Engineering Geologic Maps of Northern Alaska, Harrison Bay Quadrangle

By L. David Carter and John P. Galloway

With a section on The Digitally Revised Engineering Geologic Maps of Northern Alaska by David W. Houseknecht, Christopher P. Garrity, and Donald C. Meares

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The Digitally Revised Engineering Geologic Maps of Northern Alaska

By David W. Houseknecht[1], Christopher P. Garrity[1], and Donald C. Meares[2]

The northeastern part of the National Petroleum Reserve in Alaska (NPRA) has become an area of active petroleum exploration during the past five years. Recent leasing and exploration drilling in the NPRA requires the Bureau of Land Management (BLM) to manage and monitor a spectrum of surface activities that include seismic surveying, exploration drilling, oil-field development drilling, construction of oil-production facilities, and construction of pipelines and access roads. BLM must routinely evaluate a variety of permit applications, environmental impact studies, and other documents that require rapid compilation and analysis of data pertaining to surface and subsurface geology, hydrology, and biology. In addition, BLM must monitor these activities and assess the impacts of these activities to the natural environment. Timely and accurate completion of these land-management tasks requires information regarding the properties and areal distribution of unconsolidated geologic units that cover the surface of the area.

To support these land-management tasks, a 1:250,000 engineering geologic map of the Harrison Bay Quadrangle, Alaska (Carter and Galloway, 1985) has been digitized. This report includes a print file of the map and of the text that accompanied the original map (Carter and Galloway, 1985), as well as links to GIS files for the map. These digital geologic products provide a scientific foundation that can be integrated with other datasets to support decisions pertaining to surface activities in northeastern NPRA.

Complementary maps of a high-priority area within the Harrison Bay quadrangle also are being released (Mars and others, 2005). Those maps, published at a scale of 1:63,360, include a Digital Terrain Model based on 5-meter-resolution IFSAR (Interferometric Synthetic Aperture Radar) data, a surface classification map based on 30-meter-resolution Landsat 7 ETM+ data, and a shaded-relief surface-classification map (generated by fusing the IFSAR and ETM+ datasets).

[1] U.S. Geological Survey, Reston, VA
[2] U.S. Bureau of Land Management, Fairbanks, AK

Engineering Geologic Maps of Northern Alaska, Harrison Bay Quadrangle[3]

By L. David Carter[4] and John P. Galloway[5]

Introduction

Purpose

The purpose of this report is to present information concerning the surficial deposits and bedrock of the onshore part of the Harrison Bay Quadrangle that will be useful in making environmentally sound land management decisions. In addition, this report presents a summary of the depositional history of bedrock and unconsolidated deposits exposed in the Harrison Bay Quadrangle. Information pertinent to land management decisions is presented on maps and in tabular form on sheets 1 and 2, and the list of references following the text will lead the reader to additional sources of information regarding the geologic environment of the Harrison Bay Quadrangle.

General Setting

The Harrison Bay Quadrangle is bounded by latitudes 70° and 71° North and longitudes 150° and 153° West. About 8,020 km^2 or slightly more than half the total area is land and the remainder is occupied by the Beaufort Sea and its embayments. The principal settlement is the village of Nuiqsut, a town of about 320 people located on the west bank of Nechelik Channel, which is the westernmost distributary of the Colville River delta. Colville Village, a smaller settlement, is on Anachlik Island on the east side of the Colville River delta. Gravel airstrips are present at both settlements and commercial air service is available to Nuiqsut.

The Harrison Bay Quadrangle lies entirely within the Arctic Coastal Plain physiographic province (Wahrhaftig, 1965). Most of the map area is within the Teshekpuk Lake section of the Arctic Coastal Plain, which is a flat to gently rolling tundra-covered surface with numerous thaw lakes. The maximum altitude in the Teshekpuk Lake section is about 60 m and occurs in the southeast part of the quadrangle in an area of large, stabilized dunes. The altitudes of topographic highs gradually decrease northward, and at the coast the maximum altitudes range from 1 to 7 m at the tops of low coastal bluffs. A portion of the White Hills section of the Arctic Coastal Plain occurs in the southeast corner of the quadrangle, and is the extreme northern part of a broad, northeast-sloping plateau. The edge of the plateau in the Harrison Bay Quadrangle is a degraded, northeast trending bluff, the base of which is at an altitude of about 60 m. The plateau surface, which contains scattered thaw lakes, reaches a maximum altitude of about 125 m.

The major drainageways within the quadrangle are the Colville and Itkillik Rivers, which head in the Brooks Range. Both rivers flow within a single broad valley which at the south edge of the map is incised 35 to 40 m below the adjacent terrain. The Itkillik River joins the Colville River near the head of the Colville River delta. Streams within the Harrison Bay Quadrangle east of the valley of the Colville and Itkillik Rivers head on the coastal plain; streams west of the Colville River head on the coastal plain or in the Arctic Foothills.

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[3] Re-release of Open-File Report 85-256
[4] Anchorage, Alaska
[5] Menlo Park, California

Details of the topography are given under Topography and Drainage in the description of map units for this report. Information about the history of landscape development is incorporated in later sections.

Previous Work

The earliest geologic investigations were carried out by Schrader (1904) during a traverse across the Brooks Range, down the Anaktuvuk and Colville Rivers, and along the arctic coast to Cape Lisburne. Leffingwell (1919) made geologic observations along the Beaufort Sea coast, and summarized the observations of others who traveled the coast between 1826 and 1912. Smith and Mertie (1930) prepared a regional report on the geology of northwestern Alaska.

From 1944 to 1953 the U.S. Geological Survey aided the U.S. Navy in evaluating the resources of what was then called Naval Petroleum Reserve No. 4 (Reed, 1958), which included the part of the Harrison Bay Quadrangle west of the Colville River. Regional reports and maps based on these studies were prepared by Gryc and others (1951), Payne and others (1951), and by Lathram (1965). The geology of a part of the Harrison Bay Quadrangle was described by Brosgé and Whittington (1966). An examination of the unconsolidated deposits of the Petroleum Reserve and adjacent areas was carried out in 1949-50 by Black (1964).

Between the time of Black's fieldwork and the publication of his report, a study of the Quaternary geology of the Arctic Coastal Plain was carried out by O'Sullivan (1961). Interpretations of the late Cenozoic sea level history of the Arctic Coastal Plain are contained in O'Sullivan (1961), Black (1964), McCulloch (1967), Hopkins (1967), Sellmann and Brown (1973), Brigham (1983, 1984), and Carter and Brigham-Grette (in press).

For the past 20 years, research on the Colville River drainage basin and delta has been carried out by H.J. Walker of Louisiana State University and his students and colleagues (Walker, 1983).

