; lake, lagoon, and swamp deposits (chiefly peat and muck); wind-deposited sand and silt; and gravel and sand of the modern beach. All but the present beach and flood plains are commonly covered with tundra vegetation. Ice is an abundant constituent in most of the unconsolidated deposits; it is present as both vertical wedges and horizontal layers. The interstitial ice of the fine-grained sediments is much less spectacular but quantitatively more important.

TERTIARY OR QUATERNARY DEPOSITS

ILYIRAK GRAVEL

The oldest of the unconsolidated deposits is probably the gravel that mantles the upper flanks on the south side of the Kukpuk River valley from its junction with the Ipewik River west to the drainage of Ilyirak Creek, from which the gravel deposit is herein named the Ilyirak Gravel. The gravel covers a single relatively continuous area between altitudes of about 150 feet and about 300 feet. At the lower altitudes it is overlapped by younger stream-terrace deposits of the Kukpuk River. The upper limit seems to be erosionally controlled. Parts of the continuous blanket deposit have been found at altitudes of as much as 415 feet, pebbles are mixed with the colluvium at higher altitudes on some adjacent slopes, and, in addition, frost-broken fragments of exotic lithology (chiefly red and green chert that was probably originally derived from the Siksikpuk and Shublik Formations) were found on the crest of an adjacent ridge of Lisburne bedrock at an altitude of more than 500 feet. The deposit ranges in thickness from 0 to more than 20 feet observed in one stream cut where the base of the deposit was not exposed.

The gravels consist chiefly of well-rounded pebbles, relatively few cobbles, and generally less than 25 percent sand, silt, and clay (fig. 25*A*). The deposits are porous and relatively well drained. The most abundant lithologic types are gray and brown chert, cherty limestone, and dolomite (probably derived from the Lisburne Group), with somewhat subordinate graywacke sandstone and mudstone (probably derived from the Jurassic? and Cretaceous rocks to the east), and, most commonly in the coarse sand and granule fraction, green and red chert (probably derived from the Siksikpuk and Shublik Formations). All these may have been locally derived; however, several pebbles and small cobbles of orthoquartzite were found for which no local source is known. Locally, irregular patches of the gravel are cemented with limonite(?), but most of the deposit is unconsolidated and friable.

The age of the deposit has not been closely ascertained, but the high altitudes at which it is found suggest that it is the oldest unconsolidated deposit on the post-Cretaceous erosion surface. Stream-terrace deposits of the Kukpuk River that are at least as old as Sangamon occur at much lower altitudes in the same area. From this it is inferred that the Ilyirak Gravel is Yarmouth or older and may be as old as late Tertiary; hence, it is herein assigned a Tertiary or Quaternary age.

The environment in which the gravel was deposited is uncertain. The deposits are much more cleanly washed and better rounded than those of the younger terrace and flood plains that are clearly river deposited, yet the bulk of the Ilyirak Gravel lies wholly within a broad lowland that has apparently been carved from bedrock by the Kukpuk River and its tributary streams. The higher parts and remnant traces of the deposit are at altitudes that correspond roughly with the highest clearly recognizable strath terrace level of the Kukpuk and Ipewik River valleys, and the Ilyirak Gravel could be an old stream-deposited terrace. On the other hand, these altitudes are also approximately accordant with the altitude of the break in slope at the top of the wave-cut bedrock plain north of the mouth of the Kukpuk River (see Kachadoorian, 1966, p. 51–52 and pl. 1).

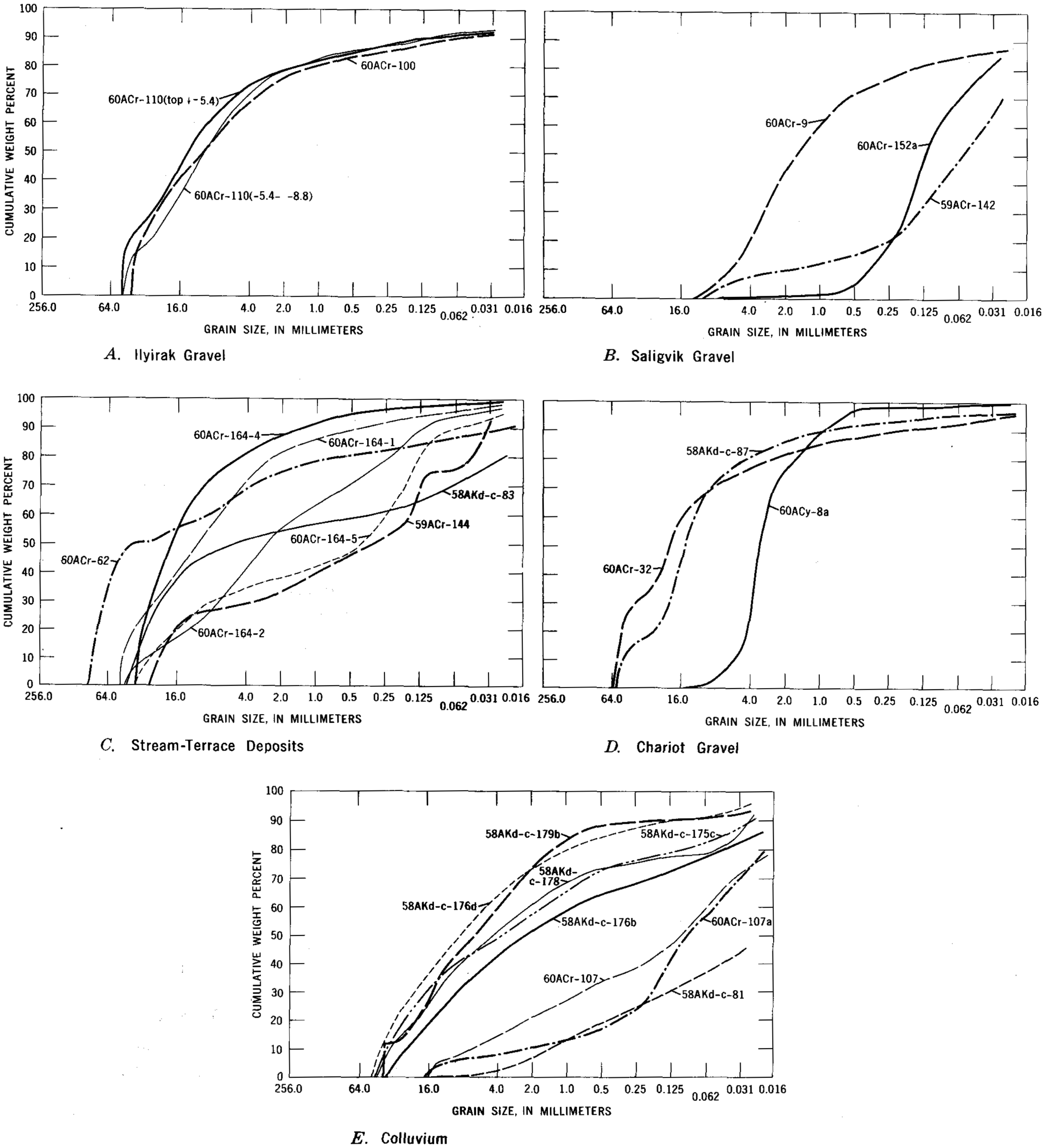


Figure 25.—Size distribution curves of samples of unconsolidated deposits.

