Prepared in cooperation with the National Park Service

Surficial Geologic Map of the Noatak National Preserve, Alaska

By Thomas D. Hamilton

Pamphlet to accompany

Scientific Investigations Map 3036

Bluff exposure along Noatak River, with water-filled kettle depressions in background. Amphitheater-like gully heads were created by thaw and flowage of ice-rich permafrost. Bluff exposures along Noatak River and its tributaries are described in Hamilton, 2009.

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Conversion Factors

Multiply	By	To obtain
Length		
millimeter (mm)	0.04	inch (in.)
centimeter (cm)	0.4	inch (in.)
meter (m)	3.28	foot (ft)
kilometer (km)	0.62	mile (mi)

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Introduction

Physical Setting

Most of the Noatak National Preserve (NNP) is centered on the Noatak River valley, which trends westward parallel to the structural grain of the Brooks Range for about 250 km from the Preserve boundary to the mouth of Kelly River. At this point, the Noatak bends sharply into a southward course that extends about 100 km farther to the coast and enters Kotzebue Sound opposite the town of Kotzebue. Through its west-trending course, the Noatak valley floor forms broad to narrow lowlands that separate the De Long Mountains to the north from the Baird Mountains to the south (Burch, 1990, p. 196–201). The map area through this sector extends between drainage divides that bound the Noatak drainage system, separating it from streams that flow north into the Arctic Ocean and south into the Kobuk River, respectively. The south-trending segment of the Noatak River skirts the west end of the Baird Mountains and lies at or just beyond the western boundary of the NNP.

The Noatak's valley widens into broad basins in two places. The upper basin, termed the Aniuk Lowland by Wahrhaftig (1965), occupies much of the eastern portion of the NNP. The lower basin, Wahrhaftig's (1965) Mission Lowland, is confined to the south by the Igichuk Hills, a bedrock ridge transverse to the course of the Noatak River a short distance above its mouth. The two lowlands and intervening deeply incised, narrow valley floor divide the Noatak drainage system into three sharply contrasting sectors. The easternmost sector, about 145 km long and centered on the Aniuk Lowland, extends downvalley to the Nimiuktuk River confluence. It is bounded by rugged highlands of the Brooks Range to the south and southeast and by generally lower Brooks Range uplands to the north. The principal tributary to this upper sector of the Noatak River is the north-flowing Cutler River system. Pleistocene-age glaciers flowed into the Aniuk Lowland from nearly all directions. During middle and late Pleistocene times, valley glaciers extended southeastward out of the De Long Mountains into the west end of the lowland. These glaciers repeatedly dammed the Noatak River, forming glacial lake Noatak (Hamilton and Van Etten, 1984; Hamilton, 2001). During the older and more extensive glacial advances, much of the Aniuk Lowland filled with proglacial lakes, which at various times overflowed northward into the Colville River system by way of Howard Pass and southward through upper Hunt River into the Kobuk River valley. At other times, the lakes discharged westward, skirting south of the ice margin to enter the lower valley of the Noatak River. A large valley glacier that originated in highlands near the head of the Noatak drainage system flowed westward to terminate in the proglacial lake at those times, as did smaller glaciers that flowed southward and northward into the basin. Numerous tall bluff exposures along the Noatak River and its principal tributaries record multiple lake stages separated by interglacial fluvial deposits (Hamilton, 2001, 2009).

Through the central sector, which begins at the the Nimiuktuk River confluence, the Noatak River turns sharply southward and then flows west again for about 60 km through a relatively narrow rock-walled valley that broadens farther west into the upper part of the Mission Lowland. The river was displaced southward into this sector by glaciers that originated in upper valleys of the De Long Mountains and that flowed southward through five principal drainage systems: the Nimiuktuk, Kaluktavik, Kugururok, Avan, and Cutler. Glacial-lake deposits are present in a narrow belt along the Noatak valley floor, and lake deposits broadly cover the floors of four of those valleys. However, glacial-lake deposits are absent from Avan River valley, which supported active glaciers until the close of the Pleistocene. Bluff exposures through this sector of the Noatak valley floor reveal glacial-lake deposits and abundant fluvial sediments that record stages of postglacial river downcutting (Hamilton, 2009).

The westernmost sector, the Mission Lowland, probably was occupied by lakes during middle and late Pleistocene times but capping sediments of loess and alluvium obscure much of their record. During middle Pleistocene time, glaciers issuing from western valleys of the De Long Mountains probably blocked an earlier westward course of the Noatak River that extended directly into the Chukchi Sea (as illustrated by McCulloch, 1967), diverting the river southward into its present position. During that interval, lakes probably formed behind massive moraine dams during times of glacier recession. Younger lake episodes may be slackwater events (as described by Waitt, 1980) that formed when outburst floods from glacier-dammed lakes farther upvalley were confined for periods of days or perhaps weeks behind the Igichuk Hills. Slackwater deposits also may have formed during the Holocene, when rapid sea-level rise flooded Kotzebue Sound and raised the base level for the lower Noatak River. River-bluff exposures generally are absent from the Mission Lowland because of Holocene alluviation; consequently the sediments that underlie the widespread blanket of loess and fine-grained alluvium are seldom evident.

The map area has an arctic climate, with long cold winters and short cool summers (Childers and Kernodle, 1981). Tundra vegetation, with low shrubs present along stream courses, predominates through the upper basin of the Noatak River. Progressively farther downvalley, riparian stands of cottonwood (*Populus balsamifera*) and then white spruce (*Picea glauca*) become increasingly dominant along the valley floor (Viereck and Little, 1975). Wetlands cover much of the Aniuk and Mission Lowlands (CAVM Team, 2003), and the Mission Lowland bears a mosaic of spruce stands and moist tundra vegetation. Most of the Noatak drainage system is included within the Arctic Foothills ecoregion of Gallant others (1995), but this seems to me a misleading generalization. The Noatak valley floor is underlain by continuous permafrost, which generally is ice-rich and lies at shallow depths. Related surface features such as ice-wedge polygons are widespread, and pingos are present locally in the Aniuk and Mission Lowlands. Permafrost generally is also continuous beneath surrounding uplands, but its ice content and depth below the surface are more variable there (Ferrians, 1965; Brown and others, 1997).

History of Investigations

Initial geologic study of the Noatak River valley was undertaken in 1911 by a U.S. Geological Survey (USGS) field party led by Philip S. Smith that portaged into the upper Noatak drainage and then traversed the river to its mouth (Smith, 1913). More detailed helicopter-supported bedrock geologic mapping was carried out later by the USGS. This work culminated in geologic maps that covered entire 1:250,000-scale quadrangles (Karl and others, 1989b; Mayfield and Tailleur, 1978) or portions of such quadrangles at larger scales (Curtis and others, 1984; Ellersieck and others, 1984; Dover and others, 2004; Mayfield and others, 1984, 1987, 1990). A derivative map of construction materials within the Baird Mountains quadrangle was compiled by Combellick and others (1993).

Regional syntheses of western Brooks Range geology include Mayfield and others (1988), Till (1989), Moore and others (1994), Dumoulin and others (2004), Slack and others (2004), and Young (2004). Other geologic studies have dealt with the igneous and metamorphic rocks of the map area (Nelson and Nelson, 1982; Boak and others, 1987; Karl and others, 1989a; Till and others, 1988; Till, 1989; Saltus and others, 2001). Mineral-resource data for individual quadrangles of the NNP region have been compiled by Mayfield and others (1983), Dover (1997a,b), and Williams (2000).

Surficial geology of the western Brooks Range was compiled from aerial photographs in 1960 by A.T. Fernald, H.W. Coulter, and E.G. Sable of the USGS. Their data were incorporated into statewide maps of surficial geology (Karlstrom and others, 1964) and glacial limits (Coulter and others, 1965). Later field mapping of the upper Noatak River valley (Hamilton, 1981, 1984a,b) led to recognition of a series of large ancient lakes created by glaciers that originated in the De Long Mountains and flowed southward to dam the Noatak River (Hamilton and Van Etten, 1984). Subsequent detailed study of river bluffs through this sector of the Noatak valley resulted in recognition and dating of interstadial deposits of middle Wisconsin age (Hamilton and others, 1987), identification of the Old Crow tephra, a widespread interglacial marker bed (Hamilton and Brigham-Grette, 1992), and paleoecologic analyses of locally rich interglacial insect and vegetation records (Elias and others, 1999; Edwards and others, 2003). An overview of the depositional record exposed in these bluffs (Hamilton, 2009) reveals a complex history of interrelated glacial advances, stages of lake formation, and episodes of river downcutting (Hamilton, 2001, 2009).

The Map

The surficial geologic map of the Noatak National Preserve (NNP) is a compilation that incorporates portions of four published USGS maps (Hamilton, 1980, 1981, 1984a,b), a USGS Open-File Report (Hamilton, 2003), and unpublished field mapping. It covers an area of about 28,700 km^2, and includes parts of eight 1:250,000-scale quadrangles.

The mapped area generally terminates at NNP boundaries, which generally follow the sharp divides that separate the Noatak drainage system from north-flowing drainages of the Alaskan North Slope and south-flowing tributaries to the Kobuk River. The mapping extends short distances beyond those boundaries where passes across divides were traversed by glaciers issuing from the Noatak drainage or by overflow waters from glacial lake Noatak. Along the western edge of the map, where the NNP boundary is unrelated to topographic features, I have extended the mapping to the nearest natural boundary, the active channel of the Noatak River, and have mapped beyond that limit only in places where surficial deposits are essential for understanding regional geology.

I have used the metric system for all heights and distances cited on the map and in this pamphlet. Metric-English conversion values are printed inside the pamphlet's front cover for ready reference. However, in the case of former lake heights and other altitude data, the original measurements generally were taken from helicopter altimeters and USGS topographic maps which recorded feet above sea level; and these measurements were later converted into meters. In addition, the topographic base used for the NNP map is derived from those USGS topographic maps, which show contours in feet. For these reasons, altitudes are presented in meters followed by the original readings in feet for the convenience of map users.

Bedrock Surface Forms

Rather than subdivide bedrock on the basis of age and lithology, I have chosen to create six bedrock divisions that reflect surface form. These units should be of value as indicators of (1) scenic attributes, (2) landslides and other natural hazards, (3) ancient lake margins, (4) former drainage channels, (5) loess sources and distribution, and (6) the source areas, flow routes, and outer limits of ancient glaciers. Some units serve as guides to the presence of unweathered bedrock exposures, which may be of particular value in areas blanketed by otherwise widespread and unbroken lake sediments or other surficial cover.

Alpine bedrock (unit B_a) generally consists of resistant rock types, such as conglomerates, massive carbonates, and intrusive igneous rocks, which form relatively high, rugged uplands. In addition, late Pleistocene glacial erosion has further steepened valley walls, sharpened ridge crests, and carved steep-sided cirque basins at valley heads. This unit therefore provides a good guide to source areas and distribution of former glaciers. Its steep glacier-carved slopes are subject to rockfalls, landslides, snow avalanches, and other alpine hazards.

