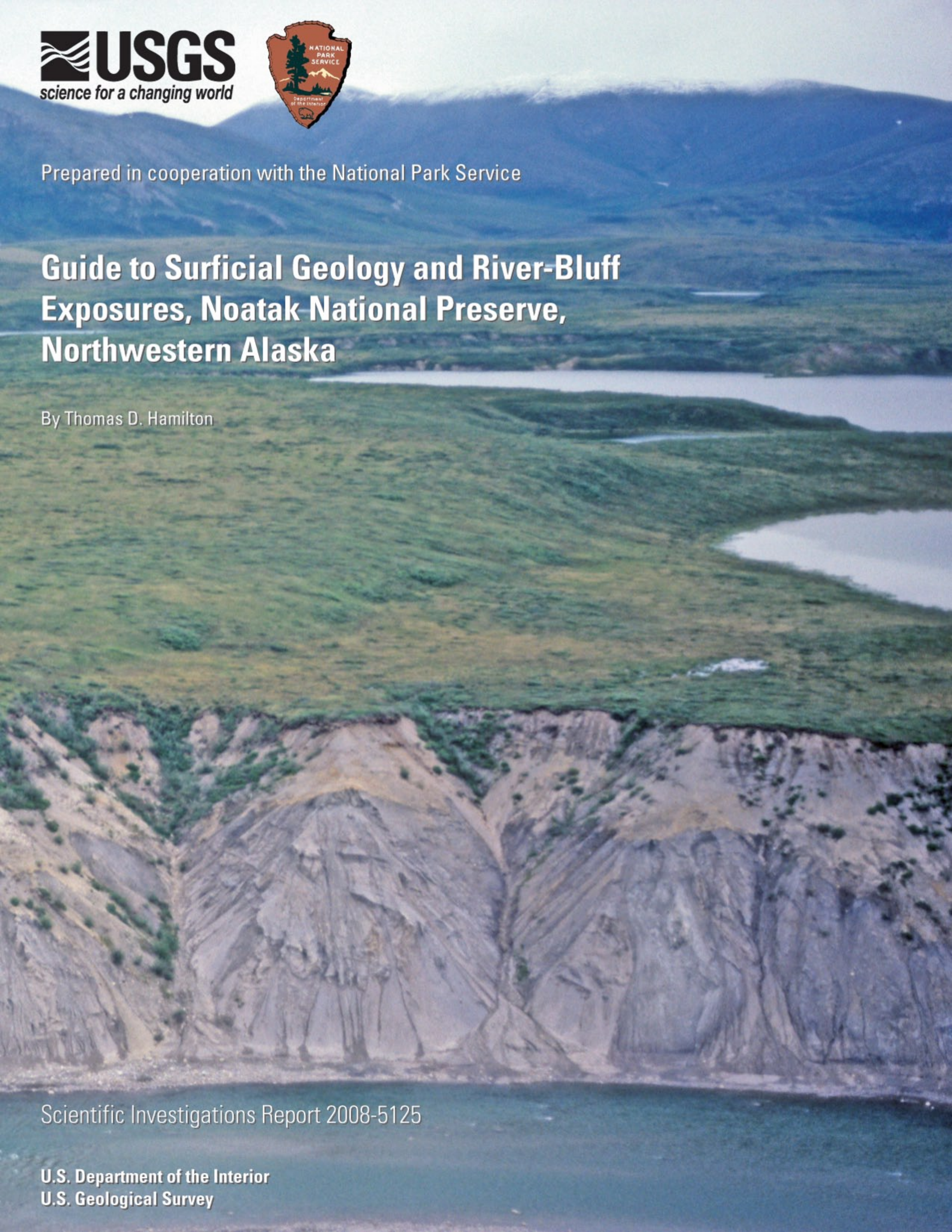

Prepared in cooperation with the National Park Service

Guide to Surficial Geology and River-Bluff Exposures, Noatak National Preserve, Northwestern Alaska

By Thomas D. Hamilton

Scientific Investigations Report 2008-5125

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER

Photograph of bluff exposure Nk-11, Noatak National Preserve, Alaska, with water-filled kettle depressions in background. Amphitheater-like gully heads have resulted from thaw and flowage of ice-rich permafrost (photo by author). Inset photographs on the back cover are (from top to bottom) (1) Ice-wedge cast in gravel at exposure Nk-29A (photo by G.M. Ashley, 7/26/83); (2) conifer log exhumed by erosion near river level at exposure Nk-37 (photo by M.E. Edwards, 7/13/95); (3) exposure Nk-27, where upper and lower diamicts are separated by remnants of eroded floodplain deposit, from point bar on opposite side of Noatak River (photo by author, 7/23/83); (4) exposure Nk-26, showing upper and lower diamicts separated by floodplain deposits that overlie alluvial gravel (photo by author, 7/19/83); and (5) varves with dropstone at exposure Cu-6 (photo by G.M. Ashley, 7/17/83).

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KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

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METRIC-ENGLISH EQUIVALENTS

TO CONVERT	MULTIPLY BY	TO OBTAIN
millimeters (mm)	0.040	inches
centimeters (cm)	0.397	inches
meters (m)	3.281	feet
kilometers (km)	0.621	miles

Guide To Surficial Geology and River-Bluff Exposures, Noatak National Preserve, Northwestern Alaska

By Thomas D. Hamilton

Abstract

From its origin in rugged granitic highlands of the central Brooks Range, the Noatak River flows westward between the De Long Mountains and the Baird Mountains before turning south to enter Kotzebue Sound. Glaciers of middle and late Pleistocene age entered the Noatak River valley from the east, north, and south. Glaciers flowed down the upper Noatak River valley from the rugged peaks at its head, merging with tributary glaciers that issued from cirque-headed valleys along its south flank. Farther downvalley, small glaciers flowed northward from the Baird Mountains and much larger glaciers issued from the De Long Mountains. The De Long Mountains glaciers expanded southward to cover parts of the Noatak valley floor; they dammed the Noatak River during successive advances, creating a series of glacial lakes. The more extensive glacial advances dammed huge lakes that filled the Aniuk Lowland to overflowing. At various times, overflow waters spilled northward through Howard Pass, southward via Hunt River into the Kobuk River system, and westward down a series of channelways that skirted south of the glacier margins.

Prominent bluffs along the Noatak River and its principal tributaries reveal glacial, glaciolacustrine, fluvial, and eolian sediments. More than 120 measured bluff exposures are described and illustrated in this report. These are dated by 92 radiocarbon age determinations and by the presence of the old Crow tephra, which was deposited about 130,000-140,000 years ago. Six geologic base maps, which cover sections of the Noatak River valley from east to west, show the locations of the river bluffs in relation to the glacial, glaciolacustrine, and fluvial deposits that cover the valley floor.

The upper Noatak River valley is dominated by a bulky end moraine near Douglas Creek that was deposited during the last glacial maximum about 25,000-15,000 ^{14}C yr BP (termed the Itkillik II phase in the central Brooks Range glacial succession). Bluffs along this section of the Noatak River reveal thick till that underlies the moraine and interfingers downvalley with outwash and upvalley with moraine-dammed lake deposits. Remnants of older river gravels that underlie the set of glacial deposits contain wood fragments that are dated at about 35,000-30,000 ^{14}C yr BP.