No exposures of the Ilyirak Gravel were found in which the original sedimentary structures could be observed. The evidence so far seems compatible with either stream-terrace or marine (or estuarine) beach depositional environments.

SALIGVIK GRAVEL

Another relatively continuous deposit of unconsolidated gravel and sand occurs at relatively high altitude (as much as 350 ft) along the east flank of Saligvik Ridge, from which it is here named the

Saligvik Gravel. The deposit trends north-northeast. The southern half forms a wedge-shaped apron along the flank of Saligvik Ridge and includes good cutbank exposures at the head of Kiligvak Creek, the type locality; the northern half forms a long, low ridge bounded on the east by the center of Saligvik Valley and on the west by Saligvik Creek, which appears to have been incised at or near the contact between the limestone bedrock ridge to the west and the unconsolidated gravel. The deposit extends both to the north and to the south of the low divide that separates Ogotoruk and Saligvik Valleys. The highest recognized parts of the deposit are at an altitude of approximately 350 feet. At the northern end, in the northwestern end of Saligvik Valley, the deposit overlies bedrock at an altitude of slightly less than 150 feet. To the south, on the west side of Ogotoruk Valley, similar gravels also overlie bedrock at altitudes as low as 150 feet.

The deposit consists almost entirely of interstratified well-rounded fine pebble to granule gravel and sand (fig. 25*B*). The internal stratification is fairly regular and even. The pebbles consist entirely of rock fragments which could have been locally derived. Graywacke is the most abundant rock type, but chert and cherty limestone are also well represented. The gravel is commonly overlain by a few inches to about a foot of silt containing abundant organic debris and a few inches to a foot of tundra vegetation. Locally, thick peat deposits (1–6 ft thick) have formed in depressions that appear to be drained thaw lakes and old stream channels at the surface of the Saligvik Gravel. Incised stream-cut exposures of the gravel show that it is more than 35 feet thick in some places. Where exposed and thawed, the deposits are well drained and friable, and there is apparently little or no clay in the interstitial matrix.

The surface expression of the gravel deposit is generally distinctive, both on the ground and in the vertical aerial photographs. The upper surface is characterized by large ice-wedge polygons separated by channels that are as much as 1½ to 2 feet deep. Where streams have been incised through the protecting mat of tundra vegetation, the gravels locally display a badlands topography, with steep-walled flat-bottomed gully, in a generally dendritic pattern, encroaching headward into the tundra-covered surface of generally more gentle relief.

The age and origin of the deposit are uncertain. The age is surely older than the river-terrace deposits of probable Sangamon or older age that truncate it on the north. The low altitude of its base on the north indicates that it is younger than the erosional gap of the Kukpuk River through the southern Lisburne Hills and the erosional tributary Saligvik Valley; however, its position on the flank of the valley indicates that the cut bedrock surfaces of both Saligvik and Ogotoruk Valleys may have been deepened on the east side of the gravel deposit after its deposition. The position athwart the divide between Ogotoruk and Saligvik Valleys seems enigmatic, particularly with regard to the lower extremities of the gravel in Ogotoruk Valley. These lower sections, however, are thin and poorly exposed. Moreover, they are in some places intimately associated with stream-terrace deposits of tributaries to Ogotoruk Creek. It is possible, perhaps probable, that these parts of the deposit are more recent stream-terrace deposits that are made up almost exclusively of gravel and sand reworked from the Saligvik Gravel at higher altitude on the flank of the valley. If so, the Saligvik Gravel probably represents deposition in an ancestral Saligvik Valley that once extended to the south considerably beyond the present divide but which has migrated northward as a result of capture by the headward erosion of south-flowing Ogotoruk Creek. In any case, the Yarmouth Interglaciation provides the youngest depositional base level with which the deposit might be correlated, and it seems quite possible that it is older still, perhaps as old as late Tertiary. The deposit, therefore, is herein assigned a Tertiary or Quaternary age.

The Saligvik Gravel is probably easiest to visualize as the deposit of a northward-flowing tributary of the Kukpuk River. However, the possibility that it is a marine or lacustrine beach deposit cannot be disregarded: the high degrees of rounding and sphericity of the pebbles, the rather well-sorted nature of interstratified sand and gravel, and the lack of abundant interstitial clay are all features that resemble those of the material of the modern beach and are distinctively different from those of the more recent stream-terrace and flood-plain deposits that are clearly related to the Kukpuk River. The chief difficulty of the beach-origin hypothesis is that a coastline at an altitude of 350 feet or more would probably have made an island or a long peninsula of the ridge along whose flank the deposit was laid, and it is hard to reconstruct the circumstances which would permit such an island or peninsula, made up chiefly of limestone bedrock, to accumulate a beach in which graywacke pebbles predominate. Adjacent bedrock units that would provide a local source of graywacke detritus would have been exposed only on nearby islands. Although a reconnaissance search was made, no deposits remotely comparable to the Saligvik Gravel were found on hillsides where islands underlain by graywacke-bearing bedrock might be expected to have accumulated beach deposits during a high stand of sea level.

Although the Ilyirak and Saligvik Gravels are similar in some of their surface expressions and in presumed minimum age, they are sufficiently different in grain size, pebble lithology, and maximum altitude to indicate that they are not directly correlative with one another. The lower maximum altitude of the Saligvik Gravel may justify the inference that it is younger than the Ilyirak Gravel.

QUATERNARY DEPOSITS

STREAM-TERRACE DEPOSITS

Several levels (and ages) of stream-terrace deposits, clearly related to present streams or their immediate ancestors, are present along the Kukpuk and Ipewik Rivers and their tributaries, as well as along the shorter streams which drain southward to the sea, such as Ogotoruk and Kisimilok Creeks. The deposits consist chiefly of subrounded to subangular cobble and pebble gravels with abundant interstratified (as well as interstitial) sand and silt (fig. 25*C*). The cobbles and pebbles consist, almost without exception, of rock types that could have been derived from the bedrock formations of the map area, upstream from the present sites of deposition.

The thickest and most continuous of the terrace deposits is one about 30 feet thick that is intermittently exposed along the Kukpuk River. In many places the upper surface of a deposit, though covered with tundra vegetation and modified slightly by ice-generated microrelief features, is little reworked and displays the relatively flat characteristic terrace form. On this flat surface, shallow lakes and swamps and their grass-covered drained basins are common. Exposures of the bedrock surface on which this terrace material is deposited are commonly within a foot of the low-water level of the present river. The thickness and relative continuousness of terrace deposits at this level indicate that this entire stretch of the river was aggraded to a base level, probably a stand of sea level, at an altitude about 30 feet above the present sea level. It seems reasonable to infer, therefore, that this river terrace correlates with the stand of sea level, about 26 feet above the present level, during which beach deposits of Sangamon age were laid down along the coast (Moore and Scholl, 1961, p. 61).

Although many, generally discontinuous, terrace surfaces are cut in the bedrock at higher altitudes along the rivers and streams, no deposits (with the possible exceptions of the Ilyirak and Saligvik Gravels, whose association with the prominent cut-terrace features is indirect at most) were found on those that were examined. At lower altitudes, terrace deposits are most common from 3–15 feet above the present stream grades. They are generally discontinuous, but locally, along some individual streams, are persistent. Most are probably younger than the Sangamon river terrace; but some, particularly those along Ogotoruk Creek, may be early Sangamon or older, because the stream-cut bedrock surface on which the Chariot Beach gravel of Sangamon age was deposited lies less than 5 feet above the present grade of Ogotoruk Creek where it cuts through the Chariot Gravel.