Bedrock exposed by stream erosion (unit B_e) consists of narrow strips of bedrock that extend along former meltwater channels or routes of glacial-lake discharge, and also more extensive tracts of bedrock, such as along Aklumayuak Creek and parts of the Noatak River, that underwent late Pleistocene downcutting. The mapped distribution of this unit provides a useful guide to Pleistocene drainage changes, and would be helpful in locating bedrock exposures in areas generally covered by surficial deposits.

Glacier-scoured bedrock (unit B_g) has been overridden and scoured by glacier ice. Areas thus designated serve as useful indicators of the extent and distribution of former glaciers. Because the glaciated surfaces commonly are streamlined and channeled in the directions of glacier flow and meltwater drainage (shown by symbols on the map), they also serve as flow-direction indicators. Glaciated bedrock generally yields excellent rock exposures in areas where other rock surfaces are weathered, frost-shattered, or silt-covered.

Silt-covered bedrock (unit B_s), designates upland surfaces that are largely obscured by fine-grained sediments or weathering products. On adjoining hillsides and valley walls, solifluction has transported and mixed these deposits, forming extensive aprons of rubbly or organic silt that thicken downslope. Areas of silt-covered bedrock generally were not glaciated during late Pleistocene time. They are common downwind from glacier-dammed lakes that served as sources of windblown silt (loess) when the lakes were freshly drained and their floors not yet revegetated. Lake beds that were exposed repeatedly by outburst floods would have been especially effective loess sources. Within the Baird Mountains, some low-lying areas of silt-covered bedrock more distant from Pleistocene lake beds are underlain by rock types such as phyllite that weather readily to yield abundant fine-grained detritus.

Wave-eroded bedrock (unit B_w) has been scoured by wave action along the margins of ancient glacier-dammed lakes. Because it occurs only locally around former lake margins, it may provide a useful guide to wind directions at times when the lakes existed. Wave-eroded bedrock also is best developed where fetch (the open-water distance across which the wind is able to generate waves) was greatest. In addition, because bedrock-surface forms can persist much longer than unconsolidated deposits, wave-scoured bedrock commonly provides the best guide to the most ancient lake levels.

Undifferentiated bedrock (B) generally designates rock masses that are intermediate in character between the other bedrock surface forms or are assemblages of diverse surface forms that are too small to map individually.

The Pleistocene Record

Glacial, Lacustrine, Eolian, and Fluvial Interactions

Surficial geologic units and their relations within the eastern half of the map area are compatible with the glacial-lacustrine-fluvial model described previously (Hamilton, 2001, 2003) for the upper Noatak basin. During each of several succeeding Pleistocene glaciations, glaciers developed in cirque-headed valleys within the upper Noatak drainage system and within the De Long Mountains. Glaciers generated within the De Long Mountains expanded down south-trending valleys and spread into lobes within lowlands along the Noatak River. Dammed by the lobes, large lakes formed and inundated the Aniuk Lowland basin for as much as 50 km upvalley from the moraine barriers (Hamilton, 2001). Although some of the older and larger lakes had outlets to the north and south by way of Howard Pass and Hunt River, most lakes probably filled and emptied repeatedly as their ice dams eroded or became buoyant (Clague and Evans, 1994; Walder and Costa, 1996; Hamilton, 2001). The resulting glacial outburst floods would have surged westward down the Noatak's narrow, rock-walled valley where the river is deflected south of the De Long Mountains, and then spread more widely across the Mission Lowland. Outburst-flood drainage of the glacier-dammed lakes must have occurred with greater frequency as ice thinned or retreated toward the close of a glaciation, with the lake refilling each time to a lower surface level. Each time a lake drained, its newly exposed floor was swept by winds that entrained fine-grained sediments and deposited them downwind as loess. The Noatak River re-established its course across the lake floor early in each interglacial, then cut down progressively to a level near that of the present day. The river bluffs created by this downcutting exhibit early-interglacial fluvial channel and floodplain deposits at levels several tens of meters above present river level, whereas full-interglacial fluvial deposits appear at or slightly below the modern river (Elias and others, 1999; Edwards and others, 2003; Hamilton, 2001, 2009). These interglacial fluvial deposits were buried and preserved beneath till-like sediments that formed during subsequent glaciations and glacio-lacustrine episodes.

Through the Noatak's remaining westward course, the river is more closely confined between the De Long and Baird Mountains. Glaciers flowed southward down major valleys of the De Long Mountains in a radiating pattern: southeastward near the Nimiuktuk River valley, and south-southwestward near the Kelly River's drainage system. Arcuate moraine ridges that are nearly obscured beneath blanketing lake deposits indicate blockage of the Noatak River at the mouths of most major valley systems. Lake deposits extend up most of these valleys for distances as great as 50 km, attesting to continued blockage of the drainage network during and perhaps following deglaciation. Downcutting of the Noatak River by as much as 50 m took place during the Holocene, and perhaps extends back into the latest Pleistocene as well.

Smaller glaciers developed on local highlands within the Baird Mountains but were mostly restricted to valley heads near the Noatak-Kobuk divide. Glaciers locally crossed divides into upper valleys of the Kobuk drainage system but generally did not extend northward far enough to intersect lowlands along the Noatak River. Parts of the Baird Mountains bear heavy loess cover that may have been largely derived from the floors of drained glacial lakes farther to the north.

The remaining stretch of the Noatak River may once have continued westward to the Chukchi Sea but it was diverted into its present southward course by glacier ice and (or) moraine barriers. Lakes may have filled the Mission Lowland during or after the drainage diversion, confined behind the transverse bedrock ridge near the river's mouth and blocked by moraine dams to the west. Although any lake deposits on the lowland floor are buried beneath blankets of loess and fine-grained alluvium, their probable subsurface presence is indicated by delta and fan-delta deposits, wave-cut notches, beach ridges, and overflow channels around the basin's margins.

Glacial Nomenclature

A consistent set of terms has been employed for glacial-geologic mapping through the central Brooks Range (Hamilton, 1986 and references therein) as well as for mapping the eastern half of the map area (Hamilton, 1980, 1981, 1984a,b). The Anaktuvuk River and Sagavanirktok River glaciations are broadly equated with multiple glacial advances of early and middle Pleistocene age, respectively; the Itkillik glaciation is equated with multiple advances during the late Pleistocene (table 1). However, glaciers in the De Long Mountains were nourished in part from moisture sources in the Bering Sea, and they probably responded somewhat differently from central Brooks Range glaciers during each glacial cycle. Younger glacial advances in the De Long and Baird Mountains are broadly equated with advances of the Itkillik succession in the central Brooks Range, but an older and much more extensive glacier advance has been designated the Cutler advance (Hamilton, 2001) because its relationship to glacial events of middle Pleistocene (Sagavaniktok River) age in the central Brooks Range is unclear. The Cutler advance may correlate more closely with the glacial advance that constructed the Baldwin Peninsula moraine near Kotzebue, which Huston and others (1990) believe formed during late-interglacial rather than full-glacial time owing to nearby moisture sources provided by interglacial flooding of the Bering platform.

Throughout the map area I have employed the unit designations used for late Pleistocene (Itkillik) glaciations in the central Brooks Range. This facilitates comparison with mapped areas farther east and also permits the uniform use of generalized designations (for example, unit id) in cases where more age-specific designations (such as id_1, id_2, and id_3) are not appropriate for glacial deposits that clearly are of late Pleistocene age. However, many glacial deposits through the central part of the map area are directly traceable into end moraines that are named for tributary drainages that join the Noatak River close to where the moraines cross the valley center (Hamilton, 2001). I consequently employ a double set of names in the map-unit descriptions: the local moraine name followed in parentheses by its probable central Brooks Range equivalent (see table 1). For middle Pleistocene glaciations, I have employed the Sagavanirktok-Anaktuvuk terminology for central Brooks Range glaciers of the upper Noatak drainage and the Cutler-Older glaciation succession for glaciers issuing from the De Long Mountains.

Table 1. *Glacial advances from the De Long Mountains and equivalent glacial advances in the central Brooks Range. MIS, marine isotope stage.*

De Long Mountains	Map unit	Central Brooks Range	Age
Neoglaciation	nd	Neoglaciation	Late Holocene
Unnamed	id_3	Late Itkillik II readvance	Late Wisconsin (MIS 2)
Avan advance	id_2	Itkillik II phase	Late Wisconsin (MIS 2)
Unnamed	id_{1C}	None recognized	Early Wisconsin (MIS 4)
Anisak advance	id_{1B}	Itkillik IB phase	Early Wisconsin (MIS 4)
Makpik advance	id_{1A}	Itkillik IA phase	Late interglacial (MIS 5d–5a)
Okak advance	----	Sagavanirktok River (late phase) (sd_2)	Middle Pleistocene
Cutler advance	cd	Sagavanirktok River (undifferentiated) (sd)	Middle Pleistocene
Unnamed older drift	od	Sagavanirktok River or Anaktuvuk River (ad)	Middle or early Pleistocene

Glacial Lakes

The Pleistocene-age lakes in the map area formed behind both glacial and moraine barriers. Lakes that were dammed by active glaciers filled and drained dramatically rather than remaining at static levels. Other lakes confined behind moraine barriers were more stable, but their surfaces lowered progressively as the moraines eroded. Consequently, the shoreline features associated with these varying lake surface levels are weakly developed and generally difficult to trace. The deposits of the former lakes are recognizable as poorly drained, ice-rich, fine-grained sediments that blanket valley floors and thin upward on lower valley sides, generally wedging out at consistent altitudes. Fan-delta deposits are common at the mouths of tributary valleys; they splay into unusually broad, low-gradient, uniformly fine-grained deposits below the levels of the former lakes. Wave-cut notches are present along the inner flanks of moraines near Nimiuktuk River and along bedrock exposures in the Aniuk and Mission Lowlands, localities where unusually great fetch (span of open water) would have allowed wave action to be particularly effective. Abraded and terraced bedrock surfaces also attest to the effectiveness of wave erosion in the two lowlands. Rare linear outcrops of well rounded fine gravel are interpreted as probable beach ridges. End moraines in some valleys become diffuse below levels that probably represent contemporaneous lake stands; other end moraines were wave-washed, leaving resistant pavements of erratic boulders on their surfaces. The upper limits of those pavements mark the maximum heights of lake stands that accompanied or followed abandonment of the moraines by glaciers.

Three principal lake stages are recognized in the map area, and a series of younger and lower lake stands occur in the Mission Lowland. The lake stages, which can be dated approximately by their interrelationships with moraines, form an important part of regional drainage history, controlling the locations of overflow channels and the timing of glacial outburst floods. The fine-grained lake deposits cause valley floors and lower valley sides to be poorly drained, resulting in shallow ice-rich permafrost, active solifluction, and other frost-related processes. The presence or absence of lake deposits of a given age can indicate the extent of contemporaneous glaciation, and former centers of glaciation are indicated by postglacial isostatic uplift of initially horizontal lake planes. The upper limits of deformed lake deposits typically become progressively higher eastward toward the heavily glaciated central Brooks Range and also northward toward the most intensely glaciated part of the De Long Mountains.