With the passage of Public Law 94-258, the National Petroleum Reserve Act of 1976, Naval Petroleum Reserve No. 4 was renamed National Petroleum Reserve- Alaska (NPRA) and was placed under the jurisdiction of the Department of the Interior. An evaluation of the potential environmental impacts of oil and gas development was published by the Department of the Interior in 1979 (U.S. Department of Interior, 1979). The U.S. Geological Survey was assigned responsibility for exploration for oil and gas, and carried out an exploration program during 1976-81 (Bird, 1981a).

This Study

This report presents information obtained by fieldwork during the summers of 1977-1984. Fieldwork during 1977 and 1978 was done in support of Chapters 105b (Environmental Impact Assessment) and 105c (Land Use Study) of the National Petroleum Reserve Act of 1976 (PL 94-258). From 1979 through 1981 fieldwork was carried out as part of the U.S. Geological Survey's Arctic Environmental Studies Program, and in 1984 fieldwork was supported by the Survey's Branch of Oil and Gas Resources. Fieldwork in 1982 and 1983 and the production of this report was done as part of the Northern Alaska Engineering Geology Project, for the purpose of providing engineering/surficial geologic information to the Minerals Management Service and the Bureau of Land Management.

Information on the subsurface geology of the Harrison Bay Quadrangle is contained in a number of reports that detail the Geological Survey's investigations in the National Petroleum Reserve in Alaska (Hittelman, 1982). This report concerns only the rocks and sediments visible in surface exposures, which occur in stream, lake, and coastal bluffs.

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Marincovich, Jr. (marine mollusks), K. A. McDougall (benthic foraminifers), J. R. O'Neil (oxygen isotope analyses), V. L. Pease and J. W. Hillhouse (paleomagnetic analyses), C.A. Repenning (marine and terrestrial vertebrates), and S. W. Robinson (radiocarbon dating). Fossil wood was identified by D. J. Christensen of the U.S. Department of Agriculture, Forest Products Laboratory. Amino acid analyses were performed by G. H. Miller at the Amino Acid Geochronology Laboratory of the Institute of Arctic and Alpine Research, University of Colorado. Thermoluminescence dating was done by Alpha Analytic, Inc., and radiocarbon dating of some samples was carried out by Teledyne Isotopes, Inc.

We thank 0. J. Ferrians, Jr., and W. E. Yeend for critical reviews of the entire report. T. A. Ager, E.M. Brouwers, D. M. Hopkins, Louie Marincovich, Jr., and C. A. Repenning provided comments which helped improve parts of the text. However, in some instances our interpretations differ sharply from one or more of these scientists, and we bear all responsibility for any errors of interpretation that remain, or for any omissions in assigning credit to others for ideas and interpretations.

Depositional History

The Harrison Bay Quadrangle contains sedimentary deposits that range in age from Cretaceous to Holocene and record an interesting geologic history that has been only partly determined. The sediments accumulated in a variety of depositional environments under contrasting climatic regimes, and sediment sources were at various times the Brooks Range, the Canadian Arctic, and an undetermined provenance.

West of the Colville River valley only upper Cenozoic unconsolidated deposits are exposed, except for one locality on the Ublutuoch River where sediments of the Tertiary Sagavanirktok Formation are exposed. In the bluffs on the west side of the Colville River, unconsolidated deposits unconformably overlie the Cretaceous Prince Creek Formation and the Sagavanirktok Formation.

East of the Colville River the Sagavanirktok Formation is exposed beneath unconsolidated deposits in valleys that incise the White Hills section of the Arctic Coastal Plain, and, to the north, in a few cutbanks of the Kachemach and Miluveach Rivers. Elsewhere, only unconsolidated deposits are exposed.

Bedrock

Prince Creek Formation

The oldest deposits exposed in the Harrison Bay quadrangle are nonmarine deltaic beds (Kp) which form part of the type section for the Kogasukruk Tongue of the Prince Creek Formation (Brosgé and Whittington, 1966). These rocks dip less than 5° to the northeast and are exposed in bluffs along the west side of the Colville River from the south margin of the quadrangle north for about 12 km. A fission track age of 50.9 +/- 7.7 Ma was obtained on a tephra from these beds (Carter and others, 1977). However, this age is now questioned owing to the discovery of Hadrosaurian (duck-billed) dinosaur remains stratigraphically above the tephra (Carter, unpublished data, 1984; Davies, in press), because dinosaurs are unknown from post-Cretaceous deposits. Although, as inferred by Gryc (1951), Late Cretaceous seems the most likely age for these deposits, the tephra is being redated to further evaluate the possibility that the dinosaur remains are Tertiary.

Sagavanirktok Formation

The Sagavanirktok Formation includes three formally named members and was defined to include all Tertiary deposits above the Prince Creek Formation and below the Gubik Formation (Detterman and others, 1975). Deposits of the Harrison Bay quadrangle that we assign to the Sagavanirktok Formation are of marine and nonmarine origin. However, we have not assigned these deposits to the formally defined marine and nonmarine members of the Sagavanirktok Formation because the Harrison Bay deposits differ from the formally defined members in terms of age, fauna, gravel-clast rock types, and environments of deposition. Only the youngest of the Harrison Bay deposits is informally named.

Unnamed Marine Deposits

Nearly flat-lying marine strata conformably or disconformably overlie the deltaic deposits of the Prince Creek Formation, and are well exposed in the Colville River bluffs from their contact with the Prince Creek Formation downstream to the end of continuous bluff exposures near Ocean Point.

The age of the marine beds is controversial. MacBeth and Schmidt (1973) first reported marine deposits near Ocean Point and examined the benthic foraminifers in them. They assigned the beds a Campanian age and referred them to the Schrader Bluff Formation, which intertongues with the Prince Creek Formation in other areas. The foraminifers are now thought to be younger (Carter and others, 1977) but have not been studied in detail. Palynological data have been interpreted to indicate a late Cretaceous age (Frederiksen and others, in press). However, marine mollusk and ostracode faunas have been interpreted to indicate a Paleocene to early Eocene (Thanetian to Ypresian) age (Marincovich and others, 1983; Brouwers and others, 1984; Marincovich and others, in press). Palynological data cited below for younger deposits indicate that the marine strata can be no younger than Paleocene. We tentatively accept a Paleocene age and assign these beds to the Sagavanirktok Formation.

The Ocean Point marine beds are important because they contain a unique fauna that suggests unusual environmental conditions and has implications for Arctic Ocean paleogeography and faunal evolution. The mollusk and ostracode faunas are strongly endemic, with only one species in each group known from faunas elsewhere, which suggests nearly complete isolation of the Arctic Ocean during late Cretaceous and early Tertiary time (Marincovich and others, in press). Further, among the genera with well-known stratigraphic ranges in other regions, some are reported only in Cretaceous and older faunas, some only in Paleogene faunas, and others only in Neogene-Quaternary faunas. New taxa may have evolved in an isolated Arctic Ocean and later migrated to the northern mid-latitudes.