CHARIOT GRAVEL

Beach and nearshore marine deposits that represent a eustatically high sea level, probably during the Sangamon Interglaciation, occur along low-lying areas of the coast, generally within a few hundred feet of the present shoreline. They are represented near the mouth of Ogotoruk Valley by an old bay-mouth bar, whose top ranges in altitude from 34 to 42 feet, and upon which the Chariot base camp was built; therefore, the Chariot Gravel is here named for these deposits. The character and distribution of these gravels, together with the associated underlying marine platform and some of the overlying nonmarine deposits, have been described in detail, and their origin and age discussed by Sainsbury and others (1965); related deposits in the Point Hope and Cape Krusenstern areas have been described by Moore and Scholl (1961, p. 61–63). Except for the relatively high-standing old bay-mouth bar at the mouth of Ogotoruk Creek and a small outcrop near the mouth of Kuropak Creek, the deposits are exposed only in vertical stream-cut or wave-cut sections intermittently along the coast. They are most generally thin layers of marine sand and gravel, sandwiched between the wave-planed bedrock surface below, and a cover of nonmarine deposits, chiefly colluvium, of variable thickness.

The deposits consist generally of friable well-rounded coarse- to fine-pebble gravel (fig. 25*D*) and interstratified sand. The bay-mouth bar deposit at the Chariot campsite seems to contain a greater-than-normal proportion of admixed silt and clay(?) thought to be wind-deposited material that has been mixed with the upper part of the gravel by percolating rainwater and seasonal frost action. The deposit there is about 25 feet thick; where observed elsewhere, the deposits range in thickness from a few inches to about 10 feet, but they could, of course, be thicker in some of the low-lying coastal areas where they are now concealed by younger nonmarine deposits.

COLLUVIUM

The most widespread of the unconsolidated deposits is colluvium; it has formed at the base of nearly every bedrock rubble slope and extends as aprons of varying width and thickness onto the gentler slopes below. It is almost invariably covered with tundra vegetation and is exposed chiefly in stream cutbanks, wave-cut bluffs along the coast, and relatively sparse frost boils. Commonly, but not invariably, there is a pronounced break in slope between steeper relatively barren bedrock rubble hillsides and the gentle well-vegetated colluvium-covered valley slopes. These slope breaks give the impression of a multitude of small discontinuous terraces. Solifluction lobes are abundant in the apronlike deposits, but where aprons have coalesced to blanket the bottoms of some small valleys, longitudinal ridges parallel to the valley axes are common. Ice-wedge polygons and tussocks are extremely rare and seem to be confined to areas where the surface is nearly flat and downslope movement has not occurred for some appreciable number of years. The thickest and best exposed of the colluvium deposits forms a prominent terrace along the coast of the Telavirak Hills. The terrace and its associated colluvium deposits have been described in detail by Sainsbury and others (1965).

The colluvium is composed of angular to subangular fragments of bedrock, generally of coarse pebble or smaller size, with variable amounts of frost-admixed sand, silt, and clay of probable aeolian origin (fig. 25*E*). Locally, the colluvium includes material derived from preexisting unconsolidated deposits which have been reworked, both with and without the addition of locally derived fragments of bedrock. The deposits are commonly less than 10 feet thick, forming thin continuous blankets over gentle bedrock slopes; but, locally, where the colluvium has filled old stream gullies, it may be as much as 20 feet thick. The coastal-terrace deposit at the foot of the Telavirak Hills, where material was apparently supplied very rapidly as the sea cliffs of Sangamon age were eroded, is as much as 100 feet thick in some places.

Colluvium forms at the base of bedrock rubble slopes, where it is mixed by frost action with finer material, both locally derived and deposited by aeolian processes. The growth of tundra vegetation insulates the underlying material so that the top of the permafrost zone rises above the base of the unconsolidated material. During the summer season, the upper 1½–2 feet of the deposit thaws and, because of the impermeability of the underlying frozen ground, becomes saturated with water. The water-saturated thawed zone is then free to move downslope. Movement is chiefly by solifluction, but in a few places, where the matted cover of tundra is broken, it may occur by mudflow and shallow slump. No direct evidence for the maximum age of the colluvium deposits has been found. Deposits are being formed and moved at the present, and because the processes by which they are formed are so intimately associated with the arctic climate, their age is presumed to range from earliest Pleistocene to the present.

LAKE, LAGOON, AND SWAMP DEPOSITS

Peat and muck, the principal constituents of swamp, lagoon, and lake deposits, are common in many parts of the low-lying coastal plain, in closed or nearly closed colluvium-filled depressions at higher altitudes (such as the low-gradient effluent drainage of Pumaknak Pond) and in the drained thaw-lake basins that are extremely common on the terrace deposits of the Kukpuk River; they are sporadically distributed across the surface of the Saligvik Gravel. Areas that are wet and swampy at present are commonly very grassy in appearance in contrast to most of the adjacent deposits of other sorts. The deposits in better drained terrain are most easily recognized where they occur in the drained basins of thaw lakes, which generally have distinctive marginal scarps. In areas where the deposits appear to have been relatively well drained for some appreciable number of years, ice-wedge polygons are common. Peat and muck are also found interbedded with many of the older terrace deposits, as well as with colluvium and wind-deposited silt and sand. Apparently many small stream channels have been filled with colluvium or flood-plain deposits above which the surface runoff was locally ponded, forming a swampy environment in which peat accumulated, in a few places to a thickness of several feet. These organic-rich layers are everywhere underlain by older unconsolidated deposits, and the present lakes, swamps, and lagoons are all floored and surrounded by older unconsolidated deposits. None within the mapped area lies directly on bedrock. Consequently, the deposits are invariably thinner than the older unconsolidated deposits that surround them.

The composition of the deposits ranges from nearly pure peat to mud containing a fairly high proportion of silt, clay, and sand commonly mixed with peaty organic material. The silt, clay, and sand probably include both aeolian detritus and that derived from older unconsolidated deposits by wave erosion of the banks of the small lakes. The deposits of Mapsorak Lagoon have been studied in detail by Moore and Scholl (1961, p. 48–50), and many characteristics of that lagoon are probably shared by the others. Because the processes of peat formation seem to be associated with tundra vegetation and (but more indirectly) with the arctic climate, the range in age of the peat and muck deposits may well be nearly the same as that of the colluvium—from earliest Pleistocene to the present. Muck is certainly forming today at the bottom of many thaw lakes, and peat with a radiocarbon age of 26,000 ± 400 years (middle Wisconsin) was sampled in the Point Hope area (Moore and Scholl, 1961, p. 63).

WIND-DEPOSITED SILT AND SAND

Silt and sand of probable aeolian origin covers much of the low-lying coastal-plain areas, as well as the lower flats and gentle slopes that are abundant in Ogotoruk and Saligvik Valleys and the valley of Kisimilok Creek. In the flat areas the deposits are commonly covered with a fairly continuous tundra mat, and ice-wedge polygons are the dominant microrelief forms. On the slopes, grassy tussocks are more common, and solifluction stripes, perpendicular to the hillside contours, are the most prominent form of microrelief. The difference in surface expression reflects the difference in stability of the active layer (the zone in which summer thaw occurs) between the relatively stable flats and the slopes down which gravity tends to induce movement during the summer period of thaw and water saturation.

