1961

Quaternary geology of the Arctic Coastal Plain, northern Alaska

John Blandford O'Sullivan
Iowa State University

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QUATERNARY GEOLOGY OF THE
ARCTIC COASTAL PLAIN, NORTHERN ALASKA

by

John Blandford O'Sullivan

A Dissertation Submitted to the
Graduate Faculty in Partial Fulfillment of
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Heads of Major Departments

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Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1961
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A study of the geology and geomorphology of the Arctic Coastal Plain, northern Alaska has been made under a grant from the Arctic Institute of North America. This paper summarizes a phase of this overall research, namely the stratigraphy and history of the Quaternary sediments.

The area, encompassed by this study (Figure 1), is bounded by the Arctic Ocean to the north and west, the Sagavanirktok River on the east and the southern boundary is approximated by 69° 30' north latitude.

The major field work was done during the summers of 1957, 1958 and 1959. Most of the field work was done along rivers, the natural highways of the area. This was necessitated by the scarcity of natural exposures inland, the difficulty of excavation in the permafrost and the laborious task of travel inland, over the tundra, by foot.

This investigation is concerned mainly with the Quaternary sediments, their nature and distribution, and the history of the area as interpreted from these sediments. The pre-Quaternary geology is treated only in so far as it affects the understanding of the genesis and history of later sedimentation. The study is not restricted to sediments of a particular environment, but attempts to group the sediments, whether marine, fluvial, or eolian, into units with similar relations both areally and with time.
Figure 1. Location and approximate extent of area covered by the report, including those areas which were examined on the ground.
AREAS VISITED

1. Utukok River
2. Keelik River
3. Meade River
4. Barrow Area
5. Drift Peak River
6. Colville River
7. Toolik - Kuparuk River
8. Irishak - Sagavanirktok River

Approximate area covered by the report.
STATEMENT OF THE PROBLEM

The major geologic investigation of northern Alaska was performed by the U.S. Geological Survey, especially during the exploration of Naval Petroleum Reserve No. 4, in the late 1940's. Because this exploration was primarily concerned with the petroleum possibilities of the area, little attention was paid to the surficial Quaternary sediments.

Schrader (48) named the Pleistocene sediments he described along the Colville River, the Gubik sand, after the Eskimo name of the river. Leffingwell (25) believes this to be in error, in that the proper native name is Kupik. Even so, since Schrader's time the terms Gubik sand, then Gubik formation, have become a catchall for almost all unconsolidated Quaternary sediments, regardless of origin. The only exceptions being the glacial deposits.

The problem then is to determine the nature of the Quaternary sediments, their distribution, relationships and depositional environments. From this information an evaluation of the usefulness of the concept "Gubik formation", as presently used, may be made. After the evaluation, a decision must be made whether to continue the present usage or to redefine and restrict the extent of the formation. If the sediments are separable into more than one distinct mappable unit, the naming of other formational units and/or facies may be appropriate.
Northern Alaska has been divided (Payne and Others (38)) into three major physiographic provinces: the Brooks Range, the Arctic Foothills and the Arctic Coastal Plain provinces. The division is based on topography as it reflects the structure and the relative erosion resistance of the underlying material. The latter two provinces have been collectively termed the Arctic Slope by Brooks (6, p. 46) and others (38). The Arctic Foothills was called the Arctic Plateaus by Smith and Mertie (50). The terminology and boundaries used in this paper are those of Payne and Others (38) unless otherwise noted (see Figure 2).

For a discussion of the Geologic history of northern Alaska, the reader is referred to (19) and (38).

Brooks Range Province

The Brooks Range is a continuation of the Canadian Rockies, across northern Alaska. The highest peaks, located in the eastern end of the range, are over 9000 feet. The peaks average 5000 - 6000 feet in the east but diminish in height to 3000 - 4000 feet in the west. Though the major portion of the range has been glaciated, at present only a few glaciers exist and these are in the eastern portion.

The range itself is composed of tightly folded, complexly
Figure 2. Physiographic subdivisions of northern Alaska. (Base map used with permission of Erwin Raisz, Cambridge, Mass.)
ARCTIC SLOPE OF ALASKA

QW Western Section
QEM Eastern Section (marine)
QEF Eastern Section (marine)
QFS Foothill Silt Surface
Ts Tertiary Bedrock High
I Intermediate Surface
S Southern Surface
SF Southern Foothills Section
BR Brooks Range Province

Boundaries by Payne and Others (1951)
Late Sangamon or Mid-Wisconsin Transgression (?)

Scale - Miles

Prepared by Erwin Raisz
for
Boston University Physical Research Laboratories
thrusted, and slightly metamorphosed Paleozoic rocks. The rocks of the northern half of the range are predominantly of Devonian and Mississippian age. The Mississippian section is composed mainly of carbonates, of these the Lisburne limestone is the most extensive. The northern boundary of the province is roughly coincident with the contact between Paleozoic and Mesozoic rocks.

Arctic Foothills Province

The Arctic Foothills province lies between the mountains to the south and the Arctic Coastal Plain to the north. The province has been further divided into the Southern and Northern Foothills sections (38).

The Southern Foothills section is structurally similar to the Brooks Range province but differs in the lesser resistance of its underlying strata. The topography is characterized by ridges and isolated hills, whose irregularity separates this section from the Northern Foothills. The ridges are composed of more resistant rocks, sandstone, limestone, chert and conglomerate, which stand above the valleys underlain by shale. The dominant rock type is shale of Triassic, Jurassic and Early Cretaceous age.

The topography of the Northern Foothills section consists of broad plateau-like, upland flats and similar smaller features which are approximately accordant in elevation. The
section is underlain by lower and upper Cretaceous strata which have been deformed into east-west trending folds. The folds are asymmetric, having a steeper north limb, and the amplitude of the folds decreases northward. The regularity of the topography has been attributed by some to the simplicity of the structure (38). Others have expressed the view that this summit accordance is due in part to Quaternary uplift of a Tertiary erosion surface (19), (21), (39) and (50).

Though the northern boundary of the foothills has been described by many investigators, some confusion exists, at least in the mind of the writer, in its exact placement and whether all have referred to the same boundary. The indefinite location of this boundary has been due in part to the quality and incompleteness of the older maps. Recent topographic mapping discloses three northward sloping surfaces within the area of the northern foothills, as delineated by (38). These surfaces are clearly shown on the Lookout Ridge and Ikpikpuk River Quadrangles, and in north-south profiles from these quadrangles in Figure 3. These surfaces truncate the structure of the underlying strata and do not seem to correspond to any lithologic differences in the underlying material. A rather abrupt escarpment (300 - 500 feet in height) bounds the northern edge of the Southern Surface, whereas the break between the two northern surfaces is not so pronounced. The northernmost of these surfaces is called the
Figure 3. Profiles across portions of the Northern Foothills section and the Coastal Plain province.

a) Profile along 157° 35' W. longitude, from 69° to 70° N. latitude.

b) Profile along 155° 22' W. longitude, from 69° to 70° N. latitude.

c) Profile along 153° 25' W. longitude, from 69° to 70° N. latitude.
NORTHERN FOOTHILLS SECTION

SOUTHERN SURFACE

INTERMEDIATE SURFACE

FOOTHILL SILT SURFACE

COASTAL PLAIN PROVINCE

ELEVATION FEET

MILES TO OCEAN

63 MILES TO OCEAN

63 MILES TO OCEAN

68 MILES TO OCEAN

COOLIDGE RIVER

TERRACE

WOLF CREEK
Foothill Silt Surface (in this paper) and is bounded on the north by a topographic scarp descending to the "coastal plain" (see Figure 4). The area lying between the Foothill Silt Surface and the abrupt escarpment of the Southernmost Surface of the Northern Foothills section is called the Intermediate Surface.

The abrupt escarpment forming the northern boundary of the Southern Surface is continuous with a break in the Cape Beaufort area, along the western coast. In opposition to this, Payne and Others (38) have shown the break along the western coast as continuous with the break between the Foothill Silt Surface and the "coastal plain". This has been, in part, a result of a tendency to equate the distribution of the lakes with the boundary of the "coastal plain". Hopkins (21) notes an ancient wave-cut cliff extending across a portion of northern Alaska, and marking the termination of an ancient erosion surface. He also states that all marine sediments of Pliocene or Pleistocene age lie seaward of this cliff, and the cliff is shown to approximate the boundary between the "coastal plain" and the foothills as given by Payne and Others (38).

Black and Barksdale (4) indicate that the oriented lakes are primarily associated with the coastal plain. They also note the increasing number of non-oriented lakes along the southern margin of the oriented lake zone, but do not assign any importance to their presence. Black and Barksdale found
Figure 4. Topographic and geomorphic break between the coastal plain and the Foothill Silt Surface in the area between the Ikpikpuk and Meade Rivers. (Taken from the index mosaic of the 1955 Twin low-oblique photography of the Meade River quadrangle.)
that, except for minor breaks, the boundary between the coastal plain and the foothills occurs as a distinct topographic break as much as 300 feet high but generally lower. Though they do not delineate the coastal plain itself, their boundary for the southern extent of the oriented lakes approximates it, and lies midway between the northern boundary of the Foothill Silt Surface and the abrupt escarpment noted previously.

The writer believes that the summit accordance of the Foothill Silt Surface represents a depositional rather than an erosional plain and that it has been dissected during the Late Quaternary. Lakes are common on some parts of the Foothill Silt Surface, and it is these lesser to nonoriented lakes in the northern part of the foothill silt area, that Black and Barksdale (4) noted above. The inclusion of the lakes in the Utukok - Kukpowruk region, to the west, within the "coastal plain" proper, and not recognizing the presence of the Foothill Silt Surface as a distinct depositional plain, led to the anomalous boundary drawn by Payne and Others (38).

Arctic Coastal Plain Province

The boundary between the Arctic Foothills and Arctic Coastal Plain provinces may be placed on the basis of drainage and relief or the extent of Quaternary marine sediments. For the purpose of this paper the writer has chosen the former criteria which yield a boundary close to that of Payne and
Others (38). Strictly speaking the latter more truly delineates the coastal plain, and because of this, previous references to the coastal plain when not including the Foothill Silt Surface were in quotation marks. The reasons for using the former criteria are: usage of a similar boundary by the U.S. Geological Survey; characteristics such as drainage, relief, vegetation etc. are more similar between the foothill silt area and those areas to the south, than between the foothill silt area and the "coastal plain"; and that most workers with whom the writer has been associated tend to consider the increased relief, better drainage, and vegetation changes to be a significant ecological break.

The Arctic Coastal Plain province, as used here, is a broad expanse of tundra, marked by low relief, numerous lakes, and generally poor drainage. This province has been subdivided into the Teshekpuk Lake and White Hills sections (19) (38).

The Teshekpuk Lake section is underlain by Cretaceous strata capped unconformably by a thin mantle (40 - 50 feet) of dominantly marine Quaternary sediments (Gubik formation). The major portion of this section lies to the west of the Colville River and comprises the area normally considered as a coastal plain. The surface continues beneath the ocean forming the shallow continental shelf, which is terminated by the slope into the Arctic Ocean Basin.
The White Hills section contains Tertiary sediments (Sagavanirktok formation) which outcrop in three large areas that rise above the general elevation of the coastal plain. These higher areas are now included by the writer within the Foothill Silt Surface. The Tertiary sediments are dominantly non-marine and are believed to be of Paleocene or Eocene age. Marine sediments of late Tertiary age (late Miocene or Pliocene) outcrop to the east, outside the area under discussion. The coastal plain sediments, of Quaternary age, are both marine and nonmarine and over 75 feet thick in much of the area.
QUATERNARY SEDIMENTATION

Coastal Plain Sediments

The coastal plain of Alaska is a broad, roughly triangular area of land bordered by the foothills on the south and the Arctic Ocean on the northeast and the northwest. The coastal plain is over 400 miles long with a maximum width of 85 miles, and encompasses roughly 25,000 square miles.

Though the coastal plain sediments are dominantly marine, eolian and lacustrine sediments underlie a large portion of the present surface. Since many nonmarine sediments along the inner margin of the coastal plain are older than some marine sediments along the outer margin it seems logical to include these sediments within the Gubik formation rather than attempt a separation which crosses time lines. The term Gubik formation is used here in its widest sense as including the unconsolidated marine and nonmarine gravel, sand, silt and clay of Pleistocene and Recent age. These sediments also include large amounts of peat and ice.

To improve readability the measured stratigraphic sections, except for a few idealized sections, have been moved to the Appendix. The locations of these sections within the coastal plain are given in Figure 5. The measured thicknesses include the ground ice, therefore the thickness of thawed material would be somewhat less. In some areas a reduction by
Figure 5. Location of sections, thickness of sediments and other information.
• F1/90 Section/Thickness of Quaternary Sediment (ft.)
• D4/100 Test Well/Thickness (ft.)

QW Western Section
QEM Eastern Section (marine)  ➔ Coastal Plain Province
QEF Eastern Section (marine)
QFS Foothill Silt Surface
Ts Tertiary Bedrock High
I Intermediate Surface
S Southern Surface
SF Southern Foothills Section
BR Brooks Range Province

Boundaries by Payne and Others (1951)
Late Sangamon or Mid-Wisconsin Transgression (?)
Fragmental Shorelines

[Diagram showing geographic sections and boundaries]
20 - 30 feet is indicated.

**Literature review**

Most of the previous information on the Quaternary sediments was obtained by the U.S. Geological Survey during the early exploration of northern Alaska and later, during exploration of the Petroleum Reserve. Smith and Mertie (50) have summarized most of the information on the geology of northwestern Alaska prior to 1930. The results of the exploration of the Petroleum Reserve are being published as a series of U.S. Geological Survey Professional Papers.

The type locality for the Gubik sand as originally described by Schrader (48) is found in the cliffs along the lower Colville River. He described the material as "A surficial deposit of brownish sand or loam about 10 to 15 feet in thickness, which unconformably overlies the beds of the Colville series (believed by him to be Tertiary and later shown to be upper Cretaceous), apparently as a continuous mantle". The Gubik sand underlies the coastal plain and was thought to be of Pleistocene age. The material is relatively free from gravel, and that which does occur is scattered. The basal portion contains fine gravel in some localities. "The deposit as a rule is structureless or without stratification planes. Owing to this fact, together with its surficial and widespread occurrence, and the homogeneity of its materials for want of a better term in field work it was called loess, but in the fear
that this term may be undesirable, it is here named the Gubik sand, after the Eskimo name of Colville River." "The fluvial-tile-delta theory, in conjunction with shallow coastal conditions and intense arctic freezing..." seemed the origin most tenable to Schrader.

Gryc et al. (20) redefined the Gubik formation as varying in thickness from a few feet to 150 feet, but ordinarily 10 - 30 feet thick, and composed of loosely consolidated cross-bedded brown or buff gravel, sand, silt and clay of predominantly marine origin. They report a maximum thickness of 30 feet exposed along the Colville River, though a thickness of 150 feet was mapped on the Kikikvarak River. The latter location is reported as 15 airline miles upstream from its confluence with the Colville River. The original report (51) on this unusual thickness does not describe the material, but gives the actual location as 18 miles upstream. A 75-foot thickness of similar (?) material 13 miles upstream from the confluence is described (51) as follows: "Gubik sand. Yellow, loosely consolidated, extremely cross-bedded, with cross-bedding at angles up to 30 degrees. Interbeds of peat up to 4 feet thick. Basal 6 inches is conglomeratic, consisting of angular fragments and well rounded rocks." Whether the thicker of these sections is within the coastal plain, is open to doubt in view of the relations and thicknesses seen over the rest of the coastal plain. The inclusion of the 150-foot
section within the coastal plain sediments would lead to an anomalous shoreward thickening. In view of the presence of thick deposits of sediments within the foothills, older than the coastal plain, and the relatively deep dissection that would of necessity accompany the exposure of a 150-foot section, it seems more probable that these sediments are within the area of foothill silt, discussed later.

Leffingwell (25) noted the occurrence of large erratics within the coastal plain sediments. Many of these erratics are striated and faceted and of lithologies not present within the Brooks Range. He called them Flaxman boulders because of their similarity to a bouldery glacial deposit on Flaxman Island. Leffingwell attributed these erratics to debris rafted into the area on the polar ice, and deposited with the sediments by melting of the ice. MacCarthy (30) listed the locations and petrographic descriptions of numerous boulders along the coast. He concurred with Leffingwell that they were not derived from the Brooks Range and were restricted to elevations below 25 feet.

MacNeil (33) has examined all the available collections of Cenozoic megafossils collected during the exploration of northern Alaska. From these he has attempted a zonation of the Gubik formation using the genus Neptunea as the characteristic element in the faunules.

Meek (36) described a Pleistocene section (here noted as
at Skull Cliff, approximately 40 miles south of Barrow Village. Here the sea cliff rises 70 - 80 feet above the ocean, as contrasted to the cliff northward to Barrow which is only 25 - 45 feet high. The contour of the surface approximates a gentle fold in the lower strata, and it is this deformation to which the cliff owes its height. Meek's description follows: "... a series approximately 45 feet thick, the lower beds of which consist of alternate layers of friable, unconsolidated, yellowish sands, and black fissile mud shales, whereas the upper portion is composed of massive beds of yellowish sand, poorly stratified, with practically no shale. Chert pebbles are scattered throughout these upper sands. Individually the lower beds seldom exceed 3 or 4 inches in thickness, but one shaly layer about 8 inches thick was noted. The series is undisturbed and in apparent concordance with the lower members in the section." Marine fossils were numerous in the upper 25 feet, though none were observed in the lower beds of shale and sand. He concluded the entire formation is likely a result of a single period of deposition, marine shells being absent in the lower beds because of unfavorable conditions. The unconsolidated materials are separated from the underlying lithified sandstones by a gently undulating surface.

Langenheim et al. (24) noted a high level gravel deposit on the Kuk between the Omalik River and Anaktuk which they refer to the coastal plain sediments. This deposit is north
of the boundary between the coastal plain and foothills.

Quaide (39) reports 30 feet to be the thickest section of marine sand that he observed in the Kuk drainage. This was located along the north shore of the Kuk estuary, near Wainwright. He also noted the presence "of occasional huge boulders of pink granitic rock several feet in diameter", within these sediments. The largest measured was nearly 5 feet. He concurred with Smith and Mertie (50) and attributed these boulders to ice rafting.

Lakes and drained lake basins are very common over the whole of the coastal plain and in portions of the foothills. Only a relatively small portion of the total coastal plain surface remains untouched by lake activity. These lakes have originated through thaw and consequent settlement of the ice saturated sediments. A striking feature of these lakes is the elongation of the basin and the uniform parallelism of the long axes of the lakes to a line 10 - 15 degrees west of north. The interested reader is referred to (7) and (8) which cover the present state of knowledge of these oriented lakes and review the literature.

Black (1) was the first to delineate an area of the coastal plain affected by intense eolian activity in the past, and to note the occurrence and distribution of presently active areas.

A separation into a western and an eastern section, which
is different from the treatment used by Payne and Others (38) facilitates the discussion of the coastal plain sediments. The boundary between these two sections is arbitrarily placed at 150° W. longitude, in the area to the north of the highland between the Itkillik and Kuparuk Rivers.

**Western section**

The Western section is the more extensive of the two, and being underlain by dominantly marine sediments best fits the definition of a coastal plain as being a recently emergent sea bottom. The southern boundary is usually characterized by a definite topographic break. This break is better defined in the area between the Meade and Ikapikpuk Rivers than elsewhere west of the Colville River. The break is less easily recognized to the west where the difference in elevation across the break decreases. The eastern part of the boundary is obscured by the presence of numerous thaw lakes and drained basins which have dissected the higher surface of the foothills. Whereas in the western portion of the section the boundary is coincident with the change from numerous oriented lakes on the coastal plain to a few poorly to nonoriented lakes in the foothills, this does not hold for the boundary east of the Meade River. In the latter area the lakes to the south of the boundary are not only numerous but slightly oriented. In general the break is more easily delineated on aerial photos, than on topographic maps. The areas are differentiated on the
basis of dunal topography, poorer drainage and lower relief on the coastal plain contrasted to greater relief, more thorough dissection and stream development within the foothills resulting in a higher proportion of that area being in slope, and a change in vegetation resulting from the better drainage.

As a rough approximation the coastal plain materials in the Western section are predominantly noncalcareous whereas those of the Eastern section are calcareous except for surface leaching. The boundary between the two is somewhat arbitrary, as the sediments of the Western and Eastern sections grade into one another and the sediments along and east of the Colville River are generally weakly calcareous.

**Marine** A generalized section of the marine coastal plain materials in the central and southern portions of the Western section is:

Unit thicknesses

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Description</th>
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<tbody>
<tr>
<td>30 - 75 feet</td>
<td>Medium to fine sand, well sorted and well rounded, generally noncalcareous, becoming somewhat finer towards the top and containing no marine macrofossils except as worn fragments. Stratification is massive or weakly developed, to strongly crossbedded depending on location. In some areas the upper half is more strongly crossbedded, in others the reverse is true (see Figure 7).</td>
</tr>
<tr>
<td>0 - 6 feet</td>
<td>Fine sandy gravel to gravelly sand, to interstratified sands and gravels, usually fossiliferous.</td>
</tr>
</tbody>
</table>
0 - 3 feet  Basal poorly sorted sand, silt and clay, highly fossiliferous, with numerous cobbles; best developed along the Meade River.

Unconformity  Relief usually less than 6 feet.

Cretaceous bedrock

As a rule the contacts are gradational and appear to indicate one period of deposition. Local beds of organic rich sand with occasional peat chunks do not seem to be indicative of an unconformity, as materials above and below are commonly identical in size and sorting (see samples M32 and M33 above and below such a horizon). The vertical variation in the sand across the area is shown by sections W3, W13 and W15 in Table 1. The upper sands along the Colville River are finer, with more silt and clay than on the Ikpikpuk and Meade Rivers. The basal material is highly fossiliferous especially in the vicinity of W17 on Meade River and along the Colville River. The basal materials are not exposed along most of the Ikpikpuk River, being obscured by the terraces, but the abundance of marine shells on the river floodplain implies a fossiliferous zone similar to that on the other rivers.

Along the Colville River gravel is normally the basal material, but a lithologic change occurs between sections W6 and W8. From section W6 northward to W8 a poorly sorted, clay-silt-sand unit, underlain by a highly fossiliferous sand to sandy gravel occurs at the base (see samples V21, V22, section
WB, Table 1). This portion thickens slightly northward to a maximum of 14 feet at WB, and appears to be unconformable with the overlying gravel. Thin beds (1 - 3 inches) of peat occur locally in the overlying gravel. It seems that these basal materials are those from which Schrader (48) collected his Pliocene (?) fossils, since he included those sediments in the Colville Series and not in the Gubik sand. There is a discrepancy in that his reported location is a few miles south of where the above sediments first outcrop. MacNeil (33), on the basis of the molluscan fauna, considers part of the sediments along the Colville River to be of a possible late Pliocene or early Pleistocene age. Part of this fauna has affinities to the Neptunea complex of the Pribilof Islands, and may have been among the earliest migrants thru the Bering Strait seaway in late Pliocene. MacNeil's locality D306(T) is adjacent to section WB. This older unit was not seen at the mouth of the Kikiakrorak River, yet a collection (33, D305(T)) from that area also contained the Pliocene (?) form. The writer believes the Pliocene (?) fauna is derived from the basal unit and not the overlying gravel and sand, consequently the collection (D305(T)) was either from a restricted exposure of the basal unit, or was from reworked material.

To the east of section WB, towards Ocean Point, the section changes rapidly. The lower half of the section is now torrentially cross-bedded sand and gravel (see Figure 8) con-
taining abundant logs (5 - 7 inches in diameter) and the basal sand-silt-clay unit mentioned previously is absent. The upper half of the section is dominantly cross-bedded sand, but contains many lenses of gravel, a feature not seen within the sand to the south. The elevation of the coastal plain above the river at W9 is 28 feet less than at W8, 1 1/2 miles to the west. The height of the exposed Cretaceous above the river is also less, by 23 feet, than at W8. The drop in the elevation of the river between these sections would increase these differences. The rapid change in the appearance, that is, into a near shore beach deposit with abundant driftwood, and in the relative elevations of the sections indicate a more recent transgression into this portion of the coastal plain. The extent of this transgression is not known. A thick (1 - 3 feet) layer of peat is exposed for 150 - 200 feet along the cliff, near the base of the sand, between sections W8 and W9. Whether this peat layer is related to the transgression or to the thin peat layers seen previously within the gravel at the base of the sand was not determined.

At section W10, 7 miles east and 2 miles south of W9, the coastal plain is 60 - 65 feet above the river and, allowing for a drop in river level, about 35 feet below the level at section W9. Whether this change in elevation results from a slight deformation of the coastal plain or a more recent transgression is uncertain. Most of the preceding rela-
ships are shown on a cross section of the coastal plain along the Colville River (see Figure 6).