Unnamed Nonmarine Deposits

Nonmarine deposits (Tsg) which we infer to overlie the marine strata are poorly exposed in the Colville River bluffs at several localities north of Ocean Point. Deposits which we correlate with these beds on the basis of gravel-clast rock types and/or similar pollen assemblages are exposed on the Ublutuoch River west of Nuiqsut, and on the Miluveach and Kachemach Rivers east of the Colville River. The deposits consist of moderately to poorly consolidated conglomerate, sand, gravelly sand, and pebbly shale with thin coal beds and locally common lignitized logs.

Many gravel clasts are composed of rock types which do not occur in nearby parts of the Brooks Range, including schist, augen gneiss or gneissic granite, granitic rocks, greisen, rhyolite, rhyolite tuff, and andesite. Clasts of these rock types as large as 1.2 m in diameter occur along the base of the bluffs containing the exposures, and some clasts have faceted shapes characteristic of glacially transported stones (Wentworth, 1936). The nearest possible source for some of the rock types is the Romanzof Mountains, which are 200 km to the east. Transportation of the exotic clasts to the Harrison Bay area by icebergs is unlikely because the deposits are nonmarine. Older deposits in the Harrison Bay area are not known to contain clasts of these rock types, so redeposition also seems unlikely as an explanation for the origin of the clasts. Determination of the source and path of transport for these clasts will certainly aid in understanding the early Tertiary paleogeography and paleoclimate of the North Slope.

Fungal spores from the deposits indicate a latest Paleocene-earliest Eocene age (J. Lentin, written communication, 1984), whereas pollen assemblages contain taxa characteristic of the lowest preserved Paleocene assemblages of Siberia and northwest Canada (Frederiksen and others, in press). According to T.A. Ager (written communication, 1985), "The pollen assemblages from the deposit contain a rich assemblage of conifer pollen types, along with several types of broadleaf deciduous tree and shrub pollen. Taxa represented include Taxodiaceae (probably <u>Metasequoia</u> and/or <u>Glyptostrobus</u>). Pinaceae (e.g., <u>Picea</u>, <u>Larix</u> type, <u>Pinus</u>), <u>Podocarpus</u>, Ulmaceae, Betulaceae, Ericales, <u>Sphagnum</u>, and several types of fern spores". And, "Reconstruction of Paleocene vegetation and climate is tenuous because of the uncertain taxonomic affinities of some pollen types, and because of the probable unreliability of applying environmental requirements of modern representatives of taxa identified in fossil assemblages of such antiquity. In broad terms, the fossil pollen and spore assemblage suggests conifer forests with a significant deciduous broadleaf component. Understory vegetation probably included <u>Alnus</u> shrubs, ferns, and <u>Sphagnum</u> may have been a significant component of the ground cover. Climate was probably temperate and moist".

At the sites sampled for pollen, exotic rock types were generally present but boulders larger than 50 cm in diameter were not observed. Perhaps the largest boulders, which we believe required glacial ice for long-distance transport, were deposited during relatively brief intervals of severe climate. If glaciation proves to have been contemporaneous with the formation of these deposits, then the sediments may have formed during a relative low stand of the sea or during a period of sea level lowering. Considering the evidence of the pollen and fungal spores, likely times for deposition would have been either the middle Paleocene or early Eocene low stands of sea level and interregional unconformities recognized by Vail and others (1984).

Kuparuk Gravel

The next youngest deposit is pebble, cobble, and boulder gravel (Tg) which has been informally referred to as the Kuparuk gravel (Carter, 1983d). This resistant unit forms bluffs on the upper slopes of valleys cut into the plateau that is part of the White Hills section of the Arctic Coastal Plain.

The age of the Kuparuk gravel is poorly known. It overlies the Paleogene deposits described above and is truncated by a bluff which we infer was formed by coastal erosion during one of the two oldest marine transgressions recorded by deposits of the Gubik Formation. These transgressions occurred during Pliocene time, most likely between 2.4 and 3.5 Ma (Carter and Brigham-Grette, in press and this report). Also, the Kuparuk gravel is older than fluvial terraces which are associated with erratics of the late Tertiary Gunsight Mountain glacial interval described by Hamilton (1979).

Exposures of the Kuparuk gravel are poor and few sedimentary structures have been observed. At one locality, clasts are supported within a clayey sand to silty sand matrix and no clast imbrication is discernable. The deposit at this site is best described as a diamicton. Gravel clasts are composed of resistant rock types common in the nearest parts of the Brooks Range including chert, quartz, quartzite, chert-pebble conglomerate, and siliceous sandstone. Clast size varies widely from place to place, and at some localities clasts as large as 1.5 m in diameter are common. The largest boulder observed was 10 m in diameter. Although no striated surfaces have been observed on these clasts, they are certainly glacial erratics and demonstrate that a Tertiary ice advance from the Brooks Range reached much farther north than previously supposed.

Unconsolidated Deposits

Unconsolidated deposits of marine, fluvial, eolian, colluvial, and lacustrine origin mantle bedrock in the Harrison Bay Quadrangle. The unconsolidated deposits exposed in the bluffs that form the west bank of the Colville River in the Harrison Bay Quadrangle are part of the type section of the Gubik Formation (Gryc and others, 1951). The Gubik Formation was defined by Gryc and others (1951) as including the unconsolidated deposits of the Arctic Coastal Plain that are of Pleistocene age, but Black (1964) broadened the definition to include Holocene deposits, and marine deposits that form part of the type section are now known to be Pliocene (Repenning, 1983). Glaciomarine deposits which were previously referred to as the Flaxman Formation (Leffingwell, 1919) recently have been reduced to member status within the Gubik Formation (Dinter, in press). Thus the Gubik Formation presently includes all unconsolidated deposits of Pliocene and Quaternary age on the Arctic Coastal Plain.

Marine Deposits

Deposits of at least six late Cenozoic marine transgressions occur within the Harrison Bay Quadrangle (table 1). We correlate one of these with the Pelukian transgression (Hopkins, 1967). The other transgressions, which cannot be securely correlated with transgressions defined by Hopkins, were recently named (oldest to youngest) the Colvillian, Bigbendian, Fishcreekian, Wainwrightian, and Simpsonian transgressions by Carter and Brigham-Grette (in press). Deposits of the three oldest transgressions are probably Pliocene and can be differentiated and correlated across the coastal plain by comparing the extent of epimerization of isoleucine (Ile) to alloisoleucine (AIle) in fossil mollusks (table 1). Deposits of the Pelukian and Simpsonian transgressions are late Pleistocene and have been dated by thermoluminescence (TL). Deposits formed between the Pelukian and

Fishcreekian transgression and dated by TL as older than 158 ka are questionably correlated with the middle Pleistocene Wainwrightian transgression.

Between the Colville and Kuparuk Rivers, late Cenozoic marine fossils have not been found south of the highly degraded bluff that truncates the Kuparuk gravel. The break in slope at the base of this bluff occurs at an altitude of about 60 m and is inferred to mark the maximum altitude reached by late Cenozoic marine transgressions on this part of the coastal plain. Present data indicate that this limit relates to either the Colvillian or Bigbendian transgression, but are inconclusive as to which of these transgressions reached the highest altitude.