The deposits are compact and saturated with water or ice; cutbanks are quickly degraded by slump and soil flow. Thickness is commonly on the order of 1 or 2 feet; locally it may be as much as 4 feet, and greater thicknesses may have accumulated in a few places where depressions or gullies as much as 20 feet deep could be concealed beneath the unconsolidated deposits. Silt and sand most commonly is underlain by colluvium or other older unconsolidated surficial material, but in some places the subjacent material is residual frost-broken bedrock.

Windblown deposits of several ages are probably present, as silt and sand are interbedded with some swamp deposits and with colluvium as well as lying upon all the other unconsolidated deposits except for the very recent flood-plain and beach sediments. Some dust is known to blow in Ogotoruk and Saligvik Valleys at present but not in amounts needed to form appreciable deposits. The most likely sources for the fine material of the aeolian deposits are the barren, unvegetated moraines and outwash plains exposed during glacial retreat. Many local low areas in which aeolian sand and silt predominate at the surface have a well-developed tundra mat and deep and well-defined ice-wedge polygons that must have been stabilized for an appreciable number of years and may be as old as late Wisconsin. The age of these deposits is, therefore, considered Pleistocene and Recent.

FLOOD-PLAIN DEPOSITS

Modern flood-plain deposits occur along the Kukpuk and Ipewik Rivers, the lower reaches of a few of their tributaries, and along a few of the shorter streams that drain south to the ocean, such as Ogotoruk and Kisimilok Creeks. The surfaces of the deposits are generally barren of vegetation, but some parts that are awash only during relatively infrequent (two or less a year) flood stages, sustain some grasses and tundra.

The deposits consist of fluvial gravel, sand, and silt. The gravels are chiefly flat elongated tabular subrounded to subangular pebbles (showing better rounding in lower reaches of small streams as well as along the rivers); large cobbles and boulders are rare. The size and shape are probably functions of the bedding characteristics and jointing of the well-indurated original bedrock. The composition of the gravels reflects that of local and upstream sources of bedrock and, to a much lesser extent, older unconsolidated deposits. The proportion of matrix sand and silt in the gravel is variable; but it is commonly much greater than might be presumed from the surface appearance of the exposed gravel bars, and may locally make up more than 50 percent of a deposit. Apparently, gentle currents of the waning flood stage winnow the finer matrix from between the topmost pebbles of the flood-deposited mixture of gravel, sand, and silt.

In the short streams that drain south to the Chukchi Sea, the flood-plain deposits probably do not exceed 10 feet in thickness. The deposits of the large rivers, although thicker than those of the small streams, probably do not exceed a few tens of feet.

BEACH DEPOSITS OF THE PRESENT SHORELINE

Recent gravel beach deposits extend along the entire coastline, continuously except for a few cliffed headlands along the sea cliffs between Crowbill Point and Cape Thompson. Beneath the sea cliffs the beach is too narrow to show on the map (pl. 1), but it is nevertheless present as a nearly continuous strand, broken by major headlands at Cape Thompson, Agate Rock, Artigotrat, and Crowbill Point (pl. 2). A narrow, but continuous beach lies along the foot of the coastal bluff at the south side of the Telavirak Hills and extends to the wider beaches of the adjacent lowlands of Ogotoruk Valley and the valley of Kisimilok Creek. Across the low-lying coastal plains to the northwest of Agarak Creek and to the southeast of Kisimilok Creek, beach deposits are continuous along the smoothly curved shoreline, in many places as barrier bars, separating the Chukchi Sea from fresh- and brackish-water lagoons. The deposits are generally barren of vegetation, but some sparse grasses may be found on the higher parts of the barrier bars, which are reached by only a few waves from the highest storms each year.

The beaches are generally confined to altitudes of less than 12 feet, though a few of the barrier bars may be as much as 15 feet above sea level. They are generally less than 40 feet wide where they are present beneath the precipitous limestone cliffs, but they are considerably wider in the low-lying coastal areas where some of the barrier beaches are as much as 300 feet wide. The beach deposits of this and adjacent areas have been studied in detail by other investigators in connection with the Chariot program (Scholl and Sainsbury, 1959; Moore, 1960; Moore and Cole, 1960; and Moore and Scholl, 1961). According to Scholl and Sainsbury (1959, p. 57–59), the deposits probably are generally less than 25 feet thick and are composed of stratified well-sorted well-rounded sandy pebble gravels consisting chiefly of fragments of fine-grained graywacke, siltstone, chert, and limestone.

GEOLOGIC STRUCTURE

A regional dip to the south or southeast is indicated by the exposure of progressively younger units from west to east on the map (pl. 1), even though westerly dips are common at surface exposures of the strata. As shown by the structure sections (pl. 1), Paleozoic and Mesozoic strata 25,000–30,000 feet thick are present in the eastern part of the area, but they have been eroded off the western part. In addition to the stratigraphic evidence, gravity data show a generally gradual decrease in simple Bouger anomalies along a northwest to southeast profile across the area (Barnes and Allen, 1961, p. 80-86), and more recent data (Barnes, oral commun., 1962) suggest that the regional gradient is more nearly east or east-northeast than southeast. All the exposed rocks have approximately the same density; therefore, the relatively smooth gravity gradient is interpreted to reflect a gradual eastward thickening of the sedimentary rocks overlying a dense layer that either slopes relatively smoothly or is so deeply buried that its irregularities are not expressed.

In the western half of the area the structure is dominated by a north-trending zone of imbricate thrust faults along which rocks of the Lisburne Group have been thrust eastward over Lisburne and younger strata. In the eastern half of the area the dominant structural features are complex high-amplitude folds and high-angle faults.

THRUST FAULTS OF THE WESTERN PROVINCE

The north-trending zone of thrust faults extends from the Chukchi Sea northward to Cape Lisburne (A. J. Collier, 1906; J. T. Dutro, Jr., E. G. Sable, and A. L. Bowsher, written commun., 1958). Four thrust sheets are present in the western part of the map area. The rocks of two of these, the Saligvik and Ibrulikorak thrust sheets, predominate at the surface. A third, the Angmakrok sheet, is only intermittently exposed along the eastern front of Saligvik Ridge beneath the younger Saligvik thrust sheet. The fourth, the Agate Rock thrust sheet, appears to be merely a large fault sliver below the Ibrulikorak fault. The Saligvik thrust sheet has an exposed width of more than 4 miles and a maximum thickness of 7,000–8,000 feet. The Ibrulikorak thrust sheet is slightly more than 8 miles wide at its widest point on the map, and its thickness ranges from about 2,000 feet at the coastline to an estimated 3,000 feet along the Kukpuk and Ipewik Rivers.