Spruce or Larch logs (driftwood) up to 9 inches in diameter are very common in the basal material on the Colville River, especially between sections W2 and W3, and at W9. Numerous logs also occur on the flood plain of the Ikpikpuk River, and are apparently derived from the coastal plain sediments since the first occurrence coincides with the coastal plain boundary, and they become more numerous northward. No driftwood was seen on the Meade River.

The ice-rafted glacial boulders described by Leffingwell (25) and MacCarthy (30) are restricted to within a few miles of the coast and below 25 feet in elevation. This restriction is biased by the limited study of the sediments inland from the coast and probably an inland decrease in the abundance of the boulders. Though the majority of those seen by the writer were along the coast, an exception was along the Meade River. At the southernmost occurrence, 2 1/2 miles south of section W15, a roughly faceted boulder was seen in the river sediments. This boulder measured 2 1/2 x 2 x 2 feet, and consisted of a well sorted chert pebble conglomerate, whose siliceous cement formed a drusy lining within the interstices. No others were found in the adjacent area. Numerous boulders occur just south of section W17, on the west bank of the river. Some are in the stream deposits whereas others are definitely in the
Figure 6. Cross section along the Colville River, from within the foothills to Ocean Point, showing the relationships between the sediments of the foothills and the coastal plain.
Gubik Sand
Pliocene (?)
Cretaceous
Younger (?), transgressive
Gubik

River Level
(assumed gradient = 3 feet/mile)
Foothill Silt

Miles

Feet

F3 Measured Section
marine sediments and, it seems likely, all are ice-rafted material. Most are of one lithology, a porphyritic diorite (?), and are highly angular. A few, of a fine grained dark igneous material, are fairly well rounded and have weakly developed facets and striations. The porphyry occurs in a restricted area at the base of the cliff, just north of Meade River Village. The three largest boulders are on the order of 2 x 1 x 1/2 feet, the largest is 2 1/2 x 1 1/2 x 1 feet, and six others are somewhat smaller but each weighed over 20 pounds. These are all within 10 feet of each other, and some may be part of a larger fragment. Scattered for 300 feet upstream from this occurrence are several hundred smaller pieces averaging 1 x 1/3 inch, with the larger up to 2 x 3/4 inch.

Along the Meade River the coastal plain is about 50 - 55 feet above the river throughout that portion studied, indicating that the gradient of the river is close to that of the coastal plain. This is probably a result of increased resistance to erosion and base level control by the underlying Cretaceous strata. On the Ikpikpuk River no Cretaceous outcrops were seen much beyond where the river leaves the foothills, and apparently the river is completely within coastal plain and alluvial sediments. The Colville River, at least to Ocean Point, is within Cretaceous bedrock which outcrops 60 - 70 feet above the river through that portion of the coastal plain.
As the rivers approach the ocean and their terrace systems become more extensive, good exposures become more rare. At section W19, on the Inaru River, only 35 feet of sediment overlies the Cretaceous which outcrops in the stream bed. Samples from the lower exposed portion, and one from the bank of a lake on the coastal plain (section W21) indicate a northward change to finer sediments.

Along the western coast the exposed section is much more variable and consequently more difficult to generalize. A coastal area was examined in the vicinity of the now destroyed Skull Cliff LORAN tower, about 23 miles southwest of Barrow Village. At this section the coastal plain is 34 feet above sea level. The basal 12 feet of the exposure is a massive to locally laminated blue-gray Cretaceous clay to silty clay. In poor exposures, and even in some good ones, it is difficult to say that an unconformity exists between the clay and the overlying sands and gravels. Lenticular bodies of sand and silt, poorly to well cemented with calcite and/or pyrite, are scattered within the clay. The fossils in these lenses are the only indication of the Cretaceous age of the clay. In most locations these enclosed lenses are not exposed unless the cliff has been recently cleaned by storm waves, since they occur close to the cliff base.

The Gubik sediments vary widely, not as much in types of sediments as in relative amounts of certain types. Therefore
Figure 7. Truncated cross-bedding of the marine sands in section W15 on the Meade River.

Figure 8. Cross-bedded and inter-stratified sand and gravel at Ocean Point, section W9, on the Colville River.

Figure 9. Exposure of the Gubik formation about 9 miles south of Barrow Village (near section W28).

Figure 10. Main unconformity within the marine sediments, as exposed in the sea cliffs 7 1/2 miles south of Barrow Village.
## Table 1. Mechanical analyses\(^a\) of the coastal plain materials - Western section

<table>
<thead>
<tr>
<th>Sample</th>
<th>Section</th>
<th>Elev.(^b)</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt+Clay</th>
<th>Md</th>
<th>So</th>
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\(^a\)The size distributions noted throughout the rest of this paper were determined by the A.S.T.M. procedure as modified by Ohu and Davidson (10). An air-jet dispersion apparatus (10) and Calgon (sodium metaphosphate) (11) were used in dispersing the samples. The carbonates were not removed prior to the analysis. The numbers under the size headings refer to U.S. Standard sieves.

\(^b\)Elevation above Gubik-Cretaceous contact.
Table 1 (Continued).

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<th>Sample</th>
<th>Section</th>
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<th>Silt</th>
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° Above base of exposure if Cretaceous not exposed.

*Recalculated without 34 percent gravel.*
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<td>W22</td>
<td>&quot;</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>04</td>
<td>W22</td>
<td>&quot;</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>011</td>
<td>W22 (nonlaminated)</td>
<td>---</td>
<td>---</td>
<td>&lt;0.9</td>
<td>23.1</td>
<td>71.0</td>
<td>2.2</td>
</tr>
<tr>
<td>012</td>
<td>W22 (laminated)</td>
<td>&quot;</td>
<td>---</td>
<td>&lt;0.6</td>
<td>39.4</td>
<td>60.0</td>
<td>3.2</td>
</tr>
</tbody>
</table>

*All material (+100) gypsum.*
the following is a generalized section of the sediments and an indication as to the variance.

Section W22: Twenty-two feet of sediment; analyses in Table 1; not from one vertical section.

Unit thicknesses

9 feet Orange sand to silt, containing occasional lenses of fossiliferous gravel to coarse sand, shells commonly articulated (Samples Cl3 and Cl).

4 feet Alternating thin beds of orange sand and blue-black silt to fine sand, gradational into overlying sand. Dark silt lenses thicker and more numerous towards the base. (C9 of lenses within sand; C17 of more dominant dark silt at base.)

6 feet White, fine sand with very thin laminations of orange sand and darker material (coal?), some of the laminations are finely cross-bedded (C10, composite 3-foot sample).

1 - 2 feet Sandy gravel, very fossiliferous.

4 - 10 inches Sand with lenses of gravel and clay, fossiliferous.

0 - 6 inches Gravel, very fossiliferous.

Undulating contact.

12 feet Blue-gray to dark gray; clay to silty clay, commonly containing lenses of sand and silt.

(Cretaceous, samples C6, C11 and C12.)
Slumping and solifluction of the surface sediments as a result of the melting of ground ice lead to generally poor exposures, especially in the lower portion of the section. The areas which are sufficiently exposed are usually separated by large distances and thus the transitional areas between different lithologies are obscured. A more general section than the one given would be: a basal gravelly sand, overlain by the white laminated sand which may in some instances be missing (and replaced by a dark silt, as sample C17), overlain by the orange sand or sand interlayered with a dark silt-sand which grades upward through a layered zone into the orange sand. The thin basal gravel may be absent, and the material under the main gravel may vary from reworked silty clay (as sample C2) to sand with lenses of gravel and clay, to reworked clay with lenses of a gravel and sand (sample C4 is a composite of gray sand lenses within such a zone).

The sediments appear to be similar to the section described by Meek (36), at Skull Cliff (section W23, see also Literature Review). The major exceptions are the much thicker section, 45 feet, and the non-fossiliferous nature of the lower half of the section at Skull Cliff.

Point Barrow is the northernmost extension of the Arctic Coastal Plain. The term, "Barrow area", is used to denote the land within a 12 mile radius of Barrow Village. The surface of the Barrow area is marked by a series of upraised beaches.
Many of these owe their present relief to the development of adjacent thaw lake basins. Other "ridges" or higher areas are remnants of the initial uplifted surface as yet apparently unaffected by thaw lakes. These are not underlain by beach gravels and sands. The northernmost ridge is well developed and, because of its resemblance to the present Point Barrow spit, leads to an impression of the present spit being the last in a sequence of regressive beaches. Yet the estuarine nature of the shoreline indicates that the most recent movement of the shoreline has been made by a transgressive ocean.

The best exposures of the Gubik formation occur in the cliffs along the western shore, south of Barrow Village. Though holes drilled during the petroleum exploration indicate the formation to be 110 - 120 feet thick (46) in this area, the maximum surface exposure is 50 feet. The sediments are predominantly marine and indicate near shore deposition. Abundant interfingering and crossbedded channel sands and gravels grading upward and laterally into shallow lagoonal sands and silts characterize the exposed portions of the formation (see Figure 9).

Due to the variability of the materials it is difficult to present a truly characteristic section, but a generalized description of the Gubik as exposed along the cliffs is:

Unit thicknesses

1/2 foot Tundra vegetation mat.
2 - 6 feet Mixed silt and peat with varying percentages of fine to medium sand.

15 - 20 feet Extremely variable percentages of sand and gravel with occasional layers of, or matrix rich in, silt and fine sand.

Unconformity.

2 - 5 feet Dark gray to brownish gray silt to fine sand and clay.

3 - 6 feet Blue-black, organic rich, sulfurous clay with occasional scattered pockets of silt, and gravel.

The upper unit shows the influence of the fluctuating shoreline, whereas the lower silts, fine sands and clays seem to reflect deposition in quieter if not deeper water.

The clay and silt unit is near the base of the cliff and occurs both above and below the beach level. The clay unit reaches its maximum elevation in the vicinity of the southern margin of Nunavak Slough, about 4 miles south of the village. Here the clay outcrops to about 6 feet above sealevel with 3 feet exposed above the beach. X-ray diffraction data have shown the predominant clay mineral is illite with minor amounts of kaolinite and montmorillonite.

A detailed section below beach level was obtained through the use of an auger which drilled a hole large enough to allow a man to enter it. The lower 22 feet of the following section was obtained by this method.
Section W25: approximately 200 yards south of section W24; analyses of the samples are given in Table 2.

<table>
<thead>
<tr>
<th>Unit thicknesses</th>
<th>Tundra surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 6 feet</td>
<td>Very fine sand to silt with chunks of peat; slumping in this section.</td>
</tr>
<tr>
<td>10 - 12 feet</td>
<td>Very sandy gravel to gravelly sand in places; gradational; poorly crossbedded.</td>
</tr>
<tr>
<td>3 feet</td>
<td>Clean well sorted medium sand.</td>
</tr>
<tr>
<td>2 1/2 feet</td>
<td>Gravel; orange stain.</td>
</tr>
<tr>
<td></td>
<td>Unconformity.</td>
</tr>
<tr>
<td>1 1/2 feet</td>
<td>Dark brownish black silty clay; fossiliferous (mainly pelecypods); sample B9.</td>
</tr>
<tr>
<td>7 1/2 feet</td>
<td>Blue-black clay with contorted stringers, lenses and bifurcating layers of a brown clay containing more ice than the black clay. Lenses average 3 - 4 inches thick; sample B3.</td>
</tr>
<tr>
<td>7 feet</td>
<td>Coarsest gravel, silty to clay matrix at upper contact. Coarse gravel, less sand, 4&quot; x 3&quot; gravel common. Some particles up to 6&quot; in diameter.</td>
</tr>
<tr>
<td>3 inches</td>
<td>Weakly calcareous compact gray fine sand, grading upwards into the gravel.</td>
</tr>
<tr>
<td>6 inches</td>
<td>Small pea gravel with very sandy matrix, weakly calcareous lenses of fine sand and silt.</td>
</tr>
<tr>
<td>1 1/2 feet</td>
<td>Gray silt, lower 8&quot; grades into darker silty clays.</td>
</tr>
</tbody>
</table>
1 inch  Fine gravel - fossiliferous.

4 inches  Gray silt with fossils.

8 inches  Paper thin laminated silt and clay, grades upward into darker silt with less clay.

1 inch  Thin gravel layer.

2 feet  Gray silt with pockets of calcareous sand, some concretionary calcareous sandstone, some gravel and contains a 2 1/2" calcareous sandstone layer; Sample B7.

1 1/2 feet  Tan silt with black lenses of silt or clay and thin gray sand lenses indurated and calcareous Sample B6.

1 foot  Black laminated sandy silt and clay with scattered 1" gravel. Grades into overlying tan silt; Sample B2.

The contact, between the gravel and the underlying silty clay, which is exposed 9 feet above sea level appears to be an unconformity. The silty clay thickens from 1 1/2 feet to 6 2/3 feet at a location 70 feet to the south.

For 1 - 1 1/2 miles south of the Village the cliffs rise about 35 feet above sea level and are primarily horizontally stratified and cross-bedded gravel overlain by 6 - 10 feet of sandy gravel to gravelly sand. Continuing southward the gravel content rapidly decreases, and the section becomes dominantly sand. The sand also decreases in size becoming a less well sorted, fine sand with appreciable silt and clay (see sample...
Table 2. Mechanical analyses of the coastal plain materials - Barrow area

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location Section</th>
<th>Depth&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>feet</td>
<td>+10</td>
<td>-10+30</td>
<td>-30+50</td>
<td>-50+100</td>
<td>-100+200</td>
<td>&lt;5μ</td>
</tr>
<tr>
<td>BP-1</td>
<td>Sand over clay silt, at south edge Dunavak Slough</td>
<td>---</td>
<td>---</td>
<td>1.0</td>
<td>1.0</td>
<td>8.0</td>
<td>59.8</td>
<td>15.2</td>
</tr>
<tr>
<td>B9</td>
<td>W25 See text</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>1.1</td>
<td>1.9</td>
<td>57.8</td>
<td>38.0</td>
</tr>
<tr>
<td>B3</td>
<td>W25 &quot;</td>
<td>1.0</td>
<td>0.6</td>
<td>0.2</td>
<td>0.6</td>
<td>0.6</td>
<td>32.0</td>
<td>65.0</td>
</tr>
<tr>
<td>B7</td>
<td>W25 &quot;</td>
<td>---</td>
<td>4.5</td>
<td>0.8</td>
<td>2.0</td>
<td>19.8</td>
<td>66.9</td>
<td>6.0</td>
</tr>
<tr>
<td>B6</td>
<td>W25 &quot;</td>
<td>2.6</td>
<td>1.4</td>
<td>0.8</td>
<td>1.2</td>
<td>2.2</td>
<td>50.8</td>
<td>41.0</td>
</tr>
<tr>
<td>B2</td>
<td>W25 &quot;</td>
<td>0.2</td>
<td>0.6</td>
<td>0.4</td>
<td>1.2</td>
<td>1.6</td>
<td>40.0</td>
<td>56.0</td>
</tr>
<tr>
<td>B37</td>
<td>Northeast corner of Footprint Lake Basin</td>
<td>3.5-4.5</td>
<td>1.1</td>
<td>0.6</td>
<td>0.8</td>
<td>10.3</td>
<td>28.3</td>
<td>31.9</td>
</tr>
<tr>
<td>B38</td>
<td>&quot;</td>
<td>6.0-6.8</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>14.2</td>
<td>43.3</td>
</tr>
<tr>
<td>B39</td>
<td>&quot;</td>
<td>9.7-10.7</td>
<td>0.9</td>
<td>0.6</td>
<td>0.3</td>
<td>1.0</td>
<td>26.1</td>
<td>37.1</td>
</tr>
<tr>
<td>B40</td>
<td>&quot;</td>
<td>12.5-13.0</td>
<td>---</td>
<td>0.2</td>
<td>0.2</td>
<td>2.6</td>
<td>20.8</td>
<td>36.2</td>
</tr>
<tr>
<td>B14</td>
<td>Hole in eastern part of northern beach ridge</td>
<td>~10</td>
<td>2.2</td>
<td>1.6</td>
<td>1.6</td>
<td>10.2</td>
<td>7.4</td>
<td>38.0</td>
</tr>
<tr>
<td>B13</td>
<td>&quot;</td>
<td>~15</td>
<td>4.1</td>
<td>0.8</td>
<td>0.4</td>
<td>13.5</td>
<td>30.5</td>
<td>33.7</td>
</tr>
</tbody>
</table>

<sup>a</sup>From surface.
Table 2 (Continued).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location Section</th>
<th>Depth(^a) feet</th>
<th>Gravel (-10+30)</th>
<th>Sand (-30+50)</th>
<th>Sand (-50+100)</th>
<th>Sand (-100+200)</th>
<th>Silt (&lt;5\mu)</th>
<th>Clay (\mu)</th>
<th>Md</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td>B23</td>
<td>W29 Brown silt and yellow sand</td>
<td>~3.5</td>
<td>7.8</td>
<td>1.8</td>
<td>1.1</td>
<td>15.6</td>
<td>23.5</td>
<td>29.2</td>
<td>21.0</td>
<td>74</td>
</tr>
<tr>
<td>B22</td>
<td>W29 Gray silt</td>
<td>~3.5</td>
<td>0.2</td>
<td>0.7</td>
<td>0.9</td>
<td>11.8</td>
<td>18.2</td>
<td>39.2</td>
<td>29.0</td>
<td>40</td>
</tr>
<tr>
<td>B21</td>
<td>W29</td>
<td>~6</td>
<td>0.5</td>
<td>0.4</td>
<td>1.1</td>
<td>15.3</td>
<td>32.5</td>
<td>37.2</td>
<td>13.0</td>
<td>74</td>
</tr>
<tr>
<td>B20</td>
<td>W29</td>
<td>~8</td>
<td>---</td>
<td>0.5</td>
<td>0.9</td>
<td>16.3</td>
<td>21.4</td>
<td>18.9</td>
<td>42.0</td>
<td>25</td>
</tr>
<tr>
<td>B19</td>
<td>W29</td>
<td>~10</td>
<td>1.5</td>
<td>1.5</td>
<td>1.8</td>
<td>16.3</td>
<td>31.3</td>
<td>33.6</td>
<td>14.0</td>
<td>78</td>
</tr>
<tr>
<td>B35</td>
<td>Footprint Lake 1.0-1.5</td>
<td>---</td>
<td>---</td>
<td>0.1</td>
<td>0.3</td>
<td>6.2</td>
<td>19.0</td>
<td>67.4</td>
<td>7.0</td>
<td>40</td>
</tr>
<tr>
<td>B32</td>
<td>Surface of western part of northern beach ridge</td>
<td>0.0-1.0</td>
<td>5.0</td>
<td>1.2</td>
<td>1.0</td>
<td>13.7</td>
<td>20.3</td>
<td>32.8</td>
<td>26.0</td>
<td>57</td>
</tr>
<tr>
<td>B36</td>
<td>Surface of flat, west of Footprint Lake Basin</td>
<td>0.0-1.0</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>10.3</td>
<td>23.1</td>
<td>40.1</td>
<td>25.0</td>
<td>41</td>
</tr>
</tbody>
</table>
The cliff gradually decreases in height and slumping of the outcrop becomes more pronounced. The cliff becomes higher and relatively less obscured, south of Nunavak Slough, as the section thickens and the gravel percentage increases. In places the section becomes predominantly gravel and gravelly sand but never as much so as in the area just south of the Village. The above variation in the sediments and accompanying change in the cliff, is a result of the cliff truncating an ancient, now uplifted lagoon.

Though many good exposures do exist along the beach, the upper portion is best exposed, whereas the lower 10 - 15 feet are often covered with debris. It is only when the occasional fall storms occur while the ocean is ice free that waves develop of sufficient magnitude to clean portions of the cliff. These storms are infrequent, the last occurring in the fall of 1958, and a previous one in the fall of 1954. The 1954 storm was the more violent and more of the cliffs were affected. The cliffs have since never been better exposed than they were then and during the following summer. They had been undercut by the storm and the breaking of the cliffs along the fractures in the ice wedge system led to extensive exposures of the ice wedges. Here, as in most cases where ice wedges are exposed by caving of the bank, longitudinal sections of the wedges predominate, and the overall appearance is one of a continuous ice sheet.
The 1958 storm, though cleaning the cliffs in a few other places, did its most extensive work about 7 miles south of the Village. Here the 50-foot cliffs are relatively unprotected since the beach is very narrow. The most striking feature of the exposures was the presence of 7 - 12 feet of highly folded dark gray fine sands and silts, overlain unconformably by laminated yellow and black sands and gravels (see Figure 10). Much of the black coloration in the sands is due to coal and iron oxide stain but in some areas the stain appeared to be petroliferous. The unconformity is also locally folded though of much lesser amplitude than the underlying sediment but is usually gently undulating. The section above the unconformity is very similar to section W27 given in the Appendix. The unconformity descends to sea level to the north and was lost in the slump of the cliff base to the south. The type of folding, the slight predominance of folds overturned to the north, and the absence of any major break in the continuity of the horizons involved indicates this deformation is not the result of ice wedge growth. In only a few places do the folded materials appear as if part of the deformation could be attributed to ice wedges, which were later destroyed during the development of the erosion surface. The silt and clay below the gravels at section W28 appear to have been locally deformed by what may have been the growth of ice wedges. The major folding is attributed to submarine slumping and/or slow
flowage of the unconsolidated sediments along a slippage plane which is not exposed. The absence of shear planes indicates either slow flowage or a highly plastic material at the time of deformation. The unconformity is comparable to that previously mentioned between the upper (sand-gravel) and lower (silt-clay) units. Extensive folding of the materials below this contact does not occur a few miles north or south of the above location, and the folding seems to be restricted to a 3 - 5 mile section of the cliff. The clay and gravel unit cited in section W25 is not present and is presumably eroded since the clay appears again to the south.

A locally exposed unconformity, apparently within the sand-gravel unit, occurs in the cliffs about 1 1/2 - 2 miles north of the Rogers-Post Monument. The unconformity is about 23 feet below the surface and 23 feet above sea level. The surface is level and continuous for a few hundred feet south along the cliff facing the beach and up the adjacent drainage as well. The sediments below this surface are deformed in a manner similar to those below the present land surface. Hence, the deformation is attributed to the past growth of ice wedges which were destroyed during the transgression of the ocean which buried the surface. Chunks of peat and organic rich sediment are common along this surface, and scarce above it. The writer has been unable to find any other locations where a comparable surface exists.
It was not possible to definitely identify the contact between the two units in any of the holes drilled in the Barrow area (46). The thick conglomerate below the clay in section W25 was not observed in any of the holes. A large cobble at the base of one core may or may not have been part of this layer, though the depth (52 feet) is compatible with the other evidence. The presence of about 6 feet of clay underlain by a calcareous sandstone at 40 - 50 feet in another hole may mark the approximate contact, since the only calcareous sandstone seen was below the contact in section W25. The above hole was just south of the northernmost lagoon in the Barrow area. The dominant lithologies reported in the holes are fine to very fine sand, often with appreciable silt and clay, and containing thin beds and/or laminae of silt and clay. Scattered pebbles seem ubiquitous in the material. Analyses of sediments taken by the author from auger holes in the Barrow area are given in Table 2. No well sorted medium sands similar to those occurring over much of the coastal plain were seen, for a rule the sediments are finer and contain much more silt and clay than those to the south. A typical sample of lake sediment and of the surface sediments are also given in Table 2.

The date of the last emergence of this area from beneath the sea has been estimated by various workers. Black (2) suggests, from his study of ice wedge growth, that the surface
of the tundra near Barrow is about 3500 years old. Rex and Taylor (41, sect. 2, p. 14) cite a stratigraphic section by Ray (40) in which a pair of Eskimo snow goggles were found at a depth of 27 feet in an ice cellar about 3/4 mile north of the present village. Since Eskimo habitation of this area dates back about 2000 years at a maximum (personal communication, R. Carter to Rex and Taylor, (41)) it is assumed that this 27 feet of sediment has been deposited in the time since then, and the area to the south cannot be much older. In 1955, K. M. Hussey collected a peat sample from a persistent horizon located at a depth of 10 inches, in the Footprint Lake Basin. A radiocarbon age of 3,540 ± 300 years was obtained for this sample (W-432) by the U.S. Geological Survey (45). A sample of peat (W-847) collected from within lake sediments at a depth of 44 inches in the same general location was dated at 9100 ± 260 years (16). Other radiocarbon dates from this area supply additional information for estimating the age of the surface. A sample (L400A) of the upper 1 - 5 inches of the A1 soil horizon on the most northern beach ridge gave an age of 3000 ± 130 years (37). The organic matter in the sample is believed to have formed in situ (56). Another peat sample (L400B) was collected from a depth of 24 inches, on the most northern beach ridge, in the area to the west of where the natural gas pipeline crosses the ridge. This sample had a radiocarbon age of 10,900 years (an average of dates from the
bulk and humic or base soluble fractions) (37). The origin of this shallow organic layer is uncertain but it is most probably related to a process within the active layer and not to a recent marine transgression. For a discussion of the problems concerning the origin of this and other shallow horizons of organic matter accumulation throughout the Arctic, see MacKay (31, 32). The surface of the area then appears to be at least 10 - 11 thousand years old, and possibly older, but more radiocarbon dates will be needed to determine a maximum age.