Middle Pleistocene and Older(?) Glaciations

Most bedrock types within the map area weather rapidly, and erratic stones consequently are rare on surfaces older than late Pleistocene. Thick deposits of windblown silt, derived from the beds of newly drained lakes, also cover many of these older surfaces. For these reasons, limits of glaciations older than late Pleistocene are difficult to determine across upland areas, and boulder weathering and other physical characteristics cannot be used to distinguish between glacial deposits or glaciated bedrock surfaces of different middle Pleistocene and older ages. In lowland areas, end moraines of middle Pleistocene age commonly become diffuse where glacier termini presumably began to float in glacier-dammed lakes. Elsewhere, glacial moraines are covered by thick blankets of younger glacial-lacustrine sediments and appear only as broadly arcuate divides between the networks of minor streams.

Broad U-shaped troughs that cross drainage divides along the north and south boundaries of the NNP may be among the oldest glacial features recognized in the map area. Remnant patches of drift are evident on the floors of some passes, and bedrock abraded by glacier ice (unit B_g) commonly is present in and around the passes. These ice-abraded surfaces exhibit smoothed and streamlined ridges, faceted valley walls, and adjoining beveled uplands. The troughs along the northeast margin of the map area were generated by ice issuing from local centers of glaciation between Howard Pass and Anisak River. Farther west, troughs probably were carved by outlet glaciers from an extensive ice cap that covered much of the highlands between Nimiuktuk and Kelly Rivers. The troughs along the western part of the map area's south margin may have been outlets from smaller individual glacier complexes that developed on prominent highlands. Drift patches and isolated erratic stones, which must originally have been present on these ice-sculpted surfaces, evidently were eradicated during a long span of postglacial weathering.

The Arctic Foothills Province beyond the northeast part of the map area contains an extensive record of early Pleistocene and late Tertiary glaciations, including evidence that the Noatak River once flowed north through Howard Pass before being diverted into its present westward course. This information is available elsewhere (Hamilton, 1984b, 1986) and will not be discussed further here.

An extensive blanket of featureless drift (unit od) that lies beyond Cutler-age deposits in the south-central part of the map area is inferred to represent a glaciation of early or middle Pleistocene age that preceded the Cutler advance. This drift is most extensive south of the Noatak River in the area between Cutler River to the east and the head of Aklumayuak Creek to the west.

Middle Pleistocene glacial deposits assigned to advances of Sagavanirktok River age are present locally through the eastern part of the map area. The largest glacier issued from the central Brooks Range and extended westward down the upper Noatak valley into the eastern part of the Aniuk Lowland. However, its drift is rarely exposed and generally occurs as subsurface features buried beneath lake deposits. The age relations between Sagavanirktok River glaciations and the Cutler advance are uncertain.

The Cutler advance represents the most distinctive glacial event of the middle Pleistocene. Its prominent end moraine, which intersects the Noatak River near the mouth of Cutler River (unit cd), was originally assigned to the late Pleistocene Itkillik glaciation (Hamilton, 1984b), but subsequent stratigraphic studies of bluff exposures along the Noatak River showed that deposition of this moraine preceded the last interglaciation (Hamilton, 2001). It may be correlative with the middle Pleistocene glacial advance described by Huston and others (1990) that created the massive Baldwin Peninsula moraine complex and with the silt-covered glacial and glacial-marine deposits (units us/d? and si/cgm) shown east of the Noatak's mouth along the north shore of Hotham Inlet.

South of the Noatak River, the Cutler moraine is traceable almost continuously westward from the mouth of Cutler River past Lake Kangilipak and into uplands opposite the mouth of Nimiuktuk River. Farther west, opposite the mouth of Kaluktavik valley, subdued drift that extends southward into the Baird Mountains may also be of Cutler age. Glacier-scoured bedrock and glacier-shaped alpine topography that trend south-southwestward across the west end of the Baird Mountains in the western part of the map area indicate that a second major ice lobe issued from Kugururok valley and flowed as far as the upper drainage network of Agashashok River. At least one minor ice tongue continued farther south, crossing a drainage divide into the upper valley of Squirrel River. A confluent glacier that issued from the Kelly drainage system probably flowed southward down the Mission Lowland to at least the Eli River area; its deposits are best exposed west of the Noatak River at locations well beyond the western boundary of the NNP, and therefore are incompletely shown on the map. These sets of glacial deposits and ice-shaped bedrock features outline prominent glaciers that flowed from the De Long Mountains southeastward up the Noatak River valley, southward into the Baird Mountains, and southwestward into the Mission Lowlands; the glaciers overrode most of the Noatak River valley from the Cutler River confluence nearly to its mouth. A glacial advance of this magnitude must have been generated by an ice cap over much of the De Long Mountains rather than by individual valley glaciers.

North of the Noatak River, drift of probable Cutler age outlines a large glacier that flowed southeastward from the upper valley of Nimiuktuk River, probably draining part of the eastern margin of the inferred De Long Mountains ice cap. The glacier probably overrode and scoured bedrock through the western part of the Iggiruk Mountains at this time because the orientations of grooved and streamlined rock surfaces are consistent with a southeasterly ice-flow direction. The drift, ice-scoured features, and associated meltwater channels are assumed to correlate with the Cutler moraine, but some of the lower-lying deposits just beyond Itkillik ice limits near New Cottonwood Creek may have formed later as part of the Okak end moraine, a subsurface feature which intersects the Noatak River at Okak Bend (Hamilton, 2001). Because thick glaciolacustrine deposits cover most of the intervening basin floor north of the Noatak River, surface exposures of glacial deposits are rare and correlations with the Cutler and Okak end moraines are uncertain.

Although a glacier-dammed lake of Cutler age must have filled the Aniuk Lowland, its deposits have been either largely obliterated by later glacier advances and stream erosion or covered by younger lake sediments. Lake deposits of this age (unit cgl) are recognized only in the upper valleys of Cutler and Anisak Rivers. Their upper limit increases eastward from about 470 m (1525 ft) above sea level (asl) to about 510 m (1680 ft) asl across the Aniuk Lowland, probably reflecting postglacial isostatic uplift. The water plane of a possibly interconnected lake in the upper Anisak drainage also rises northward to a maximum altitude of about 500 m (1650 ft) asl, probably indicating isostatic recovery from additional crustal depression beneath the De Long Mountains ice cap. The primary lake outlet must have been through Howard Pass, whose floor was at about 510 m asl, because most southern outlets would have been blocked by glaciers at this time. Lake deposits in the Howard Pass area occur at about 540, 575, and 600 m asl (1775, 1875, and 1975 ft asl), reflecting successive positions of local ice dams assigned to the Sagavanirktok River glaciation. Because their relation to water bodies of Cutler age is unclear, they are designated as Sagavanirktok-age deposits (unit sgl) on the map. Farther west, a local meltwater drainage channel near present-day Lake Kangilipak issues from the outer flank of the Cutler moraine at an altitude of about 460 m (1500 ft), and trends south into the valley of Aklumayuak Creek. That steep-sided gorgelike valley must have been established as a major meltwater conduit from the Cutler glacier. Because evidence for widespread high-level lake deposits is absent from the map area farther to the west, extensive glaciers must have covered most of that part of the De Long Mountains and the Noatak River valley during Cutler time.

Diversion of the lower Noatak River from its former westward course into the Chukchi Sea may have taken place or been completed during Cutler time owing to blockage of that route by massive end moraines. The new southward course of the Noatak must have been barred at an altitude of at least 90 m (300 ft) by the transverse bedrock ridge near its present-day mouth, because two channel-like troughs appear to have been scoured across the rock barrier at that level.

A large proglacial lake may have formed in the Mission Lowland during the deglaciation that followed the Cutler advance. Most lake sediments have been eroded or are obscured by loess, but their limits are indicated by rare overflow channels, wave-cut notches, beach deposits, and other shoreline features.

Late Pleistocene Glaciations

Glacial advances of presumed late Pleistocene age form a suite of moraines and related deposits that collectively are assigned to the Itkillik glaciation (Hamilton, 1986). The older deposits of this assemblage (termed Itkillik I) are beyond the range of radiocarbon dating, and therefore are older than about 40,000 yr. Their age formerly was controversial (Hamilton, 1994), but recent stratigraphic studies and cosmogenic dating show that even the oldest Itkillik-age deposits are younger than the last interglacial maximum (younger than about 120,000 yr). Deposits of Itkillik I age in the Noatak River valley postdate deposition of the last-interglacial Old Crow tephra (Elias and others, 1999; Hamilton, 2001), and are correlative with glacial deposits in the northeastern Brooks Range and across central Alaska that commonly yield cosmogenic ages up to 60-100 ka (Briner and others, 2005). Younger deposits of Itkillik age (termed Itkillik II), radiocarbon-dated between about 24,000 and 11,000 ^{14}C years B.P. (Hamilton, 1986), are correlative with moraines assigned to late Wisconsin glaciation elsewhere in Alaska that yield cosmogenic ages between about 26 and 11.5 ka (Briner and others, 2005; Matmon and others, 2006).

Four successively less extensive glacial advances of Itkillik age are recognized within the eastern part of the map area, and evidence for an additional advance was mapped in upper valleys of the De Long Mountains around headwaters of the Nimiuktuk River (see table 1). Glacier advances into the eastern and southeastern parts of the Aniuk Lowland and into the trough occupied by Etivlik Lake in the extreme northeast corner of the map area were in phase with those of the standard central Brooks Range glacial succession (Hamilton, 1986, 1994). Glaciers that flowed from the west into the Aniuk Lowland formed the Makpik and Anisak moraines, which are considered approximately correlative with the two advances of Itkillik I age (units id_{1A} and id_{1B}) farther upvalley. The Makpik-Anisak moraine succession postdates deposition of the Old Crow tephra (Hamilton, 2001), confirming its assignment to the Itkillik glaciation. The very localized readvance or stillstand toward the end of Itikillik I time is labeled as unit id_{1C} (a term new to this map). Younger glacial advances issued from source areas in and around the head of the Noatak valley; their deposits are assigned to Itkillik II glaciation and the late Itkillik readvance (Hamilton, 1986), and designated as map units id_2 and id_3. Comparable drift bodies within the De Long Mountains reflect very restricted glacial advances from rugged but isolated highlands and a somewhat more extensive advance down the valley of Avan River.

Contemporaneous glaciation within the Baird Mountains was restricted to a few isolated highlands, and consequently is discussed separately in a later section.

Glaciations and related events of Itkillik I age

Glacial advances of Itkillik I age in the upper valley of the Noatak River formed two closely spaced moraines separated by the shallow valley of Atongarak Creek. A comparable double moraine encloses Feniak Lake at the north margin of the Aniuk Lowland. The outer (unit id_{1A}) moraines at both localities have been modified by wave action to altitudes of about 510 m (1675 ft). Other valley glaciers of Itkillik I age in the eastern part of the map area formed end moraines south of Desperation Lake, east of Howard Pass, and in southeastern tributaries to the Cutler River, but those moraines are not differentiated into 1A and 1B subunits.