Each of the thrust sheets has moved relatively eastward or southeastward, forming an imbricate pattern as shown in the structure sections (pl. 1). The earliest thrust sheet is bounded at the base by the Angmakrok thrust fault; it was subsequently broken by high-angle faults and overridden by the Saligvik thrust sheet along the Saligvik thrust fault (pl. 2*B*); the Saligvik thrust sheet was, in turn, folded, faulted, and overridden from the west by a still later thrust sheet bounded at its base by the Agate Rock and Ibrulikorak faults (pl. 2*A*). The Akoviknak fault is probably the western tail of the Ibrulikorak fault (see structure sections, pl. 1) and could represent the upslope exposure of a zone of detachment that, to the east, broke upsection along progressively more westward fronts in successively younger pulses (Campbell, 1961c). In that event, movement on the Akoviknak fault would be the sum of the movements of all the west-dipping thrust faults, for each of which the Akoviknak would have been the upslope tail. The eastern overthrusting on the Angmakrok thrust is a minimum of 1 mile (see structure section *C–C'*, pl. 1), and an estimate of 2 or 3 miles would not be unrealistic. The movement on the Saligvik thrust is, at a minimum, 1 mile, but probably it is considerably more. The eastward overthrusting on the Ibrulikorak and Agate Rock faults is at least 2 miles and is possibly more than 5 miles. Thus, a total displacement of 7–10 miles is indicated. The displacement could be somewhat greater, but it seems unlikely that the total overthrust displacement is on the order of several tens of miles because it has not brought into juxtaposition very different lithologic facies of the same formations.

The Mississippian strata of the Saligvik and Ibrulikorak thrust sheets are generally folded into rather broad synclines and anticlines. The limbs of the structures, though cut by some high-angle faults, most of which have relatively small displacements, have relatively uniform gentle dips. Some axial zones, however, are intensely faulted and folded into tight structures of high amplitude. This is particularly striking in two synclines in the Saligvik thrust sheet, in which Siksikpuk, Shublik, and, locally, Ogotoruk rocks are infolded. In places these structures have been further modified by drag effects as they were overridden by the Ibrulikorak thrust sheet. Drag folds of varying amplitudes are common in the basal strata of the thrust sheets. Chevron forms are strikingly abundant in the zone immediately above the Saligvik thrust fault in the sea-cliff exposures just west of the mouth of Amaktusak Creek (pl. 2*B*).

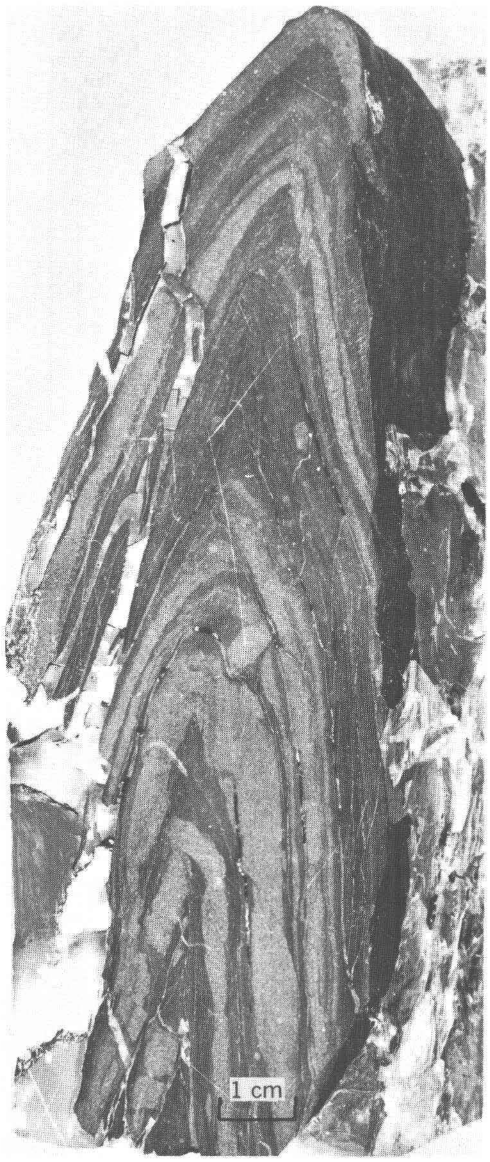


FIGURE 26.—Bedding characteristics and structural features in the Telavirak Formation. Interlaminated mudstone and sandy siltstone showing thickening, attenuation, and fracturing associated with adjustments to the tightly folded configuration in a minor anticline (a drag fold on the flank of a larger structure). The glassy material that surrounds and veins the specimen is plastic in which it was imbedded to prevent its disintegration during sawing and polishing.

FOLDING AND FAULTING OF THE EASTERN PROVINCE

In contrast to the thrust-faulted province in the western part of the map area, the eastern part is dominated by north- to northeast-trending folds and high-angle faults. The folds are generally tight, of high amplitude, and have steep-dipping limbs and tightly crumpled axial areas. Overturned folds are common, generally with both limbs dipping to the west. Minor folds of several types and widely varying amplitudes are present on nearly all the limbs of the folds (fig. 26). The high-angle faults appear to be intimately related to the folds. Axial-plane faults and bedding-plane faults are common, and slickensiding is abundant on many bedding planes within the rock units. Many of the high-angle faults appear to be zones in the crest and troughs of folds where the rocks failed by fracture, locally, rather than by flexure.

Poor exposures, lack of key beds and marker horizons, and the abundance of minor folds having amplitudes larger than the size of the outcrops combine to obscure much of the general structural picture in the areas underlain by the Ogotoruk, Telavirak, Kisimilok, and Fortress Mountain(?) Formations. The continuous projections of the longer faults shown on the map (pl. 1) are based largely on discontinuities of structure across the inferred fault traces rather than continuous exposure of the faults themselves. The major axial traces are similarly inferential, and the lines on the map serve more to illustrate the general nature of the folding and faulting than to show the precise locations of continuous readily recognizable features. Although the amplitudes of the major folds must be of the order of at least several hundred feet, it is important to note that rocks of the Shublik Formation and older units are not returned to the surface to the east of the eastern flank of Saligvik Ridge by the folding or faulting of the Ogotoruk Formation. Nor are recognizably older rocks returned to the surface by folding or faulting in any of the successively younger map units.

Joints, perpendicular or nearly perpendicular to the bedding, are common in the sandstone beds; close-spaced, locally slaty, fracture cleavage is common in the mudstone beds. In many outcrops the fracture cleavage appears to be an axial-plane cleavage, dipping steeply to the west. In many outcrops it is parallel or nearly parallel to the bedding, giving many of the mudstones a shaly aspect. In axial zones and some other structural settings, however, where the fracture cleavage intersects bedding-plane partings at oblique angles, the fractured rocks resemble pencil slates (fig. 27). Where the mudstone is rhythmically interbedded with more competent sandstone, the close-spaced fracture cleavage, which may be at angles of as much as 30° to the bedding planes, appears to be related to the differential slip of the overlying and underlying sandstone beds (fig. 28).

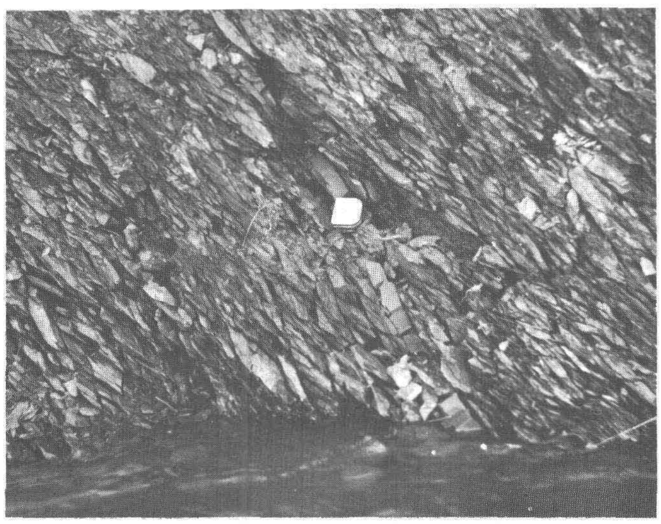


FIGURE 27.—Mudstone of the Ogotoruk Formation with one thin interbed of sandstone that expresses bedding; shows close-spaced fracture cleavage at acute angle to bedding. The straight edge of the scale case is 2 inches long.