The Aniuk River area, which includes much of the eastern Aniuk Lowland, contains older moraines derived from headwaters of the Noatak valley that lie downvalley from the Douglas Creek moraine. These older moraines are assigned to the Itkillik IA and IB advances of the central Brooks Range glacial succession. Their deposits are seldom visible in river bluffs, but associated outwash and glaciolacustrine sediments are commonly exposed. More ancient end moraines farther downvalley are buried beneath lake deposits of the Aniuk Lowland, but are traceable as subdued arcuate drainage divides and as boulder concentrations in river bluffs or along their bases.

The Cutler River area was occupied by glacial lakes assignable to three separate glacial phases. The oldest of these was probably dammed by the Cutler moraine, which crosses the Noatak valley floor near the mouth of Cutler River. The younger two are correlated with Itkillik-age deposits in the Aniuk Lowland. Glaciers of Itkillik age also flowed northwestward down the Cutler and Imelyak valley systems from cirques along the Noatak-Kobuk divide, but they did not reach the Noatak valley floor.

The western Aniuk Lowland, which extends westward from the Cutler River mouth to the lower course of Nimiuktuk River, is dominated by a series of large end moraines deposited by glaciers from the De Long Mountains and that flowed southeastward down the Nimiuktuk valley system and then up the Noatak River valley. The Cutler moraine is the most extensive of these deposits. Following the Cutler glaciation, less extensive glacial advances built end moraines near the present-day mouths of Makpik Creek and Anisak River during intervals that may correlate with the Itkillik 1A and Itkillik 1B phases in the central Brooks Range. The Cutler, Makpik, and Anisak glaciers dammed the Noatak River, creating the series of glacial lakes that covered the Aniuk Lowland. High river bluffs through this sector of the Noatak valley expose sequences of massive till and glacial-lake deposits that alternate with interglacial river gravels and organic-rich floodplain deposits. Floodplain sediments in two of the bluffs contain the Old Crow tephra, a stratigraphic marker for an early phase of the last interglaciation.

Downvalley from Nimiuktuk River, glaciers in the De Long Mountains flowed southward through the Kalaktavik, Kugururok, and Kelly drainage systems, deflecting the Noatak River into a more southerly position against the north flank of the Baird Mountains. These glaciers dammed the Noatak drainage near the mouths of their valleys, and glacial lakes subsequently expanded northward up each valley when the

glaciers receded. Ice advances of the last glacial maximum (locally termed the Avan glaciation) reached the mouth of Avan River valley, but elsewhere they were restricted to upper valleys and valley heads in the De Long Mountains and to cirques in the Baird Mountains. The reduced extent of these glaciers contrasts strongly with the much larger correlative glaciers of Itkillik II age throughout the central Brooks Range. Bluffs along the Noatak River and lower courses of its tributaries expose till and glaciolacustrine deposits, as well as terraced river gravels and floodplain deposits that formed during postglacial downcutting. In several locations, the postglacial alluvium contains wood or peat that yield radiocarbon ages of 13,000 yr BP and younger.

The sparse river-cut exposures downvalley from Kelly River exhibit mainly lake deposits, associated deltas and fan deltas, and loess. Heavy loess cover obscures much of the older terrain across this sector of the Noatak valley floor. No significant exposures were recorded downvalley from the large fan-delta deposit of Eli River, possibly because the Noatak River has been aggrading through this section of its valley during Holocene time.

Introduction

The Noatak River originates in rugged granitic highlands of the west-central Brooks Range and flows westward into Kotzebue Sound (fig. 1). Along most of this route, its valley parallels the structural grain of the Brooks Range, and separates the DeLong Mountains to the north from the Baird Mountains to the south. A short distance beyond the Kelly River confluence, the Noatak curves southward; it skirts the west end of the Baird Mountains, then intersects the coast opposite the town of Kotzebue. The valley of the Noatak River widens in two places into broad basins that contained extensive Pleistocene-age lakes. The upper basin, termed the Aniuk Lowland by Wahrhaftig (1965), extends westward