Glacial advances of Itkillik I age that originated in the De Long Mountains radiated southward through major valley systems. The Makpik and Anisak advances are most clearly differentiated in the central part of the map area, where large compound lateral moraines outline successive ice lobes that flowed southeastward out of Nimiuktuk River valley. The outer lobe (unit id_{1A}) is traceable into the Makpik moraine; the inner lobe (unit id_{1B}) extended into a probable floating ice tongue near the mouth of Anisak River and also created the basin now occupied by Lake Kangilipak. A younger unnamed recessional moraine intersects the Noatak River west of the Anisak River. The Nimiuktuk glacier was fed by a small ice cap near the valley head (note highland areas labeled B_g) and by major western tributaries that flowed down the valleys of Seagull and Tumit Creeks from sources in the north-central part of the map area.

A smaller western lobe of the Nimiuktuk glacier diverged near the mouth of Nimiuktuk valley and flowed southward through the narrow bedrock-bounded conduit now occupied by the Noatak River. The limit of the older (id_{1A}) advance of this lobe is obscured by glaciolacustrine deposits, but morainal forms buried beneath those deposits indicate that the glacier may have extended down the Noatak to become confluent with ice flowing south down the Kaluktavik River drainage system. The younger (id_{1B}) advance of the western lobe terminated about 6 km above the mouth of Aklumayuak Creek, where it formed a heavily eroded end moraine across the constricted valley floor.

Glaciers of Itkillik I age farther west formed major south-flowing systems that filled the Kugururok and Kaluktavik drainages. Patches of drift and expanses of ice-scoured bedrock (unit B_g) are exposed locally above the limits of widespread glacial-lake deposits. End moraines generally are buried beneath blankets of lacustrine sediment, but commonly are evident as the subdued arcuate ridges (shown by symbols on the map).

Glacier ice from the Kelly drainage system extended into the Mission Lowland, where it may have been confluent with glaciers from the Avan and Kugururok valleys. Drift of inferred Itkillik 1A age (unit id_{1A}) is traceable along the west flank of the Noatak valley at least as far south as the Eli River area; a younger end moraine from the three confluent glaciers, assigned to the Itkillik 1B advance (unit id_{1B}), seems to parallel the Noatak River along the south margin of its floodplain just before the river curves into its southward course.

Glacial-lake deposits of Itkillik I age in the Aniuk Lowland generally cannot be differentiated from each other, so are shown together as map unit igl_1. These deposits extend throughout the lowland at maximum altitudes that increase progressively eastward and northward from about 425 m (1400 ft) asl near the Hunt River overflow channel to maximum heights of about 510 m (1680 ft) asl at the moraine fronts of Itkillik IA age near Atongarak Creek and Feniak Lake and in the Howard Pass area. Wave-eroded segments of those moraines demonstrate that the maximum lake stand was contemporaneous with or shortly followed the Itkillik IA glacial advance. Maximum lake levels in northern parts of the lowland clearly were controlled by the level of Howard Pass (510 m asl), which is significantly higher than the head of the Hunt River overflow channel (425 m asl). Perhaps the lake drained initially southward by way of Hunt River, then later northward as the Howard Pass outlet was depressed isostatically to a lower position.

Northwest of the Aniuk Lowland, the upper limit of a probably separate Itkillik-age lake in the upper Anisak drainage was at about 470 m (1550 ft) asl. Fan-delta deposits were built along its former north shore at this level where northern tributaries to the Anisak River entered the lake, and the terminus of a Sagavanirktok-age moraine was wave-scoured up to a comparable altitude.

Through the central part of the map area, widespread lake deposits cover the floors of the four principal southern drainages of the De Long Mountains. Those lake deposits generally occur at altitudes lower than the maximum levels of lakes of Itkillik I age in the Aniuk Lowland, and they filled the lower parts of valleys vacated by glaciers of Anisak (Itkillik IB) age. Wave-eroded notches and sparse beach deposits (unit b) along the inner flank of the prominent Anisak moraine just east of the mouth of Nimiuktuk valley confirm that lake formation accompanied or followed glacier retreat there. Because these lake deposits probably began to form as glaciers of Anisak age receded, they are mapped as unit igl_{1B} to reflect that age.

Within the area vacated by the Nimiuktuk glacier, the upper lake limit is at about 370–400 m (1200–1300 ft) asl both north and south of the Noatak River (table 2 in Hamilton, 2003). That limit remains unchanged westward down the Noatak River and through the lower Kaluktavik valley, but farther north up the Nimiuktuk and Kaluktavik drainages, the upper lake limit increases to 400–410 m (1300–1350 ft) asl, probably reflecting glacial isostacy. Because lake deposits along the lower walls of these mountain valleys are heavily modified by solifluction and dissected by erosion, their upper limits are difficult to determine in most places. Lake deposits of comparable (Anisak) age and appearance are generally absent from the Kuguturok, Avan, and Kelly River valleys. This western sector of the De Long Mountains may have still been largely ice-covered when the lake began to form.

The eastern part of the lake complex must have been controlled by an overflow channel at about 400 m (1300 ft) asl that extended southward into Aklumayuak Creek from the Lake Kangilipak area. Drainage that issued from the valley of Aklumayuak Creek then flowed westward down the Noatak River valley, initially skirting southern ice margins by way of drainage channels along the north flank of the Baird Mountains. The western part of the lake complex may have drained through a pass at about 350 m (1150 ft) asl at the head of Ahliknak Creek, a northern tributary to Eli River. The increased discharge through that overflow channel may have triggered construction of the enormous fan-delta that extended westward nearly across the Mission Lowland from the mouth of the Eli's bedrock valley.

A shallow lake may have existed across much of the Mission Lowland during all or part of Itkillik I time but its extent and height are uncertain. Wave-cut notches, wave-abraded bedrock, and other shoreline features that appear to be of Itkillik I age on the basis of soil, weathering, and morphologic criteria (Hamilton, 1986) occur at altitudes of about 120 m (400 ft) near the south end of the lowland and rise to 210–230 m (700–750 ft) asl near its north end. Much of the Eli River fan-delta may have formed at this time. Possible overflow channels at 90–130 m (300–425 ft) across the Igichuk Hills indicate that the lake may have been contained behind that bedrock barrier during all or part of Itkillik I time.

Either a limited stillstand or readvance of glaciers on and around Black Mountain at the head of Nimiuktuk River took place near the close of Itkillik I time. Valley glaciers radiated southward for short distances into upper Nimiuktuk valley and probably also into Seagull Creek and headward parts of Trail Creek. In Nimiuktuk River valley, till and outwash assigned to this event (units id_{1C} and io_{1C}) were eroded by a glacial lake and overlapped by its deposits to an altitude of about 410 m (1350 ft), the characteristic upper limit for the lake of Itkillik IB age in this part of the map area. The drift must have been deposited by a glacial readvance or stillstand during a very late phase of Itkillik I glaciation.

Glaciation and related events of Itkillik II age

During Itkillik II time, the moisture necessary to nourish glaciers was extremely limited in highlands around the Bering Straits owing to glacio-eustatic sea-level depression and consequent subaerial exposure of the broad Bering Platform (Burch, 1990, p. 45–47; Balascio and others, 2005). Brigham-Grette and others (2003) have documented restricted glaciation in easternmost Russia at this time, and only limited glacial advances occurred within the De Long and Baird Mountains as well (Kaufman and others, 2004).

The most extensive glacier of Itkillik II age was generated from highlands in the west-central Brooks Range and flowed westward down the upper Noatak and Nigu valleys to terminate below Douglas Creek and west of Etivlik Lake (unit id_2). Radiocarbon ages from exposures in the Douglas Creek area show that this end moraine is of late Wisconsin age (Hamilton and others, 1987; Hamilton, 2009). Moraines and outwash from this advance show no evidence for interactions with glacial lakes in the Aniuk Lowland, but a lake that developed behind the moraine as the glacier retreated persisted from about 15,000 to 9,200 radiocarbon years ago (Hamilton and others, 1987; Hamilton, 2009).

At the north margin of the Aniuk Lowland, short valley glaciers developed within the Siniktanneyak Mountain block during Itkillik II time. Farther west within the De Long Mountains, small glaciers of similar age radiated from Misheguk Mountain, Mount Bastille, Amphitheatre Mountain and additional unnamed highlands that stand at 1075–1375 m (3500–4500 ft) altitude. These glaciers terminated within the mountain valleys of Tumit, Okotak, and Trail Creeks, and at the heads of Kaluktavik, Kugururok, and Kelly Rivers. Despite the lower-altitude source areas (925–1225 m; 3000–4000 ft asl) flanking Avan River valley, numerous cirques generated an unusually large valley glacier that flowed south and constructed the Avan moraine that intersects and possibly once crossed the Noatak valley floor. The Avan valley area must have been subjected to much heavier snowfall at this time relative to surrounding highlands.

During Itkillik II time, extensive lowlands that remained ice-free were inundated by lakes (unit igl_2). A narrow lake may have extended up the center of the Aniuk Lowland and into lower parts of Cutler River valley, but its poorly exposed sandy deposits may be largely of slackwater or deltaic origin. The upper limit of these deposits rises eastward from about 300 m (1,000 ft) asl near the mouth of Nimiuktuk valley to 360 m (1200 ft) asl in the eastern Aniuk Lowland. This increase in altitude probably is at least in part the result of isostatic uplift, but may also reflect the gradients of slow-flowing rivers.

A glacier-dammed lake occupied the broad valley floor near the mouth of Nimiuktuk River (unit igl_2). Around its shores, wave-eroded notches formed at altitudes of about 300 m (1000 ft) asl along the lower flanks of moraines of the Itkillik IB drift complex. Deposits of this glacial lake are traceable up Nimiuktuk valley and its tributaries, terminating in each drainage where the valley floor is above 340 m (1100 ft) asl. Farther west, extensive lake deposits that cover lower-lying valley floors onlap adjoining lowlands and valley sides to about 300–320 m (1000–1050 ft) asl, and the Avan moraine has been wave-eroded to a comparable height (320 m). Upper lake limits are marked by abrupt contacts between little modified lacustrine sediments below and more strongly soliflucted and dissected older deposits above. Farther north up the Kugururok, Kagvik, and Kaluktavik valleys the lake limit rises to 340–350 m (1100–1150 ft) asl, probably because of postglacial isostatic recovery. An eastern arm of the glacier-dammed lake may have extended into the Lake Kangilipak basin, where an abandoned channel that heads at 300 m (1000 ft) asl and trends south into the Aklumayuak drainage may have served as its outlet. Farther west, a lower-lying pass at about 280 m (925 ft) asl may have allowed drainage from the lake to flow south and then west around the Avan glacier during either its advance or an early phase of deglaciation.