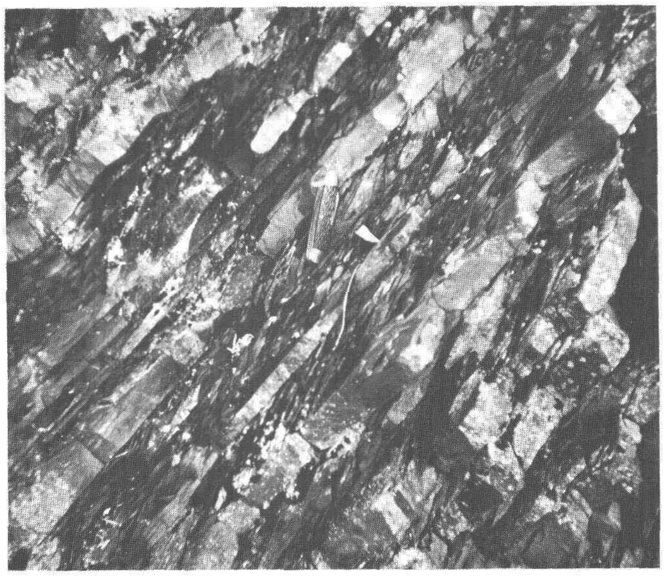


FIGURE 28.—Fracture cleavage in mudstone interbedded with sandstone in which the cleavage is not developed. Telavirak Formation.

The hypothetical thrust fault that forms the contact between the Kisimilok and Fortress Mountain(?) Formations may be related to the thrust faults of the western half of the area; however, there is no local evidence to suggest a direction or amount of displacement. Owing to the poor exposure, the possibility that this contact is an unconformity cannot be eliminated, but the generally smooth curvature of the contact and the indications that both units are discordant with the contact suggest that it may be an eastward-dipping low-angle (thrust) fault.

AGE AND ORIGIN OF DEFORMATION

The thrust faulting of the western province and the folding of the eastern province appear to be contemporaneous and are probably related to the same deforming stresses. This is indicated by the parallelism of the general trends of the folds with the fronts of the thrust sheets, by the absence in the western province limestone and dolomite strata of high-amplitude multiple folds of the type found in the less competent flysch facies beds of the eastern province, and by the absence of such high-amplitude folding of the thrust faults themselves. It seems likely that each of the thrust faults was a planar or smoothly curved surface at the time the overlying strata were displaced. The places where the thrust faults cross the stratigraphic units, therefore, indicate that some gentle folding occurred before the overthrusting. But the large areas in which the faults follow stratigraphic horizons, and which are even now only broadly folded, indicate that the Paleozoic rocks were not thrown into high-amplitude folds along with the Jurassic(?) and Cretaceous strata.

The youngest bedrock unit exposed in the known overthrust sheets is the lower part of the Ogotoruk Formation. As the Ogotoruk and Telavirak Formations form a continuous depositional sequence that probably also includes the Kisimilok Formation, the time of deformation indicated is post-Kisimilok. If the contact between the Kisimilok and Fortress Mountain(?) Formations is an unconformity, then two periods of fairly high intensity deformation would be indicated. However, the rocks of both units are contorted to about the same degree, and it seems more likely that the contact is a fault and that all of the bedrock units now exposed in the area were deposited before a single major period of deformation in post-Fortress Mountain(?) time.

Other evidence bearing on the age of deformation may be adduced from the Utukok-Corwin region to the north, where rocks as high in the section as the Nanushuk Group are evidently involved in thrust faulting of the same general structural associations as those in the western part of the Cape Lisburne Peninsula (Chapman and Sable, 1960, p. 144). Chapman and Sable (1960, p. 144) believe these structural features to be the result of eastward- and northeastward-directed tangential forces originating west of the peninsula in the Tigara uplift, which Payne (1955) describes as of Tertiary(?) age, probably post-Paleocene.

The deformation of rocks of the Chariot area and vicinity is herein interpreted to be a response to an easterly regional dip formed as a result of uplift in the vicinity of Point Hope and west of it (the Tigara uplift of Payne, 1955). The cross sections (pl. 1) show an average gradient of 7°–10° eastward on the base of the Lisburne Group. The association of easterly overthrusting with an easterly regional dip suggests that the thrusting took place by gravity gliding (Campbell, 1961c). The folding of the eastern province, with its predominance of west-dipping axial planes, took place at the same time under the same regional stresses. The difference in kinds of structure between the eastern and western provinces merely reflects the difference in response of rocks of different competence to components of gravitational force in the direction of the regional dip. The relatively competent rocks of the Lisburne Group tended to move as coherent sheets, chiefly along the numerous weakly bonded bedding planes at and near its base. The underlying mudstone-sandstone unit, being water saturated, may have served as a lubricated zone along which the overlying coherent sheets could slide, possibly aided by abnormal fluid pressures (Hubbert and Rubey, 1959). The relatively incompetent Jurassic(?) and Cretaceous rocks also tended to move downslope, but they were less confined by overburden than the more competent rocks below (and perhaps they were even buttressed laterally by the end of the eastern dip at a basin or synclinal axis in the vicinity of Cape Seppings). The response in this eastern province was chiefly by tight folding and high-angle faulting.

GEOMORPHOLOGY

The varied geomorphic features of the area represent a long and complex history of erosion and deposition. Most of it was subaerial and fluvial, but marine erosion and deposition are represented by many features at low altitudes along the coast and may have affected higher areas where the evidence is poorly preserved. Two major rivers, the Kukpuk and the Ipewik, are superposed across the general structural grain of the area. Their valleys are deeply incised into an old upland surface of very low relief. The upland surface appears to be stepped along a northwest-trending line that generally follows the northern side of the valley of the Kukpuk River. North of the Kukpuk River several north- to north-northwest-trending ridges rise to altitudes in excess of 1,750 feet. South of the Kukpuk River many ridge tops and hilltops show remnants of a low rolling surface between altitudes of 500 and 1,000 feet.

The general topographic features of areas below 500 feet appear to reflect almost exclusively the dissection of the old upland surface by minor streams that follow the general structural grain and are tributary to the Kukpuk River or drain south to the sea. Stream-cut terraces may be observed in the valleys of the Ipewik and Kukpuk Rivers at altitudes as high as 600 feet. Fluvial terrace deposits are found at lower altitudes along the rivers, and locally, as much as 30 feet of such deposits overlie cut bedrock surfaces at altitudes as low as a foot above the present low-water level of the rivers. The prominent strike valleys and ridges appear to have developed as tributaries to the Kukpuk River during its incision. Some of the streams of the strike valleys appear to have been captured; others seem to be in imminent danger of capture by the shorter steeper south-flowing streams graded to the Chukchi Sea coast.