A log collected from the base of the upper sand and gravel unit in Section W28 gave a radiocarbon age of >38,000 years (16, W-380). Because of the relatively good state of preservation, the log doesn't appear to have been re-deposited and probably does not predate the sediments by more than a short period. Therefore deposition of this upper unit began more than 38,000 years ago.

Relatively high brine contents are found at shallow depths in the sediments of the Barrow area. The water in thawed samples collected at depths of less than 10 feet has chloride contents which approximate sea water. For example, the water in samples B38, 39 and 40 in Table 2 has chloride contents of 19, 20 and 22 thousand mg/liter respectively. The indications are that as the ocean withdrew from the area, the surface sediments became frozen preventing subsurface drainage and removal of the interstitial sea water.
Alluvial The majority of the rivers crossing the coastal plain have extensive terrace development. The time consuming difficulty of gaining access to the terrace system, as well as the inaccuracy inherent in hand leveling across them, made it imprudent to attempt more than just a cursory study of their features and elevations.

A high terrace, approximately 150 feet or less above the Colville River, occurs on the south side of the river from a point just west of the junction of the Chandler River with the Colville, westward to Umiat. A yet higher terrace occurs along the Colville, but this was not visited. From topographic maps, the elevation is estimated to be 250 - 300 feet above the river. This terrace is well developed in the area of Prince Creek to the west of Umiat and extends eastward on the south side of the river to the Chandler River. The extent of this terrace is not known but from aerial photos it appears that it may extend eastward across the Chandler and Anaktuvuk Rivers and even past the Itkillik River. The highest terrace is tentatively correlated with the Foothill Silt Surface to be discussed later. The 150-foot terrace is tentatively interpreted as an alluvial valley fill resulting from the marine transgression which developed the coastal plain. At the southernmost occurrence of marine fossils seen by the writer, section W1, the coastal plain is 125 feet above the river.

Most of the other terraces seen occur in the interval...
from 15 - 30 feet above the river. Surfaces lower than 15 feet above the river are usually related to the present flood plain and are of limited extent. Any higher terraces are at a distance from the river and were not studied. A spectacular occurrence of peat is exposed under a terrace on the east bank of the river, north of the Itkillik junction. For about 10 miles the terrace is underlain by 20 - 25 feet of almost pure vegetal matter. Lenses of sand within the peat occur very rarely and then only locally. On the west bank of the river, across from the Itkillik junction, the terrace is underlain by 6 - 10 feet of peat overlain by about 10 feet of clean sand. In both instances the bottom of the peat is below river level.

The presence of a former alluvial fill along the Ikpikpuk River, within the foothills, is shown by the extensive development of a terrace 80 - 100 feet above the river. Cretaceous bedrock is commonly exposed under the terrace, but 80 feet of alluvium is exposed in places indicative of at least that much filling. This terrace is well developed from just north of Little Supreme Bluff downstream to the junction with Price River. Quaide (39) reports a terrace of similar height to be widely developed at the Kigalik-Maybe Creek junction and immediately north of the Valley of the Willows. The high terrace is interpreted as the alluvial valley fill resulting from the marine transgression which developed the coastal plain. The first occurrence, in place, of worn marine shell fragments
seen by the writer was at latitude 69° 46', section W12, on the east side of the valley. At this location the coastal plain is 100 feet above the river. William Maher and David Schalk, during an ornithological study in the area in 1958, found marine shells on the river bank, at the base of the cliff, at latitude 69° 44' (personal communication). At section F6, 4 1/2 miles downstream, the high terrace (all fluviatile material) was only 70 - 75 feet above the river, though farther to the north near the Price River junction Quaide measured a 100-foot terrace, also composed of fluviatile sediments. The upland surface of the foothills measured at the previous locality was approximately 180 feet above the stream, considerably above the adjacent coastal plain. It is probable that marine sediments occur along the east side of the river as far south as latitude 69° 40'. To the west of the river, the foothills extend to just north of the Price River junction. The river valley widens abruptly, just south of the Price River junction, with the development of an extensive terrace system as the river leaves the semiconfinement of the foothills.

Interpretation of the terraces within the foothills is complicated by the numerous local terrace levels cut by the river while downcutting in the alluvial fill. Quaide (39) called attention to the fact that many of the terraces are cut from sediments of the same age. In fact, he believed all but
the lowermost terraces, 10 - 15 feet above the river, were so formed. These local levels are a natural result of stream action, unrelated to any climatic change or movement of base level, but within these there may be general levels which have some significance. The terrace system within the coastal plain is not as complex, but is more difficult to work, due to its extent. Fairly accurate differences in elevations are difficult to obtain with a hand level, when such large distances are involved. The writer tried to group all terraces of a similar elevation and concluded there were three such groupings within the foothills (15 - 25 feet, 40 - 60 feet and 80 - 100 feet) and two (?) within the coastal plain (15 - 25 feet, and remnants of higher unmeasured (too remote) terrace). Until these terraces are studied in more detail over the entire length of the valley and those which may be significant in relation to sea level changes separated from the rest, little value can be placed on the groupings.

The major terrace groupings along the Meade River are about 18 - 22 feet and 30 - 40 feet above the river. The coastal plain appears to grade into a yet higher terrace within the foothills, similar to the situation observed on the Ikpikpuk River. But, since no work except for a flight to check the foothill silt was done upstream within the foothills, the extent of such a terrace is unknown.

Study of the Kaolak River terraces was limited to one
small area (see sections F8 and F9). Here the terraces are between 22 and 35 feet above the river. The river is entrenched within the terraces, with poorly expressed slip-off slopes. In this area the elevational difference between the foothills and the coastal plain is very slight, and one would expect an extensive valley fill to have been developed during the marine transgression. No high level terraces, as evidence of such a fill, were seen by the writer, nor were they reported by either Quaide (39) or Langenheim, et al. (24). Whether these terraces were destroyed during later removal of the fill, or were simply not recognized, or whether the present drainage system did not exist during the transgression, is not known.

Very little was done with the terraces on the Utukok River, since the river is cutting into the east side of the valley and the higher terraces there have been removed, and those on the west side are too remote. The highest terrace seen was 25 - 30 feet above the river and most others were less than 15 feet. In many cases the older terraces may be so modified as to be almost unrecognizable as terraces, and it is possible some remnants were mistaken for truncated thaw lake basins.

Eolian Present eolian activity is restricted to blow-outs in the banks of lakes and river terraces and to material moved from river flood plains, deltas and the coastal beaches. During a past period of more extensive movement the whole sur-
face of the area affected was active. This area encompasses most of the southern and central portions of the Western section. Most of the present activity is along rivers and lake banks within the area of past activity where the materials are readily moved when not stabilized by vegetation. Outside this area, blowouts in lake banks and terraces are rare and the major locations of dunal development are the deltas of the Sagavanirktok, Kuparuk and Colville Rivers, along the coast and the deltas of the rivers which drain the now stabilized area. Compared to past movement, the area affected by present eolian deposition is relatively small and is only locally important.

The area of eolian activity is now characterized by stabilized longitudinal and parabolic dunes with their gradational complex. The boundary between the foothills and the coastal plain approximates the southern boundary of the active area. The area extends from about the Colville River westward to a line 10 - 20 miles past the Meade River. The northern boundary, in the Meade River area is located around 70° 35' north latitude, just south of where the river begins to flow in a northeasterly direction. The northern boundary continues eastward to the Colville River at about this latitude. The Meade, Topagoruk and Ikpikpuk Rivers are the major streams crossing the area and along their courses, even outside the area, recent dunes are widely developed.
The eastern and western boundaries of the area are apparently the result of a lateral variation in the sediments. A slight change in sediment size could yield material either too coarse to be moved or fine enough to hold sufficient moisture to maintain a vegetation cover. Of these the latter seems most probable, and the decrease in size of the surface materials to the east and west of Ikpikpuk River is a partial verification. The northern boundary is more of a problem. Limited study of aerial photography along the boundary indicates that the boundary is transitional and not connected with a recognizable shoreline. Since the lakes in the area north of the boundary are much larger than those to the south, one is tempted to relate the boundary to either the presence of the shoreline along the boundary during the major period of activity or to a later transgression which now forms the boundary. From the limited study, mainly in the vicinity of Meade River, the writer concludes that the boundary is a result of a northward change to finer sediments which were not susceptible to eolian movement. It may be that this change in the sediments and their influence on ice content may also explain the difference in the lakes. Lastly, even if the larger northern lakes are developed on a much younger portion of the coastal plain, this transgression was not responsible for the boundary.

The stabilized dunes are most evident on aerial photographs (Figure 11) where the vegetative response to the
Figure 11. Stabilized dunes on the coastal plain and recent dunes along the river, in the Meade River area. (Location: 5 - 6 miles south of Meade River village and to the west of section W15.)

Figure 12. Low mounds characteristic of portions of the coastal plain in the Eastern section. A few pingos are also present. (Location: 7 miles north of section Ell, and 3 miles west of the Kuparuk River.)
thicker active layer and better drainage is shown by tonal differences. They are not as obvious on the ground because of the broad low outline. The eolian surface materials reflect local conditions during the time of active deposition and movement. These sediments may be as much as 10 feet thick in inter-dunal areas and correspondingly thicker within dunes. A typical surface sequence is a thick basal peat (1 - 3 feet) containing little inorganic material, overlain by an equally variable thickness of banded peat-sand mixtures and then by the present vegetation mat, usually 1 - 6 inches in thickness. The banded sequence reflects the ability of the vegetation to re-establish itself and/or keep pace with deposition under varying rates of deposition. Many peat predominant layers indicate a low rate of sand deposition, whereas other layers are almost pure sand with a loose network of organic material indicating the vegetation was just able to keep up with deposition. No extensive, relatively thick, layers of clean peat which would serve as a basis for recognizing major breaks in the period of eolian activity, were seen. It would appear that there has been only one period of activity and that the conditions which allowed this movement developed a considerable time after the initial establishment of the vegetation as indicated by the basal peat. Any further work in this area should be accompanied by radiocarbon dating to determine the beginning of the active period and its duration, and to dis-
cover whether indications of more than one active period can be found. Analyses of eolian sands taken from active blowouts and from the sandy portion of the tundra mat are given in Table 3.

Black (1) believes the majority of the older, now stabilized dunes were formed in a climate slightly warmer than at present. A thicker active layer and resultant improvement in soil drainage under a warmer climate would presumably lead to a drier surface soil and sparser vegetation, which are conditions favorable to eolian activity. Black thinks such a climate could have been produced in the post-Pleistocene optimum. All the major stabilized dunes are aligned with the present wind pattern, that is dominant winds from the east-northeast with a secondary maximum from the opposite quarter, the west-southwest. A more precise dating of the period of activity would give an indication of the stability in the wind circulation pattern for this area.

Eastern section

The Eastern section encompasses the area from 150° west longitude, eastward to the Sagavanirktok River. The area farther east appears to have had a similar history, based on a comparison of the aerial photography of the two areas. This generalization is probably valid up to the Canning River, but continuing eastward the glacial outwash and piedmont alluvial complex of the mountains predominates. The coastal plain then
Table 3. Mechanical analyses of Eolian materials of the coastal plain

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>+30</td>
</tr>
<tr>
<td>M26</td>
<td>Blowouts in terrace, south of section W15, Meade River</td>
<td>0.1</td>
</tr>
<tr>
<td>M28</td>
<td>Blowouts in terrace, south of section W15 and also M26</td>
<td>0.1</td>
</tr>
<tr>
<td>M1</td>
<td>Tundra-eolian surface sequence at end of airstrip, Meade River Village</td>
<td>0.1</td>
</tr>
<tr>
<td>M27</td>
<td>Blowouts in terrace, end of airstrip, Meade River Village</td>
<td>0.1</td>
</tr>
<tr>
<td>I1</td>
<td>W20; Tundra-eolian surface sequence, Inaru River</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>K30</td>
<td>Blowouts in terrace; 2 miles north of Section Ell, Kuparuk River</td>
<td>1.4</td>
</tr>
<tr>
<td>K23</td>
<td>Ell; Tundra-eolian surface sequence, Kuparuk River</td>
<td>0.3</td>
</tr>
<tr>
<td>K27</td>
<td>Dunes on terrace, east of Ell, Kuparuk River</td>
<td>0.2</td>
</tr>
</tbody>
</table>
becomes a narrow, possibly discontinuous, belt extending eastward into the Canadian Arctic.

This section differs from the Western section in that the marine coastal plain no longer abuts upon the Foothills province, but a broad area of fluviatile-deltaic sediments now occurs between the marine coastal plain and the Foothills. Because of the contemporaneous and interfingering nature of the marine and nonmarine portions of the coastal plain in this area, a well defined boundary between the two cannot be drawn.

Though the extent of the coastal plain is somewhat more easily delineated where the coastal plain abuts against the Itkillik-Kuparuk Highland and the Franklin Bluffs, even here a sharp line cannot be drawn. In general, the boundary between the foothills and the fluviatile portion of the coastal plain is indistinct as a result of having been badly dissected by both streams and the action of thaw lakes and further obscured by processes of mass-wasting. Solifluction is sufficient in this area to reduce the topographic break between two areas to a gentle slope, easily missed in the field and hard to delineate on many aerial photos.

The Toolik-Kuparuk and Ivishak-Sagavanirktok Rivers are the two major drainage systems of this section. The Toolik-Kuparuk system has its headwaters within the Foothills at the present time, but it appears as if piracy by the Sagavanirktok River has, in the past, captured that portion of the Toolik
drainage, previously within the mountains. Neither the Toolik nor the Kuparuk Rivers have appreciable carbonate rocks within their drainage basins, so at present the majority of the bedload is noncalcareous. The Ivishak-Sagavanirktok River system differs greatly from the Toolik-Kuparuk system to the west. These rivers flow in broad braided channels and because of their steeper gradient as well as larger more permanent water supply in the mountains, are more competent than the Kuparuk and Toolik Rivers. The Ivishak and Sagavanirktok Rivers have a thick stratigraphic section of carbonate rocks within their drainage basins, and consequently have a highly calcareous bedload. Carbonate analyses of samples from the present river terraces are given in Table 4 (see a later section for the analytical method used). The outcropping belt of carbonates, and related strata, is over 20 miles wide where crossed by the Ivishak River.

The southernmost portion of the coastal plain is composed of nonmarine sediments, the result of fluviatile-deltaic deposition by the major river systems when the ocean stood within the present interfluve area. These sediments are highly calcareous, commonly containing over 40 percent carbonate by weight (see Table 5). Northward the carbonate content decreases within the marine portion. The alluvial materials associated with the present Sagavanirktok River are calcareous, whereas the materials of the Toolik-Kuparuk terrace system are
Table 4. Mechanical analyses of Ivishak-Sagavanirktok terrace materials

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Sample Section</th>
<th>Elev. a</th>
<th>Gravel (ft. +10)</th>
<th>Sand (ft. -10+)</th>
<th>Silt (ft. -30)</th>
<th>Clay (ft. -50)</th>
<th>Md (ft. -100)</th>
<th>So (ft. -200)</th>
<th>&lt;5µ</th>
<th>µ</th>
<th>MCO₂ b</th>
<th>Dolomite c</th>
</tr>
</thead>
<tbody>
<tr>
<td>S28 El</td>
<td>Surface of 20- 21.5</td>
<td>0.3</td>
<td>0.4</td>
<td>2.3</td>
<td>7.1</td>
<td>68.4</td>
<td>21.5</td>
<td>16</td>
<td>2.38</td>
<td>37.2</td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>terrace, blue in color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S27 E1</td>
<td>Below sample 17- 19</td>
<td>0.2</td>
<td>0.9</td>
<td>9.7</td>
<td>16.4</td>
<td>57.8</td>
<td>15.0</td>
<td>31</td>
<td>2.75</td>
<td>52.1</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S28, brown in color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S11 E1</td>
<td>Surface of 15- 16</td>
<td>0.2</td>
<td>0.3</td>
<td>4.9</td>
<td>12.7</td>
<td>64.9</td>
<td>17.0</td>
<td>27</td>
<td>2.73</td>
<td>47.0</td>
<td>15.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S26 E1</td>
<td>Surface 2 ~8 feet, low terrace</td>
<td>0.1</td>
<td>0.7</td>
<td>23.6</td>
<td>32.7</td>
<td>35.9</td>
<td>7.0</td>
<td>86</td>
<td>1.95</td>
<td>43.2</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>S20 E4</td>
<td>Surface 2 3-5 feet, low terrace</td>
<td>0.3</td>
<td>0.3</td>
<td>0.7</td>
<td>3.4</td>
<td>11.6</td>
<td>69.2</td>
<td>14.5</td>
<td>33</td>
<td>2.43</td>
<td>24.4</td>
<td>19.5</td>
</tr>
<tr>
<td>S36 E5</td>
<td>Surface 2 2-4 feet, low terrace</td>
<td>2.7</td>
<td>7.5</td>
<td>16.0</td>
<td>18.7</td>
<td>39.0</td>
<td>16.0</td>
<td>62</td>
<td>3.73</td>
<td>21.8</td>
<td>15.9</td>
<td></td>
</tr>
<tr>
<td>S18 E6</td>
<td>Surface 1 1/2 feet, low terrace</td>
<td>0.3</td>
<td>0.2</td>
<td>0.4</td>
<td>8.2</td>
<td>24.4</td>
<td>56.0</td>
<td>10.5</td>
<td>49</td>
<td>2.10</td>
<td>25.6</td>
<td>17.4</td>
</tr>
</tbody>
</table>

aElevation above river.
bBy weight of total sample; M refers to Ca and Mg.
cBy weight of carbonate fraction.
Table 5. Mechanical analyses of coastal plain materials - Eastern section

<table>
<thead>
<tr>
<th>Sample Location Section</th>
<th>Elev. (^a)</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
<th>(&lt;5\mu)</th>
<th>(\mu)</th>
<th>MCO (^b)</th>
<th>Dolo- (^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft.</td>
<td>+30</td>
<td>-30+</td>
<td>-50+</td>
<td>-100+</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S2 E2 Silt just over gravel</td>
<td>40-41</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>0.8</td>
<td>1.7</td>
<td>55.3</td>
<td>42.0</td>
<td>7.6</td>
<td>3.94</td>
<td>49.3</td>
</tr>
<tr>
<td>S3 E2 Upper 2 ft., ~68 bluff edge</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>1.0</td>
<td>10.9</td>
<td>80.4</td>
<td>7.5</td>
<td>45</td>
<td>1.32</td>
<td>24.3</td>
<td>32.5</td>
</tr>
<tr>
<td>S5 E2 Upper 1 ft., ~74 bluff edge</td>
<td>---</td>
<td>1.0</td>
<td>0.4</td>
<td>1.8</td>
<td>2.0</td>
<td>68.8</td>
<td>26.0</td>
<td>15</td>
<td>2.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S14 E2 Upper 2 ft., in lake bottom</td>
<td>---</td>
<td>0.3</td>
<td>0.1</td>
<td>0.8</td>
<td>2.0</td>
<td>83.6</td>
<td>13.2</td>
<td>29</td>
<td>1.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S16 E2 Sand just over gravel</td>
<td>40-41</td>
<td>---</td>
<td>0.2</td>
<td>5.9</td>
<td>44.9</td>
<td>22.9</td>
<td>18.0</td>
<td>8.2</td>
<td>150</td>
<td>1.68</td>
<td>47.0</td>
</tr>
<tr>
<td>S10 E3 Silt over sand (S17)</td>
<td>47-48</td>
<td>---</td>
<td>1.4</td>
<td>3.0</td>
<td>14.3</td>
<td>15.7</td>
<td>46.6</td>
<td>19.0</td>
<td>40</td>
<td>3.40</td>
<td>43.4</td>
</tr>
<tr>
<td>S17 E3 Sand just over gravel</td>
<td>45-47</td>
<td>---</td>
<td>0.2</td>
<td>4.0</td>
<td>38.2</td>
<td>31.9</td>
<td>20.7</td>
<td>5.0</td>
<td>130</td>
<td>1.62</td>
<td>42.5</td>
</tr>
<tr>
<td>K6 E8 From top of pinga, below vegetation</td>
<td>---</td>
<td>&lt;0.1</td>
<td>1.4</td>
<td>24.3</td>
<td>36.5</td>
<td>31.0</td>
<td>6.7</td>
<td>100</td>
<td>1.72</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Elevation above river.  
\(^b\) By weight of total sample; M refers to Ca and Mg.  
\(^c\) By weight of carbonate fraction.
<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Elev. ft.</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>% &lt;5μ</th>
<th>% 50</th>
<th>% 100</th>
<th>% 200</th>
<th>KCO₃</th>
<th>Dolerite</th>
</tr>
</thead>
<tbody>
<tr>
<td>K16 From river</td>
<td>25-28</td>
<td>-0.2</td>
<td>4.0</td>
<td>21.0</td>
<td>33.3</td>
<td>35.5</td>
<td>6.0</td>
<td>90</td>
<td>1.74</td>
<td>43.2</td>
<td>10.5</td>
</tr>
<tr>
<td>K21 Surface</td>
<td>~35</td>
<td>3.0</td>
<td>3.4</td>
<td>3.5</td>
<td>16.2</td>
<td>16.3</td>
<td>39.0</td>
<td>21.6</td>
<td>46</td>
<td>4.24</td>
<td>19.5</td>
</tr>
<tr>
<td>K13 Broad</td>
<td>---</td>
<td>4.0</td>
<td>7.4</td>
<td>7.2</td>
<td>19.2</td>
<td>17.9</td>
<td>35.3</td>
<td>13.0</td>
<td>80</td>
<td>2.95</td>
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</tr>
<tr>
<td>K32 Adjacent</td>
<td>---</td>
<td>1.4</td>
<td>5.9</td>
<td>14.5</td>
<td>10.3</td>
<td>46.9</td>
<td>21.0</td>
<td>35</td>
<td>4.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K31 Sand lenses</td>
<td>---</td>
<td>0.6</td>
<td>4.0</td>
<td>61.1</td>
<td>27.2</td>
<td>5.1</td>
<td>2.0</td>
<td>170</td>
<td>1.26</td>
<td>37.5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>K29 Sand</td>
<td>17-19</td>
<td>1.0</td>
<td>1.7</td>
<td>7.6</td>
<td>37.0</td>
<td>34.7</td>
<td>15.0</td>
<td>4.0</td>
<td>140</td>
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<td>22.6</td>
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<tr>
<td>K13 Sand</td>
<td>14-16</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>9.7</td>
<td>62.3</td>
<td>22.9</td>
<td>5.0</td>
<td>95</td>
<td>1.32</td>
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Table 5 (Continued).

<table>
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<tr>
<th>Sample</th>
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<th>Elev. ft.</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
<th>% MOn</th>
<th>% Dolo-</th>
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<td></td>
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<td>-30+</td>
<td>-50+</td>
<td>-100+</td>
<td>50</td>
<td>100</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>K24</td>
<td>El3 Surface</td>
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<td>4.8</td>
<td>7.3</td>
<td>25.8</td>
<td>22.4</td>
<td>27.6</td>
<td>12.0</td>
<td>106</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>old lake basin</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>K10</td>
<td>El4 Sand in</td>
<td>4.0</td>
<td>5.6</td>
<td>9.7</td>
<td>32.0</td>
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<td>17.2</td>
<td>17.1</td>
<td>140</td>
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<td></td>
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<td>7.3</td>
<td>8.0</td>
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<td>29.5</td>
<td>21.0</td>
<td>70</td>
<td>5.55</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>old lake basin</td>
<td></td>
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<td></td>
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<tr>
<td>K19d</td>
<td>El4 Surface</td>
<td>4.0</td>
<td>5.2</td>
<td>7.4</td>
<td>23.8</td>
<td>15.9</td>
<td>30.2</td>
<td>17.5</td>
<td>86</td>
<td>3.98</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

These three samples are over a mile apart.
calcareous only where carbonates have been derived from the coastal plain sediments of the interfluve. A large portion of the rivers are within their terrace systems, and fresh cuts into the upland adjacent to the river are rare. Bedrock is seldom exposed within the coastal plain, consequently the total thickness of unconsolidated sediment is usually indeterminate. Within the nonmarine portion of the coastal plain, the unconsolidated sediments are at least 75 feet thick, 40 feet of gravel being overlain by 35 feet of silt to fine sand at section E2 on the Sagavanirktok River. Fresh water fossils occur in the base of the sand at section E3. To the west on the Toolik River, section E8, 35 feet of sand is exposed above river level though no gravel is exposed at the base. The presence of a basal gravel is implied by a coarse gravel, containing cobbles up to 6 inches, exposed in the top of pingo near Section E8, where the sand has been removed by solifluction. The typical nonmarine sediment is a gray, calcareous, fine sand to silt, well sorted (except the near surface samples) and consists of angular to subangular grains, with abundant shistose rock fragments. Northward the major changes are less shistose fragments, and carbonates and an increase in rounding, yellow iron stained grains and multicolored chert. These changes reflect the movement of sediment into the area along the shoreline. The underlying gravel becomes finer and more sandy to the north. Crossbedding, interstratification of
sand and gravel, and rapidity of lateral changes also increase. Analyses of the coastal plain sediments are given in Table 5. The samples are generally high in total carbonate with a low dolomite percentage, an exception being S3, a sample near the surface which has been leached. It is possible that the surface sediments were somewhat higher in dolomite, that is, similar to the present river materials, and that leaching has tended to concentrate the dolomite, thereby increasing the dolomite percentage of the remaining total carbonate.