Evidence for lower lake stands also occurs within the Kelly drainage system and across northern parts of the Mission Lowland, where shoreline features commonly cluster at about 210 and 170 m asl (700 and 500 ft, respectively). Although part of their height probably is due to isostatic uplift of the northern upland, the ultimate cause of these lake stands is uncertain. No significant barrier of Itkillik II age is recognized in or below the Mission Lowland.

Parts of the map area that were unglaciated during Itkillik II time were subjected to intense periglacial activity. Some of these surfaces were consistently above lake level, but others must have been exposed subaerially as the lake repeatedly burst out through its ice dam and then refilled. These nonglaciated areas exhibit extensive solifluction slopes that are inactive or weakly active today. Where surface or near-surface bedrock is present, stabilized frost-shattered rubble represents formerly active felsenmeer (Washburn, 1980, p. 219–223) on upland surfaces, and stabilized sheets or aprons of talus rubble are widely present on slopes. The weathered and lichen-covered surfaces of some bedrock blocks that were partly detached from their outcrops demonstrate that displacement by frost wedging has ceased. These inactive periglacial features provide a useful guide to the limits of Itkillik II-age glaciation.

Glaciation in the Baird Mountains

Only a few small glaciers of middle(?) to late Pleistocene age were generated within the Baird Mountains west of the Cutler River drainage. The advances of those glaciers were marked by moraines (units id and id_1) and outwash near valley heads and by adjoining freshly ice-scoured surfaces. The most extensive advance, about eight kilometers in length, issued from a cirque in rugged but unnamed highlands at the head of Akikukchiak Creek. Outwash that spilled eastward from this advance formed a local terrace (unit tg) in an adjoining valley, which also has a small morainal deposit at its head. Two short glaciers about 3-4 km in length developed from cirques on the north face of Mt. Angayukaqsraq near the south-central margin of the map.

Other valley-head glacial deposits (unit d) lack morainal ridges and surface erratics but form arcuate bodies bordered by former ice-marginal channels. These features could be of either late or middle Pleistocene age. They outline a north-flowing glacier that extended about 4 km from a cirque on Tutatalak Mountain to the valley of Akikukchiak Creek. Similar subdued glacial deposits (unit d?) associated with abraded and channeled bedrock (unit B_g) occur a few kilometers beyond the limits of Itkillik-age drift in the two other localities described above.

The Pleistocene-Holocene Transition and Subsequent Holocene Events

A final readvance of alpine glaciers in the central Brooks Range generated end moraines and ice-stagnation deposits (unit id_3) around Etivlik Lake in the northeast corner of the map area. Radiocarbon dates from localities elsewhere in the central Brooks Range show that this readvance took place between about 12,800 and 11,500 ^{14}C yr B.P. (Hamilton, 1986, 1994). Surprisingly, no evidence for this readvance seems to be present within the upper Noatak River valley.

In the De Long Mountains, end moraines were deposited at about this time near the mouth of a cirque-headed tributary valley at the north flank of Misheguk Mountain and in several mountain valleys between headward parts of Trail and Tumit Creeks and near the heads of Avan and Kelly Rivers. Patches of drift (units d and d?) on the floors of these and neighboring steep mountain valleys may also date from the same interval.

Because of the high seasonal discharge of the Noatak River (Childers and Kernodle, 1981), incision through lake deposits of Itkillik age probably was rapid. However, as the river continued downcutting, it would have been superimposed on bedrock and moraines along parts of its course. Downcutting would have been impeded for some time at those levels until it could incise the barriers, resulting in terrace formation. Because of the map's small scale, every individual river terrace segment that was formed during downcutting cannot be shown. Therefore, I have combined those terrace remnants into a maximum of four general terrace levels (tg_1, tg_2, tg_3, and tg_4).

Through the Aniuk Lowland, late-glacial river downcutting began by about 13,600 ^{14}C yr B.P. at levels perhaps 30 m above the present-day river (Hamilton, 2001). Radiocarbon-dated terrace remnants about 15 m above the present river level indicate that the Noatak may have flowed at that lower level for an undetermined interval about 10,000 yr B.P. Terrace remnants through the Aniuk Lowland generally are too small to show on the map.

Farther west, the highest consistent terrace level (tg_1) is recognized along the entire stretch of the Noatak River from the mouth of Nimiuktuk River westward to the Kelly River area. This terrace commonly stands about 50 m above modern river level, but it ranges between about 40 and 60 m high along some sectors of the river (Hamilton, 2003, table 3). The terrace must have formed when stagnant glacier ice was still present on the valley floor, because at several localities (the mouth of Nimiuktuk River is a good example) its surface bears kettle lakes and kettle depressions. The Noatak River may have reoccupied this level several times as breaching of the ice dam near Avan River caused outburst floods that drained the lake.

Terraces at about 25–35 m above modern river level (tg_2) occur most consistently along the Noatak River from just above Aklumayuak Creek to the Kugururok River confluence. These terraces also extend for short distances along the lower courses of Kugururok and Kaluktavik Rivers. Unit tg_2 is principally associated with end-moraine complexes of Itkillik IB age, indicating that massive boulder-rich deposits across the valley floor must have retarded river downcutting at those places. Terrace remnants at comparable heights above river level occur sparsely in the Aniuk Lowland and elsewhere along the river, but they generally are too small to map. Two radiocarbon ages of about 13,300 ^{14}C yr B.P. were obtained from a 25-m terrace near the mouth of Aklumayuak Creek (Hamilton, 2009), and a somewhat higher (35 m) bluff a short distance downvalley yielded a similar age of about 13,150 yr B.P. These ages, and a slightly older radiocarbon determination from the Aniuk Lowland (Hamilton, 2001, 2009) indicate that the Noatak River must have been downcutting through the interval about 35–25 m above its modern level at about 13,600–13,000 14C yr B.P. Radiocarbon ages representing this time span are relatively common within the central Brooks Range (Hamilton, 1986), and evidently mark a time of widespread recolonization by shrubs and peat-forming plants under conditions of increasing temperature and moisture (Bigelow and Powers, 2001). Perhaps vegetation was able to stabilize the river's floodplain sufficiently at this time to permit better preservation of alluvial terrace remnants.

Terraces at about 15 m above river level (tg_3) are widespread along segments of the Noatak River in the Aniuk Lowland and, farther downriver, below Aklumayuak Creek, and in the stretch between Kugururok and Kelly Rivers. Just above the mouth of Kelly River, bluff deposits standing 20 m above river level represent a terrace of probably comparable or slightly greater age. Thaw-lake deposits and basal peats in thaw depressions near the crest of that bluff yielded radiocarbon ages of about 9,200 and 9,400 ^{14}C yr B.P. (Hamilton, 2009). The thaw lakes and depressions, which formed under higher summer temperatures of the early Holocene warm interval (Bigelow and Powers, 2001), do not provide a direct date on river height, but they do provide a minimum limiting age on river downcutting from that level. They differ only slightly in age from the 10,000-year-old 15-m terrace remnant in the Aniuk Lowland (Hamilton, 2009).

An extensive lower terrace (tg_4) stands at about 8–10 m above river level. This feature is recognized around the mouths of Cottonwood Creek and Nimiuktuk and Kelly Rivers, and also along the stretch of the Noatak River between the Cottonwood Creek and Kelly River confluences. Unit tg_4 is also mapped along Kugururok River opposite Lake Kaiyak. Although alluvial surfaces at this level have been preserved elsewhere, they are too small to map separately or are indistinguishable from older floodplain deposits (unit al_1).

In the Mission Lowland, terrace deposits are rare and most are only a few meters above river level. Terraces are inset within fan-delta sediments along Eli River and near the mouth of Agashashok River, suggesting that fan-delta formation may have ceased by the close of the Pleistocene or shortly thereafter.

Because of its low altitude and position close to the mouth of the Noatak River, the Mission Lowland probably responded to eustatic sea-level rise during the Holocene. Flooding of the Bering Platform would have caused base level for the river to rise significantly, impeding its discharge and causing it to aggrade its silt-rich suspended load across the Mission Lowland floor. Strong upvalley winds would have entrained silt from the aggrading river system, and perhaps also from the beds of former Pleistocene lakes. Much of this silt was laid down as a thick blanket of loess across northern parts of the lowland. Because of Holocene alluviation, bluff exposures are absent from the Mission Lowland; and thick blankets of eolian and alluvial silt ensure that surface exposures of Pleistocene-age deposits are rare.

Glacial deposits of late Holocene (Neoglacial) age are common in cirques through the central Brooks Range (Ellis and Calkin, 1984), where they generally are limited to locations close to the termini of present-day glaciers. Modern glaciers within the Noatak National Preserve occur only near the head of Imelyak River (near the map's southeast margin), where two very small cirque glaciers are present. Consequently, drift of Neoglacial age is rare in the map area. Very small deposits (unit nd) are associated with the two modern glaciers, and several drift deposits that may be of comparable age occur within the De Long Mountains at the bases of steep north-facing cirque headwalls between headward parts of Trail and Tumit Creeks and in highlands along the east flank of Avan River valley.

Following deglaciation of cirques and upper valley heads, talus rubble began forming on lower parts of cirque and valley walls that were oversteepened by glacial erosion. Within upper valleys glaciated during Itkillik II time, active talus accumulations are so numerous and closely spaced that they are shown as symbols rather than named depositional units. Older talus accumulations that have become stabilized, weathered, and lichen-covered (unit tr_i) are more characteristic of cirques and valley heads that were not glaciated during Itkillik II time, and therefore they may serve as useful relative-age indicators.