No glacial moraine or outwash deposits have been found, nor are there any topographic features of clearly glacial origin.

The line of wave-faceted north- and northeast-trending ridges that marks the present coastline seems to have been well established at nearly its present position by the end of Sangamon time. Wave erosion on the present coast is actively attacking bedrock only along the cliffs and headlands west of the Chariot site; even above those cliffs there are steep slopes which probably represent the degraded cliffs of the earlier coastline of Sangamon age.

A detailed description of the many minor landforms and microrelief features of the area was not attempted. The microrelief features are of types relatively common in arctic climates, and their general origin and development have been described by several workers in other areas (Hopkins and Sigafoos, 1951; Washburn, 1950; Sigafoos and Hopkins, 1952; Sharp, 1942). Notably absent are such prominent features as pingos and elongated oriented lakes.

GEOLOGIC HISTORY

The sequence of sedimentary rocks represents nearly continuous marine conditions from Early Mississippian through Early(?) Cretaceous time. The unnamed unit of Early and Late Mississippian age represents chiefly shallow-water marine deposition, with some intertonguing of possible nearshore nonmarine deposits. A gradual deepening of marine conditions started before and continued during deposition of most of the Nasorak Formation. The upper 1,600 feet of the Nasorak probably represents miogeosynclinal conditions and grades upward to the shallower marine platform associations represented by deposits of the Kogruk(?) Formation. The apparent discontinuousness of the Tupik Formation and the interbedding of facies similar to it within the underlying Kogruk(?) suggest that most probably this facies was deposited in disconnected shallow basins of the general platform association. The absence of a sequence of recognizable Pennsylvanian rocks is not accompanied by any evidence of extensive subaerial erosion, and there is no reason to infer that the area was emergent at that time. However, the possibility of post-Tupik pre-Siksikpuk erosion cannot be neglected. The thin continuous deposits of the Siksikpuk and Shublik Formations suggest generally long-lived stable marine conditions at some depth below wave base through most of the Permian and Triassic, followed in Jurassic or Cretaceous time by eugeosynclinal conditions that persisted at least into Early Cretaceous time. The apparent disconformity between the Shublik and Ogotoruk Formations does not seem to represent significant subaerial erosion, for the upper *Monotis*-bearing limestone zone of the Shublik is present wherever the two formations are in unfaulted contact. Even if the Jurassic Period is not represented by sedimentary deposits, though it seems more likely that it is, there is no evidence that it was a period of emergence in this area. Except for sporadic marine deposition of the Pleistocene Gubik Formation in the coastal plain of the Utukok-Corwin area (Chapman and Sable, 1960, p. 69, table 2), no significant marine deposits are known to occur in this region above the top of the Nanushuk Group, which was assigned by Chapman and Sable (1960, p. 69) to an Early and Late Cretaceous age. The Corwin Formation, the topmost formation of the Nanushuk Group, includes nonmarine facies, suggesting that the Utukok-Corwin area was emergent during Late Cretaceous time and intermittently during much of the later part of Early Cretaceous time.

All the bedrock units now exposed in the area were probably deposited before the deformation that resulted in the thrust faulting and folding. Some minor folding, probably associated with early phases of the Tigara uplift, certainly preceded the main episode of thrust-fault displacement. The main deformation probably took place in several pulses, as each thrust sheet was folded and broken by high-angle faults before it was overridden by the next higher sheet. Some late, anticlimatic folding is indicated by the folding and high-angle faulting of the highest of the imbricate thrust sheets, the Ibrulikorak. The age of the major deformation is uncertain, but it is most probably Late Cretaceous or early Tertiary. Payne (1955) suggests that uplift in the vicinity of the Lisburne Hills (the Tigara uplift) occurred during a post-Paleocene orogeny; he also indicates strong deformation of the Brooks Range geanticline at that time.

The subsequent history of the area appears to be chiefly one of erosion which reduced the area of the Tigara uplift and adjacent parts of the Arctic Foothills physiographic province to a surface of relatively low relief. The ancestral Kukpuk and Ipewik Rivers established their west-trending drainage either on an erosion surface of such low relief that the bedrock structure and lithology had little effect or possibly on flat-lying younger deposits that have since been completely eroded off. Certainly by middle Pleistocene time the major rivers were draining westward toward what had been the higher parts of the Tigara uplift. The development of a westward-moving drainage indicates that a general westerly surface slope had formed in an area where the Tigara uplift had previously established an eastward-dipping regional structure. This suggests tectonic subsidence of the Tigara uplift area in post-Tigara pre-middle Pleistocene time. Some of the folding of the Ibrulikorak thrust sheet may have occurred in association with the westward tilting. The record of Sangamon deposits and pre-Sangamon erosion surfaces on which those deposits lie indicates that most of the modern drainage was well established and many of the smaller streams had cut to very nearly their present grades before the Sangamon Interglaciation, and that the major landforms were well outlined by middle Pleistocene time.

REFERENCES CITED

Barnes, D. F., and Allen, R. V., 1961, Preliminary results of gravity measurements between Kotzebue and Point Hope, Alaska, *in* Kachadoorian, Reuben, and others, Geologic investigations in support of Project Chariot, Phase III, in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI-779, p. 80-86; prepared on behalf of the U.S. Atomic Energy Comm.

Campbell, R. H., 1960a, Areal geology of the Ogotoruk Creek Chariot test site and adjacent areas to the west and north, northwestern Alaska, *in* Kachadoorian, Reuben, and others, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI-753, p. 37-41, pls. 2, 3; prepared on behalf of the U.S. Atomic Energy Comm.

——— 1960b, Generalized stratigraphic section of the Lisburne group in the Point Hope A-2 quadrangle, northwestern Alaska, *in* Short papers in the geologic sciences: U.S. Geol. Survey Prof. Paper 400-B, p. B337-B339.

——— 1961a, Transfer of geologic data from aerial photographs to topographic maps by direct tracing, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-C, p. C368-C370.

——— 1961b, Areal geologic maping in the Cape Thompson area, Alaska, *in* Kachadoorian, Reuben, and others. Geologic investigations in support of Project Chariot, Phase III, in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI-779, p. 28-42, fig. 3, pl. 1; prepared on behalf of the U.S. Atomic Energy Comm.

——— 1961c, Thrust faults in the southern Lisburne Hills, northwest Alaska, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Prof. Paper 424-D, p. D194-D196.

——— 1965a, Nasorak Formation, Point Hope area, northwest Alaska, *in* Cohee, G. V., and West, W. S., Changes in stratigraphic nomenclature 1963; U.S. Geol. Survey Bull. 1194-A, p. 22-25.

——— 1965b, Ogotoruk Formation, Point Hope area, northwest Alaska, *in* Cohee, G. V., and West, W. S., Changes in stratigraphic nomenclature 1963: U.S. Geol. Survey Bull. 1194-A, p. 25-26.

Campbell, R. H., 1965c, Telavirak Formation, Point Hope area, northwest Alaska, *in* Cohee, G. V., and West, W. S., Changes in stratigraphic nomenclature 1963: U.S. Geol. Survey Bull. 1194-A, p. 26-28.

——— 1965d, Kisimilok Formation, Point Hope area, northwest Alaska, *in* Cohee, G. V., and West, W. S., Changes in stratigraphic nomenclature 1963: U.S. Geol. Survey Bull. 1194-A, p. 28-29.