Probably the best exposure of ground ice within the Arctic Slope occurs just north of section E2. Though the cliffs are fairly clean for about 6 miles north and a few miles south because of recent river activity, the upper part of the section, composed of fine sand and silt, is badly slumped. Only in those few locations where the river is actively cutting into the coastal plain are the ice wedges well exposed (see Figure 13). Since the undercut cliff breaks along planes of weakness and these tend to occur in the tensional fractures within the ice wedge system, the fresh exposure is of dominantly longitudinal sections along rather than across the wedges. This results in an exposure which at first glance appears to be a massive ice sheet. It is this habit of breaking along the ice wedges in the cliff, that has given rise to many reports of massive ice sheets in the permafrost. Though massive ice sheets may occur elsewhere, none have ever been
seen by the writer in northern Alaska. Closer observation ordinarily allows a differentiation to be made between the ice in the longitudinal section of the wedges and that in the wedge junction where a wedge is cut across. The transverse sections extend to the bottom of the wedge system whereas a longitudinal section may or may not, and with progressive thaw the longitudinal exposure tends to thin vertically yielding a serrate lower boundary. But, in most exposures along caving banks, this criterion is not observable due to the presence of the caved block. In the exposure previously mentioned, this feature is clearly evident and frequently part of a longitudinal section has been thawed away exposing the material within the polygon. The ice wedges extend downward approximately 40 feet and continue into the underlying gravel.

A peculiar feature of the terrain in much of the northern portion of the coastal plain is the presence of very low (1 - 3 feet) broad mounds which stand above the coastal plain. Because of their gentle slopes, they are not easily seen on the ground, yet are quite striking on the aerial photographs (Figure 12), as a result of vegetation changes due to enhanced drainage. The material in the mounds is slightly sandier than the sediment surrounding them (see samples K13 versus K32 in Table 5). The material in the mounds is a buff to yellow-orange color, as contrasted to the grays and blue-grays of the surrounding material. This color change appears to be more of
an oxidation-reduction response to drainage and active layer thickness than to a basic difference in the material. These mounds extend outward from the Itkillik-Kuparuk Highland and the Franklin Bluffs for over 10 miles among the lakes and drained basins of the coastal plain. Though most of the mounds are low, and extremely broad in relation to height, a few higher mounds do occur. Most of these were seen on aerial photos so no measurements are available. They are not to be confused with the pingos which are also numerous on the coastal plain. They differ from the pingos in being broader, not associated with past lake basins, and are in some cases interconnected to form a larger ridgelike area. The origin of these mounds is uncertain, but the writer thinks they are more closely related to erosional remnants resulting from the development of the thaw lakes, than to frost action phenomena in the surface materials. Again these mounds are different from any seen elsewhere on the coastal plain, and are not the small ice-cored or peat mounds reported from other places in the Arctic.

A very faint break occurs between the area north of the Itkillik-Kuparuk Highland, and the terrace system of the Kuparuk River to the east. This break is actually west of the westernmost terrace and forms an area bounded by the coastal plain containing mounds on the west and the terrace system on the east. Mounds also occur east of the terrace system.
Whether this break is a result of a younger marine inundation along the axis of the river or an extremely old terrace, whose identifying morphology has since been destroyed by thaw lakes, solifluction and polygonal ground formation is uncertain. A more extensive aerial photographic study of this area and the interfluve would be necessary before a distinction would be forthcoming.

Numerous erratics are present along the coast at the mouth of the Kuparuk. Leffingwell (25) mentioned the abundance of these boulders along this particular part of the coast, in his discussion of what he termed the Flaxman formation. Leffingwell is probably correct in referring these boulders to ice rafted glacial debris though well-developed facets and striations are rare. Some were definitely derived from the coastal plain sediments, being in place, or up a drainage away from the ocean, or with a calcareous stain similar to that deposited on gravels in the sediments. As a rule the erratics are found in local concentrations, as one would expect if they were ice rafted either in the past or from the present ice. These concentrations contain rocks of varied lithology implying a heterogeneous source. Quartzites, granites with pegmatitic inclusions and granite gneisses of different types commonly occur together. Some concentrations though, contained but a single lithology. The largest fragment measured was 3 x 4 x 4 feet.
Figure 13. Ice wedges exposed along the Sagavanirktok River, near section W2. Cliff height is about 75 feet above the river.

Figure 14. Crestal accordance of the Foothill Silt Surface. View west from section F7 on the Meade River.

Figure 15. Erosion pattern of the foothill silt on Bronx Creek. (Location: 7 1/2 miles northwest of section F5 on the Ikpikpuk River.)

Figure 16. Stratification of the silt, within the foothills, as seen on a weathered surface. (section F5 on the Ikpikpuk River.)
Though very little time was spent on the terraces, the terrace development on both rivers seemed to be mainly a sequence of unpaired terraces resulting from normal river activity undisturbed by sea level fluctuations. The only indications of possible sea level changes are the break in the coastal plain along the Kuparuk mentioned previously, a similar, lower, discontinuous break occurring in the same area, and a buried peat in one of the terraces. This terrace is located 2 miles north of section Ell. Here 7 feet of fairly clean sand with occasional thin organic horizons towards the top, overlies 8 feet of apparently clean peat. The base of the peat is not exposed. Due to their remoteness from the river, the higher terraces on the Sagavanirktok River were seldom examined, and no specific conclusions can be drawn.

Foothill Silt Surface

During the stratigraphic study of the Quaternary marine sediments of the coastal plain, traverses across the coastal plain were extended south into the Northern Foothills section. Thick sections of calcareous silt were found exposed in the high river bluffs within the foothills. The maximum thickness measured contained 130 feet of silt. The silt, in most instances, lies upon an alluvial section. Study of the silt was conducted primarily in the area west of the Colville River. Here the belt of silt is approximately 250 miles long and 10 -
30 miles wide.

**Literature review**

Schrader (48) is the first to note the occurrence of calcareous silt along the Colville River. He mentions 40 - 50 feet of Upper Colville series outcropping near the Anaktuvuk-Colville junction. Schrader describes this series as, "... nearly horizontally stratified beds of fine gray, slate-colored or ash-colored calcareous silts, containing faunal remains". The faunal remains described by him are from a location much farther north and in the opinion of the author, not necessarily in the same material. Schrader assigned a Pliocene age to the upper Colville Series. The term "Colville Series" is now restricted by the U.S. Geological Survey to the upper Cretaceous, and the unconsolidated silts are considered here to be Pleistocene in age. He placed the boundary between the foothills and the coastal plain, as exposed in the cliffs on the west side of the Colville River, near the junction of the Anaktuvuk and Colville Rivers. Later work, (38), places this boundary near Sentinel Hill, about 15 miles farther downstream. They also show the distribution of Pleistocene sediments to extend south to the junction of the Anaktuvuk and Colville Rivers. The writer assumes this indicates a recognition of Schrader's silt but an exclusion from the coastal plain materials. What their interpretation is of the silt is not given, though the omission is understandable due to the
broad nature of the report.

Smith and Mertie (50) have summarized the information on the geology of northwestern Alaska obtained during previous explorations, but little mention has been made of the silt deposits.

More recent investigations were made by the U.S. Geological Survey during exploration of U.S. Naval Petroleum Reserve No. 4 between 1945 and 1953. These studies were primarily concerned with the structure and stratigraphy of the bedrock with little consideration being given to the unconsolidated Quaternary materials. Consequently, much of the information on the unconsolidated materials obtained during this exploration is still unpublished. Some information is available in open-file reports of the U.S. Geological Survey, and the published reports on the test wells drilled during the exploration. A few test wells and core tests were drilled within the area underlain by the silts. The Kaolak Test Well (14) logged approximately 100 feet of surficial unconsolidated materials. These appear to be fine sand, silt or clay in the upper portion with sand and gravel in the basal portion. No marine microfossils were found in any of the samples. The Meade Test Well (14) penetrated approximately 11 feet of surficial material, and marine Pleistocene Foraminifera were found as contaminants in samples of the underlying Cretaceous. A much larger number of holes were drilled in the Oumalik area (42).
All the deeper holes, a total of seven, within a 6-mile radius, indicate thicknesses of from 12 - 40 feet. Ten shallow foundation holes drilled to about 50 feet, indicate four locations in which greater than 50 feet of unconsolidated material was found. The rest ranged from 40 - 49 feet. The detailed descriptions of the foundation cores indicate silt and clay in the upper 30 - 50 feet with sand and gravel restricted to the lower portions, though pebbles are reported scattered through part of the silt. No mention is made of whether the surficial material is calcareous or not. Two core tests, Oumalik No. 1 and Ikpikpuk No. 1, drilled 1/4-mile apart, had a difference in elevation of 75 feet for both the surface and the bedrock.

Livingstone et al. (28), during a limnological study of arctic lakes, visited East Oumalik Lake which lies just south of the coastal plain, and west of the Ikpikpuk River. They speak of this area as the transitional zone between the coastal plain and the foothills. The area is described as having a higher elevation and greater local relief than the coastal plain and instead of a simple plain, consists of a pocked and dissected plateau. No mention is made of the possible significance or origin of this area. The maximum depth of East Oumalik Lake is 12 meters (39.6 feet), and the surface of the level upland around the lake is 16 meters (52.8 feet) above the water. The total relief is then 28 meters or 92 feet. The lake owes its existence to the thawing of permafrost and
the included ice. They do not think much, if any, silt has left the basin, and on this basis estimated the original ice content of the sediments at 68 percent of the total volume. Therefore, we have a minimum thickness of sediment and ice of over 92 feet, though the ice content is probably much less since their initial assumptions lead to a high estimate. The calcareous nature of the materials is shown in the hardness of the lake water for East Oumalik and an adjacent lake. These lakes reportedly have 116 and 128 ppm, as CaCO₃, respectively.

Gryc (19, p. 111) notes: "Much of the northern foothills section is covered by a thin layer of a variety of unconsolidated sediments collectively called the Gubik formation". This is apparently a reference to the silt as well as alluvial stream deposits, but is of little value.

Quaide (39) investigated the upper portions of the Ikpikpuk River and the Avalik and Kaolak Rivers which are tributaries to the Kuk. This study was concerned with the Pleistocene vertebrate fauna and its stratigraphic relationships. He refers the accordance in elevation along the Ikpikpuk to an uplifted Tertiary erosion surface, called the Oldland Surface. He also noted "Cappings of younger sediments may exist beneath the tundra cover, but such deposits were not seen". The writer will agree that the area in the vicinity of the junction of Kigalik River and Maybe Creek may owe its surface accordance to erosion, but the area from about the Valley of the Willows
north to the coastal plain is underlain by silt and is depositional.

Black (1) recognized loess a few inches to several feet thick along the west bank of the lower Colville River. From this description it is uncertain whether Black is referring to the calcareous silts of Schrader or to the silty surficial portions of the Gubik sand. Black does indicate on his location map the presence of loess in the area of Schraders' silt. Schrader called the surficial portion of the Gubik sand "loess" in his field notes, but preferred the former term since he considered the deposit fluviatile-marine in origin.

In a description of the Gubik formation, Black (3) states his intermediate unit, of clean, well sorted, marine sand, grades upward into loess in the southern and southeastern portion of the coastal plain. Since the nature of the paper, an abstract, precluded further detail, it is uncertain whether this is a recognition of the foothill silt or not.

Langenheim et al. (24) do not report extensive unconsolidated sediments from the upper Kaolak River. Instead they note that the higher prominent topographic surface, formed by the general crestal level of the interfluves, is underlain by Cretaceous bedrock mantled only by recent tundra soil. The surface is presumed to be of erosional origin. Yet in this area a few relatively large lakes occur, whose presence is best explained by thaw into a thickness of surficial materials.
An extensive investigation of the surficial materials of the Arctic Slope was performed by Boston University Physical Research Laboratory under contract to the Air Force in the early 1950's, but these reports are unavailable.

**Distribution**

The area of foothill silt forms a belt within the northern edge of the Northern Foothills section. It is bounded on the north by the coastal plain, and on the south by the Intermediate Surface. The Intermediate Surface rises 100 - 150 feet above the foothill silt area, and is best developed in the area south of the Meade River. The Intermediate Surface becomes either narrow or discontinuous east of the Iqpikpuk River and west of the Utukok River, and the Foothill Silt Surface is then bounded by the 300 - 500 foot escarpment of the Southern Surface. Whether the Intermediate Surface is present east of the Colville River is not known.

**West of the Colville River** The drainage pattern of the Foothill Silt Surface is characterized by consequent north flowing streams, whereas that of the adjacent area to the south is strongly controlled by bedrock structure. The surface of the foothill silt area is a gently northward sloping plain which rises from an elevation of 100 - 200 feet along the northern margin to about 400 - 600 feet at the southern edge. The lakes and rivers are set into this surface, with a local relief of 160 feet along the rivers. Yet numerous broad
interfluves are still undissected and preserve the summit accordance (see Figure 14). This plain is underlain by thick (up to 130 feet) deposits of calcareous silt overlying an alluvial section.

The erosion surface at the base of the unconsolidated sediments has a relief of over 100 feet, especially along the Ikpikpuk and Kaolak Rivers. The buried topography appears to be a gently rolling surface, slopes of an order of 1 - 3 degrees are not inconsistent with the outcrop pattern, though the actual abruptness of the relief is obscured. Because of this relief, the thickness of the overlying sediments varies from over 170 feet to less than 50 feet.

A typical section exposed within the area of foothill silt is as follows:

Unit thicknesses

**10 - 130 feet**  Calcareous silt, well sorted, and weakly stratified. Stratification best where emphasized by organic fines, or on a weathered surface. Grades into or overlies sharply the underlying sand.

**0 - 20 feet**  Sand to gravelly sand, well sorted, calcareous except near base.

**0 - 10 feet**  Fine to medium noncalcareous gravel, most of which is derived from underlying Cretaceous.

**Unconformity.**

**Cretaceous**  In the thicker sections, may be below
river level or obscured by terrace material.

The basal sands and gravels are restricted to the thicker sections, that is in the valleys of the erosion surface. Scattered pebbles and higher sand contents do occur in the basal materials of the thinner sections. Along the Colville River the basal sands and gravels contain numerous logs, beds of twigs and limbs and other organic debris. Similar organic concentrations were not seen in the basal materials on any of the other rivers. In only one location was an upward change back into sand observed. This occurred at section F6\(^1\) on the Ikpikpuk River. There the basal 100 feet of the silt is composed of 6 percent sand, and 16 percent clay. The sample from 114 feet above the base of the silt is 19 percent sand, and 14 percent clay. At 128 feet the material is 77 percent sand and 6 percent clay. The absence of other similar sections is probably a result of the small number of sections examined. The maximum thicknesses of the unconsolidated sediments and silt seen along the rivers are given in Table 6.

Minor textural variations both vertically and regionally are easily missed if only field descriptions and limited sampling are used. This is especially true in the finer materials. Consequently, the writer does not feel justified in interpreting more than general relationships. Most of the

\(^1\)To improve readability the stratigraphic sections referred to in the text have been placed in an appendix.
Table 6. Maximum sections measured

<table>
<thead>
<tr>
<th>River</th>
<th>Section</th>
<th>Thickness of silt</th>
<th>Total thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colville</td>
<td>F2</td>
<td>~90'</td>
<td>120'</td>
</tr>
<tr>
<td>Ikpikpuk</td>
<td>F6</td>
<td>~120'</td>
<td>&gt;160'</td>
</tr>
<tr>
<td>Meade</td>
<td>F7</td>
<td>120'</td>
<td>&gt;146'</td>
</tr>
<tr>
<td>Kaolak</td>
<td>F8</td>
<td>100 - 120'</td>
<td>&gt;170'</td>
</tr>
<tr>
<td>Utukok</td>
<td>F15</td>
<td>35'</td>
<td>75'</td>
</tr>
</tbody>
</table>

samples are three to four foot composites and will not reflect local size variations within the silt. The method of mechanical analysis used is given in a previous portion of the paper. One should note, that because of the relatively thorough dispersion obtained with the above method, higher clay contents consequently smaller median diameters and often poorer sorting are obtained than with many other procedures. The size distribution of the silt and sand along the Colville, Ikpikpuk, Meade and Kaolak Rivers is given in Tables 7 and 8. The cumulative curves for the above silt and related sand are shown in Figure 17. The median diameters and sorting coefficients are shown in Tables 7 and 8. The definition of the above measurements are given by Krumbein and Pettijohn (23, p. 230 - 235). The results of size analyses of the material along the Utukok River are given in Table 9.

The average particle size distribution of the silt (excluding the Utukok samples and the basal materials) is 6 percent sand (13 percent using 50 micron as lower limit), 76
Table 7. Mechanical analyses of silt, Foothill Silt area

<table>
<thead>
<tr>
<th>Sample</th>
<th>Section</th>
<th>Elevation^</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>feet</td>
<td>&gt;74µ</td>
<td>&gt;62.5µ</td>
<td>&gt;50µ</td>
<td>74-5µ</td>
<td>&lt;5µ</td>
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<tr>
<td>V2</td>
<td>F1</td>
<td>20 - 22^b</td>
<td>5.0</td>
<td>6.0</td>
<td>9.0</td>
<td>75.0</td>
<td>20.0</td>
</tr>
<tr>
<td>V3</td>
<td>F1</td>
<td>72 - 74^b</td>
<td>7.0</td>
<td>10.0</td>
<td>13.0</td>
<td>76.5</td>
<td>16.5</td>
</tr>
<tr>
<td>P2</td>
<td>F5</td>
<td>48 - 51</td>
<td>8.0</td>
<td>12.0</td>
<td>19.0</td>
<td>69.0</td>
<td>23.0</td>
</tr>
<tr>
<td>P3</td>
<td>F5</td>
<td>74 - 77</td>
<td>1.2</td>
<td>2.0</td>
<td>4.0</td>
<td>79.8</td>
<td>19.0</td>
</tr>
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<td>P5</td>
<td>F5</td>
<td>108 - 112</td>
<td>3.0</td>
<td>5.0</td>
<td>12.0</td>
<td>79.0</td>
<td>18.0</td>
</tr>
<tr>
<td>P13</td>
<td>F6</td>
<td>32.5 - 34.5</td>
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<td>9.0</td>
<td>17.0</td>
<td>79.0</td>
<td>15.0</td>
</tr>
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<td>P9</td>
<td>F6</td>
<td>98 - 102</td>
<td>6.5</td>
<td>10.0</td>
<td>16.0</td>
<td>77.5</td>
<td>16.0</td>
</tr>
<tr>
<td>P12^c</td>
<td>F6</td>
<td>144 - 148</td>
<td>19.0</td>
<td>23.0</td>
<td>31.0</td>
<td>67.0</td>
<td>14.0</td>
</tr>
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<td>M35</td>
<td>F7</td>
<td>75 - 77</td>
<td>10.0</td>
<td>11.0</td>
<td>15.0</td>
<td>71.5</td>
<td>18.5</td>
</tr>
<tr>
<td>M36</td>
<td>F7</td>
<td>98 - 101</td>
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<td>7.0</td>
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<td>77.5</td>
<td>17.5</td>
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<td>M37</td>
<td>F7</td>
<td>128 - 131</td>
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<td>10.0</td>
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<td>77.0</td>
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</tr>
<tr>
<td>M39</td>
<td>F7</td>
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<td>11.0</td>
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</tr>
<tr>
<td>A3</td>
<td>F8</td>
<td>5 - 8^d</td>
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<td>4.5</td>
<td>9.0</td>
<td>88.0</td>
<td>9.0</td>
</tr>
<tr>
<td>A4</td>
<td>F9</td>
<td>15 - 17^d</td>
<td>7.0</td>
<td>9.0</td>
<td>13.0</td>
<td>73.5</td>
<td>19.5</td>
</tr>
<tr>
<td>A1^c</td>
<td>F9</td>
<td>28 - 31</td>
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<td>61.5</td>
<td>20.5</td>
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<td>A2</td>
<td>F9</td>
<td>67 - 70</td>
<td>8.0</td>
<td>10.0</td>
<td>13.0</td>
<td>74.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Average 14 samples</td>
<td>---</td>
<td>6.2</td>
<td>8.3</td>
<td>12.8</td>
<td>75.9</td>
<td>17.9</td>
<td>16.4</td>
</tr>
</tbody>
</table>

^a Above river.
^b Above Gubik/Cretaceous contact.
^c Not in average.
^d Above lake.
Table 8. Foothill Silt area; mechanical analyses of basal sand and sandy silt

<table>
<thead>
<tr>
<th>Sample</th>
<th>Section</th>
<th>Elev. a feet</th>
<th>Gravel</th>
<th>Sand -10+30</th>
<th>Sand -30+50</th>
<th>Sand -50+100</th>
<th>Sand -100+200</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1 Colville b River</td>
<td>---</td>
<td>0.6</td>
<td>2.5</td>
<td>6.8</td>
<td>13.5</td>
<td>58.6</td>
<td>18.0</td>
<td>34</td>
<td>2.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V4 F2</td>
<td>20-22</td>
<td>&lt;0.1</td>
<td>0.4</td>
<td>1.7</td>
<td>10.8</td>
<td>47.0</td>
<td>31.1</td>
<td>9.0</td>
<td>84</td>
<td>1.42</td>
<td></td>
</tr>
<tr>
<td>V5 F2</td>
<td>25-27</td>
<td>&lt;0.1</td>
<td>2.3</td>
<td>9.0</td>
<td>19.1</td>
<td>58.5</td>
<td>11.0</td>
<td>46</td>
<td>1.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>V6 F3 Basal foot</td>
<td>0.1</td>
<td>0.7</td>
<td>1.2</td>
<td>2.4</td>
<td>22.2</td>
<td>63.4</td>
<td>10.0</td>
<td>46</td>
<td>1.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P10 F6 Ikpikpuk River</td>
<td>30-32 c</td>
<td>---</td>
<td>0.2</td>
<td>16.5</td>
<td>35.5</td>
<td>38.8</td>
<td>9.0</td>
<td>78</td>
<td>1.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P11 F6</td>
<td>160-161 c</td>
<td>---</td>
<td>1.2</td>
<td>42.8</td>
<td>32.2</td>
<td>17.8</td>
<td>6.0</td>
<td>135</td>
<td>1.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M38 F7 Meade River</td>
<td>44-47 c</td>
<td>&lt;0.1</td>
<td>0.9</td>
<td>35.7</td>
<td>38.2</td>
<td>17.1</td>
<td>8.0</td>
<td>130</td>
<td>1.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A6 F8 Kaolak River</td>
<td>23-24 c</td>
<td>0.1</td>
<td>0.6</td>
<td>20.6</td>
<td>56.8</td>
<td>16.9</td>
<td>5.0</td>
<td>120</td>
<td>1.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A10 F9</td>
<td>20-21 c</td>
<td>4.0</td>
<td>7.3</td>
<td>12.4</td>
<td>42.3</td>
<td>17.8</td>
<td>12.2</td>
<td>4.0</td>
<td>190</td>
<td>1.61</td>
<td></td>
</tr>
</tbody>
</table>

a Above Gubik/Cretaceous contact.

b Two miles upstream from section Fl; sample of thawed material slumped from top of cliff.

c Above the river.
Table 9. Foothill Silt area; samples from along the Utukok River

<table>
<thead>
<tr>
<th>Sample</th>
<th>Section</th>
<th>Elev. ft.</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td>U7</td>
<td>F10 Surface;</td>
<td>~85</td>
<td>1.5</td>
<td>2.2</td>
<td>7.6</td>
<td>11.0</td>
<td>47.6</td>
<td>29.0</td>
</tr>
<tr>
<td>U8</td>
<td>F12 Surface;</td>
<td>~75</td>
<td>1.0</td>
<td>1.5</td>
<td>13.8</td>
<td>11.7</td>
<td>44.8</td>
<td>26.5</td>
</tr>
<tr>
<td>U4</td>
<td>F12 Sand, 3'</td>
<td>~60</td>
<td>1.0</td>
<td>2.6</td>
<td>2.5</td>
<td>45.5</td>
<td>23.8</td>
<td>12.6</td>
</tr>
<tr>
<td>U17</td>
<td>F12 Sand imme-</td>
<td>~55</td>
<td>23.0</td>
<td>2.6</td>
<td>2.2</td>
<td>27.2</td>
<td>19.1</td>
<td>13.9</td>
</tr>
<tr>
<td></td>
<td>diately over gravel, 3' samples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U20</td>
<td>F12 Material</td>
<td>~60</td>
<td>5.0</td>
<td>1.0</td>
<td>1.8</td>
<td>34.2</td>
<td>18.3</td>
<td>22.7</td>
</tr>
<tr>
<td></td>
<td>flowing from area of ground ice thaw</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U14</td>
<td>F14 Just over gravel</td>
<td>25-29</td>
<td>3.0</td>
<td>0.4</td>
<td>0.8</td>
<td>11.8</td>
<td>9.4</td>
<td>49.6</td>
</tr>
<tr>
<td>U18</td>
<td>F15 Just over gravel</td>
<td>50-52</td>
<td>2.0</td>
<td>1.1</td>
<td>1.4</td>
<td>16.2</td>
<td>10.4</td>
<td>41.9</td>
</tr>
<tr>
<td>U10</td>
<td>Sandy silt over 14+15 gravel 5 1/2 miles south of Fl6</td>
<td>---</td>
<td>0.4</td>
<td>0.6</td>
<td>11.6</td>
<td>7.9</td>
<td>49.5</td>
<td>30.0</td>
</tr>
</tbody>
</table>

*aAbove the river.*
Table 9 (Continued).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Section</th>
<th>Elev. feet</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>+10</td>
<td>-10+50</td>
<td>-30+50</td>
<td>-50+</td>
<td>-100+</td>
<td>&lt;5μ</td>
<td>μ</td>
</tr>
<tr>
<td>U2</td>
<td>Sandy silt over gravel 4 miles south of F16</td>
<td>11-14</td>
<td>6.0</td>
<td>1.8</td>
<td>1.9</td>
<td>19.6</td>
<td>10.7</td>
<td>42.0</td>
</tr>
<tr>
<td>U12</td>
<td>Sand over gravel 1 mile south of F16</td>
<td>15-17</td>
<td>---</td>
<td>0.4</td>
<td>1.7</td>
<td>61.5</td>
<td>29.1</td>
<td>2.3</td>
</tr>
<tr>
<td>U9</td>
<td>F16</td>
<td>40-42</td>
<td>---</td>
<td>0.3</td>
<td>2.2</td>
<td>44.6</td>
<td>23.8</td>
<td>17.1</td>
</tr>
<tr>
<td>U15</td>
<td>F16</td>
<td>56-57</td>
<td>---</td>
<td>&lt;0.1</td>
<td>2.0</td>
<td>52.2</td>
<td>22.9</td>
<td>14.8</td>
</tr>
</tbody>
</table>
Figure 17. Particle size distribution areas for the sand and silt underlying the Foothill Silt Surface. (13 samples of silt and 5 samples of sand)

Figure 18. Stratification of the silt, underlying the Foothill Silt Surface, emphasized by concentrations of organic matter. Located in section F5, on the Ikpikpuk River.
percent silt and 18 percent clay. The upland materials along the Utukok were much more sandy (> 20 percent), higher in clay (> 25 percent), and consequently more poorly sorted. Pebbles are generally absent in the silt sections though they seemed to occur frequently in the sandy silt of the Utukok River.