Acknowledgments

This map integrates recent field studies with previous mapping that, in easternmost parts of the map area, dates back as far as 1978. At least eight helicopter-supported field operations and five traverses down the Noatak River spanned the succeeding years up to 2005, and each of those projects had its own colleagues, field assistants, and helicopter and (or) fixed-wing aircraft pilots. I truly regret that I cannot thank each of these individuals separately and acknowledge their often unique contributions. Full support for geologic studies through the eastern part of the map area was furnished initially by the U.S. Geological Survey (USGS), and partial support continued subsequently through its Emeritus program. Later stages of the project that encompassed the western half of the map area were supported by the U.S. National Park Service (NPS), initially through the efforts of Robert Gal. The final (2005) season of field mapping and subsequent preparation of this map and accompanying report was directed by Bruce A. Giffen, with funding by the NPS through its Geologic Resources Evaluation Program. The digital map files for the eastern part of the Noatak National Preserve (NNP) were created under NPS contract to Earth Satellite corporation (Rockville, MD); those for the western part of the NNP were constructed by GIS personnel of the USGS. Keith Labay, in particular, provided patient and expert editorial assistance, including input on color schemes, electronic symbols, and layout. Thanks also to Bruce Giffen, John P. Galloway, and Robert B. Blodgett for their constructive and thorough reviews of the map and report.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

[Map units shown in parentheses, such as (id), indicate thin and generally discontinuous deposits over near-surface bedrock. Map units shown with slashes, such as us/d, indicate deposits of the first unit above known or inferred subsurface deposits of the second unit (color represents upper unit). Units of either type are described below only where additional explanation is necessary. Units queried where uncertain]

FAN DEPOSITS

af **Steep alpine fan deposits (Holocene to late Pleistocene)**—Coarse, very poorly sorted, subangular to subrounded silty sandy gravel at mouths of avalanche chutes and steep canyons. Upper segment generally channeled, with levees of angular to subangular coarse debris. Subject to snow avalanches during winter, slushflows during spring snowmelt, and debris flows during summer. Surface gradients generally 12° to 25°, intermediate between gradients of alluvial fans and talus cones

af_i **Inactive alpine fan deposits (late Pleistocene)**—As described in unit af. Generally weathered and covered with sod and vegetation. Some are periglacial relics that formed beyond limits of ice advances of last major (Itkillik II) glaciation

f **Fan deposits (Holocene to late Pleistocene)**—Range from poorly sorted, weakly stratified, subangular, silty, sandy coarse gravel at mouths of steep canyons to moderately sorted and stratified subrounded sandy fine gravel at mouths of large tributary valleys with relatively gentle gradients. Locally subject to icings (aufeis) during winter

f_a **Active fan deposits (Holocene)**—As described in unit f. Differentiated only on large compound fans to distinguish active from inactive fan elements

f_i **Inactive fan deposits (Holocene to late Pleistocene)**—As described in unit f. Generally weathered and covered with sod and vegetation

fd **Fan-delta deposits (late Pleistocene)**—Alluvial-fan deposits, as described in unit f. Grade downslope into deltaic and lacustrine facies (well sorted and generally well stratified sand, silt, and fine gravel). Commonly associated with glaciolacustrine deposits

fd_2 **Fan-delta deposits, younger component (late Pleistocene)**—Alluvial-fan and delta deposits, as described in unit fd. Form younger element of large, smooth-surfaced, low-gradient deposit south of Eli River beyond mouth of its bedrock valley

fd_1 **Fan-delta deposits, older component (late Pleistocene)**—Alluvial-fan and delta deposits, as described in units fd and fd_2. Form eroded remnants around unit fd_2. Surfaces are higher and more deeply dissected by streams than unit fd_2

ALLUVIUM

al **Alluvium, undivided (Holocene)**—Varies from moderately sorted, subangular to subrounded, stratified, coarse gravel in upper valleys to muddy, fine gravel and gravelly mud along slow-flowing stretches of major streams. Along smaller streams, unit includes fan, floodplain, and low terrace deposits that are too small to be designated separately

al_2 **Modern alluvium (Holocene)**—Gravel to gravelly mud, as described in unit al. Generally unvegetated and subject to annual flooding. Commonly subject to aufeis formation. Differentiated only along principal streams

al_1 **Low alluvial-terrace deposits (Holocene)**—Gravel to gravelly mud, as described in unit al. Mantled with 0.3–1 m of silt, sand, turf, and peat, and generally vegetated. Form terraces generally within 3–4 m of modern stream levels. Differentiated only along principal streams

al_{sa} **Alluvium, sand facies (Holocene to late Pleistocene)**—Moderately sorted to well-sorted, fine to medium sand, parallel bedded to slightly crossbedded, commonly with thin interbeds of sandy peat or organic silty fine sand. Deposited initially by slow-flowing streams within basins partly dammed by end moraines in valleys of Noatak and Cutler Rivers and Amakomanak Creek. Upper 1–2 m locally reworked by wind into sand sheets and dunes. Commonly grades downward into lacustrine deposits

al_s **Alluvium, silt facies (Holocene)**—Moderately sorted to well-sorted silt, parallel bedded to cross-bedded, commonly with interbeds of organic silt and peat. Forms channel and floodplain of small sluggish stream that crosses glacial-lake deposits south of Eli River fan-delta

gr **Gravel deposits, undifferentiated (late Pleistocene)**—Gravel and sandy gravel of diverse origins and composition. Generally applies to isolated, gravelly erosion remnants of uncertain composition and origin. Deposits along Noatak valley floor typically are lag concentrates formed from glacial deposits by wave erosion

gr_{fn} **Gravel deposits, fine-grained (Holocene to late Pleistocene)**—Subrounded small pebbles, with some platy stones up to large pebble size. Mapped in southwest part of map area north of Agashashok River mouth, where deposits may represent remnants of fan or fan delta of Agashashok River, reworked by wave action along former lake margin. Also present near outer flank of Cutler moraine west of Cutler River mouth

TERRACE DEPOSITS

tg **Terrace gravel, undivided (late to middle Pleistocene)**—Alluvial gravel and sandy gravel, commonly capped by flood-plain deposits of silt, sand, or peat up to 1–2 m thick. May locally have thicker mantle of eolian silt or thaw-lake deposits

tg_4 **Terrace gravel, lowest-level (Holocene)**—Alluvial gravel, as described in unit tg. Forms broad alluvial surfaces 8–12 m above river level along Noatak River and lower courses of several triburaties. Thaw lakes common

tg_3 **Terrace gravel, low-level (Holocene)**—Alluvial gravel, as described in unit tg. Silt and peat cover thicker than on unit tg_4. Forms terrace surfaces about 15 m above Noatak River and lower Kaluktavik and Kelly Rivers. Thaw lakes common

tg_2 **Terrace gravel, intermediate-level (late Pleistocene)**—Alluvial gravel, as described in unit tg. Silt and muskeg cover thicker than on unit tg_3. Forms terrace surfaces 25–35 m above Noatak River and lower courses of some tributaries. Some kettle lakes present

tg_1 **Terrace gravel, highest-level (late Pleistocene)**—Alluvial gravel, as described in unit tg. Generally bears thick (up to 3–5m?) silt and muskeg cap. Forms terrace surfaces about 50 m above Noatak River. Kettle lakes common

COLLUVIAL DEPOSITS

c **Colluvium, undivided (Holocene to middle Pleistocene)**—Mixed solifluction deposits (unit s) and talus-rubble deposits (unit tr) in sheets and aprons more than about 0.5 m thick. Most extensive on moderate to steep slopes above and beyond limits of ice advances of Itkillik age. Also common on upper slopes below exposed or near-surface bedrock

c_m **Colluvium-filled mountain valley (Holocene to middle Pleistocene)**—Colluvial deposits mixed with alluvium. Mapped in narrow mountain valleys, where individual deposits are too small to be designated separately. Talus predominates on steep upper slopes; solifluction, fan, and debris-fan deposits predominate on lower slopes. These colluvial deposits interfinger with alluvium toward valley center. Generally restricted to valleys that were not glaciated during Itkillik (late Pleistocene) time

s **Solifluction deposits (Holocene to late Pleistocene)**—Very poorly sorted, unstratified to weakly stratified, stony silt and organic silt; forms smoothly graded, gently to moderately sloping sheets and aprons more than 0.5 m thick. Platy to elongate stones generally oriented parallel to slope. Most common beyond outer limits of Itkillik-age drift; locally present on deposits of Itkillik I age

av **Avalanche tracks and deposits (Holocene)**—Angular unsorted unstratified loose rock rubble, commonly with intermixed woody plant debris. Form tongues and fans along lower walls of mountain valleys. Associated with tracks and chutes where soil and vegetation are generally absent and that commonly are bordered by zones of damaged trees or shrubs. Recognized only in deep mountain valleys near southeast margin of map area

pr **Protalus rampart deposits (Holocene)**—Unsorted, unstratified, coarse angular rock debris forming arcuate low ridges. Associated with persistent snowbanks in shaded sites, commonly at bases of cirque headwalls. Subject to rockfalls during spring thaw rg **Rock-glacier deposits, undifferentiated (Holocene to late Pleistocene)**—Coarse angular rock debris, as described in unit rg_a. Active and inactive components either undetermined or too small to be mapped separately

rg_a **Rock-glacier deposits, active (Holocene)**—Very poorly sorted, unstratified, coarse angular rock debris with matrix of silt and fine rubble; contains abundant interstitial ice. Upper surfaces generally unvegetated, unweathered to moderately weathered; lichen cover sparse. Frontal slopes barren, steep (35°–38°), and highly unstable; they meet upper surfaces at abrupt angle. Subject to slow downslope motion. Fed by talus cones and aprons, which commonly are too small to show on map. Form lobate deposits along bases of valley walls and tongue-shaped deposits within cirques. Tongue-shaped deposits commonly overlie stagnant glacier ice

rg_i **Rock-glacier deposits, inactive (Holocene to late Pleistocene)**—Coarse angular rock debris, as described for unit rg_a, but lacking interstitial ice. Upper surfaces and frontal slopes weathered, covered by lichens, and commonly partly covered by sod and vegetation. Frontal slopes grade into upper surfaces without abrupt angles

tr **Talus rubble (Holocene to late Pleistocene)**—Angular, unsorted rock debris, as described in unit tr_a. Active and inactive components either undetermined or too small to be mapped separately

tr_a **Talus rubble, active (Holocene)**—Angular, unsorted, unstratified rock debris forming cones and aprons more than 2 m thick and generally sloping 30°–33° along lower flanks of mountain valleys and on cirque headwalls. Also forms thinner and generally discontinuous sheets over many uplands mapped as bedrock. Generally unvegetated, unweathered to slightly weathered; lichen cover sparse to absent. Subject to rockfalls from slopes above, especially during spring thaw

tr_i **Talus rubble, inactive (Holocene to late Pleistocene)**—Angular rock debris, as described in unit tr_a. Generally weathered and lichen covered, and with partial sod cover at some localities. Thin (less than 1–2 m) blankets of stabilized talus occur on many uplands mapped as undifferentiated bedrock

ls **Landslide deposits (Holocene to late Pleistocene)**—Unsorted, unstratified, coarse to fine, angular rubble, commonly with matrix of finer debris; form lobes below detachment scars and slide tracks on steep rock walls. Subject to rapid downslope movement and long periods of relative stability. Most common in upper mountain valleys near north and south margins of map area

fl **Flow deposits (Holocene to late Pleistocene)**—Very poorly sorted stones in abundant muddy matrix. Generally originate in slumps and terminate as lobes. Mapped primarily on Noatak valley floor between Avan and Kelly Rivers. Many smaller flows occur in glaciolacustrine deposits exposed along Noatak River and its principal tributaries, but these generally are too small to constitute mappable units

SAND, SILT, AND ORGANIC DEPOSITS

sa **Sand deposits (late Pleistocene)**—Moderately sorted, fine to medium sand, horizontally bedded to slightly crossbedded, commonly with thin interbeds of sandy peat or organic silty fine sand. Form terraces up to 25 m high within basins partly dammed behind end moraines in upper Noatak and Nigu River valleys

si **Ice-rich silt deposits (Holocene to late Pleistocene)**—Silt deposits, more than 1–2 m thick in swales and other depressions; commonly with ice-wedge polygon networks. Mapped primarily along lower course of Noatak River below Eli River

us **Upland silt deposits (Holocene to early Pleistocene)**—Poorly sorted to moderately sorted, generally unstratified, silt, organic silt, and slightly stony silt draped over uplands of low to moderate relief. Formed from windblown silt (loess) that was mixed by frost action with local organic matter and weathering products. Generally has tussock cover broken by frost boils. Commonly grade downslope into thick, massive, organic-rich silt or into solifluction deposits

m **Muskeg (Holocene to middle Pleistocene)**—Peat, organic silt, and organic detritus more than 1–2 m thick in areas of restricted drainage where water table is at or close to surface. Mapped only along passes to Squirrel River in extreme southwest corner of map area