——— 1966, Areal geology, in Wilimovsky, N.J., and Wolfe, J. N., eds., Environment of the Cape Thompson region, Alaska: U.S. Atomic Energy Comm. PNE-481, p. 57-84.

Chapman, R. M., and Sable, E. G., 1960, Geology of the Utukok-Corwin region, northwestern Alaska; U.S. Geol. Survey Prof. Paper 303-C, p. 47-167.

Collier, A. J., 1960, Geology and coal resources of the Cape Lisburne region, Alaska: U.S. Geol. Survey Bull. 278, 54 p.

Dunbar, C. O., and Rodgers, John, 1957, Principles of stratigraphy: New York, John Wiley & Sons, 356 p.

Folk, R. L., 1959, Practical petrographic classification of limestones: Am. Assoc. Petroleum Geologists Bull, v. 43, no. 1, p. 1-38.

Friedman, G. M., 1959, Identification of carbonate minerals by staining methods: Jour. Sed. Petrology, v. 29, no. 1, p. 89-97.

Goddard, E. N., chm., and others, 1948, Rock-color chart: Washington, Natl. Research Council (repub. by Geol. Soc. America, 1951) 6 p.

Gryc, George, Patton, W. W., Jr., and Payne, T. G., 1951, Present Cretaceous stratigraphic nomenclature of northern Alaska: Washington Acad. Sci. Jour., v. 41, no. 5, p. 159-167.

Haaf, E. ten, 1959, Properties and occurrence of turbidities, *in* Symposium—Sedimentology of recent and old sediment: Geologie en mijnbouw (NW. ser.), 21E Jaarg., p. 217-222.

Hopkins, D. M., and Sigafoos, R. S., 1951, Frost action and vegetation patterns on Seward Peninsula, Alaska: U.S. Geol. Survey Bull. 974-C, p. 51-101.

Hubbert, M. K., and Rubey, W. W., 1959, Mechanics of fluid-filled porous solids and its application to overthrust faulting, [Pt.] 1 *of* Role of fluid pressure in mechanics of overthrust faulting: Geol. Soc. America Bull., v. 70, no. 2, p. 115-166.

Imlay, R. W., 1959, Succession and speciation of the pelecypod *Aucella*: U.S. Geol. Survey Prof. Paper 314-G, p. 155-169.

Kachadoorian, Reuben, 1961, Abstract and general introduction, *in* Kachadoorian, Reuben, and others, Geologic investigations in support of Project Chariot, Phase III, in the vicinty of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI-779, p. 1-12; prepared on behalf of the U.S. Atomic Energy Comm.

Kachadoorian, Reuben, 1966, Geographic setting, *in* Wilimovsky, N. J., and Wolfe, J. N., eds., Environment of the Cape Thompson region, Alaska: U.S. Atomic Energy Comm. PNE-481, p. 45-56.

Kachadoorian, Reuben, Campbell, R. H., Sainsbury, C. L., and Scholl, D. W., 1959, Geology of the Ogotoruk Creek area, northwestern Alaska; U.S. Geol. Survey TEM-976; open-file report, Oct. 14, 1959, 43 p.

Keller, A. S., Morris, R. H., and Detterman, R. L., 1961, Geology of the Shaviovik and Sagavanirktok Rivers region, Alaska: U.S. Geol. Survey Prof. Paper 303-D, p. 169–222.

Kindle, E. M., 1909, The section at Cape Thompson, Alaska: Am. Jour. Sci., ser. 4, v. 28, p. 520–528.

Kuenen, P. H., 1957, Sole markings of graded graywacke beds: Jour. Geology, v. 65, no. 3, p. 231–258.

Leffingwell, E. de K., 1919, The Canning River region, northern Alaska: U.S. Geol. Survey Prof. Paper 109, 251 p.

Moore, G. W., and Cole, J. Y., 1960, Coastal processes in the vicinity of Cape Thompson, Alaska, *in* Kachadoorian, Reuben, and others, Geologic investigations in support of Project Chariot in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI–753, p. 41–55; prepared on behalf of the U.S. Atomic Energy Comm.

Moore, G. W., and Scholl, D. W., 1961, Coastal sedimentation in northwestern Alaska, *in* Kachadoorian, Reuben, and others, Geologic investigations in support of Project Chariot, Phase III, in the vicinity of Cape Thompson, northwestern Alaska—preliminary report: U.S. Geol. Survey TEI–779, p. 43–65; prepared on behalf of the U.S. Atomic Energy Comm.

Patton, W. W., Jr., 1956a, New formation of Jurassic Age, *in* Gryc, George, and others, Mesozoic sequence in Colville River region, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 2, p. 213–218.

——— 1956b, New and redefined formations of Early Cretaceous age, *in* Gryc, George, and others, Mesozoic sequence in Colville River region, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 2, p. 219–223.

——— 1957, A new upper Paleozoic formation, central Brooks Range, Alaska: U.S. Geol. Survey Prof. Paper 303–B, p. 41–45.

——— 1959, Geology of the upper Killik-Itkillik region, Alaska: U.S. Geol. Survey open-file report, Aug. 13, 1959, 142 p.

Payne, T. G., 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–84, scale 1:5,000,000.

Sable, E. G., and Dutro, J. T., Jr., 1961, New Devonian and Mississippian formations in DeLong Mountains, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 585–593.

Sainsbury, C. L., and Campbell, R. H., 1959, Geologic strip map of part of Kukpuk River, northwestern Alaska: U.S. Geol. Survey open-file report, Sept. 17, 1959, 10 p.

Sainsbury, C. L., Kachadoorian, Reuben, Campbell, R. H., and Scholl, D. W., 1965, Marine platform of probable Sangamon age, and associated terrace deposits, Cape Thompson area, northwestern Alaska: Arctic, v. 18, no. 4, p. 230–245.

Scholl, D. W., and Sainsbury, C. L., 1959, Marine geology and bathymetry of the nearshore shelf of the Chukchi Sea, Ogotoruk Creek area, northwest Alaska: U.S. Geol. Survey TEI–606, 68 p., prepared on behalf of the U.S. Atomic Energy Comm.; also U.S. Geol. Survey open-file report.

Schrader, F. C., 1902, Geological section of the Rocky Mountains in northern Alaska: Geol. Soc. America Bull, v. 13, p. 233–252.

Sharp, R. P., 1942, Soil structures in the St. Elias Range, Yukon Territory: Jour. Geomorphology, v. 5, no. 4, p. 274–301.

Sigafoos, R. S., and Hopkins, D. M., 1952, Soil instability on slopes in regions of perennially-frozen ground [Alaska]: Natl. Research Council, Highway Research Board Special Rept. 2, p. 176–192.

Smith, P. S., and Mertie, J .B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U.S. Geol. Survey Bull. 815, 351 p.

Washburn, A. L., 1950, Patterned ground: Rev. canadienne geographie, v. 4, no. 3–4, p. 5–59.

Williams, Howel, Turner, F. J., and Gilbert, C. M., 1954, Petrography—an introduction to the study of rocks in thin section: San Francisco, Calif., W. H. Freeman & Co., 406 p.; repr., 1958.

INDEX

[Italic page numbers indicate major references]

☆ U.S. GOVERNMENT PRINTING OFFICE: 1967—O 215-321