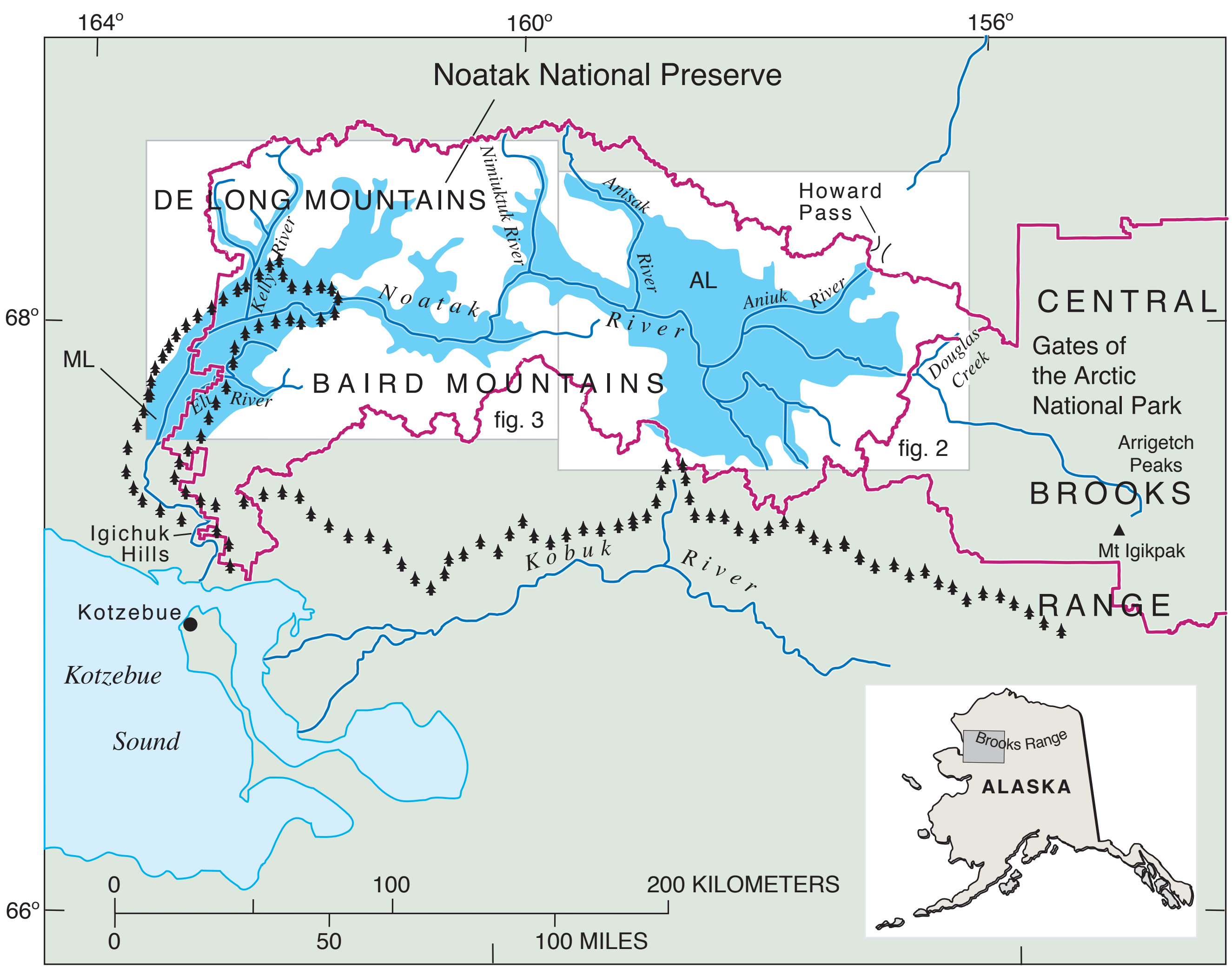


Figure 1. Noatak River region, northwest Alaska, showing boundaries of Noatak National Preserve and mapped extents of glacial lakes (dark blue). Easternmost lake is centered over Aniuk Lowland (AL), also known as upper Noatak basin. Westernmost lake extends southward into Mission Lowland (ML). Tree symbols show northward limit of spruce (from Edwards and others, 2003). Figures 2 and 3 show locations of measured sections. Modified from Hamilton, 2001.

from below Douglas Creek to near Anisak River. The lower basin, termed the Mission Lowland by Wahrhaftig (1965) extends southward from near Kelly River to the Igichuk Hills, a northeast-trending bedrock ridge about 25 km inland from the coast. For about 310 km of its course, beginning near Douglas Creek and ending below Kelly River, the Noatak and its tributaries flow within the Noatak National Preserve.

The upper Noatak basin, or Aniuk Lowland, has a maximum width of about 80 km and extends about 90 km downvalley (fig. 2). This depression is centered along the Noatak River, and it is drained additionally by three principal tributaries to the Noatak: the Anisak and Aniuk Rivers, which flow southward from the De Long Mountains, and the Cutler River system, which drains northern parts of the Baird Mountains and the south-central Brooks Range. During glacial phases of the middle and late Pleistocene, valley and piedmont glaciers flowed southeastward out of the Nimiuktuk valley system and dammed the Noatak River, forming glacial lake Noatak (Hamilton and Van Etten, 1984; Hamilton, 2001). The more extensive advances filled much of the basin with glacier ice and with proglacial lakes, which overflowed at various times northward via Howard Pass, southward down Hunt River into the Kobuk River valley, and westward around the ice margin into the lower valley of the Noatak River. A large glacier that originated in highlands near the head of the Noatak valley system terminated in the lake at those times, as did smaller glaciers that flowed from uplands north of Feniak Lake and near the heads of Cutler and Imelyak River valleys. During the late Pleistocene, less extensive ice advances from the Nimiuktuk River area dammed a narrow water body that extended up the basin center. Valley glaciers in the upper Noatak, near Feniak Lake, and within the Cutler River drainage system formed prominent end moraines beyond the lake margins at those times.

Below the Nimiuktuk River confluence, the Noatak bends sharply southward; it flows south and then west for about 90 km through a relatively narrow valley that terminates in Noatak Canyon, a rock-walled gorge just above the mouth of Kugururok River (fig. 3). The river was pushed into this position by glaciers that originated in the De Long Mountains

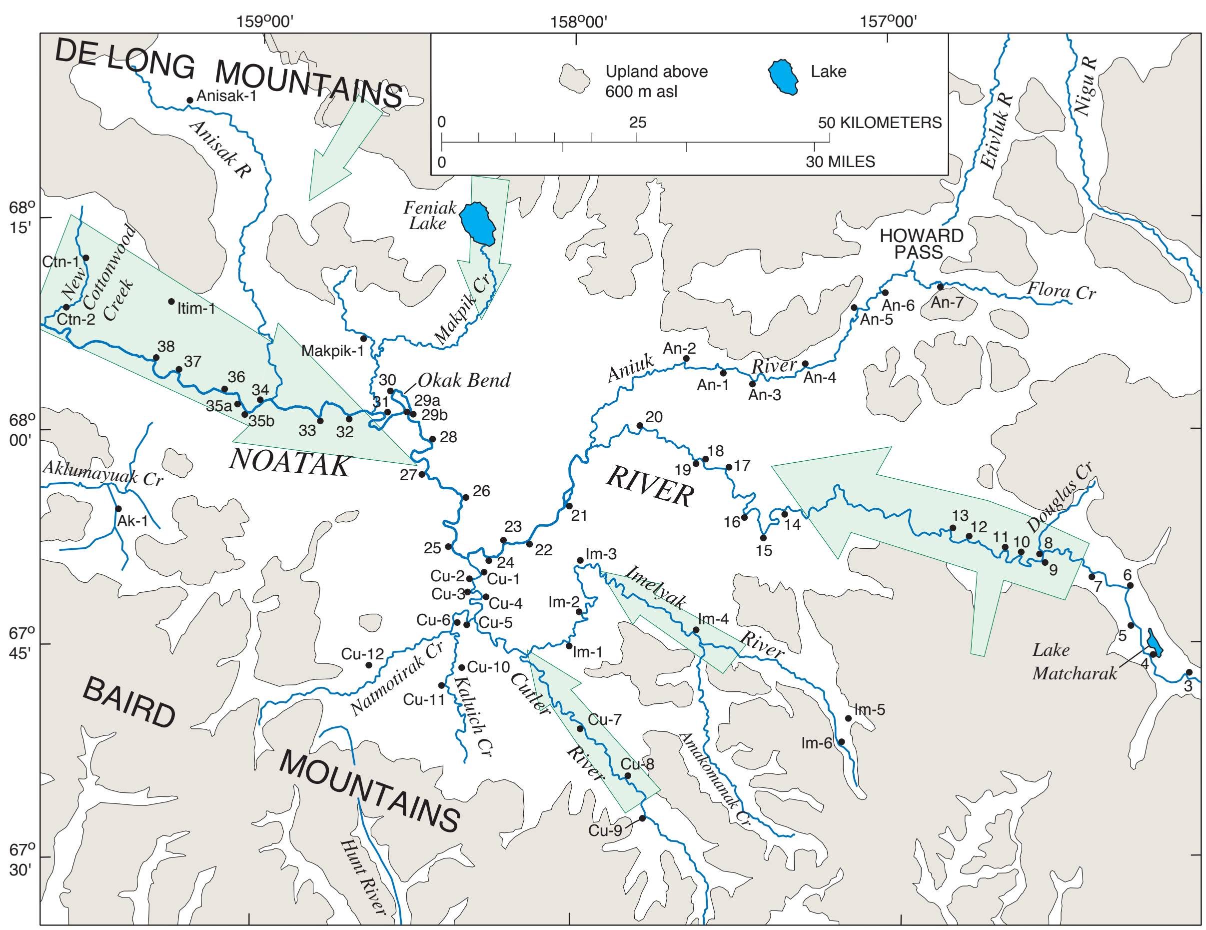


Figure 2. Upper Noatak basin (Aniuk Lowland) showing major drainages and locations of measured sections (see figs. 5, 18, 34, and 54 for geologic settings). Numbers without prefixes refer to Noatak River bluffs (designated Nk in figs. 5, 18, and 34, and in text). Arrows show major Pleistocene glacial-flow directions, with size of arrow proportional to glacial discharge.

and that flowed southward through the Kelly, Kugururok, and Kaluktavik valley systems. Glacial-lake deposits are present along the valley floor upstream from the former ice dams created by those glaciers.