LACUSTRINE, GLACIOLACUSTRINE, AND GLACIAL-MARINE DEPOSITS

General

b **Beach deposits (Holocene)**—Moderately well sorted, coarse to medium sand, commonly mixed or interbedded with platy fine gravel. Locally forms ridges of poorly sorted, gravelly sand to sandy coarse gravel where mixed by ice shove. Small deposits occur locally around most lakes, but deposits of mappable size occur around Lake Narvakrak and along east shore of Feniak Lake. Older deposits (late Pleistocene unit mapped as b?) occur at margins of glacial lakes along lower course of Noatak River and locally farther upvalley

dt **Deltaic deposits (Holocene to late Pleistocene)**—Generally well stratified sand, gravelly sand, and sandy fine gravel; deposited by streams at lake margins. Commonly build outward into lake, and overlie fine-grained lacustrine deposits. Mapped only at north ends of Feniak and Desperation Lakes and at southwest corner of Lake Kangilipak

dt_s **Silty deltaic deposits (Holocene)**—Deltaic deposits, as described in unit dt; predominantly silt. Some sand present, but larger clasts almost entirely absent. Mapped only at Noatak River mouth in extreme southwest corner of map area

l **Lacustrine deposits (Holocene to late Pleistocene)**—Clayey silt, silt, and sand, commonly well stratified; grade into sand and gravelly sand near former shorelines and sandy fine gravel near former river mouths. Commonly include beach deposits too small to be designated separately. Mapped primarily along receding lake margins or beds of lakes that have recently drained

tl **Thaw-lake deposits (Holocene)**—Weakly stratified to nonstratified silt, organic silt, and clayey to sandy silt; generally contain abundant ice as lenses, wedges, and interstitial grains. Occupy thaw basins in glacial-lake deposits on valley and lowland floors

Within Brooks Range

igl **Glacial-lake deposits of Itkillik age (late Pleistocene)**—Stony silt to stony silty clay, with some silty fine sand, massive to faintly bedded. Contain sparse to abundant subangular to subrounded pebbles, cobbles, and small boulders that commonly are striated. Grade into gravelly sand to sandy fine gravel near former stream mouths. Mapped as compound unit (for example igl/B, igl/id, igl/io) where deposit drapes or overlies bedrock, drift, outwash, or other glacial deposits. Arcuate map symbols designate end moraines of preceding glacial advances that later were draped by lake deposits. Upper limits locally marked by wave-cut scarps, wave-scoured bedrock, and beach deposits

igl_2 **Glacial-lake deposits of Avan (Itkillik Phase II) age (late Pleistocene)**—Glacial-lake deposits, as described in unit igl. Associated with moraine dam at mouth of Avan River. Upper limits generally well defined. Form extensive deposits on floors of Kelly, Kugururok, and Kaluktavik River valleys and narrow belt incised within older glacial-lake deposits along Noatak valley floor through Aniuk Lowland

igl_1 **Glacial-lake deposits of Itkillik Phase I age (late Pleistocene)**—Glacial-lake deposits, as described in unit igl. Upper limits commonly obscured by solifluction. Widespread across floor of upper Noatak basin (Aniuk Lowland) up to altitudes that rise progressively eastward from about 425 m (1400 ft) to 510 m (1680 ft) asl

igl_{1B} **Glacial-lake deposits of Anisak (Itkillik Phase IB) age (late Pleistocene)**—Glacial-lake deposits, as described in unit igl, that formed within southern valleys of De Long Mountains during ice recession from Anisak moraine. Associated with erosional scarps along inner flanks of Anisak moraine. Upper limits elsewhere commonly obscured by solifluction. Filled Kaluktavik, Kugururok, and Kelly River valleys during or following their deglaciation; locally present up to 425 m (1400 ft) asl in upper parts of those drainages

igl_{1A} **Glacial-lake deposits of Makpik (Itkillik Phase IA) age (late Pleistocene)**—Glacial-lake deposits, as described in unit igl, that formed during early phase of Itkillik glaciation. Locally present up to 500 m (1650 ft) asl between Feniak and Desperation Lakes

sgl **Glacial-lake deposits of Sagavanirktok River age (middle Pleistocene)**—Glacial-lake deposits, as described in unit igl. Confined by moraines of Sagavanirktok River age near Feniak Lake and in Howard Pass area

idt **Deltaic deposits of Itkillik age (late Pleistocene)**—Generally well stratified sand and sandy fine gravel, as described in unit dt. Formed near mouths of streams that flowed into glacial lakes of Itkillik age; typically overlie and interfinger with fine-grained deposits of those glacial lakes sdt **Deltaic deposits of Sagavanirktok River age (middle Pleistocene)**—Deltaic deposits, as described in units dt and idt. Mapped along north side of Anisak River valley between Picnic and Setting Sun Creeks. Also occur as flat-topped deposit 15 m high on south side of Flora Creek at distal end of outwash terrace of Sagavanirktok River age. On south side of Howard Pass, composite unit igl/sdt is probable deltaic deposit that is covered by thin glaciolacustrine sediments

cgl **Glacial-lake deposits of Cutler age (middle Pleistocene)**—Glacial-lake deposits, as described in unit igl. Formed beyond Cutler moraine and preserved above limits of unit igl_1 in Cutler and Anisak River valleys. Surfaces commonly dissected by stream networks. Mapped as composite unit cgl/sd where lacustrine deposits overlap end moraines of Sagavanirktok River age

Mission Lowland

ml **Lacustrine and other fine-grained deposits (Holocene to late Pleistocene)**—Silt, ice-rich silt, and sandy silt, with some sand and sandy fine gravel. Formed in part by lacustrine processes and in part by slow-moving floodwaters retarded by narrow outlet (Igichuk Hills) near mouth of Noatak River. Generally concealed beneath thick loess cover

ml_2 **Younger lacustrine and other fine-grained deposits (Holocene to late Pleistocene)**—Fine-grained sediments, as described in unit ml; broadly distributed across Noatak valley floor. Maximum altitudes rise northward from about 15 m (50 ft) near Agashashok River mouth to 140 m (450 ft) near mouth of Kelly River. May have formed largely by alluviation of Noatak River in response to Holocene sea-level rise

ml_1 **Older lacustrine and other fine-grained deposits (late Pleistocene)**—Fine-grained sediments, as described in unit ml. Extend beyond limits of unit ml_2 up to various altitudes as high as 260 m (850 ft) asl. Commonly associated with lake-margin features such as overflow drainage channels and other shoreline features

si/cgm **Glacial-marine deposits of Cutler(?) age (middle Pleistocene)**—Pebbles, cobbles, and small boulders, commonly striated; in gray silty matrix. Exposed only in coastal bluffs along north shore of Kotzebue Sound. Overlain by 7–10 m of ice-rich silt that may be eolian in origin; therefore is designated as composite unit

GLACIAL DRIFT AND ICE-CONTACT GRAVEL

d **Drift, undifferentiated (late to early Pleistocene)**—Glacial deposits, as described in unit id, of uncertain age

Late Holocene glaciation (Neoglaciation)

nd **Drift of neoglacial age (Holocene)**—Unsorted unstratified angular rubble; forms lobes and arcuate ridges with steep and commonly unstable slopes. Clasts unweathered to slightly weathered; generally unvegetated except by lichens. Restricted to cirques at higher altitudes, commonly near valley heads

nd_2 **Drift of late neoglacial age (Holocene)**—Angular rubble, as described in unit nd; forms lobes and arcuate ridges of ice-cored drift with steep, unstable frontal slopes. Unvegetated, unweathered to slightly weathered, and with lichens sparse to absent. Restricted to cirques, and generally associated with active glaciers

nd_1 **Drift of early neoglacial age (Holocene)**—Angular rubble, as described in unit nd. Forms more subdued lobes and ridges with stable frontal slopes; generally eroded by axial streams. Weathered and lichen encrusted, with partial sod cover in some localities

Itkillik glaciation

id **Drift of Itkillik age, undifferentiated (late Pleistocene)**—Unsorted to poorly sorted, generally unstratified, compact till; ranges in composition from muddy sandy gravel to gravelly muddy sand, with local stratified ice-contact deposits as described in subunit ik_3. Contains faceted and striated stones up to large boulder size

id_3 **Drift of late Avan (late Itkillik Phase II) readvance (late Pleistocene)**—Glacial deposits, as described in unit id, with irregular morphology and narrow-crested moraines. Loess cover generally absent, and exposed stones very slightly weathered. Oxidation has penetrated only 20–30 cm into well-drained deposits. Most extensive around Etivlik Lake and on Nigu valley floor in northeast corner of map area. Locally present in higher valley heads within De Long Mountains

ik_3 **Kame and kame-terrace deposits (late Pleistocene)**—Thick and extensive deposits of moderately sorted sand and sandy gravel; upper surfaces level to sharply conical and well drained, and generally with steep ice-contact flanks. Associated with stagnating glaciers of late Itkillik Phase II age in Etivlik Lake-Nigu valley area

id_2 **Drift of Avan (Itkillik Phase II) age (late Pleistocene)**—Glacial deposits, as described in unit id. Form sharply defined arcuate drift belts with narrow-crested (generally 1–3 m) moraines, prominent knob and kettle morphology, and conspicuously channeled outwash trains. Loess and solifluction cover generally lacking on crests and upper slopes. Exposed boulders are slightly to moderately weathered; oxidation has penetrated 40–50 cm into well-drained deposits. Most swales have no solifluction deposits, and abandoned meltwater channels commonly are floored with thin sod mats above coarse gravel. Overlapped by glacial-lake deposits to about 180 m (600 ft) altitude, and wave-eroded to altitudes locally as great as 320 m (1060 ft) in western part of map area

ik_2 **Kame and kame-terrace deposits (late Pleistocene)**—Thick and extensive deposits of sand and gravel, as described in unit ik_3. Most extensive within drift of Itkillik Phase II age on floor of upper Noatak valley near east margin of map area

id_1 **Drift of Itkillik Phase I age, undivided (late Pleistocene)**—Glacial deposits, as described in unit id. Moraine crests generally 5–10 m wide and partly bare of loess; upper slopes blanketed by stony organic silt (loess and colluvium) 0.5–2 m thick; swales filled with deposits of ice-rich organic silt 2–5 m thick. Morphology locally more subdued where overlapped by glaciolacustrine deposits. Forms extensive hummocky drift bodies beyond limits of Itkillik Phase II drift. Shown in parentheses (id_1) where drift is thin and patchy, and also where drift of Itkillik Phase I age has been mixed with silt, rock rubble, and organic detritus on hill slopes or lower valley walls to become a compound (glacial + colluvial) deposit