Colvillian

Deposits of the Colvillian and Bigbendian transgressions generally form the basal 2 to 5 m of map unit QTas, which coincides with the "landform referred to as Terrace I by Carter and Galloway (1982). Except for one locality on the Miluveach River where the deposits of these two transgressions are superposed and separated by an unconformity, differentiation of the deposits generally requires determination of AIle/Ile values for fossil mollusks. Valves of Hiate1la arctica from Colvillian deposits yield AIle/Ile values of .236 +/- .022, whereas those from Bigbendian deposits give AIle/Ile values of .136 +/- .014.

Colvillian deposits extend to altitudes of at least 40 m and are well exposed in bluffs along the Colville River from the south edge of the Harrison Bay Quadrangle north for about 10 km. They unconformably overlie Cretaceous or lower Tertiary strata throughout the extent of the exposures, and they generally are overlain by unconsolidated fluvial deposits. However, at one locality they are overlain by 1 to 1.5 m of Bigbendian deposits. Along this part of the bluffs, a femur of the North Atlantic harp seal (Pagophilus groenlandica) was found as float (Repenning, 1983), and could have been derived from either Colvillian or Bigbendian deposits. When Repenning's paper was written, the presence of marine deposits of two ages in the Colville River bluffs had not been established by amino acid geochemistry and it was assumed that the harp seal was from beds correlative with the Bigbendian II deposits near Ocean Point.

Cobbles and boulders locally occur at the base of Colvillian deposits. Rock types present include those characteristic of the Kuparuk gravel (Tg) and those which occur in the Paleogene conglomerate (Tsg). The simplest explanation for the occurrence of these clasts at the base of the Colvillian deposits is that they were incorporated by erosion of the Kuparuk gravel and Paleogene conglomerate during the Colvillian transgression. Some boulders derived from the Paleogene conglomerate occur 15 to 20 km southwest of the nearest outcrop of these deposits, perhaps indicating that the boulders were transported shoreward by sea ice.

Mollusks from deposits of the Colvillian transgression form a diverse assemblage that includes the extinct whelk Neptunia Lyrata leffingwelli (L. Marincovich, Jr., written communication, 1984). The fauna includes taxa of Pacific origin and thus post-dates the opening of Bering Strait, which occurred between 3 and 3.5 m.y. ago (Hopkins, 1972; Gladenkov, 1981). The Colvillian transgression may correlate with Hopkins' (1967) Beringian transgression as defined for the type locality at Nome.

Bigbendian

Deposits of the Bigbendian transgression are best exposed in bluffs along the Colville River from near Ocean Point upstream for about 10 km, where they consist of a basal, transgressive, gravelly beach sand about 1 m thick overlain by about 4 m of well-bedded sandy silt. The basal bed contains cobbles and boulders like those described for Colvillian deposits. The maximum altitude at which Bigbendian deposits have been identified is about 35 m.

Pollen spectra from Bigbendian beds indicate that nearby vegetation was probably coniferous forest dominated by spruce and with significant amounts of tree birch and minor pine and fir, somewhat similar to the modern Anchorage area (Nelson, 1981; Nelson and Carter, in press). If this analogy is correct then permafrost was at most discontinuous and limited to north-facing slopes. A relatively mild climate is also suggested by the presence of sea otter (Enhydra?) remains (Repenning, 1983 and written communication, 1985) and by the mollusk fauna, which is richer than the Colvillian fauna and includes the gastropod Littorina squalida (J. Rosewater, written communication to L. Marincovich, Jr., 1984) and the bivalve Clinocardium californiense (Deshayes) (L.

Transgression	Maximum Elevation Reached (m)	Age	Alle/Ile[1] Colville River/ Fish Creek Area	Alle/Ile[1] Chukchi Sea Coast Area[2]	Tentative Correlation with Hopkins (1967)
Simpsonian	7	70 Ka to 80 Ka	-	-	-
Pelukian	10	120 Ka to 130 Ka	-	.014 +/- .002	Pelukian
Wainwrightian?	20	> 158 Ka	-	.038 +/- .007	-
Fishcreekian	25	1.87 Ma to 2.48 Ma	.086 +/- .004 (6)[3]	.090 +/- .018	-
Bigbendian	> 35, < 60	> 2.48 Ma	.136 +/- .014 (12)[3]	.150 +/- .025	Anvillian
Colvillian	> 40, < 60	< 3.5 Ma	.236 +/- .022 (8)[3]	.235 +/- .017	Beringian

[1] Ratios for the total fraction of Hiatella artica.
[2] From Brigham, 1985.
[3] Number of analyses.

Table 1. Marine transgressions of the Harrison Bay Quadrangle

Marincovich, Jr., personal communication, 1985). The modern northern limit of both mollusk taxa is Bering Strait. Modern sea otters cannot tolerate severe sea ice conditions (Schneider and Faro, 1975), and the presence of sea otter remains suggests that the Beaufort Sea was at best seasonally frozen during the Bigbendian transgression.

Carter and Galloway (1982) proposed that the Bigbendian deposits correlate with Hopkins' (1967) Anvilian transgression, but Repenning (1983) referred them to Hopkins' second Beringian transgression. Both suggestions may be correct inasmuch as D.M. Hopkins (written communication, 1985) now believes that the marine deposits on St. George Island which he proposed formed during a second. Beringian transgression may instead represent the Anvilian transgression. The marine deposits on St. George Island have a minimum age of 2.19 Ma (Hopkins, 1967, fig. 3). Repenning (1983) indicated a possible age of between 1.7 and 2.6 Ma for the marine deposits near Ocean Point based on the stage of evolution exhibited by the fossil sea otter remains. However, he favored an age of between 1.7 and 2.2 Ma because he considered the period 2.2 to 2.6 Ma to be an unlikely time for the transgression based on Shackelton and Opdyke's (1977) conclusion that the first major accumulation of continental ice in the northern hemisphere occurred between about 2.2 and 2.4 Ma. We think it more probable that the Bigbendian transgression preceded this climatic deterioration and occurred between 2.4 and 2.6 Ma.

Fishcreekian

The Fishcreekian transgression is named for fossiliferous deposits exposed along the north side of Fish Creek (Carter and others, 1979) where cut banks expose marine beds beneath the eolian sand of map unit Qe. Hiatella arctica from these sediments yield AIle/Ile values of .086 +/- .004 (table 1). Other deposits that may be equivalent to the marine beds underlie the fluvial deposits of map unit Qam and occur beneath the eolian deposits of the southern part of map unit Qem.

The Fish Creek locality is particularly important because sedimentary structures and fossil mollusks at this site define the position of relative sea level during a part of this high sea-level event, and several mollusk taxa allow conclusions to be drawn about the paleoenvironment. Further, measurements of magnetic polarity, and marine vertebrate and invertebrate fossils provide constraints on the interpretation of the age of the transgression.