Much of the lower Noatak basin, or Mission Lowland, lies beyond the western boundary of the Noatak National Preserve, and is not illustrated in figure 3. A series of broad lakes probably filled this basin during middle and late Pleistocene time, but poor exposures obscure their record. Some of the lake stages may be slackwater deposits (as described by Waitt, 1980) that formed when glacial outburst floods were dammed for periods of days or perhaps weeks where the Noatak River crosses the Igichuk Hills through a narrow gorge. Other deposits that may be lacustrine in origin are obscured by thick loess that was scoured from exposed sediments on the basin floor by strong southerly winds.

This report describes the deposits of Quaternary age that are exposed in bluffs along the Noatak River and its tributaries through the segment of its valley that lies within the Noatak National Preserve (see fig. 1). The bluffs discussed and illustrated in this report were examined during traverses down the Noatak River at various times between 1979 and 2000. River bluffs in tributary drainages were accessed by foot where close to the Noatak River and by helicopter where in more distant locations. The bluff exposures, which stand as high as 86 m, provide a basinwide stratigraphic record of alternating lake stages and alluvial episodes, and of glacial expansions and wastage. This report is divided into six geographic sections arranged in a downvalley succession. Each section is introduced by a base map that relates every individual bluff exposure within that section to its local geologic setting. These geologic maps are generalized to make relations between bluff stratigraphy and corresponding terrain units as clear as possible. See Hamilton (in press) for a more detailed surficial geologic map of the Noatak region.

Although it generally was recognized that lobes of glacier ice from the De Long Mountains had flowed south across the Noatak River valley (Karlstrom and others, 1964;

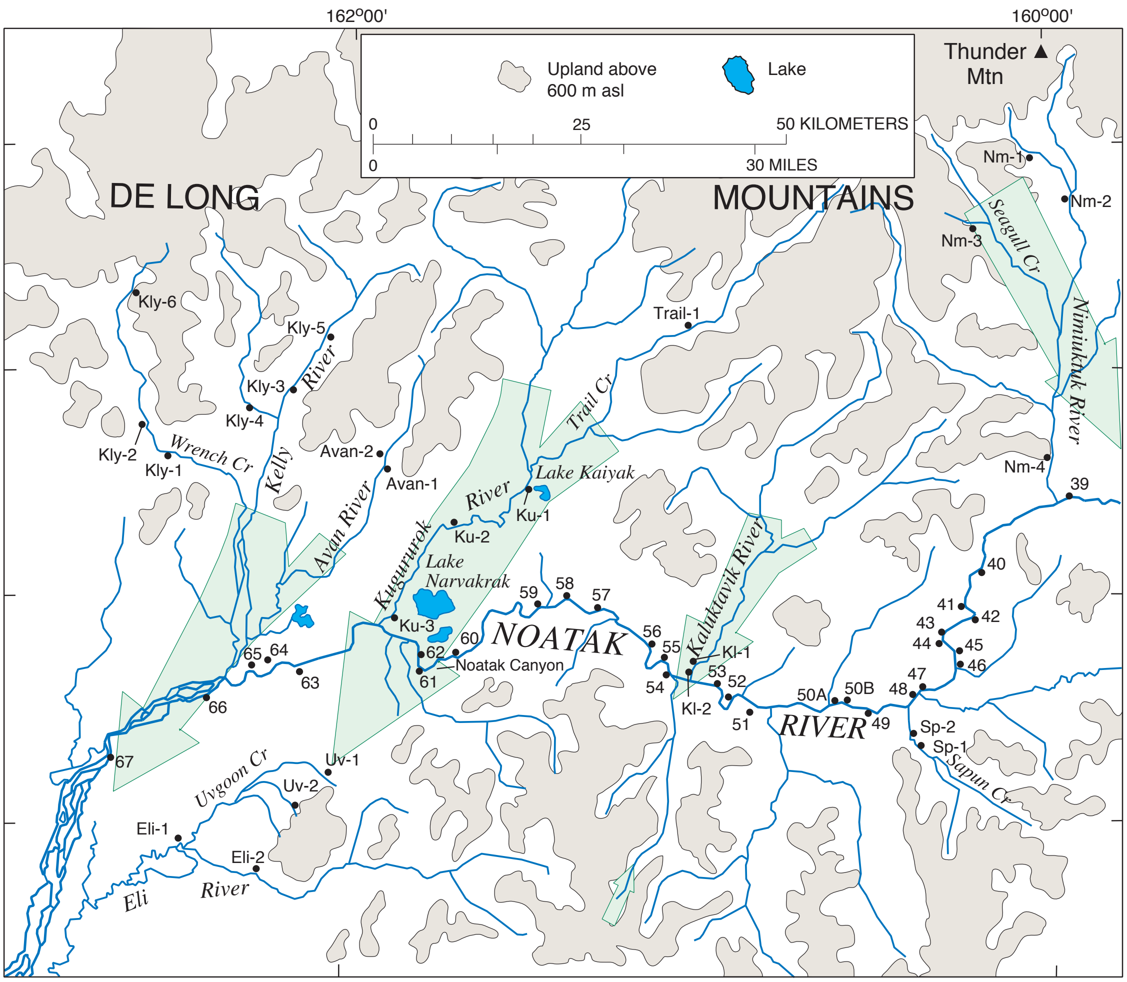


Figure 3. Middle Noatak River valley and lower Noatak basin (Mission Lowland), showing major drainages and locations of measured sections, (see figs. 82 and 115 for geologic settings). Numbers without prefixes refer to Noatak River bluffs (designated Nk in figs. 82 and 115, and in text). Arrows show major Pleistocene glacial-flow directions, with size of arrow proportional to glacial discharge.

Table 1. Glacial advances recognized in the De Long Mountains and their central Brooks Range equivalents.

[Modified from Hamilton, 2003. MIS, marine isotope stage]

Local Glacial Advance	Central Brooks Range Equivalent	Probable Age	
Neoglacial	Neoglaciation	Late Holocene	
Unnamed	Late Itkillik II readvance	Late Wisconsin (MIS 2)	Late Pleistocene[2]
Avan	Itkillik II		
Unnamed	None recognized	Early Wisconsin (MIS 4)	
Anisak	Itkillik IB		
Makpik	Itkillik IA	Later interglacial (MIS 5d-5a)	
Okak	None recognized		
Cutler	Sagavanirktok River	Middle Pleistocene[1]	
Unnamed older drift	Sagavanirktok River or older	Middle Pleistocene or older	

[1]The middle Pleistocene is defined by Richmond and Fullerton (1986) as beginning at the Bruhnes/Matuyama geomagnetic field reversal, which has been dated at about 780,000 years ago (Baksi and others, 1992). It ended at the beginning of the last interglacial maximum (marine isotope stage 5e) about 130,000 yr B.P.

[2]The late Pleistocene is defined as beginning with the last interglacial maximum (MIS 5e). It ended about 10,000 yr B.P. at the beginning of the Holocene postglacial interval.