This difference in materials between the Utukok River and the rivers to the east is but one of several differences. Along the Utukok River the erosional contact with the Cretaceous is gently rolling but not marked by the high relief seen on the adjacent Kaolak River, consequently the basal gravel is continuous. The gravel and the overlying sand and sandy silt both thicken northward. The maximum measured thickness was 75 feet, just south of where the base is no longer exposed, if the thickening continues uniformly a thickness of over 90 feet at section F16 may be estimated.

The surface of the foothill silt area, west of the Utukok River, is also markedly different from that to the east. Along the Utukok River, and between the Utukok and Kukpawruk Rivers, the number of thaw lakes and drained basins cut into the surface increases northward leading to a gradual lowering of the surface. The end result of the sequence of development and drainage of the thaw lakes is a plain marked by local topographic highs, mounds and ridges, which represent those portions of the original surface unaffected by lake action.
Three of these higher areas, located 3 miles from the ocean between the Utukok and Kokolik Rivers are shown in Figure 19. Section Fl6 is from one of the high mounds, not a pingo, standing about 30 feet above the general level of the area. This mound appears to be a remnant of the high surface seen upstream and to have the general elevation and relief of similar highs in the area. Gravel outcrops to about 10 - 12 feet above the river, both beneath the mound and upstream and downstream beneath the plain. If the previous interpretation of the distribution, shape and relationships of these topographic highs to drained lake basins as indicating a widespread lowering of the surface due to removal of ground ice by thaw lakes is correct, then the geomorphic importance of thaw lake formation and migration as a gradational agent has yet to be fully appreciated.

This general lowering of the plain, coupled with the presence of numerous lakes and drained basins, has led many of the previous workers to place this area between the Utukok-Kukpawruk Rivers within the coastal plain, and exclude the laterally equivalent higher area just east of the Utukok River.

Chemical and X-ray fluorescence analyses In order to determine the lateral and vertical variations in the silt unit as well as its relation to the underlying sand, chemical analyses of the carbonate fraction and X-ray fluoresc-
cence analyses of the heavy mineral fraction were performed.

The analytical method used was basically the versenate (EDTA) titration of Cheng et al. (9) with minor modifications. CalVer II (obtained from Hach Chemical Co., Ames, Iowa) was used as the calcium indicator instead of murexide. The samples (8 - 16 grams) were leached with 150 ml. of 1.0 N HCl, vacuum filtered and diluted to 1 liter. A 25 or 50 ml. aliquot of the acid leachate was then analyzed for calcium and magnesium. "Calcite" and "dolomite" percentages were calculated from the analyses assuming the pure minerals to be present. This assumption leads to an error in the actual calcite-dolomite percentages, since some magnesium is present in the calcite, and calcium and magnesium are not necessarily in a one to one ratio in the dolomite. But it is felt that such an error would not effect comparisons to a great degree, since a similar error would be inherent in all calculations.

The total analysis of a silt sample may not be directly compared to that of a sand since variations, both in total carbonate and the ratio of calcite to dolomite, occur in the various size fractions. Therefore the sand and silt samples analyzed were separated into size fractions. These were then analyzed separately, so that comparisons could be made with respect to the same material.

The results of these determinations on samples from two sections, are given in Table 10. The difference between the
Figure 19. Relief developed in the area just west of the Utukok River as a result of the partial removal of ground ice by thaw lakes. (Location: 3 miles east of the ocean, and 4 miles south of the Utukok delta.)

Figure 20. Relief developed by the action of thaw lakes in the area just north of the Echooka-Ivishak junction. (Location: in the area of section E1.)
Table 10. Chemical analyses of carbonate fraction of selected size fractions of two silt sections

<table>
<thead>
<tr>
<th>Size fraction</th>
<th>&lt;0.149 and &gt;0.074 mm.</th>
<th>&lt;0.074 and &gt;0.053 mm.</th>
<th>&lt;0.053 and &gt;0.044 mm.</th>
<th>Total sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location and Elevation</td>
<td>Ca(^b)/Mg</td>
<td>MgO(^c)</td>
<td>Dolomite</td>
<td>Ca(^b)/Mg</td>
</tr>
<tr>
<td>P11 Ikpikpuk River(^e)</td>
<td>160-161'</td>
<td>8.31</td>
<td>5.0</td>
<td>20.1</td>
</tr>
<tr>
<td>P12 Ikpikpuk River(^e)</td>
<td>144-148'</td>
<td>6.68</td>
<td>4.6</td>
<td>24.5</td>
</tr>
<tr>
<td>P9</td>
<td>98-102'</td>
<td>6.26</td>
<td>5.0</td>
<td>26.0</td>
</tr>
<tr>
<td>P13 Ikpikpuk River(^e)</td>
<td>32.5-34.5'</td>
<td>7.35</td>
<td>4.9</td>
<td>22.5</td>
</tr>
<tr>
<td>P10</td>
<td>30-32'</td>
<td>8.70</td>
<td>4.5</td>
<td>19.4</td>
</tr>
<tr>
<td>M37 Meade River(^f)</td>
<td>128-131'</td>
<td>1.86</td>
<td>9.5</td>
<td>68.0</td>
</tr>
<tr>
<td>M36 Meade River(^f)</td>
<td>98-101'</td>
<td>2.06</td>
<td>10.9</td>
<td>63.5</td>
</tr>
<tr>
<td>M35 Meade River(^f)</td>
<td>75-77'</td>
<td>2.12</td>
<td>10.4</td>
<td>62.3</td>
</tr>
<tr>
<td>M38 Meade River(^f)</td>
<td>44-47'</td>
<td>1.60</td>
<td>10.9</td>
<td>75.0</td>
</tr>
</tbody>
</table>

\( ^a \) Above river.  \( ^b \) Mole ratio.  \( ^c \) By weight of total sample.  \( ^d \) By weight of carbonate fraction.  
\( ^e \) Section F6, Ikpikpuk River.  \( ^f \) Section F7, Meade River.
sands and silts when analyzed on the basis of total sample is readily apparent. Only a limited number of size fractions are available for comparison since the overlap of the size distributions between the silt and sand is small. The fractions were prepared by dispersing the samples, as for mechanical analysis, and then decanting off the finer particles. The remaining portion was dried and separated with the appropriate sieves.

Two general trends are noted for each section. In the Ikpikpuk samples there is an increase in the carbonate content with decrease in size and a less marked increase in the dolomite percentage with decrease in size. In the Meade samples there is a maximum in the carbonate content with decreasing size and a decrease in dolomite percentage with decreasing size. These trends hold for both silt and sand, but do not hold for the sample as a whole, only for those fractions analyzed, as comparison to the total sample analyses shows. For example, if in the Meade silts, a decrease in dolomite and carbonate continued with decrease in size, the total analyses should be much lower in both of these, than any of the analyzed fractions since the average of the sample is weighted by the smaller sizes. But it is seen that the total is greater in both percent dolomite and carbonate than the smallest analyzed fraction implying a reversal to the trend. The important conclusions to be drawn are that the sand is more
closely related to the silt, for each case, than are the silts
to each other. Whereas the total analyses for the silts are
somewhat similar, the analyses for the coarser fractions are
very dissimilar. The coarser fractions of the Meade silts
have a much higher carbonate and dolomite percentage than do
the corresponding fractions from the Ikpikpuk. A more de­
tailed study of more size fractions in other samples would be
necessary, to verify what trends do exist for the whole sam­
ple, before one could attempt to explain the trends.

No petrographic studies or undisturbed thin sections were
made of the silt to determine the presence of secondary car­
bonates. Secondary carbonate concretions of the type normally
associated with calcareous silts were not seen at any of the
exposures. The chemical analyses indicate the majority of the
carbonate is primary since one could not account for the vari­
ation in composition with size, nor the consistency between
samples, with a secondary origin. The absence of secondary
concretions is a result of the lack of water movement thru the
silt due to permafrost.

Chemical analyses of the carbonate fraction were also run
on other samples of the silt and underlying sand. These anal­
yses were of the total sample only. The results of these
analyses are shown in Table 11. An areal variation in the
dolomite percentage is immediately apparent from the analyses.
The west to east variation across the area is tabulated as
Table 11. Chemical analyses of foothill sands and silts

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>River Section</th>
<th>Approx. Elev.</th>
<th>% Sand (&gt;74μ)</th>
<th>Ca/Mg (mole ratio)</th>
<th>% Carbonate (by wt. of total sample)</th>
<th>% Dolomite (by wt. carbonate fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U4</td>
<td>Utukok</td>
<td>F12</td>
<td>~60</td>
<td>75</td>
<td>2.07</td>
<td>2.4</td>
<td>63.0</td>
</tr>
<tr>
<td>U17b</td>
<td>&quot;</td>
<td>F12</td>
<td>~55</td>
<td>66</td>
<td>2.24</td>
<td>3.1</td>
<td>60.0</td>
</tr>
<tr>
<td>U14</td>
<td>&quot;</td>
<td>F14</td>
<td>27</td>
<td>25</td>
<td>2.36</td>
<td>8.9</td>
<td>57.5</td>
</tr>
<tr>
<td>U18</td>
<td>&quot;</td>
<td>F15</td>
<td>51</td>
<td>30</td>
<td>2.68</td>
<td>6.1</td>
<td>52.5</td>
</tr>
<tr>
<td>U6</td>
<td>&quot;</td>
<td>near F15</td>
<td>10-14</td>
<td>48</td>
<td>2.57</td>
<td>5.2</td>
<td>54.0</td>
</tr>
<tr>
<td>U10</td>
<td>&quot;</td>
<td>between F15 and 16</td>
<td>15</td>
<td>20</td>
<td>3.22</td>
<td>8.9</td>
<td>45.5</td>
</tr>
<tr>
<td>A2</td>
<td>Kaolak</td>
<td>F9</td>
<td>68</td>
<td>8</td>
<td>2.94</td>
<td>13.2</td>
<td>48.5</td>
</tr>
<tr>
<td>A1</td>
<td>&quot;</td>
<td>F9</td>
<td>29</td>
<td>18</td>
<td>2.80</td>
<td>11.6</td>
<td>50.5</td>
</tr>
<tr>
<td>A4</td>
<td>&quot;</td>
<td>F8</td>
<td>16c</td>
<td>7</td>
<td>2.70</td>
<td>13.6</td>
<td>52.0</td>
</tr>
<tr>
<td>A3</td>
<td>&quot;</td>
<td>F8</td>
<td>6c</td>
<td>3</td>
<td>2.99</td>
<td>13.1</td>
<td>48.0</td>
</tr>
<tr>
<td>A6</td>
<td>&quot;</td>
<td>F8</td>
<td>23</td>
<td>78</td>
<td>2.13</td>
<td>9.3</td>
<td>62.0</td>
</tr>
<tr>
<td>M37</td>
<td>Meade</td>
<td>F7</td>
<td>130</td>
<td>8</td>
<td>2.99</td>
<td>14.4</td>
<td>48.0</td>
</tr>
<tr>
<td>M36</td>
<td>&quot;</td>
<td>F7</td>
<td>100</td>
<td>5</td>
<td>3.02</td>
<td>14.8</td>
<td>47.8</td>
</tr>
</tbody>
</table>

a Above river.
b Analysis on (- No. 8) fraction.
c Above lake.
Table 11 (Continued).

<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>River Section</th>
<th>Approx. Elev. ft.</th>
<th>% Sand (&gt;74µ)</th>
<th>Ca/Mg (mole ratio)</th>
<th>% Carbonate (by wt. of total sample)</th>
<th>% Dolomite (by wt. carbonate fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M35 Meade</td>
<td>F7</td>
<td>76</td>
<td>10</td>
<td>2.97</td>
<td>13.2</td>
<td>48.3</td>
<td></td>
</tr>
<tr>
<td>M38</td>
<td>F7</td>
<td>46</td>
<td>75</td>
<td>1.87</td>
<td>8.5</td>
<td>68.0</td>
<td></td>
</tr>
<tr>
<td>P5 Ikpikpuk</td>
<td>F5</td>
<td>110</td>
<td>3</td>
<td>3.47</td>
<td>15.7</td>
<td>42.7</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>F5</td>
<td>75</td>
<td>12</td>
<td>3.56</td>
<td>16.3</td>
<td>42.0</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>F5</td>
<td>50</td>
<td>8</td>
<td>3.42</td>
<td>13.5</td>
<td>43.3</td>
<td></td>
</tr>
<tr>
<td>P11</td>
<td>F6</td>
<td>160</td>
<td>77</td>
<td>5.80</td>
<td>5.2</td>
<td>27.7</td>
<td></td>
</tr>
<tr>
<td>P12</td>
<td>F6</td>
<td>146</td>
<td>19</td>
<td>3.97</td>
<td>12.9</td>
<td>38.2</td>
<td></td>
</tr>
<tr>
<td>P9</td>
<td>F6</td>
<td>100</td>
<td>6.5</td>
<td>3.56</td>
<td>14.5</td>
<td>42.0</td>
<td></td>
</tr>
<tr>
<td>P13</td>
<td>F6</td>
<td>33</td>
<td>6</td>
<td>3.78</td>
<td>14.2</td>
<td>39.7</td>
<td></td>
</tr>
<tr>
<td>P10</td>
<td>F6</td>
<td>31</td>
<td>53</td>
<td>5.31</td>
<td>8.1</td>
<td>30.0</td>
<td></td>
</tr>
<tr>
<td>V1 Colville</td>
<td>--</td>
<td>--</td>
<td>23</td>
<td>4.54</td>
<td>12.7</td>
<td>34.3</td>
<td></td>
</tr>
<tr>
<td>V3</td>
<td>F1</td>
<td>73&lt;sup&gt;d&lt;/sup&gt;</td>
<td>7</td>
<td>4.66</td>
<td>17.0</td>
<td>33.6</td>
<td></td>
</tr>
</tbody>
</table>

<sup>d</sup>Above contact.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>River Section</th>
<th>Approx. Elev. (ft.)</th>
<th>% Sand (&gt;74µ)</th>
<th>Ca/Mg (mole ratio)</th>
<th>% Carbonate (by wt. of total sample)</th>
<th>% Dolomite (by wt. carbonate fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V2</td>
<td>Colville</td>
<td>F1</td>
<td>21</td>
<td>5</td>
<td>4.23</td>
<td>10.4</td>
<td>36.4</td>
</tr>
<tr>
<td>V5</td>
<td></td>
<td>F2</td>
<td>26</td>
<td>31</td>
<td>4.55</td>
<td>11.1</td>
<td>34.3</td>
</tr>
<tr>
<td>V4</td>
<td></td>
<td>F2</td>
<td>21</td>
<td>60</td>
<td>4.39</td>
<td>7.1</td>
<td>35.0</td>
</tr>
<tr>
<td>V6</td>
<td></td>
<td>F3 Base</td>
<td>27</td>
<td>27</td>
<td>5.12</td>
<td>12.6</td>
<td>31.0</td>
</tr>
<tr>
<td>K1</td>
<td>Kuparuk</td>
<td>E10</td>
<td>~85</td>
<td>49</td>
<td>9.52</td>
<td>9.9</td>
<td>18.1</td>
</tr>
<tr>
<td>K2</td>
<td></td>
<td>E10</td>
<td>~85</td>
<td>79</td>
<td>17.51</td>
<td>17.5</td>
<td>10.1</td>
</tr>
</tbody>
</table>
follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>Silt</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utukok</td>
<td>&gt;50%</td>
<td>~60%</td>
</tr>
<tr>
<td>30 miles (distance between rivers)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaclak</td>
<td>~50%</td>
<td>~62%</td>
</tr>
<tr>
<td>66 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meade</td>
<td>~48%</td>
<td>~69%</td>
</tr>
<tr>
<td>58 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ikpikpuk</td>
<td>~41%</td>
<td>~30%</td>
</tr>
<tr>
<td>78 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colville</td>
<td>~34%</td>
<td>~35%</td>
</tr>
</tbody>
</table>

East of the Colville River, the dolomite percentage decreases rapidly to 10 - 20 percent on the highland between the Itkillik and Kuparuk Rivers. (See samples K1 and K2, Table 11, collected northwest of the junction of the Kuparuk and Toolik Rivers at section E10.) The variation in the basal sand is much more erratic. The explanation of this variance may lie within the much greater range of sizes and size distributions all labeled sand, whereas the silts are fairly uniform both in sorting as well as median size. In many cases only one sand sample is available from an area, whereas a number of samples might yield an average more in line with the silts. The conclusion is still that the sands and the silts have similar source areas, and those factors which cause the areal variation in the sands are also responsible for the variation in the silts. Whether this increase in dolomite content westward from the Colville River is due to a change in relative thicknesses of dolomite and limestone in the Paleozoic carbonate section of the Brooks Range, a change in the
actual composition of the calcite and dolomite minerals, an effect of a changing calcareous content of the Cretaceous, or any combination, is not known to the writer. The distance of travel from the source to the depositional area with a tendency towards an increase in the dolomite percentage of the carbonate fraction due to the removal of the more soluble calcite might also be considered. This latter does not seem to be a major factor since this process would also decrease the total carbonate content with the increase in dolomite, and the total carbonate fraction does not change significantly. A process of the type mentioned previously might explain minor variations in similar size materials where a decrease in carbonate content is often accompanied by a slight increase in dolomite percentage.

Another possible means of determining whether the silt and underlying sand had a similar source would be to determine the trace elements present in each. If the trace element suite was radically different between the sand and the silt, this would be an indication of a different source. If the trace element suite of the sands varied areally and the silts had a similar variance, then a similar source would be indicated. An X-ray fluorescence analysis was decided upon as a fairly rapid method of characterizing the sediments. To concentrate the trace elements present, it was assumed they were predominantly in the heavy mineral fraction. To facilitate
comparison between the sand and silt, the bulk sample was first separated into size fractions. The heavy mineral fraction was then separated from the particular size fraction by use of bromoform in a separatory funnel.

The X-ray fluorescence analyses were run on a General Electric diffractometer (Model XRD-5) using a tungsten tube for excitation and a sodium chloride analyzing crystal. The samples were mounted in a bakelite holder. A time constant of 3 seconds, a scan rate of 2° per minute, a chart speed of 1 inch per minute and a log chart scale were used. One sample was scanned to 110°. Since very few peaks, and these second order, occurred above 48 - 50 degrees, the rest of the samples were run to approximately 50 degrees. Samples from five valleys were run, five silts and four sands. The results of the fluorescence analyses are shown in Figure 21. The material analyzed was between 74 and 150 microns (fine sand). It was planned to run more than one size fraction if some variations were observed. The heavy mineral percentages of the size fraction analyzed are given in Table 12.

The information gained from these analyses is inconclusive, since no variation in the elements occurs either areally or with type of sediment. Since no areal variation occurs in the sand, this indicates a uniformity (in so far as this particular type of analysis is concerned) in the element suite across the area. Therefore one is not justified in concluding
Figure 21. X-ray fluorescence analysis curves of the heavy minerals of the fine sand fraction (74 - 150 microns) of some sands and silts underlying the Foothill Silt Surface. The element, its emission line, and order are given above the peak.
Table 12. Heavy mineral content of fraction between 74 and 150 microns

<table>
<thead>
<tr>
<th>Sample</th>
<th>% of total sample in size fraction</th>
<th>% Heavy minerals(^a) (based on total wt. of fraction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ul4</td>
<td>9.4</td>
<td>0.72</td>
</tr>
<tr>
<td>A1</td>
<td>12.0</td>
<td>1.21</td>
</tr>
<tr>
<td>A6</td>
<td>56.8</td>
<td>1.87</td>
</tr>
<tr>
<td>M35</td>
<td>8.0</td>
<td>1.51</td>
</tr>
<tr>
<td>M38</td>
<td>38.2</td>
<td>1.57</td>
</tr>
<tr>
<td>P13</td>
<td>3.9</td>
<td>0.60</td>
</tr>
<tr>
<td>P10</td>
<td>35.5</td>
<td>0.56</td>
</tr>
<tr>
<td>V5</td>
<td>19.1</td>
<td>1.89</td>
</tr>
<tr>
<td>V4</td>
<td>47.0</td>
<td>1.52</td>
</tr>
</tbody>
</table>

\(^a\)Bromoform: density > 2.71; calcite floats readily.

that since the silt does not differ from the sand, they have the same source. A difference in source cannot be distinguished if no variation exists in the element content within an area.

The interpretation of some of the peaks in Figure 21 is somewhat arbitrary for a few elements. This is due to the absence of the K-beta peak, because of the small amount present, which is needed to distinguish between the possible interpretations based on the K-alpha peak. In such a case the
The most common element of those possible was chosen. The unusual occurrence of bromine is due to the incomplete removal of bromoform by the acetone wash. The few differences that occur are not consistent, in that a minor peak missing in a sand and present in the overlying silt, is present in the nearest occurring sands and vice-versa. Some of this variability especially in the low intensity peaks is due to particle size, sample absorption and especially mineral segregation during packing and other variables. Occasionally a peak was missing in a run, whereas it was present in a rerun with repacking of the sample. Grinding the sample, fusion in borax or some other treatment might lead to more reproducible results, but this was not done since no great variation was observed. A more sensitive analysis, such as emission spectrography, might be of more value.

Of more value in deciding whether a difference in source exists are the data on the heavy mineral percentages (Table 12). A variation in the heavy mineral content, for the size fraction analyzed, exists across the area. This variation is similar for both the sand and the silt. In some cases the silt has a higher percentage than the corresponding sand, in others the reverse is true. But, no extreme differences occur. On this basis the sand and silt appear to have had a common source and origin.