From the base upwards, the deposits at this locality consist of 3 to 4 m of distinctly to indistinctly bedded dark-gray silt (unit 1) containing scattered granules of chert and quartz, sparse sand interbeds and sand-filled burrows, scattered mollusk fragments, and a few thin woody stems. Overlying the silt is 5 to 9 m of fossiliferous, brown to gray sand, pebbly sand, and silt (unit 2) that is predominantly trough cross-bedded but includes evenly bedded zones which are relatively thin and discontinuous. Detrital wood and comminuted organic debris are common. Above this is 6 to 7.5 m of poorly exposed, brown, locally cross-bedded sand to pebbly sand (unit 3) that contains scattered shell fragments. Capping the bluff is 8 m of eolian sand (unit 4). Units 3 and 4 are nonmarine deposits which post-date the Fishcreekian transgression.

On the basis of the lithology, stratigraphy, and faunas of the deposits, Carter and others (1979) proposed that units 1 and 2 were part of a bay-or estuary-mouth system which formed while sea level was about 20 or 22 m above present mean sea level. This altitude is coincident with that at the base of a wave-cut scarp 30 km east of Fish Creek and 5 km west of the Colville River delta, and Carter and others (1979) inferred that the Fish Creek deposits and the wave-cut scarp were part of the same coastal system. The scarp truncates the land-form (Terrace I of Carter and Galloway, 1982) beneath which the deposits of the Colvillian and Bigbendian transgressions occur, and correlation of the scarp and the Fish Creek deposits is in agreement with the sequence of marine transgressions indicated by AIle/Ile measurements on marine mollusks, evidence for minimum sea level positions during the two older transgressions, and superpositional relations along the Chukchi Sea coast (Brigham, 1984).

We continue to support these conclusions but have refined our interpretation of depositional environments. Unit 2 was initially interpreted as a beach deposit, but further studies of the sedimentary structures indicate that the deposits formed in a tidal channel. A strong dominant current is indicated by sets of large-scale cross-strata as thick as 4 m, which have consistent fore-set dips to the north-northeast. A nearly opposed subordinant current is indicated by ripple stratification which climbs up the dip of the fore-set beds, and by sets of medium scale cross-strata which have fore set dips nearly opposed to those of the large scale sets. Detrital organic debris and silt occur as laminae and thin strata which separate sand beds of the fore-sets, and are interpreted as slack water deposits formed at high tide. The north-northeast-setting dominant current suggests that ebb flow was responsible for most sedimentary structures at this locality. Inasmuch as the Beaufort Sea is microtidal now and probably was when these deposits formed, the bedforms preserved were probably continuously subaqueous during their formation. The ostracode fauna reported in Carter and others (1979), which includes both marine and nonmarine ostracodes, supports the interpretation of unit 2 as forming in a tidal channel.

Ostracodes reported from unit 1 by Carter and others (1979) indicate a nearshore marine or marginal marine environment as would be expected for fine- grained, possibly estuarine sediments associated with tidal channel deposits. More recent collections by E.M. Brouwers (written communication, 1984) contain the fresh water ostracode Cytherissa lacustris (Sars, 1863), which we feel supports this interpretation, but also includes an undescribed and extinct species of Pterygocythereis, a genus which today is not commonly found in the environments inhabited by the other taxa reported from this unit. Rather, modern Pterygocythereis species are confined to the Atlantic Ocean and are most common in middle to outer shelf water depths (E. Brouwers, written communication, 1985). In spite of the presence of Pterygocythereis, we interpret unit 1 as having formed by rapid sedimentation in a nearshore, shallow water environment on the basis of the other ostracode taxa, and for the following additional reasons: (1) the presence of several species of benthic foraminifers (Elphidium excavatum alba Feyling-Hansen, Elphidium friqidum Cushman, and Elphidium orbicularis Brady), all of which tolerate relatively low salinities and are most common at water depths of less than 10m, and one of which (Elphidium orbicularis) is common off river mouths (K. A. McDougall, personal communication, 1985), (2) an absence of dinoflagellates (T.A. Ager, personal communication, 1985), (3) the paucity of ostracodes (8 valves and 2 fragments from 10 samples) (E. Brouwers, written communication, 1979 and 1984), (4) the absence of whole valves of marine mollusks, (5) the abundance of plant debris, including woody stems, (6) the presence of coarse laminae (sand and granules) that contain woody plant debris and comminuted, thin, very fragile shell fragments (fresh water?), and (7) the presence of freshwater algal types, which in one sample represent about 10% of the pollen and spore sum (T.A. Ager, personal communication, 1985).

Marine mammal remains and several mollusk taxa provide information about the marine environment during the Fishcreekian transgression. In 1978 a femur of Enhydra? was collected by us, and later collections contained a molar of Enhydra? (C.R. Repenning, written communication, 1985). The occurrence of sea otter suggests that during the Fishcreekian transgression the Arctic Ocean was ice-free or only seasonally frozen as it was during the Bigbendian transgression. A warmer sea than today is also indicated by the presence of the bivalve Clinocardium californiense, whose modern northern limit is Norton Sound, and the gastropods Aforia circinata. and Littorina squalida which presently range no farther north than Bering Sea (L. Marincovich, Jr., written communication, 1984). Pollen assemblages from units 1 and 2 and detrital wood from unit 2 provide evidence for terrestrial conditions during deposition of these beds.

Pollen assemblages were analyzed by T.A. Ager (written communication, 1985). Some samples from both units could not be interpreted due to an absence of pollen or extensive reworking of older pollen. Thus it is not possible to reconstruct vegetation conditions for some of the interval represented by the deposits. However, those samples from unit 2 which contained interpretable assemblages are dominated by pollen of herbaceous taxa (sedges, grasses, and composites), but contain pollen of Betula (probably dwarf birch), and Ericaceae (e.g. blueberries), and small amounts of Alnus (alder), Picea (spruce), and Pinus (pine). The last three are interpreted to be present as a result of long-distance transport and/or reworking. Small amounts of Larix (larch) pollen are also present, and wood from this unit has been identified as Larix (D.J. Christensen, written communication, 1985), indicating that larch was present nearby. Accordingly, we interpret the vegetation to have been shrub-herb tundra with scattered larch trees or a larch taiga similar to the modern vegetation of parts of northeastern Siberia.

Those samples from unit 1 which contain interpretable pollen assemblages have assemblages similar to those of unit 2, except for higher amounts of Betula pollen and generally higher amounts of Picea and Pinus pollen. In two samples, pollen from spruce and pine together make up from 17% to 20% of the total pollen and spores, whereas in samples from unit 2 they compose from 2.5%to 8% of the total. This suggests that either spruce and pine were growing closer to the site during the deposition of unit 1, or that regional wind conditions were different, or both (T.A. Ager, personal communication, 1985).