Coulter and others, 1965; McCulloch, 1967), the consequent formation of large glacier-dammed lakes was seemingly not anticipated by those workers. The likely presence of such lakes in the upper Noatak basin was first suggested by Stephen C. Porter (University of Washington, personal commun., 1973). Subsequent geologic mapping in the Noatak's upper basin (Hamilton, 1984a, 1984b) and farther west (Hamilton, 2003 and in prep.) documented wave-cut notches and beach, deltaic, and other glaciolacustrine deposits of multiple lake stages that were associated with end moraines of five or more glacial advances of middle and late Pleistocene age (Hamilton and Van Etten, 1984; Hamilton, 2001).

A consistent set of terms has been employed for glacial-geologic mapping through the central Brooks Range (Hamilton, 1986, 1994, and references therein; Hamilton and Porter, 1975), and use of these terms has been extended into upper parts of the Noatak River valley. The Sagavanirktok River glaciation is equated broadly with multiple glacial advances of middle Pleistocene age, about 780,000 to 125,000 years before present (yr B.P.) (table 1). Glacial advances of presumed late Pleistocene age (about 125,000 to 10,000 yr B.P.) form a suite of moraines and related deposits that collectively are assigned to the Itkillik glaciation (table 1). The older deposits of this assemblage (termed Itkillik I) are beyond the range of reliable radiocarbon dating (about 38,000 yr in northern Alaska according to Hamilton and Ashley, 1993), but correlative deposits in the northeastern Brooks Range and across central Alaska yield cosmogenic ages up to 60,000 to 100,000 yr B.P. (Briner and others, 2005). A younger set of deposits (termed Itkillik II) is radiocarbon-dated to be between about 24,000 and 11,000 ^{14}C yr B.P. (Hamilton, 1986).

Glaciers in the De Long Mountains, in contrast, were nourished largely from moisture sources west of the Brooks Range in the Bering and perhaps Chukchi Seas, and probably responded somewhat differently than central Brooks Range glaciers during each glacial cycle. For this reason, I employ terms used in the central Brooks Range for glacial advances within the upper Noatak River valley and as general time horizons, but use local names for end moraines generated by glaciers issuing from the De Long Mountains. Those features are named for tributary drainages that join the Noatak River close to where the moraines cross the valley center (Hamilton, 2001, 2003). Local moraine names and their probable central Brooks Range equivalents are listed in table 1.

The Noatak National Preserve 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 in the upper Noatak River valley and in headward parts of its tributaries. Vegetation patterns are more complex downvalley from Cutler River, where riparian stands of cottonwood (*Populus balsamifera*) extend along the Noatak and lower parts of some triburtaries. Spruce (*Picea*) occurs within the lower Noatak River valley (see fig. 1), and extends as riparian stands upvalley to just above Noatak Canyon. The Noatak valley floor is underlain by continuous permafrost, and permafrost generally also is continuous beneath surrounding uplands (Ferrians, 1965; Brown and others, 1997).

Bluff exposures were sampled for radiocarbon age determinations where suitable organic material was available. The 92 radiocarbon ages discussed on the following pages and summarized in appendix 1 are all expressed in radiocarbon years, as reported by the dating laboratories. They are not converted into calendar years because, for the older ages, the conversion values used may be subject to future modifications. Where sets of radiocarbon ages are discussed, they generally are expressed as thousands of years B.P., abbreviated as ka. Wood fragments sampled for radiocarbon dating were identified at the U.S. Department of Agriculture's Forest Products Laboratory in Madison,

Table 2. Characteristics of tills versus glaciolacustrine deposits, upper Noatak basin.

[From Hamilton, 2001]

Till	Glaciolacustrine deposits
Underlying deposits commonly truncated by erosion and (or) glacially tectonized	Underlying deposits generally undisturbed; may be transitional upward to marsh or pond deposits
Lower contact sharp; generally erosional	Lower contact sharp to gradational; no erosion of underlying beds
Generally massive, with no vertical trends in clasts or matrix except at top of unit	Basal sediments commonly are rhythmites. Main body of unit may be crudely bedded, with cut-and-fill structures and interbeds of water-washed muddy gravel
Matrix commonly sandy silt to silty sand	Matrix generally clayey silt to gritty clayey silt
Highly compact; stands in vertical faces	Generally uncompacted and ice-rich; flows readily upon thawing
Strongly jointed, with oxides along joint planes	No jointing; dark gray color without oxides
Commonly fissile, with platy stones parallel to fissility	Fabric generally absent; compressional deformation common beneath dropstones

Wis. They are referenced in the text as "USDA-FPL," followed by the date of the written communication in which the identification was reported. Color designations of soils and sediments are from the Munsell Soil Color Chart (Munsell Color Co., Baltimore, Md).

A major problem in interpretation of bluff sediments along the Noatak River and its tributaries is determining the origin of bouldery diamicts. These unsorted and unstratified deposits could have formed either by direct glacial deposition as till or at short distances beyond the ice front as proximal glaciolacustrine sediment. Although superficially similar, till and glaciolacustrine deposits differ in many characteristics (table 2), and generally have different vertical successions (fig. 4). Till typically is massive, strongly jointed, and highly compact; and it supports vertical faces on river bluffs. Lower contacts generally are sharp and erosional, with underlying sediments commonly deformed by the overriding glacier. Proximal glaciolacustrine sediments, in contrast, have a more clayey matrix; they tend to have crude stratification and basal stone-free facies. Water-washed beds of muddy gravel, which are interstratified with unsorted deposits or fill erosional channels within them, may represent intervals of sudden drainage of the lake due to breaching of its glacial dam (as described elsewhere by Waitt, 1980, and Walder and Costa, 1996). The stone-free basal sediments, which generally are about a meter thick and commonly include rhythmites, may have formed during an initial shallow-lake stage or when glacier ice was too distant to contribute dropstones to the site. In contrast to the stable and near-vertical faces of till deposits, glaciolacustrine sediments tend to flow readily where exposed along the faces of river bluffs. The till must have been compacted and partly dewatered by overriding glacier ice, becoming "dry" permafrost (permafrost with negligible water content) when later frozen. In contrast, the glaciolacustrine sediments probably were water-saturated during deposition; they later became ice-rich permafrost that is subject to thaw, collapse, and flowage on bluff faces.

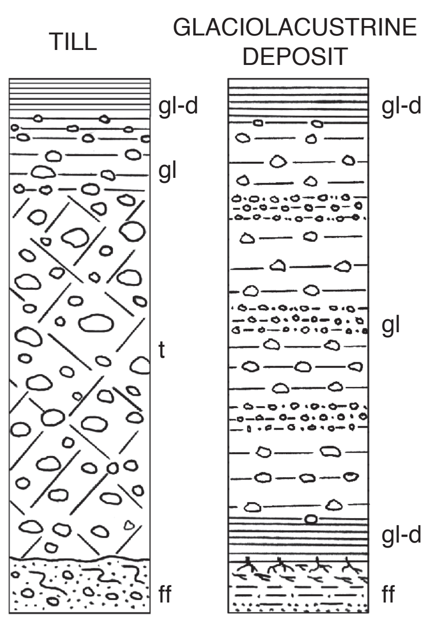


Figure 4. Typical vertical succession in till contrasted with vertical succession in glaciolacustrine deposits, as observed in upper Noatak River basin. Facies designations: ff, floodplain deposit; gl, proximal glaciolacustrine deposit; gl-d, distal glaciolacustrine deposit; t, till. From Hamilton, 2001.