**Paleontology**

Vertebrate remains are very common
on a few of the rivers crossing the foothill silt area, notably the Ikpikpuk River and the tributaries to the Kuk (the Avalik, Ketik and Kaolak Rivers). Of the vertebrate remains, the Muskox, Horse, Mammoth and Giant Bison are most common. The stratigraphic association of these remains is uncertain since almost all are found either in the alluvial terraces or as "float". All of Quaide's (39) material was found in such locations. Only one specimen that the author has seen, a mammoth skull, has appeared to be in the foothill sediments. This specimen was found, in the basal sands, near the forks of the Kaolak River by Bill Maher in 1957. All the vertebrate material collected by Otto Geist (University of Alaska), on the Ikpikpuk in 1959, was in the river alluvium (oral communication). This is not meant to imply that all or any of the vertebrate remains have washed out of the upland. A few specimens found by Geist on the Ikpikpuk appeared to have been in place in the alluvial terraces. The majority of specimens are found in such a position that it is uncertain whether they came originally from the upland or from the alluvium.

A cervical vertebra, found on the Ikpikpuk as "float" near section F5, has been identified by the National Museum as belonging to *Mammut americanum* (American Mastodon). To the best of the writer's knowledge, unless some of the material collected by O. Geist during 1959 and 1960 has been so identified, this is the first Mastodon material reported north of
the Brooks Range.

No marine vertebrate remains have been reported by Quaide (39), Smith and Mertie (50) or Geist, from the area south of the coastal plain.

Some micropaleontologic work has been done by the U.S. Geological Survey (14, 42). They report Pleistocene marine Foraminifera from the Meade Test Well, as contamination of the Cretaceous samples. No Pleistocene marine fossils were reported from the Kaolak Well, even though a thicker section was penetrated. The Oumalik core tests and test wells did not yield any Pleistocene Foraminifera. A few fresh-water ostracodes were found but could have come from the surficial lacustrine deposits. Mollusk fragments were reported but their origin was not given.

A preliminary examination of the silt samples, by the writer, for microfossils was unrewarding as none was found. A more detailed examination by Richard Faas (Graduate Assistant) of six samples which were thought to be the most likely to contain marine fossils if any were present, was equally unrewarding. Minor ostracode fragments of undetermined environment were found, but no Foraminifera.

Spruce logs have been reported occurring along the Ikpikpuk by both Quaide (39) and Smith and Mertie (50). Those reported in Smith and Mertie (50) were within the coastal plain and interpreted as marine driftwood. Quaide's southernmost
occurrence was a log a few miles south of section F6. The southernmost log the writer encountered was in the same general area and logs became more numerous downstream. Paul Sellman, geologist with Geist's field party in 1959, reported a log a few miles farther upstream, but did not observe another until he reached the lower location (oral communication). Quaide interpreted these logs as evidence for the presence of spruce within the drainage basin of the Ikpikpuk River during the late Pleistocene. The absence of logs farther upstream, the coincidence of the initial occurrence with the southern margin of the coastal plain on the east side of the river and the profusion of logs from this area north, leads the writer to conclude the logs are driftwood.

The only logs the writer found definitely within the upland were on the Kaolak and Colville Rivers. Only one log, approximately 6 inches in diameter, was found on the Kaolak. Langenheim et al. (24) reported logs up to 8 inches in diameter in the alluvium of the Kaolak. Logs are very plentiful along the Colville River within the basal sands and gravels. Some local areas on the Colville, which appear to have been old stream channels, contain many logs and thick layers of twigs and small branches. These local wood concentrations, containing much gravel, are frequently 10 - 15 feet thick. The logs from the Colville and Kaolak Rivers have been identified by B. Francis Kukachka (U.S.D.A. Forest Products Lab.) as
Larch (probably *Larix laricina*).

A radiocarbon age of >36,000 years Bpec. was obtained on a Larch log (L-301) (37) from the Kogosukruk River (a tributary to the Colville). This log was reported to come from the contact between the Cretaceous and the Pleistocene Gubik formation. The author believes that from the published location, this log was from beneath the silts in the underlying gravels and inland from the contact with the predominantly marine sediments.

These logs are probably evidence of the tree line crossing the drainage divide of the Brooks Range during the Pleistocene. Those on the Colville are easier to explain than the logs on the Kaolak, since the Colville and its tributaries drain a large area adjacent to the divide. The logs on the Kaolak may indicate a change in regional drainage since its deposition. The relief upon the Cretaceous is evidence for the burial of an older drainage system not necessarily related to the present pattern. If the concentration of wood on the rivers was small it could have been easily missed, therefore an explanation for its absence is not in order.

**East of the Colville River** The area east of the Colville will be covered in more general terms, extrapolating and correlating the information obtained at a few localities within the area to that outside it. Three highland areas rising above the general coastal plain level occur to the east
of the Colville River. These higher areas are underlain by Tertiary materials of the Sagavanirktok formation. The Tertiary sediments, generally unconsolidated, are gently folded with a very slight northward dip over most of the area. These three areas are the highland extending northward between the Itkillik and Kuparuk Rivers, the White Hills area to the south of the Toolik-Kuparuk River junction and Franklin Bluffs to the east of the Sagavanirktok River. The latter is the type locality of the Sagavanirktok formation. Though included within the White Hills section of the Coastal Plain province by Payne and Others (38), the writer believes they are more closely related, topographically and genetically, to the Foothill Silt Surface.

The White Hills area was examined in only one location (Section E7), on the Toolik River. Here the upland surface of the area had considerable relief with more resistant strata forming hills upon an otherwise gently rolling surface. All the materials on this surface were of Tertiary age as far as the writer could tell. The White Hills stand over 200 feet above the plain just east of section E7. This location lies in the break between the coastal plain and the foothills. The boundary between these, is transitional, badly dissected and not easily delineated. The more rolling foothills with their greater relief gradually give way northward thru a zone of increased lake activity and considerable local relief due to
a sequence of thaw lake formation and drainage, into the coastal plain having more numerous lakes and much lower local relief. No exposures of the underlying material are available other than in holes dug thru the active layer into the permafrost. Sample K28 (Table 13), from this area, seems to be within the foothills, though possibly it is not. It has been affected by leaching and reworking by both lakes and solifluction, and seemed to be fairly representative, at least texturally, of the materials encountered.

The northern boundary of the high surface between the Itkillik and Kuparuk Rivers is shown very distinctly by the radial drainage down the slopes onto the coastal plain, the change in vegetation from the sloping to the poorly drained land, and the abrupt increase in the number of lakes on the coastal plain materials. Section E10 is located on the break between this high surface and the coastal plain. No exposures in river cutbanks were available in this area, and consequently all data were obtained from holes dug through the active layer and as far into the permafrost as possible. Because it was not possible to get fresh exposures, the samples may be partially leached and not indicative of the material as a whole. The materials on this upland, within the small area covered, were mainly medium to fine calcareous sand with scattered gravel. Commonly the material within the active layer is noncalcareous as a result of leaching. Two samples,
Table 13. Analyses of materials on the highlands east of the Colville River

<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Elev. (^a)</th>
<th>Gravel</th>
<th>Sand (^b)</th>
<th>Silt (^c)</th>
<th>Clay (^d)</th>
<th>Md</th>
<th>So (^e)</th>
<th>% Car-arbonate (^f)</th>
<th>% Dolo-mite (^g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Section</td>
<td>feet</td>
<td>+10</td>
<td>-10+</td>
<td>-50+</td>
<td>-100+</td>
<td>&lt;5μ</td>
<td>μ</td>
<td></td>
</tr>
<tr>
<td>K28</td>
<td>E7</td>
<td>Surface</td>
<td>2 feet</td>
<td>---</td>
<td>---</td>
<td>2.4</td>
<td>5.4</td>
<td>4.6</td>
<td>62.6</td>
</tr>
<tr>
<td>K1</td>
<td>E10</td>
<td>Surface</td>
<td>1 foot</td>
<td>~85</td>
<td>2.0</td>
<td>7.9</td>
<td>21.4</td>
<td>18.0</td>
<td>31.2</td>
</tr>
<tr>
<td>K2</td>
<td>E10</td>
<td>1 foot</td>
<td>~85</td>
<td>&lt;0.2</td>
<td>14.4</td>
<td>37.4</td>
<td>27.2</td>
<td>14.7</td>
<td>6.0</td>
</tr>
<tr>
<td>S9</td>
<td>E1</td>
<td>2 - 2 1/2 feet below surface</td>
<td>---</td>
<td>---</td>
<td>0.6</td>
<td>0.4</td>
<td>0.3</td>
<td>64.7</td>
<td>34.0</td>
</tr>
<tr>
<td>S35 (^e)</td>
<td>E5A</td>
<td>Surface; ~170</td>
<td>1 - 1 1/2 foot sample</td>
<td>2.3</td>
<td>1.3</td>
<td>8.0</td>
<td>4.8</td>
<td>46.6</td>
<td>37.0</td>
</tr>
<tr>
<td>S41 (^e)</td>
<td>E5A</td>
<td>Surface; ~170</td>
<td>1 - 1 1/2 foot sample</td>
<td>1.8</td>
<td>1.6</td>
<td>8.9</td>
<td>4.8</td>
<td>45.9</td>
<td>37.0</td>
</tr>
</tbody>
</table>

\(^a\) Above the river.
\(^b\) By weight of total sample.
\(^c\) By weight of carbonate fraction.
\(^d\) Probably leached.
\(^e\) Samples, 4 feet apart.
<table>
<thead>
<tr>
<th>Sample Location</th>
<th>Eleva feet</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Md</th>
<th>So</th>
<th>% Carb-</th>
<th>Dolomite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td></td>
<td>+10</td>
<td>-10+</td>
<td>-50+</td>
<td>-100+</td>
<td>&lt;5µ</td>
<td>µ</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>S44 E5B Surface;</td>
<td>---</td>
<td>---</td>
<td>0.4</td>
<td>1.4</td>
<td>4.8</td>
<td>70.4</td>
<td>23.0</td>
<td>21</td>
<td>2.38</td>
</tr>
<tr>
<td>1 - 1 1/2 foot sample about 1 mile from E5A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S23f E6 1 foot</td>
<td>~78</td>
<td>---</td>
<td>10.6</td>
<td>41.4</td>
<td>25.8</td>
<td>13.2</td>
<td>9.1</td>
<td>155</td>
<td>1.62</td>
</tr>
<tr>
<td>sample just over tertiary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S25 E6 1 foot</td>
<td>~78</td>
<td>&lt;0.1</td>
<td>12.8</td>
<td>41.4</td>
<td>30.9</td>
<td>10.6</td>
<td>4.2</td>
<td>160</td>
<td>1.55</td>
</tr>
<tr>
<td>sample just over tertiary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S20 E4 Surface</td>
<td>3-5</td>
<td>0.3</td>
<td>1.0</td>
<td>3.4</td>
<td>11.6</td>
<td>69.2</td>
<td>14.5</td>
<td>33</td>
<td>2.43</td>
</tr>
<tr>
<td>of terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S36 E5 Surface</td>
<td>2-4</td>
<td>&lt;0.1</td>
<td>10.3</td>
<td>16.0</td>
<td>18.7</td>
<td>39.0</td>
<td>16.0</td>
<td>62</td>
<td>3.73</td>
</tr>
<tr>
<td>of terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S18 E6 Surface</td>
<td>4.5-6</td>
<td>0.3</td>
<td>0.6</td>
<td>8.2</td>
<td>24.4</td>
<td>56.0</td>
<td>10.5</td>
<td>49</td>
<td>2.10</td>
</tr>
<tr>
<td>of terrace</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

fBased on (-10) fraction, 18 percent gravel omitted.
a silty sand overlying a clean well sorted sand, obtained from the slope off the high surface about 60 feet above the coastal plain, are given in Table 13. A very gentle slope then continued to rise southward; from the topographic map this is estimated at less than a 150-foot change in 9 miles.

The area (El), on the Sagavanirktok, is similar in many respects to the area around section E7 on the Toolik, the main departures being in the increased development of lakes, and their now-drained basins, leading to greater local relief in the foothills (see Figure 20) and the more diffuse boundary. The elevational difference between the river and the upland decreases very gradually northward, in the foothills, then remains fairly constant within the coastal plain. The coastal plain extends southward into the foothills along the Sagavanirktok River. This extension is evident along the west side of the river and southward to the junction with the Ivishak River. Sample S9 was taken from a relatively undissected portion of the upland. The noncalcareous to weakly calcareous nature of the material is attributed to leaching since outcrops are nonexistent and all samples were taken from shallow excavations. That some carbonates are present is evidenced by the calcareous salt concentrations on the surface of some frost boils and in the material of some solifluction slopes. Similar situations have been seen where initially calcareous material has been leached within and slightly below the pre-
sent active layer yet frost boils in the vicinity have a calcareous surface crust. Though no natural exposures were available, the sample is fairly representative of those materials seen. In a few solifluction slopes, scattered well rounded gravels were seen mixed within the silt, the gravel was usually small but rare cobbles up to $6 \times 4 \times 3$ inches were seen.

The Franklin Bluffs were studied in more detail since a longer period of time was spent in that area and the writer was able to revisit the area at a later date. The majority of materials exposed in this area are Tertiary sands and gravels. The highest part of the Franklin Bluffs, at its southernmost extent, is over 500 feet above the river. The surface dips gently to the north and lies about 90 feet above the river at the northernmost site studied, section E6, 11 miles downstream. The low dip of the strata is also to the north. When viewed from a distance, the upland surface is gently rolling with a few higher areas towards the south of more resistant gravel standing in relief. The upland surface of the Franklin Bluffs may be in part a stripped plain on a resistant gravel.—The Sagavanirktok formation as exposed in the Franklin Bluffs and White Hills is composed predominantly, if not entirely, of nonmarine sediments. Calcareous Tertiary materials were not found in either area.

A thin mantle (usually 2 - 4 feet) of calcareous silt to
Fine sand occurs on much of the upland surface north of the high southern area and in the solifluction slopes off the surface. The maximum measured thickness was 12 feet at E6, of which only the lower 4 feet were exposed. These deposits were originally considered to be eolian material from the flood plain of the Sagavanirktok River. The river deposits much silt and fine sand on the flood plain during the spring melt-off and some is carried toward the bluffs by strong summer winds from the southwest. This and the fact that the calcareous material mantles Tertiary sediments which when traced laterally are overlain by noncalcareous Tertiary sediments made the eolian origin feasible. The reappraisal of the eolian origin stems from a closer look at the materials in the laboratory and the study of adjacent areas. Some of the coarser material is calcareous and not Tertiary sediments mixed in during downslope movement, though the latter has occurred in some instances. This calcareous sand is too large to have been moved up the bluffs and over the area by the wind. The absence of a large amount of organic matter, other than buried chunks of peat, would eliminate slow eolian deposition which should encorporate considerable vegetal material in the deposit.

Chemical analyses of the material on the upland have been run (Table 13) but this information in itself does not negate an eolian origin, since the carbonate content is not dissimi-
lar to the present river material. The samples of the present river material, listed in Table 13, were taken from the upper 1 - 2 feet of material underlying the lower terraces, 3 - 5 feet above summer water level. The terrace materials have somewhat less dolomite than a sample (S44) from the upland, for a similar carbonate content. But this is within the possible variation due to difference in size distribution. The variance of samples S23 and S25 may be similarly explained, with the added factor of leaching. The extremely high dolomite and low total carbonate content of S41 and S35 could be explained by preferential leaching of calcite and concentration of the dolomite, since the samples are within the active layer and subject to water movement. Samples S35 and S41 are from the top of the bluffs, and 1/4 mile inland from the bluff at section E5, whereas sample S44 is about 1/2 mile to the northeast and from an area which has probably received the material from a higher area still farther to the east.

However, examination of the samples under a binocular microscope leads to different conclusions. The particles of samples S23 and S25 are much better rounded than comparable material in the terraces and lack the high percentage of shistose fragments characteristic of the river material. Samples S35, S41 and S44 differ from the river material in a low percentage of dark minerals and in that respect differ from the other upland samples S23 and S25. They are also more iron
stained than the other materials. The particles of sample S44 are somewhat better rounded than the river material, especially in the coarse sand fraction. The difference in dolomite and carbonate contents between S44 and S35, S41 may be partially a result of leaching but the materials also appear to have had a different source. The high dolomite samples appear more angular, even in the coarser fractions, and contain an abundance of amber colored chert fragments not seen in a comparable amount in any other samples or in the Tertiary. The differences between these samples leads to the conclusion that a very small portion, if any, of the material is derived from the present river, and that the upland materials themselves vary considerably over the area.

Portions of the surface of the Franklin Bluffs, the high upland between the Itkillik and Kuparuk Rivers and the area inland of the southern margin of the coastal plain are considered by the writer to be remnants of a once more extensive upland surface. The southern portion of the Franklin Bluffs, most of the White Hills and other high areas to the south, stood in relief above this surface. The origin of this surface is covered in more detail in the following section on the origin of the foothill silt.

**Origin of the foothill silt**

**Eolian** The majority of the silt is well within the limits of materials ascribed by other authors to an eolian
origin (Table 14). Comparing size distributions, the foothill silt is sandier than the silt from the Mississippi and Missouri River areas but less so than the Alaskan and European silts. The Kansas and Nebraska silts have less fine sand but more very fine sand (if 50 microns is used as limit) than the foothill silt. The foothill silt is seen to have a smaller median diameter than the Kansas, and about equal to the European silt, but to be intermediate in sorting, the Kansas silt being better sorted. On the whole, the foothill silt falls within the range of sizes for material from other widespread silt deposits.

The silt is extensive and uniform, both laterally and vertically. These characteristics are often mentioned in favor of an eolian origin. The silt is adjacent to source areas usually considered favorable, the glaciated Brooks Range and the broad coastal plain.

What are then the possible source areas of the silt, if eolian? These are:

1) The present coastal plain
2) The valley of the Colville and its tributaries which were glacier fed in the past
3) The present river valleys

A sharp topographic break occurs between the area of the silt and the coastal plain. This break is clearly seen between the Meade and Ikpikpuk Rivers. The topographic relief,
Table 14. Comparison of foothill silt to other widespread silts

<table>
<thead>
<tr>
<th>Location</th>
<th>Ref. No. of samples</th>
<th>Sand &gt;74μ</th>
<th>&gt;62.5μ</th>
<th>&gt;50μ</th>
<th>Silt &lt;5μ</th>
<th>&lt;3.9μ</th>
<th>&lt;2μ</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Big Delta, Alaska</td>
<td>(27)</td>
<td>72</td>
<td>14.6</td>
<td>---</td>
<td>72.9</td>
<td>12.5</td>
<td>---</td>
<td>Taken from mid-depth in the profiles</td>
</tr>
<tr>
<td>Matanuska Valley, Alaska</td>
<td>(27)</td>
<td>52</td>
<td>7.9</td>
<td>---</td>
<td>78.0</td>
<td>14.1</td>
<td>---</td>
<td>Taken from mid-depth in the profiles; Md = 25μ; So = 1.98</td>
</tr>
<tr>
<td>Fairbanks, Alaska</td>
<td>(52)</td>
<td>31</td>
<td>4.6</td>
<td>---</td>
<td>80.2</td>
<td>15.2</td>
<td>---</td>
<td>Taken from mid-depth in the profiles</td>
</tr>
<tr>
<td>Fairbanks, Alaska</td>
<td>(52)</td>
<td>70</td>
<td>3.9</td>
<td>---</td>
<td>82.7</td>
<td>13.4</td>
<td>---</td>
<td>Includes the above middepth samples</td>
</tr>
<tr>
<td>Kansas (Sanborn formation)</td>
<td>(53, 54)</td>
<td>58</td>
<td>3.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.2</td>
<td>16.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>88.9</td>
<td>7.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.9</td>
</tr>
</tbody>
</table>

<sup>a</sup>Estimated from cumulative curves.
<table>
<thead>
<tr>
<th>Location</th>
<th>Ref. No.</th>
<th>No. of samples</th>
<th>Sand &lt;74μ</th>
<th>Sand 62.5μ</th>
<th>Sand &gt;50μ</th>
<th>Silt &lt;5μ</th>
<th>Silt &lt;3.9μ</th>
<th>Silt &lt;2μ</th>
<th>Clay &lt;5μ</th>
<th>Clay &lt;3.9μ</th>
<th>Clay &lt;2μ</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Missouri River Bluffs</td>
<td>(17)</td>
<td>50</td>
<td>2.6</td>
<td>---</td>
<td>---</td>
<td>80.9</td>
<td>16.5</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td>Three sections near the bluffs Pisgah, Crescent City and Turin</td>
</tr>
<tr>
<td>Iowa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mississippi River Bluffs</td>
<td>(49)</td>
<td>19</td>
<td>---</td>
<td>---</td>
<td>1.5</td>
<td>90.7</td>
<td>7.8</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td>Two sections averaged; 0.1 and 1.8 miles from bluff; Md = 27μ</td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower Miss. River Valley</td>
<td>(47)</td>
<td>3</td>
<td>2.5</td>
<td>---</td>
<td>8.0</td>
<td>84.5</td>
<td>13.0</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nebraska</td>
<td>(5)</td>
<td>359</td>
<td>3.0</td>
<td>---</td>
<td>16.0</td>
<td>57.0</td>
<td>28.0</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western Europe</td>
<td>(55)</td>
<td>15</td>
<td>9.4</td>
<td>---</td>
<td>73.8</td>
<td>---</td>
<td>16.8</td>
<td>---</td>
<td></td>
<td></td>
<td></td>
<td>Md = 25μ; So = 2.15</td>
</tr>
<tr>
<td>Foothill silt</td>
<td>---</td>
<td>14</td>
<td>6.2</td>
<td>8.3</td>
<td>12.8</td>
<td>75.9</td>
<td>17.9</td>
<td>16.4</td>
<td>13.7</td>
<td></td>
<td></td>
<td>Md = 24μ; So = 1.96</td>
</tr>
</tbody>
</table>
vegetation, drainage pattern and shape of thaw lakes developed are all very different between the two areas. The coastal plain materials, immediately north of the topographic break, are predominantly noncalcareous sands, well sorted, and containing less than 10 percent silt and clay. Though the coastal plain shows evidence of considerable eolian activity in the past (1), because of the type of material available, it cannot serve as the source of silt containing primary carbonates. The coastal plain is younger than the foothill silt, and the topographic break is a wave-cut cliff marking the southern extension of the present coastal plain materials.

The modern valley of the Colville can be eliminated as a possible source because of the absence of appreciable silt, just north of the river. Those wells drilled in this area (Titaluk; Knifeblade 1, 2 and 2A; Wolf Creek 1, 2 and 3; and the Umiat Wells) did not penetrate any appreciable thickness of surficial material. A Colville source would not explain the thickening of the silt to the north, nor the similarity between the silt and the basal sand.

The present river valleys are an unlikely source since at the present time the bed load is noncalcareous, except where the river is actively eroding one of the silt bluffs. This would seem to indicate that insufficient carbonates are present in the bedrock of the drainage basins to supply the necessary primary carbonates. The valleys are relatively narrow
compared to the height of the valley walls, the general relationships indicating that the valleys are cut into the silt. The relatively narrow valleys are insufficient to explain the presence of thick silt deposits at appreciable distances from the nearest valley.

Noneolian There are many differences between these accumulations of silt and those normally assigned to an eolian origin.

The distribution of the silts is not of a mantling nature. The lower contact has a local relief not reflected in the upland surface. This could be partially explained by a reduction of the initial relief through solifluction, which is active on slopes greater than a few degrees. The preservation of stratification in many areas though, negates the possibility of solifluction's accounting for the major thickening in the valleys.

The erosion pattern (Figure 15) indicates that the section is continuous back from the cutbank face, and that the thickness is not a result of slumping. Neither the Kaolak well, which penetrated approximately 100 feet of unconsolidated material nor the deep lake thawing into the silt in the Oumalik area, is located on a river. The stratification (Figures 16 and 18), especially that characterized by organic fines, is not typical of materials referred to an eolian origin. Some eolian silts have been reported (15, 29) to be
locally stratified, due to the action of rain, rill wash etc. The stratification is not conspicuous on fresh surfaces unless emphasized by concentrations of organic matter. On older exposures, which have been etched by erosion, slight differences in size, sorting and compaction become more obvious emphasizing the stratification. The presence of finely divided organic matter horizons, not buried surface vegetal mats, indicates little oxidation of the material. Consequently, the adjacent relatively organic free sections are believed to be an initial condition and not due to oxidation of previously buried vegetal material. This initial low organic content reduces the probability of an eolian origin. The permafrost conditions which prevail now probably prevailed, though to varying degrees, during most of the Pleistocene. The slow decay of organic material under these conditions should result in abundant plant remains scattered throughout the silt if it is eolian, rather than the local stratified distribution which exists. A local area on the Ikpikpuk (section F5) contains numerous cross-bedded silt and twigs in a 3-foot layer, that appears to be a small channel concentration.

The size analyses do not show any regional variation such as that shown by Smith (49) for Illinois loess or Davidson et al. (17) for Iowa loess.