The difference in pollen assemblages between the two units suggests the possibility that they are of different ages. However, we think it most probable that both units formed during the same transgression, and that during this transgression there were minor changes in climate and vegetation. We draw this conclusion because of paleomagnetic data presented below, and because 3 km upstream on Fish Creek, marine mud exposed at the same altitude as unit 1 contain paired valves of Hiatella arctica (L. Marincovich, written communication, 1979) which yield the same amino acid ratios-as those for H. arctica from the tidal channel deposits (unit 2) which overlie unit 1.

The pollen assemblages from the tidal channel deposits (unit 2) are similar to those from the late Pliocene or early Pleistocene Cape Deceit Formation (Gitterman and others, 1982), and suggest a severe terrestrial climate. This is in marked contrast to the conditions indicated for the marine realm. A relatively warm ocean adjacent to a cold land provides conditions favorable for the build-up of ice sheets (Ruddiman and Mclntyre, 1979), and it is possible that the Fishcreekian transgression, even though it occurred during an interglacial interval, was coincident with glaciation in the Brooks Range and in the Canadian Arctic. Hamilton (1981) proposed that a northern moisture source nourished glaciers in the Brooks Range during the Gunsight Mountain glacial interval, and perhaps this ice advance was coincident with or closely related in time to the Fishcreekian transgression. The informally named Tuapaktushak beds exposed along the Chukchi Sea coast (Brigham, 1984) and correlated by amino acid geochemistry with the Fish Creek deposits (Carter and Brigham-Grette, in press) contain dropstones and exhibit deformational structures and striated boulder pavements that D.M. Hopkins (personal communication, 1984) believes could have been produced by stranded icebergs.

Paleomagnetic analyses were made on 20 samples from units 1 and 2 at Fish Creek. Five of the determinations are considered unreliable because of unreasonable declinations. The remaining samples were directionally stable and indicate reversed polarity (V.Pease, written communication, 1985). The fact that both units 1 and 2 possess reversed polarity supports the conclusion that both units formed during the same transgression. Paleomagnetic analyses also were attempted for deposits of the Colvillian and Bigbendian transgressions but polarity could not be determined.

Consideration of the sequence of marine transgressions, the paleomagnetic evidence, the palynological data, and the marine fauna leads to the conclusion that the Fishcreekian transgression occurred between 1.87 and 2.48 Ma. The Fishcreekian transgression is younger than the Bigbendian transgression, which, if Repenning (1983) is correct, occurred no more than 2.6 Ma. Because the Fish Creek deposits have reversed magnetic polarity, they must have formed during the Matuyama Superchron and they can be no older than 2.48 Ma. The pollen data support this conclusion, when considered in the light of data from elsewhere. For example, Zagwijn (1974) has shown that there was a dramatic change in vegetational type in the Netherlands as a result of climatic cooling near the Gauss-Matuyama boundary. At about the same time (2.5 Ma), Shackelton and others (1984) report a brief ice rafting episode in the North Atlantic which was followed by a major glacial event about 2.37 Ma. This sequence of climatic deterioration is similar to that inferred from Pacific Ocean deep sea cores (Shackelton and Opdyke, 1977), the terrestrial record on New Zealand (Stipp and others, 1967), and data from the Gulf of Mexico (Beard and others, 1982). Climatic cooling at this time appears to have been world-wide, and we think it unlikely that tundra or larch taiga vegetation would have been present during an interglacial interval on the Arctic Coastal Plain prior to the start of this cooling event.

The Enhydra? molar recovered from the Fish Creek tidal channel deposits exhibits a stage of evolution comparable to the Enhydra? from Ocean Point (C.A. Repenning, personal communication, 1985) and therefore is most likely no younger than 1.7 Ma (Repenning, 1983). This conclusion is supported by the mollusk fauna, which has a boreal aspect and is more similar in this respect to the fauna of the Tjornes beds of Iceland than to that of the lower Breidavik beds which overlie them. The lower Breidavik beds contain mollusk faunas of a more arctic aspect and are interbedded with tillites. According to Gladenkov (1981, Table 2) the base of the Breidavik beds occurs just above the Olduvai Chron (referred to by him as the Gilsa event) and the top of the Tjornes deposits is about 2 Ma. Thus both the mollusks and the marine vertebrate fauna suggest that the Fishcreekian transgression occurred prior to the Olduvai Chron, which began about 1.87 Ma.

We think it most probable that this high sea level event corresponds to one of the O^{18} minima recorded in deep sea cores. In the North Atlantic Ocean, significant O^{18} minima within the Matuyama Superchron and prior to the Olduvai Chron occurred at about 2.15, 2.25, and 2.41 Ma (Shackleton and others, 1984). The oldest of these post-dates the first evidence of climatic cooling and immediately predates the first major glacial episode, and we tentatively correlate the Fishcreekian transgression with this O^{18} minimum.

Wainwrightian?

Glaciomarine deposits similar to the Flaxman Member of the Gubik Formation, which is described below, have been dated by TL as older than 158 ka. These deposits occur beneath eolian sand in the northern part of map unit Qem. They most likely represent a Simpsonian-type transgression that occurred before the Pelukian transgression (Carter, 1983d). However, they may be an offshore facies formed during the Wainwrightian transgression (Carter and Brigham-Grette, in press)

Pelukian

The Pelukian transgression was defined by Hopkins (1967) as occurring during the last interglacial interval and producing shoreline features and deposits a few meters above present sea level that can be traced discontinuously around the coast of western and northern Alaska. Beach deposits of last interglacial age in the Harrison Bay Quadrangle are exposed in bluffs along the north shore of Teshekpuk Lake and can be traced eastward to Harrison Bay and northwestward to near Barrow. These deposits occur at altitudes that range from 1 m at their base to perhaps as much as 10 m at their top. In the Harrison Bay Quadrangle, these deposits occur along the north edge of map unit Qs, where they overlie marine mud and are disconformably overlain by lacustrine or deltaic deposits and by eolian sand. Spruce driftwood is common locally in the deposits and the foraminifera and ostracode faunas indicate more open water and warmer climatic conditions than presently prevail (Hopkins and others, 1981). Amino acid ratios determined for the bivalve Hiatella arctica are barely distinguishable from those determined for modern specimens (Brigham, 1983), and preclude an age greater than the last interglacial episode. Oxygen isotope analyses of the bivalve Astarte borealis show that their O^{18} content is about the same as that of modern A. borealis shells (J.R. O'Neil, written communication, 1984), suggesting a correlation with oxygen isotope stage 5e. This correlation is supported by seven TL dates on the beach deposits and underlying muds that range from 108.5 ka to 140 ka and average 123.5 ka. The altitude of beach deposits formed during the Pelukian transgression is about the same as that estimated for the eustatic high-stand during isotope stage 5e based on evidence from oceanic islands and other continental shelves (Cronin and others, 1981), and suggests that this part of the western Arctic Coastal Plain has been tectonically stable for the past 125,000 years. The Pelukian transgression can be confidently correlated with the informally named Walakpa beds of the Chukchi Sea coast (Brigham, 1983).