Although I use the metric system throughout this report, former lake heights and other altitude data are presented also in feet. This is because the original measurements generally were read in feet above sea level from helicopter altimeters and topographic maps, then later converted into meters. Geologic terms used in this report are defined in the Glossary section, with definitions in some cases tailored to their specific applications to the Noatak River valley.

Upper Noatak River Valley

Introduction

This sector of the Noatak River valley extends from the Lake Matcharak area through a prominent moraine belt below

Douglas Creek (fig. 5). Bluff exposures along this stretch of the river consist of: (1) till, ice-contact deposits, and proximal outwash of the moraine belt, and (2) glaciolacustrine sediments, fan-delta deposits, and slackwater deposits that aggraded in a depositional basin behind the moraine complex as the glacier retreated (Hamilton, 1984 and in press). Eleven stratigraphic sections, five of them with radiocarbon dates, were measured along this stretch of the Noatak River. Two additional exposures (Nk-1 and Nk-2) closer to the valley head are low (8-10 m) river cuts into fan deposits that formed within the last 1,000 yr (Hamilton and Brubaker, 1983); they are not discussed further or illustrated herein.

The easternmost exposures documented in this report (Nk-3 through Nk-5) are low (8-17 m) river bluffs near Lake Matcharak. The Noatak valley floor here contains ice-stagnation deposits with numerous kettle lakes. Tributary streams that enter from the south and southwest have built extensive late-Holocene fan deposits that overlie probable fan deltas of latest Pleistocene and early Holocene age (Hamilton, 1984a). River bluffs expose late-glacial basin-filling deposits overlain by Holocene alluvium.

Through the stretch between Lake Matcharak and Douglas Creek, the Noatak River occupies a broad Holocene floodplain incised within lacustrine terraces and remnants of ice-stagnation deposits. Exposures NK-6 through and Nk-8, measured along the Noatak River 11 to 0.5 km upvalley from Douglas Creek, stand 17-30 m high. They expose alluvial terrace gravel underlain by lacustrine and related deposits that formed behind the Itkillik II moraine dam during glacier wastage.

Farther downriver, the Noatak River plunges through the moraine belt in a steep, narrow, boulder-filled gorge. Bluff exposures standing 30-70 m high (Nk-9 through Nk-13) exhibit lacustrine and ice-stagnation deposits upstream from the gorge, diamict and alluvium within the gorge, and proximal outwash farther downvalley.

Exposure Nk-3

A south-facing cutbank at the apex of a meander bend of the Noatak River 4 km southeast of Lake Matcharak stands 11 m high, exposing very sandy fine gravel capped by 2.5-3.5 m of floodplain deposits (fig. 6). Peat from the base of the floodplain sequence is dated at 10,000 ±145 yr B.P. The frost-churned upper 0.7 m of the exposure marks the active layer above a former permafrost table. At one locality along the bluff, stony clayey silt extends through an interval 2.6-5.8 m below the ground surface. Many tabular stones in the silt are inclined, as if dumped in from above. The silt probably represents an oxbow or kettle lake in the alluvium, which later filled with overbank deposits.

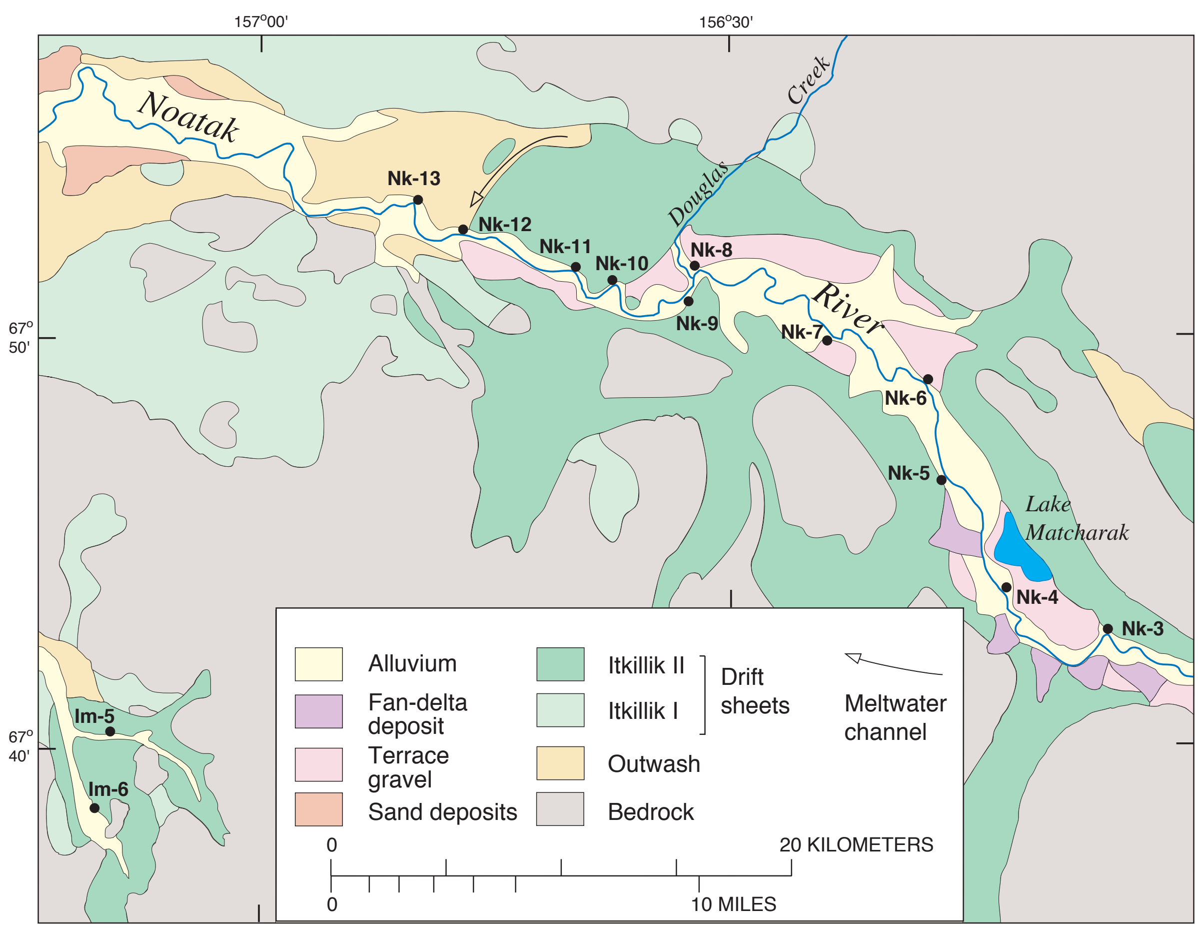


Figure 5. Generalized geologic map, Douglas Creek area, upper Noatak River valley.