The silt appears to be genetically related to the underlying coarser materials, especially the sands. This is indi-
cated by the chemical analyses and the gradational contact frequently found between the sand and silt. The upward gradation through 120 - 130 feet of silt into a clean, well-sorted fine sand is atypical of an eolian section. The occurrence of occasional pebbles, though admittedly infrequent, is also suspect, as is the lateral gradation into the sandy silt of the Utukok River.

The marine Foraminifera in the Meade Well (and the possibly marine (?) mollusk fragments in the Oumalik Wells) indicate that some of the silt is of marine origin. How much is marine cannot be estimated since the stratigraphic location and distribution of such fossils are unknown.

An interesting speculation concerns the origin or source of the somewhat high (21 ppm. or 13.2 percent) chloride content of the water of East Oumalik Lake reported by Livingstone et al. (28). If a portion of the upper sediments are marine, and if the material became frozen shortly after the retreat of the ocean, before subsurface drainage could remove the interstitial sea water, then a lake thawing into this material could be expected to have a somewhat high chloride content. Otherwise, this might be hard to explain, since it is difficult to attribute the chloride to ocean derived, wind borne salt.

A fluviatile-marine origin for the silt neither presents any major problems nor contradicts the available evidence.
The absence of marine fossils in the samples collected by the writer does not rule out the postulated origin since most of the samples were collected below the slumped upper portion of the exposures. These samples may have been either below the material expected to be marine or may have been inland from the marine portion of the silts.

The silt is interpreted as having been deposited during a Pleistocene marine transgression into a portion of the Northern Foothills section. The relief upon the Cretaceous bedrock was developed by a system of rivers, which at that time originated in the Brooks Range. These rivers, possibly glacier fed, with their headwaters in the Paleozoic carbonate section, supplied the necessary sediment. The advancing sea caused alluviation of the valleys and burial of the previous topography. The lower part of the section, sands and gravels are alluvial since the bedrock relief has not been truncated by the sea. The basal silts are similarly alluvial, with an upward transition to silt deposited in a marine environment as the sea moved over the area. This might explain the relative scarcity of marine fossils, since the marine sediments would be thin and subjected to lacustrine reworking at the surface. The ocean may not have covered the area completely, the remainder being a broad deltaic plain of low relief, similar to those present along the arctic coast today. The ultimate result would be the depositional plain now recognized in
the summit accordance. The transition into sand on the Ikpikpuk may be the result of marine reworking of the silt and the formation of a beach deposit, or it may indicate a channel deposit within the silt. Since the lateral extent of this sand is unknown, and no other evidence is available, the actual origin cannot be determined at present. It seems likely that the break between the area of foothill silt and the Intermediate Surface is a wave-cut cliff marking the limit of the transgression, but more field work in that area is necessary for a more definite conclusion.

The high surface east of the Colville River, noted in a previous section, is correlated with the surface of the foothill silt. The abundance of sand definitely indicates a non-eolian origin, and the presence of higher areas standing above the surface, especially portions of the Franklin Bluffs, implies an alluvial plain in that area rather than marine deposition. Correlation with the surfaces described by Lewis (26) to the east of the Canning River, is not yet possible.
In deciphering the history of an emergent coastal plain, one is tempted to correlate surfaces with eustatic and glacio-eustatic changes in sea level as recorded in other coastal areas. Before such correlations are accepted the possibility of isostatic rebound due to glacial unloading and/or recent tectonic movements must be considered and their relative influence determined. Since the area was not glaciated, and the Brooks Range to the south was not extensively glaciated, glacial rebound must be assumed to be small. Toward the east, this assumption might not be as valid since the mountain front is now adjacent to the coastal plain and widespread, large-scale rebound is indicated by extensive raised beaches still farther east in the Canadian Arctic Archipelago (58). The effect of tectonic movements are not as easily determined. The tectonic stability of an area may be partially indicated by the degree of horizontality of the uplifted surfaces. Parallelism or lack of it between two or more terraces may be used if some of the terraces are discontinuous. This may also yield information as to the time and magnitude of local tectonic movements, if such exist. Fairbridge, in a recent compilation of information on eustatic sea level changes, gives an idealized correlation of Pleistocene stands of sea level (18, p. 123). Attempted correlations with such a sequence,
even if the area were shown to be tectonically stable and unaffected by glacial rebound, must still be used with reservation until more is known about the exact cause of the eustatic changes. If they are, in part, due to polar shift or other geodetic changes (18, p. 107 - 110), eustatic changes in the middle latitudes are not directly correlative to those in the higher latitudes. Determination of the ages of these and other high latitude surfaces could in fact help evaluate the geodetic component of the eustatic changes.

Determination of the basic information dealing with surface elevations is hampered by incomplete topographic coverage of sufficient accuracy. The area is covered by base maps, of a reconnaissance nature, with a contour interval of as much as 500 feet; only local areas along streams are shown in more detail. A new topographic map series, with a contour interval of 100 feet, is becoming available. However, of the twelve maps covering the area under discussion, only five are presently available. Comparison of the new maps with the old indicates discrepancies of 200 - 300 feet in the 500-foot contour line, alone; consequently, usage of the older maps for correlation of surfaces is not practicable. As noted previously, the Northern Foothills section is composed of three surfaces; the Southern, the Intermediate, and the foothill silt area. These are separated from each other and the coastal plain by definite topographic breaks and are best developed
in the area of the Meade River drainage system. Eastward from this area, the Intermediate Surface narrows and is lost in the upper Ikpikpuk drainage system. The surface is either absent to the east of the Ikpikpuk or so well dissected that pending more complete, detailed topographic coverage, these surfaces cannot be recognized in this area. Westward, the surface again narrows and from about the Utukok River west is very narrow and possibly discontinuous. The present coverage for that area is also unreliable. Whether any sediments mantle the Intermediate and Southern Surfaces is not known. Collier (12) noted two surfaces at 500 and 800 feet in the Cape Lisburne Region but, at present, these can not be correlated with the other surfaces.

Some Quaternary tectonic movements are indicated by slight elevational differences in the surfaces across the area. The southern boundary of the marine coastal plain rises from about 50 feet in elevation, south of Wainwright on the western coast, to about 300 - 400 feet on the Colville River and then drops to 150 feet in the Kuparuk-Sagavanirktok area. The nonmarine portion, within the latter area, rises to an elevation of about 300 - 500 feet. The elevational variance and general northeast trend of the contour lines across the Kuparuk-Sagavanirktok area suggests an uplift to the east. The southern boundary of the Foothill Silt Surface rises from about 400 feet at the Ketik River to about 700 feet midway
between the Ikpikpuk and Colville Rivers, or within the area for which good coverage is available. The location of this boundary, east of the Colville River, is not well known but appears to be at about 800 - 900 feet in elevation just east of the Ivishak River.

The elevational difference between the coastal plain and the Foothill Silt Surface rises from an almost imperceptible amount in the vicinity of the Kuk drainage to about 200 feet in the area of the Itkillik-Kuparuk highland and the Franklin Bluffs. The diffuseness of the boundary between these two plains in the Ikpikpuk-Colville area seems to be the result of dissection due to lake and stream development, coupled with a slight, east trending flexure of the coastal plain in that area. The possible presence of this synclinal flexure is indicated by the shift to east and west of drainage flowing northward from the foothills and a bedrock as well as surface low between the Kogosukruk and Kikiakrorak Rivers, along the Colville River (see Figure 6).

The abrupt escarpment, to the south of the Intermediate Surface, rises 300 - 500 feet to a general elevation of 1000 - 1200 feet. This escarpment is probably the one which Hopkins (21) would correlate with the outline of the marine basin formed by the depression of the Bering-Chukchi platform in late Pliocene. The formation of the Bering Seaway allowed the migration of a Pacific molluscan fauna into the Arctic and
Atlantic Oceans. If we accept this wave-cut (?) cliff as late Pliocene in age, then quite different interpretations of the tectonics involved in attaining its present elevation have been presented by different authors. Hopkins would relate the present elevation of about 700 feet south of Meade River to uplift, as those areas which he considers stable have sediments ranging in age from late Pliocene to late Pleistocene near, or less than 125 feet above, present sea level (21, p. 1523). However, such an elevation approximates the 660-foot stand of late Pliocene sea level in Fairbridge's idealized correlation of sea level changes from stable areas (18, p. 123). The author believes both are true to an extent; there has been some uplift of the Arctic Slope, and Fairbridge's basic hypothesis of eustatic sea level changes with time is valid. The author feels the association of late Pliocene and late Pleistocene faunas near present sea level on the Pribilof Islands and in the Nome area (34) is more indicative of steady subsidence rather than stability. The westward tilt of the inner margin of the coastal plain is a result of both uplift in the east and depression on the west. If any Tertiary sediments were deposited west of the Colville River, they were probably removed either by the Pliocene transgression or by later erosion, since none have yet been identified.

Lowering of sea level during the Nebraskan and Kansan glaciation, allowed the development of a drainage system on
the emergent plain. The ancient river valleys are now buried by the foothill silt and associated alluvial deposits which may be of Yarmouth age. The alluviation during the Yarmouthian transgression filled the valleys and finally covered much of the area of foothill silt. The break between this area and the Intermediate Surface may be a wave-cut cliff marking the maximum transgression. A Yarmouth rather than an Aftonian age is based on the mammoth, *Mammuthus primigenius*, found in the alluvial sediments on the Kaolak River. This specimen, now in the museum of the Arctic Research Laboratory, was identified by O. Geist (University of Alaska). Part of the Colville drainage may have been in existence during the Yarmouthian transgression, though it is believed most of the drainage from the mountains had not yet been captured by the Colville but rather flowed northward. The 250 - 300-foot terrace in the vicinity of Umiat is correlated with this inundation. It is worthy of note that the extensive terrace developed near Prince Creek, just upstream from Umiat, appears continuous along Wolf Creek into the foothill silt area (see Figure 3c). The Intermediate Surface may be of Aftonian age, in that the Aftonian transgression may have been coextensive with the previous late Pliocene inundation. In such a case the high escarpment would mark the extent of both transgressions.

The inner margin of the coastal plain is considered to be Sangamon in age. This marine transgression which created the
break between the coastal plain and the foothill silt area, caused alluviation of the Colville, Ikpikpuk and Meade Rivers. This valley filling, of >80 feet on the Ikpikpuk River, is reflected in the high terraces along these rivers, the 80-100-foot terraces on the Ikpikpuk and the 150-foot terrace on the Colville. An uncertainty arises in whether the inner margin of the marine coastal plain in the Western section is correlative with that in the Eastern section. The lower elevation of the inner margin of the marine portion of the coastal plain in the Eastern section without an accompanying decrease in the Foothill Silt Surface, the rapid change in the sediments in the vicinity of Ocean Point on the Colville River (section W9), and the somewhat sharp drop in the coastal plain surface to the east of Ocean Point (section W10), seem to indicate a more recent transgression in that area. Yet evidence of a higher stand of sea level in the Eastern section was not found.

It is difficult to judge the age of a surface such as the coastal plain, by criteria applicable in the middle latitudes. The slow growth and decay of organic matter in the present environment and the short period annually, during which streams are active erosive agents, are conditions not existing on other landscapes. Rivers such as the Meade, Topagoruk and Ikpikpuk head within the foothills and their main supply of water is the annual snowfall which is rapidly dissipated in
the spring. Most of the summer their current is very slow and frequently the rivers are nothing more than a series of pools. These rivers, except for the deeper pools, freeze to the bottom in the winter as does the active layer in the river alluvium. Consequently, during the early part of the spring melt-off, much of the erosive capability of the high stream flow is blunted by the frozen sediments, and during the late summer when the sediments are most easily eroded, there is little if any discharge.

A Sangamon age is postulated for the coastal plain on the basis of the vertebrate fauna found by Quaide (39) in the alluvial fill of the Ikpikpuk River. Quaide placed this major advance as either Sangamon or a Wisconsin interstadial; of these the former seems the most likely. All of the "in place" vertebrate finds were in terraces between 20 and 60 feet above the river. At present there is no definite evidence upon which to decide whether these terraces indicate a more recent transgression than that which formed the inner margin or are simply a terrace sequence cut from the 80 - 100-foot valley fill.

Transgressions more recent than the Sangamon maximum may be found in the sediments, but are obscured over much of the surface of the Western section by the more recent eolian activity. The area of larger lakes, which extends across the northern portion of the coastal plain from Peard Bay eastward
to near the Colville River, may be a reflection of an offshore gradation to finer sediments or it may indicate a transgression since middle Sangamon time. Indirect evidence of a transgression of this magnitude is found in the erosion surface at Barrow. The greater thickness of sediment over the basal unconformity in the Meade-Ikpikpuk area as compared to that overlying the unconformity at Barrow suggests that the unconformities are not equivalent and that a more recent transgression has occurred. It seems probable that the silts and clays below the unconformity in the Barrow area are, in part, the offshore facies of the inland sands and that the sediments correlative to the Pliocene (?) section along the Colville River may occur at depth in the Barrow area. Radiocarbon dating indicates this transgression to be older than 38,000 years B.P. The relationship of the Ikpikpuk River delta to the northernmost part of the coastal plain is also suggestive of a previous shoreline. This is especially true just west of Teshekpuk Lake, where a large area of alluvial terrace-deltaic sediments having no present connection with the ocean occurs. The sudden shift in the direction of the Meade River drainage from NNW to ENE indicates differential uplift of the northwestern part of the coastal plain. Further uplift along the northern margin of the coastal plain may have been the cause of the regression. Whether this uplift is a recurrent movement along the Barrow arch (19) is uncertain.
Radiocarbon dating has yielded a minimum age of 10 - 11,000 years for the surface at Barrow. Though some controversy exists regarding the maximum lowering of the ocean during the Wisconsin, how close present sea level was approached during the Wisconsin interstadials and the magnitude of fluctuations during the past 5000 years, most agree (18, 21, 35) that 10 - 11,000 years ago the ocean was 100 - 150 feet lower than at present. Therefore a marine surface 10 - 11,000 years old would require 100 - 150 feet of uplift and of a sufficient rate to stay ahead of the rise in sea level during the Recent. A slightly older surface would require a somewhat greater uplift. The literature reveals the uncertainty in where sea level stood during the mid-Wisconsin interstadial (Bradyan ?) 30 - 50,000 years B.P. One of the difficulties has been that the supposed Bradyan (?) marine terrace and deltaic plain is near the limit of previous radiocarbon dating technology. With the increased range of the technique, to about 70,000 years (57), it is hoped this problem may soon be resolved.

Considering the numerous overlapping drained thaw-lake basins, the probable length of time necessary for the initiation, growth and eventual drainage of such a lake, and the retarding effect of the Wisconsin climate on thaw processes it does not seem unreasonable to attribute the emergence of the Barrow area to the retreat of the ocean during the early Wis-
consin or a mid-Wisconsin interstadial transgression which has since been uplifted. Only more precise dating of the surficial sediments will enable a differentiation to be made. The Recent rise in sea level has resulted in the estuarine coastline seen all across the Alaskan Arctic.

Only very general estimates of times and magnitudes of uplift may be made by a comparison to Fairbridge's (18) maximum stands of sea level. This comparison is necessarily tentative due to uncertainties in the applicability of these measurements to the higher latitudes and the correctness of either correlation. Comparing Fairbridge's 60-foot Sangamon maximum to the present inner margin of the coastal plain, depression to the west and uplift of ~250 feet to the east is noted. The Yarmouth maximum is 120 feet higher than the Sangamon maximum according to Fairbridge. The inner margin of the coastal plain is about 300 feet lower than that of the Foothill Silt Surface, indicating 150 - 200 feet of uplift during the Illinoian. If the inner margin is a deltaic plain and not a marine terrace, a lesser uplift is indicated. The 150 feet between the Yarmouth and Aftonian maximums compares favorably with the 200 feet between the inner and outer margins of the Intermediate Surface. These interpretations indicate a total uplift of about 300 feet since the Aftonian maximum. If very little uplift occurred during the Nebraskan, Fairbridge's Citronelle shoreline (200 meters) would be about.
950 - 1000 feet or still within the high escarpment (wave-cut cliff?) to the south of the Intermediate Surface.

Some indications of a slightly higher stand of sea level, approximating 6 - 10 feet, during very recent times is seen in the somewhat emergent deltas of the Sagavanirktok, Kuparuk and Colville Rivers, and in the wave-cut platform around part of Barter Island noted by Leffingwell (25).

Correlation and synthesis of some scattered information on sea level changes seen in the field or on aerial photography has not been possible. A few rather fragmental emergent shorelines or possible shorelines have been noted on the map (Figure 5), or in the discussions of certain areas, and more are sure to be found in any detailed study of the available photography. The two locations of peat underlying the terraces of the Kuparuk and Colville Rivers indicate a period of alluviation which covered the former terraces to a depth of about 10 feet. The present terraces stand 15 - 20 feet above the river and whether the alluviation was a consequence of recent or much earlier sea level fluctuations is not possible to say.
CONCLUSIONS

It is the purpose of this section to consider the past usage of "Gubik formation" in light of present knowledge. In the writer's conversations with others, some have indicated the desire to restrict the term to the marine sediments. This does not seem to be desirable since it would necessitate a naming of the nonmarine facies equivalent. Others indicate a preference for restriction of the term to Pleistocene sedimentation, excluding the Recent sediments. Following present usage of Recent as indicating the last 10,000 years, little material of lacustrine, eolian and alluvial origin would be excluded, and this would be almost indistinguishable from similar sediments that would be included.

Consequently, the writer favors a continued usage of the term Gubik formation to indicate the Quaternary marine and associated sediments of the coastal plain and their lateral equivalents within the foothills.

The Foothill Silt Surface, although truly a part of the coastal plain, has not been included in previous usage of that term. The writer feels that this silt does form a distinct, mappable unit of distinctive lithology; it has not been previously described in any detail in connection with the Gubik formation; therefore, naming of this as a formational unit is warranted. Though problems are encountered such as whether to
include the older, possibly equivalent sediments in the Barrow area and along the Colville, and the fact that this, as well as the Gubik formation, includes recent lacustrine sediments, these are felt to be outweighed by the value of recognizing the silt as distinct from the coastal plain proper. On this basis the writer tentatively designates the foothill silt, the Ikpikpuk formation, and the Ikpikpuk River Valley the type area. This designation excludes the older basal Gubik sediments until more definite age relationships are established. It is possible that a more detailed study of the Pliocene (?) sediments along the Colville River, and the subsurface sediments in the Barrow area may justify the recognition and naming of still another formation.

The type section of the Ikpikpuk formation is the exposure at section F5, Figure 22, on the Ikpikpuk River. At the type section the entire exposure is of unconsolidated sediment, the underlying Cretaceous appearing to be at or near river level. The upper 125 feet of the exposure is massive to finely stratified, calcareous silt. Locally the stratification is emphasized by concentrations of fine organic matter. The lower 20 feet is masked by river alluvium. A principal reference section, to supplement and denote variations from the type is section F6, Figure 22. At this location the basal sand is exposed (though the base is not), as is an upward gradation into a well sorted calcareous sand.
Figure 22. Location of type section and reference section of the Ikpikpuk formation. (Map taken from the Ikpikpuk River quadrangle of the U. S. Geol. Survey, Alaska topographic series.)
RECOMMENDATIONS FOR FUTURE STUDY

In concluding a reconnaissance study of such a large and varied area, one is always left with more problems than have been solved, and even those tentative solutions which have been forwarded always seem a little less conclusive than the writer desires. The writer is always prone to point out those areas in which he would like to see further work done, while others might perhaps consider restudy of portions of the present work to be more valuable.

In such a frame of mind, the following are those areas which deserve primary consideration in any further study:

1) Determining the extent of the Intermediate Surface especially west of the Utukok River, and the age of related sediments, if present.
2) Study of the Colville River Valley, its alluvial terraces, and its drainage history with respect to piracy of north flowing streams.
3) Extent of the 300-foot Colville terrace eastward, and its relation to the sediments in the southern part of the Itkillik-Kuparuk Highland.
4) Relationship of the inner margin of the marine coastal plain in the Eastern versus the Western sections.
5) Relationship of the Foothill Silt and other
Surfaces to the pediment (?) gravels of (22) and (26), to the west of the Sagavanirktok River.

6) An active radiocarbon dating program, for those coastal and surface sediments, within range of the method.


41. Rex, R. W. and Taylor, B. J. Investigation of the littoral sediments of the Point Barrow area (Typed written manuscript): Washington, D. C., Office of Naval Research, Geography Branch, (ca. 1953).


The field study, which forms the basis for this thesis, was done during the summers of 1957, 1958, and 1959. The Sagavanirktok, Meade and Kuparuk Rivers were visited in 1957, the Utukok and Ipiikpuk Rivers in 1958, and the Upper Meade, Colville and Kaolak Rivers in 1959. These investigations were part of a combined field effort with members of other fields of discipline, mainly Botany and Pedology. The investigation was made possible by a grant from the Office of Naval Research through the Arctic Institute of North America. The logistic support, without which a program of this areal extent could not have been accomplished, was supplied by the Arctic Research Laboratory under the direction of Max C. Brewer. The Arctic Research Laboratory is maintained by the University of Alaska through a contract with the Office of Naval Research.

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writer's ideas and also forced him to secure more data to support his convictions, are gratefully acknowledged.

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Stratigraphic Sections

Coastal plain

Western section

Colville River

Section W1: Mouth of the Kogosukruk River.

Unit thicknesses:

28 feet Buff to yellow orange sand, somewhat finer toward the top, and in places weakly calcareous. Basal 2 - 3 feet conglomeratic, with predominant size less than 3/4 inches but contains a few cobbles up to 8 inches in diameter. The basal portion is very fossiliferous, mainly marine pelecypods.

96 feet Cretaceous bedrock.

Section W2: Approximately 1 mile, north of W1, just south of a deep gulley.

Unit thicknesses:

45 feet The basal gravel is somewhat thinner than at W1, less fossiliferous and locally absent. The sand is more calcareous toward the base, though generally noncalcareous. The section is mainly medium sand, little silt or fine sand, with occasional lenses of coarse sand to gravel, containing marine shell fragments, near the base.
56 feet Cretaceous bedrock.

North of this section, logs up to 9 inches in diameter, become very common in the basal portion. The sediment is still marine as evidenced by abundant macrofossils.

Section W3: Located about 1/2 mile south of the Kikiakrorak River junction.

Unit thicknesses:

45 feet

8 feet Interbedded sand and peat, related to eolian activity in the area as evidenced by the repeated sequence of burial and regrowth of the surface vegetation.

9 feet Strongly cross-laminated sand. The cross-lamination is emphasized by bands of coarse sand, one grain thick, which weather out in relief.

22 feet Predominantly medium sand, horizontally bedded.

6 feet Sand with numerous lenses of gravel, these lenses are weakly cross bedded and become more numerous toward the base. Cobbles up to 6 inches in diameter are common. Macrofossils appear to be restricted to this portion.

35 feet Cretaceous bedrock.

Section W4: One mile north of section W3.

Unit thicknesses:
35 feet

7 - 10 feet  Thin bedded sands and organic rich sediment, lacustrine in origin and contains abundant fossils identical to those in the present lakes.

25 - 27 feet  Similar to preceding section. Basal gravelly sand is thinner, and macrofossils are again restricted to the basal sediment.

68 feet  Cretaceous bedrock.

Wood is not abundant in the basal portion north of the Kikiakrorak junction, though still highly fossiliferous.

Section W5: Three miles north of the mouth of the Kikiakrorak River.

Unit thicknesses:

50 feet  Medium to fine sand, weakly calcareous locally with no pronounced stratification except in the basal sands and gravels.

56 feet  Cretaceous bedrock.

Section W6: Located 4 1/2 miles north of the Kikiakrorak junction at latitude 70° 03'.

Unit thicknesses:

56 feet

6 feet  Alternating thin beds of peat and sand attributed to eolian activity.

44 - 41 feet  Predominantly sand as before, more cross bedded than previously, becoming
finer toward the top. The basal gravel is more fossiliferous than any previous locality on the Colville.

6 - 9 feet Transitional zone containing reworked Cretaceous sand and clay admixed with considerable gravel and very fossiliferous (marine).

68 feet Cretaceous bedrock.

A thin (2 - 2 1/2 inch) layer of clean peat, which extends about 10 feet along the cliff, occurs about 11 feet from the base, overlying the transitional zone. Tracing the lateral extent of this peat as a possible discontinuous layer was not possible due to local slumping of the exposure.

Section W7: Located 1 3/4 miles north of W6, at latitude 70° 04.7'.

Unit thicknesses:

50 feet

6 - 8 feet Alternating sand and peat of eolian origin.

27 - 29 feet Medium to fine sand, weakly calcareous in places.

15 feet Predominantly gravel and including the transitional zone of the previous section, both are extremely fossiliferous.

68 feet Cretaceous bedrock.