Simpsonian

The Simpsonian transgression is defined as the transgression during which the Flaxman Member of the Gubik Formation was deposited. The Flaxman Member occurs locally along the Beaufort Sea coast to altitudes of about 7 m. In the Harrison Bay Quadrangle these deposits form the upper part of map unit Qm. They consist of a few meters of glaciomarine erratic-bearing silt, clayey silt, and si1ty sand, and they are overlain locally by regressive sand, beach, deltaic, or fluvial deposits. The erratic stones are of Canadian provenance and rock types include dolomite, diabase, pyroxenite, granite, and quartzite (McCarthy, 1958). Erratics occur to within a few hundred meters of the southern limit of the deposit, and so were being supplied at the peak of the transgression (Hopkins, 1982). Their transport to the Beaufort Sea coast by icebergs records the breakup of an ice sheet in the Canadian Arctic. Remains of Pacific marine mammals, including ribbon seal (Histriophoca fasciata) and gray whale (Eschrichtius sp.) (Repenning, 1983), indicate that a connection with the Bering Sea existed at this time. Mollusk, ostracode, and foraminifera faunas are depauperate and include no extralimital species (Hopkins and others, 1981). The Simpsonian transgression was a brief event of a distinctly different character than the interglacial transgressions discussed above.

Eleven TL dates on sediment of the Flaxman Member range from 53 ka to 81 ka. Six of these are between 71 and 76 ka and a uranium-series date on whale bone from Simpsonian deposits is 75 ka (J.L. Bischoff, written communication, 1984). Finite radiocarbon dates previously obtained for organic remains from Simpsonian deposits (Carter, 1983d) are apparently erroneous, and the Simpsonian transgression most probably occurred between 70 ka and 80 ka.

Because the western part of the Arctic Coastal Plain has been tectonically stable for at least the past 125 ka, the altitude of the Simpsonian deposits cannot be attributed to tectonism. Furthermore, marine deposits exposed near sea level on the Atlantic Coastal Plain were deposited about 75 ka (Cronin and others, 1981; Cronin and others, 1984), suggesting that the Simpsonian transgression was not a local event but represents a eustatic sea level higher than that of today. However, marine mollusk shells from Simpsonian deposits are enriched in O^{18} relative to modern specimens from the Beaufort Sea, indicating that more glacial ice was present during the Simpsonian transgression than occurs today. Oxygen isotope data from deep sea cores for this time interval also indicate large volumes of glacial ice.

Cronin and others (1984) proposed that the paradox of high sea level 75 ka co-occurring with extensive glacial ice could be explained by large volumes of floating glacial ice in polar regions. The Flaxman Member does indeed document that floating glacial ice was present in the Arctic Ocean, but the discrepancy between the sea level and isotope records is so large that an extraordinary amount of floating glacial ice would be required to reconcile them. Possible mechanisms to provide an enormous amount of floating glacial ice would be a surge of the East Antarctic ice sheet or disintegrations of the west Antarctic ice sheet. Either of these would cause a rapid rise in sea level (Wilson, 1964; Mercer, 1978; Hollin, 1982) and might lead to the catastrophic breakup of unstable marine-based ice over the central Canadian Shield (Denton and Hughes, 1983). Recent studies of amino acid geochemistry of marine mollusk shells in the Hudson Bay region do indeed indicate that the Hudson Bay Lowlands were evacuated of Laurentide ice and inundated by marine waters about 75 ka (Andrews and others, 1983).

Fluvial and Deltaic Deposits

Fluvial deposits consist of Pliocene gravelly sand (Tgs) which underlies the deposits of map unit QTas east of the Itkillik River, Pliocene and Pleistocene sand and gravelly sand which overlies the marine deposits of map units QTas and Qam, Pleistocene sand and gravelly sand which composes the alluvial terrace deposits of map unit Qat, and Holocene and latest Pleistocene sandy alluvium of map unit Qa1.

The oldest deposits (Tgs) are very poorly exposed and they have yielded no fossil plants or animals. The fluvial deposits of map units QTas and Qam form broad alluvial plains which are not related to modern river valleys. Pollen studies show that some of the deposits formed during glacial intervals (Nelson, 1981), and spruce, larch, and poplar macrofossils indicate that other deposits formed during interglacial episodes (Carter and Galloway, 1982; Carter, unpublished data). These deposits contain a rich paleoenvironmental record and detailed sampling of key localities should be carried out.

Fluvial terrace deposits are confined to modern river valleys but probably are stratigraphically complex and formed over a long period of Pleistocene time. The oldest of these deposits underlie ancient flood plains of the Miluveach and Kachemach Rivers which are graded to the base of a scarp that trends perpendicular to the two rivers (Carter and Galloway, 1982). The scarp may be of fluvial or marine origin. If it is of marine origin it probably formed during the Fish Creek transgression.

Younger Pleistocene fluvial terrace deposits occur on both sides of the Colville and Itkillik Rivers. These deposits underlie several terrace surfaces and their ages are undetermined. Fossil spruce logs have been collected at several localities (Carter and Galloway, 1982), suggesting that the deposits formed during interglacial intervals.

Holocene and latest Pleistocene alluvium forms flood plains and low terraces along modern streams of the Harrison Bay quadrangle. These young deposits have not been studied in detail, but radiocarbon dating of correlative deposits in adjacent quadrangles indicate that the terraces formed between 8 ka and 14 ka, which suggests that the streams in the Harrison Bay Quadrangle were not deeply entrenched during late Wisconsin low stands of sea level.

Extensive deltas (Qd) of silt and sand have formed at the mouths of the Colville River and Fish Creek since sea level reached its present position during middle or late Holocene time. The thickness of these deposits has not been determined, but they may not be thicker than 15 m, which is the approximate depth of the thalweg of the main distributary of the Colville River delta. Extensive studies of the geomorphology of the Colville River delta and processes of erosion and deposition there have been carried out by Walker (1983).

Eolian Deposits

Eolian deposits consist of a blanket of silt and very fine sand in the southeastern part of the quadrangle that is referred to here as upland sand and silt (Qus), and of eolian sand that forms stabilized dunes, sand sheets, and fossil sand wedges elsewhere.

The upland sand and silt is very poorly exposed and has been examined only in reconnaissance fashion. It overlies the Kuparuk gravel and forms the surface deposits of the plateau that makes up this part of the White Hills section of the Arctic Coastal Plain. The deposits accumulated over a long period of time and the most recent episode of deposition was most likely during either the late Wisconsin or early Holocene intervals of eolian sediment transport documented for other parts of the coastal plain (Carter, 1983a). The sediments have been reworked in many places by lacustrine, fluvial, and colluvial processes, and form the matrix for the deposits mapped as colluvium within the area of the plateau. These colluvial deposits contain the bones of extinct Pleistocene mammals such as horse and bison.