Exposure Nk-4

A west-facing cutbank 17.6 m high near the south end of Lake Matcharak intersects a nearly level alluvial surface that is widespread around the lake. The bluff exposes slackwater sand deposits with horizontal beds 1-2 cm thick, overlain by gravel that contains rounded to subrounded stones up to large cobble size with some very small (up to 40 cm diameter) boulders also present (fig. 7). Small abraded wood fragments scattered 0.4 m below the top of the sand unit at one locality are dated at >40,000 yr B.P. They probably were redeposited from older sediment. The bluff is capped by frost-mixed, slightly oxidized, stony sandy silt that is overlain by peat and modern sod.

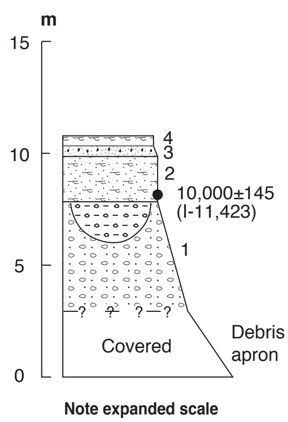
Exposure Nk-5

An east-facing river bluff near the north edge of a large alluvial fan west of Lake Matcharak stands 16.8 m high, with only basal sections exposed. Its terrace-like upper surface matches in height the extensive terrace around Lake Matcharak. The measured section (fig. 8) may represent a younger terrace remnant inset within the older ice-stagnation and basin-filling deposits that cover most of this stretch of the valley floor. Exposed sediments primarily are fine Noatak River gravel that includes granule-sized rock chips characteristic of local alluvial fans. A gravel-filled burrow is present in the sand and silt deposit that separates the gravel units.

Exposure Nk-6

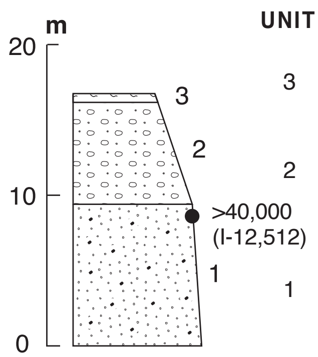
A southwest-facing cutbank 25.6 m high intersects partly eroded remnants of a postglacial valley floor about midway between Douglas Creek and Lake Matcharak. The basal unit in the exposure (unit 1) consists of coarsening-upward sediments that probably were deposited in a broad, shallowing body of standing water (fig. 9). Thixotropic, gray, structureless clayey silt grades upward into fine sand and silty very fine sand that form parallel laminations 1-3 cm thick and ripple-drift sets 6-8 cm thick with drapes of silty fine sand up to 3.5 cm thick. The upper part of the unit consists of well sorted and well bedded fine and medium sand. Overlying alluvial gravel (unit 2) is capped by frost-churned, stony, peaty silt that thickens and thins above the channeled gravel surface.

A 16-m terrace is attached to the downvalley end of exposure Nk-6 by a slip-off slope that formed during river downcutting. The terrace face exposes alluvium and capping deposits similar to those seen farther upvalley at exposure Nk-5.



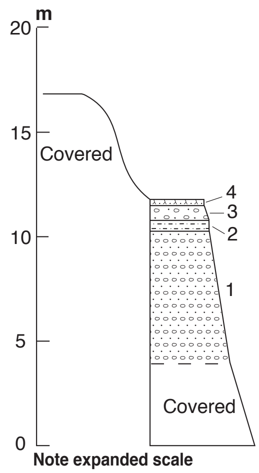
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	0.5	**Peat and silt.** Peat, silty peat, and gray peaty silt; horizontally layered. Contains gastropod shells. **Floodplain deposit.**
3	0.6	**Sand and fine gravel.** Slightly crossbedded silty fine sand with gravel lenses. Overlain by nonbedded, silty, sandy, fine gravel that contains many vertical stones. **Overbank deposit.**
2	2.1	**Peat.** Dark reddish brown (5YR 2.5/2) woody peat. Contains scattered pebbles, granules, and sand grains; horizons of calcareous algae; beds of silty peat; and lens of fine gravel. **Floodplain deposit.**
1	5+	**Fine gravel.** Granules, pebbles, and sparse small cobbles, with beds of medium sand 4-6 cm thick. Stones in top 15 cm have minor oxide staining and vertical fabric, and are intruded into base of unit 2. **Alluvium.**

Figure 6. Exposure Nk-3. North side Noatak River 4 km southeast of Lake Matcharak. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



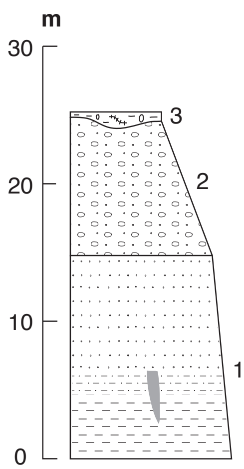
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.8	**Peat and silt.** Sod and peat (0.3 m) above 0.5 m frost-mixed olive brown (2.5Y 4/4) stony sandy silt. **Bluff cap.**
2	6.1	**Gravel.** Rounded to subrounded stones up to large cobble size, with rare very small boulders, in matrix of medium to coarse sand with granules. **Recessional outwash?**
1	9.9	**Sand.** Light gray, massive to faintly laminated, fine to medium sand with dispersed pebbles. **Fluvial slackwater deposit.**

Figure 7. Exposure Nk-4. North side Noatak River opposite south end of Lake Matcharak. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	0.2	**Sod and sandy sod. Bluff cap.**
3	0.7	**Gravel.** Rounded to subrounded pebbles and small cobbles in matrix of grayish brown (10YR 5/2), poorly sorted, fine to coarse sand with granule-sized rock chips. **Alluvium + fan deposit.**
2	0.5	**Sand and silt.** Gray (2.5Y 5/5) slightly clayey silt to silty fine sand, alternating with grayish brown (10YR 5/2) fine sand to poorly sorted coarse to fine sand in parallel beds 3-15 cm thick. **Floodplain deposit.**
1	6.5+	**Sand and gravel.** Beds 40-50 cm thick of subrounded pebbles and small cobbles in matrix of poorly sorted fine to coarse sand with granules; alternate with parallel beds 10-25 cm thick of laminated well-sorted fine sand and clayey silt. **Fluvial slackwater + fan deposits.**

Figure 8. Exposure Nk-5. South side Noatak River 3.5 km northwest of Lake Matcharak.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.4 - 1.3	**Stony, peaty silt.** Light gray to light yellowish brown (10YR 6/1 to 10YR 6/4) silt with frost-mixed, vertically oriented stones and with deformed lenses of reddish brown peat. **Floodplain deposit.**
2	10.2 - 9.3	**Sandy gravel.** Matrix-free granule-pebble-small-cobble gravel at base. Coarsens upward into rounded to subrounded pebbles, cobbles and sparse very small boulders in matrix of poorly sorted medium to coarse sand with granules. Channeled upper surface. **Alluvium.**
1	15	**Sand and silt.** Gray, structureless, clayey silt; grades upward into rythmically laminated fine sand and silty fine sand cut by cast of syngenetic ice wedge. Capped by fine and medium sand in parallel wavy beds 2-8 cm thick. **Basin-fill deposit.**

Figure 9. Exposure Nk-6. North side Noatak River 11 km east-southeast of mouth of Douglas Creek.