ik_1 **Kame and kame-terrace deposits (late Pleistocene)**—Unusually extensive and thick deposits of water-washed sand and gravel deposits, as described in unit ik_3, deposited within drift of Itkillik I age

id_{1C} **Drift of late Anisak (Itkillik Phase IC) age (late Pleistocene)**—Glacial deposits, as described in unit id. Formed by late stillstand or readvance of residual glaciers near head of Nimiuktuk River valley and within upper valley of Seagull Creek

id_{1B} **Drift of Anisak (Itkillik Phase IB) age (late Pleistocene)**—Glacial deposits, as described in unit id. Form separate inner moraines within drift complexes of Itkillik Phase I age. Includes Anisak moraine, a prominent end moraine at mouth of Anisak River, and drift on floor of upper Noatak valley above Atongarak Creek. Overlapped by glacial-lake deposits to altitudes of about 400 m (1300 ft)

id_{1A} **Drift of Makpik (Itkillik Phase IA) age (late Pleistocene)**—Glacial deposits, as described in unit id. Form separate outer moraines within drift complexes of Itkillik Phase I age. Includes Makpik moraine, near mouth of Makpik Creek, and moraine complex in upper Noatak valley just below Atongarak Creek

ik_{1A} **Kame and kame-terrace deposits (late Pleistocene)**—Unusually thick and extensive deposits of water-washed sand and gravel, as described in unit ik_3, deposited within drift of Itkillik Phase 1A age

i-c **Ice-contact meltwater deposits (late Pleistocene)**—Meltwater-washed sand and gravel, as described in unit ik_3. Commonly associated with finer grained glaciolacustrine deposits. Probably formed by accelerated melting of debris-covered stagnant glacier ice where in contact with transgressing glacial lake. Most common on lateral and end moraines of Anisak (unit id_{1B}) advance on Noatak valley floor between Anisak and Nimiuktuk Rivers

Sagavanirktok River glaciation

sd **Drift of Sagavanirktok River age (middle Pleistocene)**—Poorly sorted nonstratified till; probably ranges in composition from silty sandy bouldery gravel to clayey stony silt, with local deposits of moderately well sorted and stratified gravel. Moraines relatively subdued and generally discontinuous. Generally covered by thick (>3 m) blanket of silt, stony silt, and organic silt (loess, solifluction, and marsh deposits), but crests of some ridges and knolls yield limited exposures of weathered gravel and erratic boulders of resistant lithologies. Designated only in eastern part of map area

sk **Kame and kame-terrace deposits (middle Pleistocene)**—Unusually thick and extensive deposits of water-washed sand and gravel, as described in subunit ik_3, deposited against drift of Sagavanirktok River age. Mapped only north of Aniuk River 22 km southwest of Howard Pass

sd_2 **Drift of late Sagavanirktok River age (middle Pleistocene)**—Till and stratified ice-contact deposits, as described in unit sd. Forms inner moraine belts within drift complexes in eastern part of map area

sd_1 **Drift of early Sagavanirktok River age (middle Pleistocene)**—Till and stratified ice-contact deposits, as described in unit sd. Forms outer moraine belts within drift complexes in eastern part of map area. Generally more dissected and more subdued by mass wastage than deposits of unit sd_2

Cutler glaciation

cd **Drift of Cutler age (middle to early Pleistocene)**—Till and stratified ice-contact deposits, as described in unit sd. Formed by east-flowing glacier from De Long Mountains that deposited massive end moraine near mouth of Cutler River. Designated only in western part of map area. Because glacier may have responded to different controls, Cutler advance may not correlate with advances of early or late Sagavanirktok River age mapped in eastern part of map area

Sagavanirktok River or older glaciation

od **Older drift (middle to early Pleistocene)**—Bouldery till and gravel of uncertain composition, as described in unit sd. Lies beyond limits of glacial deposits of Cutler age in south-central part of map area. Generally forms featureless deposits buried beneath thick mantle of fine-grained loess and colluvium. Commonly identifiable only by presence of erratic boulders in stream beds

Anaktuvuk River glaciation

ad **Drift of Anaktuvuk River age (early Pleistocene)**—Bouldery glacial deposits of uncertain composition overlain by continuous cover of organic silt (loess, solifluction, and thaw-lake deposits) generally more than 2–3 m thick. Erratic boulders consist only of most resistant rock types (quartzites and granites). Forms subdued till plains and low broad morainal ridges with gentle (1° to 2°) flanking slopes except where steepened by glacial erosion. Former swales and kettles generally filled with ice-rich, silty, organic colluvial and lacustrine deposits more than 5 m thick. Deeply and broadly dissected by streams. Designated only in northeastern part of map area

GLACIAL OUTWASH AND INWASH

Itkillik glaciation

io **Outwash of Itkillik age, undivided (late Pleistocene)**—Moderately well sorted and stratified sandy gravel; forms aprons and valley trains in front of moraines of Itkillik age and terrace remnants farther downvalley. Largest stones decrease in size from subrounded cobbles and very small boulders near moraine fronts to rounded to subrounded pebbles and granules farther downvalley

io_3 **Outwash of late Avan (late Itkillik Phase II) readvance (late Pleistocene)**—Gravel aprons and valley trains, as described in unit io. Associated with or downvalley from end moraines assigned to late Avan readvance in Trail Creek valley and near Etivlik Lake. Also present near mouths of cirque-headed tributary valleys near head of Avan River. Generally lacks loess and peat cover, and is oxidized to depth of only 20–30 cm

io_2 **Outwash of Avan (Itkillik Phase II) age (late Pleistocene)**—Sandy gravel, as described in unit io. Generally lacks loess cover. Forms terraces up to about 30 m high in front of end moraines of Avan (Itkillik Phase II) age on floor of upper Noatak valley and in valleys that traverse rugged highlands of De Long Mountains and in eastern part of map area. Stones etched, fractured, and pitted to 30–40 cm depth; oxidized to depths of 30–45 cm

io_1 **Outwash of Itkillik Phase I age (late Pleistocene)**—Sandy gravel, as described in unit io. Generally has cover of silt, organic silt, and peat 0.5–4 m thick. Forms terraced aprons and valley trains beyond end moraines of Itkillik Phase I age, and also terrace remnants near head of Aklumayuak Creek. Commonly grades downvalley into thick sandy basin-fill deposits or silty glaciolacustrine deposits

io_{1C} **Outwash of late Anisak (late Itkillik Phase IC) age (late Pleistocene)**—Sandy gravel, as described in unit io. Associated with end moraines of inferred late Anisak age. Forms terrace remnants in valley of Seagull Creek and near head of Nimiuktuk River

io_{1B} **Outwash of Anisak (Itkillik Phase IB) age (late Pleistocene)**—Sandy gravel, as described in unit io. Associated with Anisak moraine and with other end moraines of inferred Anisak (Itkillik Phase IB) age

io_{1A} **Outwash of Makpik (Itkillik Phase IA) age (late Pleistocene)**—Sandy gravel, as described in unit io. Associated with Makpik moraine and with other end moraines of Makpik (Itkillik Phase 1A) age

ii_2 **Inwash of Avan (Itkillik Phase II) age (late Pleistocene)**—Well sorted to moderately sorted and stratified gravelly sand and sandy fine gravel; commonly grades upvalley into sandy gravel. Deposited near mouths of nonglaciated tributaries blocked by glaciers of Avan age. Forms benches and terraces that abut outer flanks of lateral moraines or outer faces of drift lobes

ii_1 **Inwash of Itkillik Phase I age (late Pleistocene)**—Gravelly sand and sandy gravel, as described in unit ii_2. Forms deposits that abut drift of Itkillik Phase I age

ii_{1B} **Inwash of Anisak (Itkillik Phase IB) age (late Pleistocene)**—Gravelly sand and sandy gravel, as described in unit ii_2. Forms deposits that abut drift of Itkillik Phase IB age

ii_{1A} **Inwash of Makpik (Itkillik Phase IA) age (late Pleistocene)**—Gravelly sand and sandy gravel, as described in unit ii_2. Forms deposits that abut drift of Itkillik Phase IA age

Sagavanirktok River glaciation

so **Outwash of Sagavanirktok River age (middle Pleistocene)**—Moderately well sorted and stratified gravel to sandy gravel. Forms trains and aprons beyond end moraines of Sagavanirktok River age in eastern part of map area. Commonly forms terraces up to 40 m high near moraine fronts. Stones generally weathered; and matrix generally oxidized to several meters depth. Typically covered by 1–2 m or more of loess, solifluction, and marsh deposits

so_2 **Outwash of late Sagavanirktok River age (middle Pleistocene)**—Sandy gravel, as described in unit so. Associated with end moraines of late Sagavanirktok River age in eastern part of map area

so_1 **Outwash of early Sagavanirktok River age (middle Pleistocene)**—sandy gravel, as described in unit so. Associated with drift of early Sagavanirktok River age in eastern part of map area

Cutler glaciation

co **Outwash of Cutler age (middle Pleistocene)**—Sandy gravel, as described in unit so. Forms terrace remnants associated with southern lateral moraine of Cutler advance near head of Aklumayuak Creek

BEDROCK SURFACE FORMS

[Bedrock units are differentiated on basis of surface morphology only, without consideration of age or composition]

B **Bedrock, undifferentiated**—Outcrops too small or too variable to classify, or intermediate in character between other bedrock surface forms. Relief generally moderate; most crests expose bare rock and most lower slopes vegetated. Talus generally rare to absent, and typically inactive where present

B_a **Bedrock, alpine**—Generally unweathered; forms steep-sided, sharp-crested ridges that have been sharpened by glacial erosion. Dissected by avalanche chutes and (at higher altitudes) by cirques and nivation basins. Lower flanks commonly mantled with talus and with debris fans at bases of avalanche chutes. Commonly includes stream deposits, talus rubble, and other colluvial deposits too small to designate separately

B_e **Bedrock exposed by stream erosion**—Unweathered to slightly weathered; forms generally steep slopes along flanks of meltwater drainage channels or recently incised stream systems

B_g **Bedrock, glacier-scoured**—Smoothed and abraded by overriding glacier ice. May exhibit faceted ridge spurs, ice-marginal drainage channels, stoss-and-lee topography, U-shaped divide crossings, and other features characteristic of glacial erosion. Generally well exposed; commonly streamlined in direction of ice flow and channeled by meltwater. Black arrows show flow directions of ice; white arrows show flow directions of meltwater

B_s **Bedrock, silt-covered**—Moderate relief; silt cover generally present over all but the highest and steepest slopes. Most common near Pleistocene lake beds and other sources of airborne silt (loess), but also locally present where silt is generated by weathering of shale or other fine-grained readily disaggregated rock

Bedrock, wave-eroded—Scoured by wave abrasion; has planed surface or series of terracelike surfaces, with scattered erratic clasts. Commonly associated with wave-cut notches and wave-built platforms. Mapped within and along north flank of Aniuk Lowland. Designated by diagonal line pattern

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