Eolian sand deposits in the remainder of the quadrangle formed during several intervals of eolian sediment transport which occurred in contrasting climatic regimes during Pleistocene and Holocene time. Stabilized linear dunes as much as 20 km long, 1 km wide, and 30 m high form the major part of the eolian sand of map unit Qe. These large dunes form the northeastern part of a sand sea that covered more than 11,000 km^2 of the Arctic Coastal Plain (Carter, 1981, 1983a). The time of initiation of the dune field has not been determined, but radiocarbon ages of herbaceous plants from eolian and lacustrine sand within the dune field indicate that the dunes were active from before 36,000 to nearly 12,000 yr B.P. Bedding attitudes, dune-ridge orientations, and measurements of pseudo-crosslamination formed by climbing adhesion ripples demonstrate a wind regime similar to that of the present and indicate that the dominant directions of sand-moving winds were easterly to northeasterly. Stratification types within the dunes indicate deposition under predominantly dry conditions. Few interdunal pond deposits have been identified, suggesting that rainfall and snowmelt were insufficient to regularly inundate interdunal depressions. Buried snow or ice has not been observed in the dune sand, and deformational structures that could be attributed to the melting of snow or ice are rare. Snow cover over the dunes is inferred to have been patchy at most.

In spite of this evidence for aridity on the Arctic Coastal Plain, radiocarbon dating of fossil bones indicates that before 28 ka vegetation in the Arctic Foothills was sufficient to support such large herbivores as mammoth, horse, and bison. However, none of the dates on these mammals is less than 28 ka, and few organic remains have been found in deposits between 14,500 and 28,000 years old in contrast to both older and younger deposits. Cold, arid conditions evidently intensified during late Wisconsin time-coincident with the expansion of glaciers in the Brooks Range.

In support of this conclusion, TL dating of fossil sand wedges which are as much as 7 m deep and 3 m wide and extend upwind of the dunes for more than 100 km shows that they formed during late Wisconsin time (Carter, 1983c and unpublished data). Sand wedges are forming today in the drier parts of Victoria Land, Antarctica (Pewe, 1959; Black and Berg, 1963; Berg and Black, 1966), in some parts of the Sverdrup Islands of arctic Canada (Hodgson, 1982),and in northern Greenland (C. Hjort, written communication, 1983). They form in a manner analogous to ice wedges, which commonly underlie the borders of nonsorted polygons in tundra covered arctic areas. Both sand and ice wedges grow as a result of repeated formation and filling of thermal-contraction cracks in permafrost; ice wedges form when the cracks fill with snow, hoarfrost or meltwater (Leffingwell, 1915; Lachenbruch, 1962), whereas sand wedges form when the cracks fill with sand that trickles down from the surface. Sand wedges developed on the Arctic Coastal Plain as wind-driven sand moving across the coastal plain toward the dunes dropped into open thermal-contraction cracks. The sand wedges record barren ground and document an absence of surface water from the time the thermal contraction cracks formed in middle and late winter until they filled with eolian sand. This suggests that significant sand movement occurred before spring and that snow cover was patchy or absent as inferred for the dunes.

About 12 ka the dunes were stabilized and the development of organic soils began across the coastal plain (Carter, 1983c). In conjunction with soil development, ice wedge growth was initiated locally on the previously barren plains north and east of the dunes. About 11 ka a new phase of eolian sand movement was initiated that resulted in the formation of a sheet of eolian sand from 1 to 7 m thick that blanketed the dunes and extended beyond them tithe north. This sand-sheet forms the upper part of map units Qe and Qem. Climatic conditions during this episode of eolian sand movement were warmer and drier than those of today (Carter and others, 1984). Eolian sand movement ceased about 8 ka when the development of organic soils stabilized the sand surface.

Small parabolic and longitudinal dunes up to 1 km long and a few meters thick developed over the area of the sand sheet during late Holocene time. This episode of eolian sand movement was probably coincident with the neoglacial expansion of glaciers in the Brooks Range. If so, then destabilization of the sand surface was probably initiated by cooler and drier climatic conditions than those of today.

Thaw-Lake Deposits

Thaw lakes began developing about 12 ka following the climatic amelioration that terminated late Wisconsin glaciation (Lewellen, 1972b; Sellmann and others, 1975; Brown and others, 1980; Carter, unpublished data). Since stabilization of the eolian sand sheet about 8 ka, the thaw lake cycle has perhaps been the dominant form of landscape modification away from rivers and streams. The cyclic development, orientation, and origin of thaw lakes has been extensively studied in the Barrow area (Black and Barksdale, 1949; Britton, 1957; Brewer, 1958a; Livingstone and others, 1958; Carson and Hussey, 1960, 1962, 1963; Brown, 1965; Hussey and Michelson, 1966; Carson, 1968; Black, 1969, 1976; Morrissey, 1979). Sellmann and others (1975) subdivided the coastal plain into areas containing thaw lakes of similar size, shape, and development of orientation. Their map unit boundaries approximate the boundaries of the lithologically defined map units for the Harrison Bay Quadrangle.

The thaw-lake cycle begins when ponding occurs at the surface. This can occur as a result of the disruption of insulating vegetation and consequent melting of ground ice followed by surface subsidence to create a small basin. The pond may deepen and expand laterally by thaw of subjacent and adjacent ice-rich permafrost, and as a result of wind-induced erosion by waves and currents. Wind-induced erosion produces the lake elongation that is so distinctive on the Arctic Coastal Plain (Carson and Hussey, 1962). The prevailing east-northeast and west-southwest winds create waves and currents which build protective shelves on the downwind shores and concentrate erosion on the north-northwest and south-southeast shores. Lake-basin depth is determined by the ice content of the underlying materials and their potential for thaw settlement. Lake expansion may continue until a lower lake basin or stream is intercepted and the lake drains. Following drainage, the lake bed is refrozen to form new ice-rich permafrost and ice wedges begin to grow. During refreezing, pingos (ice-cored conical hills) commonly develop in lake basins which are underlain by thick granular materials (Galloway and Carter, 1978; Carter and Galloway, 1979). After refreezing, a new thaw lake cycle may begin. The parts of the landscape that occur between thaw-lake basins and that either have not been affected by the thaw-lake cycle or have not been affected for several thousand years have a much higher ice content than recently drained lake beds or the beds of existing lakes.

The character of thaw-lake deposits depends upon the character of the materials in which the thaw-lake basin develops. However, as explained in the description of map units, thaw lake deposits generally have a higher organic content than adjacent sediments, owing to the incorporation of eroded tundra vegetation.

Colluvial Deposits

Colluvial deposits are of minor extent in the Harrison Bay Quadrangle. They are poorly exposed and the history of deposition has not been adequately determined. Some of the deposits are relict and contain the remains of extinct Pleistocene mammals. These deposits commonly underlie paired terraces in tributaries to main valleys in the southeast corner of the quadrangle. They contain abundant organic debris and may date to the warm period that occurred from 12 ka to 8 ka (Carter and others, 1984). If so, then the mammal bones were most likely incorporated in the deposits by colluvial processes.

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