North of section W7, a change in the profile of the outcrop corresponds to a change in the materials. Previously the
profile was one of a steeply sloping face in the Cretaceous, a gently sloping to flat bench at the base of the gravel, and a steep slope to the top of the cliff. As the transitional zone develops, laterally, into more distinct units, the break in slope moves from the top of the Cretaceous to the top of the transitional zone, over a resistant unit composed of compact sand, silt and clay with scattered gravel.

Section W3: Middle of the pronounced river bend, at latitude 70° 06', just upstream from Ocean Point.

Unit thicknesses:

54 feet

6 - 8 feet Alternating sand and peat, of eolian origin.

28 - 30 feet Buff medium to fine sand strongly cross-bedded, and locally calcareous.

4 feet Fossiliferous gray sand which varies laterally into a similar thickness of sandy gravel. Locally this unit contains a very high peat content.

In an adjacent location, just downstream, a 1 - 3-foot layer of peat, extending 150 - 200 feet along the cliff was seen in this unit, and similar more local concentrations were seen upstream.

Unconformity Within the Gubik formation.

12 feet Interlayered clay
and sand, the sand occurs as thin beds (1 inch or less) be­
tween sandy clay layers (10 - 12 inches thick), with occasion­
al lenses of fine gravel.

2 feet Gray sand, fossiliferous (marine), and similar in appearance to underlying Cretaceous sandstones.

56 feet Cretaceous bedrock.

Section W9: Ocean Point, last occurrence of high bluffs along the west side of the river.

Unit thicknesses:

52 feet Gubik sand and gravel.

The lower half is dominantly cross-bedded and interstratified sand and gravel, containing abundant logs (5 - 7 inches in diameter). The upper half is sand with lenses of gravel. Gravel occurs much higher in the section here than in any pre­vious location along the river.

33 feet Cretaceous bedrock.

Section W10: Located 7 miles east of Ocean Point, and about 2 miles to the south.

Unit thicknesses:

39 feet

11 feet Covered in slope, contains some coarse calcareous sand with lenses of gravel, exposed in lake bank on coastal plain.

11 - 13 feet Noncalcareous
sand above the gravel grading upwards into finer more calcareous sand. In one location, beds of orange and pink sand, similar to that seen in the Tertiary, were present.

15 - 17 feet Gravel containing lenses of noncalcareous sand and occasional cobbles up to 8 inches in diameter.

20 - 25 feet Alluvial terrace.

The orange and pink sands, noted in the above section, were probably derived from the Tertiary materials underlying the high upland between the Itkillik and Kuparuk Rivers, which lies 9 miles to the east. None of the green and white chert pebbles characteristic of the Tertiary were seen.

Section W11: Located 18 miles to the north of W10, and 10 miles due south of the ocean, at latitude 70° 18' on the east side of the delta.

Unit thicknesses:

22 feet Medium to fine sand, weakly to noncalcareous, with scattered gravel. The base of the sediment is not exposed. This section is along an unnamed river entering from the east. The coastal plain approximates 25 feet above the Colville River at this location.

Ikpikpuk River

Section W12: Located at latitude 69° 46' on the east side of the valley.

Unit thicknesses:
50 feet Basal foot is sandy gravel grading upward through gravelly sand and into massive medium sand, well sorted, and noncalcareous. Much of the basal gravel is derived from the Cretaceous, and contains occasional marine shells. The thickness varies between 40 - 55 feet, thickening northward along the exposure.

50 feet Cretaceous bedrock.

Section W13: Twelve miles north of the Price River junction, at latitude 70° 02'.

Unit thicknesses:

70 - 75 feet Predominantly noncalcareous well sorted medium sand. In the upper half the sand is finer and the cross-laminations are more pronounced and steeply dipping than in the lower half. Lenses of coarse sand and gravel are restricted to the basal 2 - 3 feet of the exposure. A few badly worn marine shell fragments occur in the basal gravelly sand.

20 feet Alluvial terrace sediments. The base of the section was not seen, but the abundance of marine shells in the recent river deposits indicates an extremely fossiliferous basal zone.

Meade River

Section W14: Located at 70° 05' 30" North Latitude, 157° 09' West Longitude.

Unit thicknesses:
47 feet  Well sorted, noncalcareous medium sand, horizontally stratified.

3 - 5 feet  Cretaceous bedrock, exposed with an undulating erosion surface. This section is located on the break between the coastal plain and the foothills. Upstream from this section, within the foothills, the Cretaceous outcrops are thicker and more extensive.

Section W15: Located 22 airline miles to the north of W14, at latitude 70° 25'.

Unit thicknesses:

50 - 55 feet  Medium, noncalcareous sand, well sorted with little coarse sand or gravel except as occasional lenses. A few worn marine shell fragments were seen in the basal material. In the lower half of the exposure, the sands are more cross-bedded and steeply dipping.

0 - 6 feet  Cretaceous bedrock, which lies near river level over most of the area, with the outcrops occurring as irregularities on the erosion surface.

The more steeply dipping sands of the lower unit were sharply truncated by the gently cross-bedded to almost horizontal sands of the upper unit. These units were also separated by concentrations of organic matter in the form of peat chunks and fine vegetal debris. Whether this is evidence for an unconformity within the section or a purely local condition could not be determined since slumping of the loose sand ob-
scoured most of the cut. Since none of the cuts farther downstream showed similar relationships, the condition appears to be local.

**Section W16:** Located 4 miles northwest of W15, at latitude 70° 28' north, east side of river.

Unit thicknesses:

60 feet  Medium, noncalcareous, well sorted sand as before, very little gravel at base. Marine fossils present but not plentiful at base of exposure. A 2 - 3 inch organic rich layer occurs about 12 feet from the base, and is continuous for about 100 feet before lost in the slump. Predominant stratification is horizontal.

6 feet  Cretaceous bedrock.

**Section W17:** Located 4 miles northwest of W16 at latitude 70° 30' north, east side of river.

Unit thicknesses:

50 - 55 feet  Predominantly sand as before, basal 2 - 3 feet is a highly fossiliferous clay-sand-gravel mixture, poorly sorted and containing cobbles up to 8 inches in diameter. The basal material grades either directly or through about 3 feet of fine gravel into the well sorted sand. Very few macrofossils, other than as worn fragments, occur above the basal portion.

5 - 10 feet  Cretaceous bedrock, usually closer to 6 feet. The thicker Cretaceous exposures
are of a resistant sideritic (?) claystone which appears to occur as concretionary or local concentrations in the Cretaceous and which form local highs on the Gubik-Cretaceous erosion surface.

Section W18: Located about 8 1/2 miles north of W17, at latitude 70° 37' north.

Unit thicknesses:

46 feet  Mainly sand, well sorted, weakly cross-bedded and noncalcareous. Basal 1 - 2 feet of fossiliferous poorly sorted gravel and clay.

4 feet  Cretaceous bedrock, locally outcrops to 6 feet.

Inaru River

Section W19: Located 12 miles northeast of W18 at longitude 157° 08' 30" west.

Unit thicknesses:

35 feet  Upper 2/3 covered by slump. Lower 1/3 predominantly silt to fine sand, marine fossils common in the basal foot of gravel.

Cretaceous outcrops at stream level.

Section W21: A section from the bank of a lake on the coastal plain, located about 30 miles west and 6 miles south of W19, at latitude 70° 41' north, longitude 158° 28' 30" west.

Unit thicknesses:
20 feet Fine, well sorted, non-calcareous sand. Most of the exposure is badly slumped. Two to three feet of peat underlies most of surface in this location. The base of the sediment was not exposed.

Section W22: In text.
Section W23: In text.

Barrow Area

Section W24: Approximately 1 1/2 miles south of the beginning of the cliffs at Barrow Village.

Unit thicknesses:

2 feet Peat and silt. Top 6" peat. Chunks of gravelly peat in basal 4".

3 feet Buff, sandy, silty fine gravel.

18 feet Cross-bedded and horizontally bedded sands and gravels; fossiliferous; in some locations fossils extremely plentiful.

Base of cliff 11 feet above sea level.

Section W25: In text.
Section W26: Located approximately 5 3/4 miles south of Barrow Village, and 200 yards south of the first major drainage south of Nunavak Slough.

Unit thicknesses:

Tundra surface.
1 foot Gravelly sand mixed with peat.

1 foot Brownish-gray sandy silt.

4 feet Burnt orange to light brown sand with dark streaks of iron oxide.

1 1/2 feet Dark gray sandy silt.

6 inches Thin bedded gray-brown sand and gravel with iron cement concentrated in gravel.

5 feet Rather clean brown-gray medium sand with stringers of concentrated dark iron stain.

1 foot Fine gravel, heavily stained with black iron oxide.

Unconformity (?)

6 feet Dark gray silt which is covered by slump to base of cliff. Appears to be the silt that overlies the black clay.

Base of cliff 9 feet above sea level.

Section View: Located 6 1/2 miles south of Barrow Village.

Unit thicknesses:

Tundra surface.

2 feet Gray sandy and gravelly peat.

7 feet Yellow-brown, and dark red-brown streaks in gravelly sand -- contorted.
11 feet Light gray to yellow gravelly sand -- contorted.

6 inches Light gray medium textured sand.

4 feet Alternating light medium sand and dark brown sand cemented with iron oxide.

1 inch Iron cemented gravel.

1 foot Light gray to yellow brown fine sand.

16 inches Dark brown stained fine sand.

2 feet Slump above base of cliff.

Base of cliff 11 feet above sea level.

Section W28: Approximately 9 1/5 miles south of Barrow Village.

Unit thicknesses:

Some slumping and loss of upper portion of section.

1 foot Mixed peat, silt and gravel.

12 feet Yellow-brown sand with some gravel.

6 feet Well bedded, poorly sorted sand and gravel with a considerable amount of black iron oxide.
2 1/2 feet  Finely crossbedded sand with large quantities of coal.

1 1/2 feet  Laminated gray sand and gravel.

2 feet  Coarsely laminated, alternating sand and gravel.

1 foot  Fairly clean gray sand.

3 feet  Crossbedded gray to yellow brown sand, concentrations of black iron stain in bedding.

2 1/2 feet  Fossiliferous sands and gravels with considerable quantities of coal.

Unconformity (?) 4 feet  Sandy silt, gray brown silt horizons very badly contorted, contains stringers of sand that appear to come from the horizon above. Bottom of this silt appears to be a transitional interfingering of clay and silt into the black Gubik clay.

3 - 4 feet  Slump at base of cliff.

Bottom of cliff  4 feet above sea level.

Tundra surface  Approximately 45 feet above base of cliff.

Section W29: One-half mile south of Imikpuk Lake, Barrow Area; an auger hole in what may have been a lake or lagoonal basin.
Unit thicknesses:

3 inches Tundra vegetation mat.
1 foot Gray silt and clay.
2 inches Peat layer, ice lenses throughout.

3 feet 9 inches Gray silt mixed with brown silt, peat and yellow sand. Lenses and pockets of one in the other. Pockets, stringers and lenses of ice (samples B22 and B23).

2 feet The above grades into and mixes with a yellowish sand with darker silt pockets, ice throughout (sample B21).

2 feet 4 inches The above grades into and mixes with a darker silt and fine sand. Some light colored sand in pockets and lenses. Much ice, about 50 percent (sample B20).

6 inches Yellowish silt and sand, 50 percent ice (sample B19).

Eastern section

Sagavanirktok River

Section E2: Eleven miles north of the Sagavanirktok-Ivishak junction at latitude 69° 40' north, east side of the river.

Unit thicknesses:

35 feet Calcareous fine sand and
silt, badly slumped due to thaw of the enclosed ground ice.

40 feet Coarse gravel, calcareous, containing occasional lenses of coarse sand, up to 10 inches thick. Stratification dominantly horizontal, with a few areas farther north in which the gravel was strongly channeled and cross cutting.

**Bedrock near river level** Implied by local occurrence of Cretaceous or Tertiary float.

Section E3: Located 6 1/2 miles north of E2 at latitude 69° 45' 30" north, east side of river.

**Unit thicknesses:**

**15 (?) feet** Material from a solifluction slope off the Franklin Bluffs, two miles to the north, which rise about 400 feet above this section.

**35 (?) feet** Calcareous fine sand and silt, upper contact obscured, so thickness is an estimate. Material predominantly fine sand with thin scattered beds of silt, and occasional beds of silt up to 1 foot thick. A bed of silt, 1 foot thick, a foot above the gravel, contained numerous fresh water snails and pelecypods.

**17 feet** Coarse calcareous gravel, massive to weakly stratified.

**23 feet** Tertiary bedrock, up to 5 feet of relief on the erosion surface.
Toolik-Kuparuk River

Section E8: Fourteen miles southeast of the Toolik-Kuparuk junction, at latitude 69° 46' 30".

Unit thicknesses:

35 feet Gray, fine sand to silt, highly calcareous (43 percent by weight, carbonate), with abundant shistose rock fragments.

Base of section Not exposed, continues beneath river level.

Though the contact is not exposed along the river, the sand overlies a coarse gravel containing cobbles up to 6 inches in diameter. This gravel is exposed where the sand has been removed by solifluction from the top of a nearby pingo, which rises 90 - 95 feet above the general surface level.

Section E9: Nine miles downstream from E8.

Unit thicknesses:

20 - 25 feet Massive sand, with scattered pebbles.

5 - 10 feet Gravel.

Base of section Not exposed; continues beneath river level.

Section Ell: Located at latitude 70° 03' 30" north and longitude 149° 13' 30" west, east side of river.

Unit thicknesses:

2 - 5 feet Gravelly sand and silt,
calcareous.  

**20 - 23 feet**  
Crossbedded calcareous gravel, containing lenses of sand, up to 6 inches thick, especially near the top.

*Base not exposed*  
Continues beneath river level.

**Section El2:** Located 17 miles northeast of Ell, at latitude 70° 17' north, east side of river.

**Unit thicknesses:**

**4 - 8 feet**  
Medium to fine calcareous sand, a few badly worn Foraminifera were found in a sample of the sand.

**16 feet**  
Calcareous gravel, finer, less cross-bedded and containing more sand than at the previous section.

*Base not exposed*  
Continues beneath river level.

**Section El3:** Located 5 1/2 miles north of El2, at latitude 70° 21' 20" north, west side of river.

**Unit thicknesses:**

**20 feet**  
Upper half is predominantly fine calcareous sand, overlying with an undulatory contact the lower fine sandy gravel. The section is variable, the sand locally containing abundant lenses of gravel and coarse sand, with a similar relation in the gravel. Pleisto-
cene foraminifera are fairly common in the sand.

Section El4: Located on the coast, near the mouth of the Kuparuk River, in the estuary of Fawn Creek. The sea cliff varies from 5 - 11 feet in height, and the coastal plain rises inland to a height of 16 - 18 feet. The dominant material is medium to fine calcareous sand, with local concentrations of sandy gravel associated with beach ridges (?).

Foothill silt surface

Colville River

Section Fl: Fourteen miles north of the Anaktuvuk-Colville junction.

Unit thicknesses:

90 feet

70 feet Calcareous silt, containing 5 - 7 percent sand.

20 feet Cross-bedded and channelled sands and gravels, gravels occur mainly in the lower 10 feet.

Cretaceous Not measured, probably over 140 feet.

Section F2: Nineteen miles north of the above junction.

Unit thicknesses:

121 feet
36 feet  Covered section, probably silt.

57 feet  Silt, basal portion quite sandy.

28 feet  Sand and gravel; clean sand in upper 10 feet; predominantly medium gravel in lower 10 feet.

105 feet  Cretaceous; measured from the river.

Section Fj: Twenty-two miles north of the junction, near Sentinel Hill. The section is much thinner and the upland is also lower, since this is the area of the break onto the coastal plain.

Unit thicknesses:

62 feet  Covered section, probably silt.

28 feet  Silt, sandy toward base with scattered gravel along the base.

68 feet  Cretaceous.

In most sections measured along the rivers, the top of the bluff slopes gently up to the Foothill Silt Surface, consequently part of the section is covered. The unconformity between the Cretaceous and Quaternary is undulatory with a local relief of 10 - 20 feet, and up to 50 feet over greater
distances. Large quantities of wood consisting of both logs and twigs, and the thickest occurrences of the basal gravel, appear to be largely restricted to valleys in the buried erosion surface.

**Ikpikpuk River**

**Section F4**: Twenty miles north of the junction of Kigalik River and Maybe Creek.

Unit thicknesses:

- **35 - 45 feet** Silts and fine sand mostly covered and badly slumped.
- **100 - 110 feet** Cretaceous.

The lower contact of the silt is buried by slump and the silt thickness is a minimum since it does not include all the slope to the Foothill Silt Surface.

**Section F5**: Two miles ENE of section F4; also 20 miles north of the above junction.

Unit thicknesses:

- **125 feet** Silt, minimum thickness. Stratified on weathered surface, and locally emphasized by organic matter concentrations.
- **20 feet** Alluvial river terrace, Cretaceous outcrops in river.

A slight slope to the Foothill Surface was not measured. Three samples (3-foot composite) distributed up the exposure, average 6 percent sand, 74 percent silt and 20 percent clay.
Section F6: Located 32 miles north of the above junction. In this location the Foothill Silt Surface is on the west side of the river and the coastal plain on the east is about 60 70 feet lower in elevation.

Unit thicknesses:

10 feet Covered.

10 feet Fine calcareous sand (77 percent sand)

130 feet Silt, stratified on weathered surface; upper 20 feet grades into the sand.

10 feet Calcareous fine sand; sharp break with overlying silt.

15 - 25 feet Alluvial river terrace.

The lower 110 feet of the silt contains 6 percent sand, 78 percent silt and 16 percent clay. A sample from 115 feet above the base of the silt yielded 19 percent sand, 67 percent silt and 14 percent clay. Sand was also noted in locally eroded areas on the bluffs, at some distance from the section, but slump and vegetation prevented an accurate estimate of its thickness.

Meade River

Section F7: Located 36 miles south of Meade River Village and 10 miles south of the inland boundary of the coastal plain, at latitude 69° 58' north.

Unit thicknesses:
15 feet Covered section; appears to be silt.

105 feet Silt; not noticeably stratified.

26 feet Fine calcareous sand (75 percent sand).

20 feet Alluvial river terrace.

An average of three samples (3-foot composite) within the silt unit yielded 8 percent sand, 74 percent silt and 18 percent clay.

**Kaolak River**

**Section F8:** Located at first bluffs, on the east, downstream from the junction of the east and west forks of the Kaolak River. This junction is at latitude 69° 57' 30" north, 13 miles upstream from the junction of the Kaolak and Avalik Rivers.

**Unit thicknesses:**

40 feet Calcareous silt, containing 7 percent sand and 18 percent clay (exposed in the bank of a lake on the upland).

99 feet Covered in bluff and slope to upland.

6 feet Calcereous medium sand; upper contact in slump.

25 feet Fine gravel; containing beds
of weakly calcareous sand, up to 10 inches thick, towards the top.

The bluff is mostly covered by slump, and gives way to a gentle slope to the upland between 100 - 120 feet above the river. A mammoth skull was found, apparently in place, just above the gravel. Assuming the sand over the gravel to be 20 feet thick, the silt section would be close to 120 feet in thickness.

Section F9: Located 2 miles north of the above junction, after the river swings far to the east, at latitude 69° 59' 15" north.

Unit thicknesses:

- **20+ feet** Covered, appears to be silt.
- **100 feet** Calcareous silt, lower portion sandy (18 percent sand at 7 feet above the base), grading rapidly into the typical silt (8 percent sand at 46 feet above base).
- **11 feet** Fine gravel, noncalcareous, reworked Cretaceous material, locally contains lenses of medium to coarse noncalcareous sand in the upper portion.
- **11 feet** Cretaceous bedrock.

The covered section is somewhat thicker than given above, since part of the slope to the Foothill Silt Surface was not measured.

Utukok River
Section F10: Located at longitude 160° 30' west, 28 1/2 miles SSW from section F8 on the Kaolak River and 25 1/2 miles NW of the junction of Carbon Creek with the Utukok River.

Unit thicknesses:

12 - 20 feet Coarse gravel, much of which is derived from the underlying Cretaceous, overlain by about 5 feet of sand and silt.

65 - 75 feet Cretaceous bedrock.

The truncation of the underlying Cretaceous strata is pronounced and easily seen on aerial photos. The unconsolidated materials which overlie the Cretaceous are readily delineated since a prominent flattening of the slope of the bluffs occurs at the base of the gravel.

Section F11: Located 10 miles northwest of section F10, at latitude 69° 42' 30" north.

Unit thicknesses:

34 feet Sand and silt, calcareous, mostly covered.

16 feet Coarse gravel.

40 feet Cretaceous.

Section F12: Located 7 miles NW from F11, at latitude 69° 47' 30" north.

Unit thicknesses:

30 feet Mostly covered; basal portion
is fine sand.

10 feet Basal fine gravel.
35 feet Cretaceous bedrock.

Samples taken from the Foothill Silt Surface show the materials are more sandy than those seen on other rivers. The materials contain up to 28 percent fine sand and a few pebbles.

Section F13: Located 7 1/2 miles downstream from section F12 at longitude 161° 13' west. This section was not measured but simply estimated from the river.

Unit thicknesses:

35 - 40 feet Sand and silt; all but lower 5 - 10 feet covered.

20 feet Cross-bedded gravel.
15 feet Cretaceous bedrock.

Section F14: Approximately 3 miles downstream from section F13 at longitude 161° 20' west.

Unit thicknesses:

21 feet Sand and silt; a 4-foot composite sample immediately above the gravel consisted of 3 percent gravel, 22 percent sand, 50 percent silt and 25 percent clay.

10 - 15 feet Gravel; thickness depends on location of lower contact.
10 - 15 feet Cretaceous; upper contact in slump.
The upland was 46 feet above the river, but appeared to be part of an old drained lake basin since it was below the level of the Foothill Silt Surface. Two miles downstream (section Fl4a), the upland was measured at 80 feet. In this latter location the sand and silt unit was 55 feet thick.

Section Fl5: Located 8 miles downstream from section Fl4a at longitude 161° 43' west.

Unit thicknesses:

- 35 feet Silt and sand; all but lower 5 feet covered.
- 40 feet Fine gravel; some sand lenses toward the top.
- 10 feet Cretaceous; upper contact not definite.

The material immediately over the gravel was 30 percent sand, 42 percent silt and 28 percent clay. North of this section, Cretaceous bedrock is no longer exposed above the river level.

Section Fl6: Located 12 1/2 miles downstream from section Fl5, and 5 1/2 miles from the ocean.

Unit thicknesses:

- 50 feet Sand and silt; badly masked by thawing of ground ice and accompanying solifluction.
- 11 feet Fine gravel; base not exposed.

The material above the gravel contains much silt in the
slump which was not sampled. Those samples taken near the top of the section consisted of 74 percent sand, 16 percent silt and 10 percent clay.

Test wells

No. 1 East Oumalik (ref. 42) See text for discussion.
No. 2 Oumalik (ref. 42) See text for discussion.
No. 3 Meade (ref. 14) See text for discussion.
No. 4 Kaolak (ref. 14) See text for discussion.
No. 5 Fish Creek Well (ref. 44) This well is located 30 miles west and 1 1/2 miles north of section W11 at latitude 70° 19' 15" north, longitude 151° 58' 08" west.

The ground elevation at the well is 16.5 feet and 50 feet of Gubik sediments were penetrated. The material is predominantly fine to medium sand with some gravel and contains marine Foraminifera.

No. 6 East Topagoruk No. 1 (ref. 13) Located 38 miles north and 17 miles west of section W13, at latitude 70° 34' 37.5" north, longitude 155° 22' 39" west.

Ground elevation at this well is 50 feet, and approximately 70 feet of the Gubik formation were penetrated. The sediment is fine to medium sand, with gravel towards the base and containing marine Ostracoda and Foraminifera.

No. 7 Topagoruk No. 1 (ref. 13) Located 12 miles west and 3 1/2 miles north of the East Topagoruk Well at latitude 70° 37' 30" north, longitude 155° 55' 36" west.
The ground elevation is 23 feet and approximately 40 feet of the Gubik formation were penetrated. The material is lithologically similar to that in the East Topagoruk Well, but no marine microfossils were found.

The discrepancy between the thicknesses in the above wells may be partially accounted for if one, the Topagoruk Well, is located on a terrace rather than the coastal plain itself.

No. 8 Simpson No. 1 (ref. 43) Located 26 miles north of the East Topagoruk Well and 15 feet above sea level.

The exact thickness of the Gubik formation is uncertain but was placed at 10 feet on the basis of the first occurrence of Cretaceous Foraminifera. The material is predominantly sand with indications of clay and contained more gravel than the North Simpson Well.

No. 9 North Simpson No. 1 (ref. 43) Located 7 miles north and 9 miles east of the Simpson Well and is approximately 15 feet above sea level.

About 75 feet of Gubik sand was penetrated, though the base of the section was not definitely located. The material is predominantly sand with some gravel and indications of clay. The clay may be more extensive than indicated by the sample, since much would be lost during removal of the drilling mud.

No. 10 Barrow Special Holes (ref. 46) See text for discussion.