Exposure Nk-7

A northwest-facing cutbank at the apex of a meander bend 7 km upvalley from the mouth of Douglas Creek stands 29.7 m high; it intersects a kettle-pocked erosion remnant of the former Noatak valley floor. The north end of the exposure contains sand overlain by thick gravel (fig. 10). Beds within the sand (unit 1) dip downvalley at 2°–5°. The gravel (unit 2) consists of rounded to subrounded stones up to 55 cm diameter with sand interbeds 15-20 cm thick. Frost churning has affected the surface cap of sod and silt (unit 3), which contains some stones admixed from the underlying gravel. Peat 10 cm above the base of the bluff cap at one locality is dated at 2,660 ± 80 yr B.P.

Near the midpoint of the bluff, unit 1 thickens to 26.5 m and consists of fine sand with interbeds of medium sand and fine gravel. All beds dip downvalley at about 15°, and climbing ripple sequences are common. The unit clearly is deltaic.

Near the downvalley end of the bluff, deltaic sand with gravel interbeds overlies 5.4 m of highly deformed sand beds. Formerly near-horizontal parallel beds of fine to medium sand 5-6 cm thick have been folded, contorted, segmented, and rotated, probably by melt of nearby glacier ice.

The surface of the erosion remnant contains three pond-filled kettles. Two kettles have water levels about 20 m above the river; the third kettle has been breached by the river and partly filled with sediments to about the level of the modern floodplain. Kettle-like ponds within this sediment fill suggest that ice blocks may still have been present after the river downcut to about its present level.

Exposure Nk-8

A cutbank along the north side of the Noatak River just above the mouth of Douglas Creek intersects an 18-m alluvial terrace that is inset within the Itkillik II moraine belt. Separate sections were measured at the east and west ends of the exposure, as described previously by Hamilton and others (1987).

The eastern (upvalley) section consists dominantly of deltaic foreset beds that dip downvalley at angles as steep as 26° near the base of the section, decreasing upward to 6°-8° (fig. 11). Fine to medium sand, stony sand, and fine gravel alternate in beds 10-50 cm thick. A bed of black autochthonous peat 2-8 cm thick at the contact between the gravel and the underlying deltaic beds is dated at 9,280 ±150 yr B.P. The peat extends through the eastern part of the bluff, indicating that deltaic sediments were exposed subaerially for some time before the Noatak River overran the site.

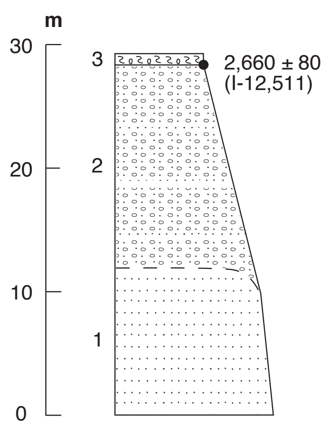
Near the center of the exposure, the deltaic sediments grade downward and westward into gray horizontally bedded, well sorted fine sand with some 20-cm interbeds of clayey silt to silty fine sand. Small wood fragments and rootlets from along bedding planes 1.4 m below the upper contact of this unit are dated at 15,030 ±200 yr B.P.

Near the west end of the bluff, dark gray organic silt grades upward into sandy fine gravel. Overlying coarser gravel (unit 2) consists of rounded to subrounded pebbles, small cobbles, and some larger cobbles in a sparse sandy matrix. The gravel thickens downvalley, where an inactive fan of Douglas Creek is graded to the gravel terrace.

Exposure Nk-9

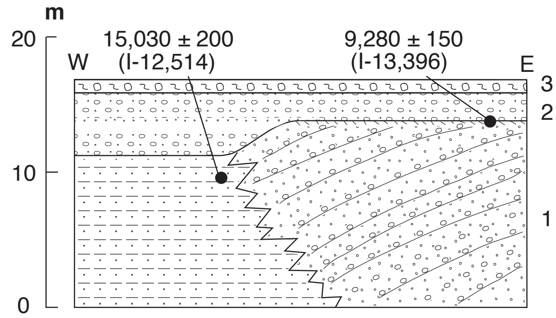
A prominent bluff on the southeast side of the Noatak River 1.5 km below Douglas Creek intersects an eroded remnant of the Itkillik II drift sheet whose irregular upper surface rises to a maximum height of 36.7 m. A terrace-like bench 13 m high is cut into its east flank, and a surface equivalent to the 17-m terrace of exposure Nk-8 abuts its south flank.

Beds of fine sand at the base of the section (fig. 12) show northeastward (upvalley) apparent dips, but associated structures indicate an updip flow direction (about 275°). This anomaly indicates that the present dip of the beds probably developed postdepositionally, perhaps by deformation associated with wastage of stagnant glacial ice. Coarse alluvial gravel above the sand contains clasts up to 32 cm diameter. A possible deltaic deposit with east-dipping beds caps the section.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.7	**Sod and silt.** Sod above silty sod and humic silt. Some nearly vertical stones near base. **Bluff cap.**
2	<19	**Gravel.** Pebbles, small cobbles, and sparse larger stones in abundant sand-granule matrix. Contains sparse beds of fine to medium sand. **Alluvium.**
1	>10	**Sand.** Well sorted fine to medium sand, in parallel sets with some ripple-drift cross-lamination. Locally deformed by faulting. Upper contact obscured by gravel drape. **Deltaic deposit.**

Figure 10. Exposure Nk-7. South side Noatak River 7 km east-southeast of mouth of Douglas Creek; north end of bluff. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.7	**Sod and silt.** Surface sod above gray to brown stony silt with deformed lenses of brown peat. **Bluff cap.**
2	4.8-2.5	**Gravel.** Pebbles, small cobbles, and some larger cobbles in sparse sandy matrix. Some sand interbeds. **Alluvium.**
1	12.0-14.3	**Sand and silt.** Steeply dipping sand, stony sand, and small-pebble gravel; alternating in beds 10-50 cm thick. Capped by bed of black peat 2-8 cm thick. Grades westward into horizontally bedded fine sand, silty fine sand, and clayey silt. **Deltaic and lacustrine beds.**

Figure 11. Exposure Nk-8. North side Noatak River 0.5 km above mouth of Douglas Creek. Frontal view of exposure. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure Nk-10

A weathered bluff on the north side of the Noatak River 3.5 km west of Douglas Creek has a poorly exposed face 56 m high, and rises inland at a gentler angle for 7 m more to an irregular kame and kettle surface. The bluff intersects the inner edge of the Itkillik II end-moraine complex. It exhibits silt above stony silt, with stones becoming abundant below 26 m height (fig. 13).

The silt (unit 2) contains rhythmites of alternating coarse silt and slightly clayey fine silt, with sparse dropstones. Some ripple-drift cross-laminations occur within thicker layers, but beds generally are parallel. Couplets 0.4-5 cm thick occur in packets of 10-40 thin or thick couplets, with thickness being fairly constant within each packet. The coarse and fine layers of each couplet show equivalent thickness variations, suggesting formation by turbidity currents rather than annual sediment cycles (G.M. Ashley, Rutgers University, oral commun., 7/5/83). The beds are tilted, folded, and cut by normal faults, with intensity of deformation increasing downward. They dip southwest at 10°-12°, possibly due to the melt of underlying glacier ice.

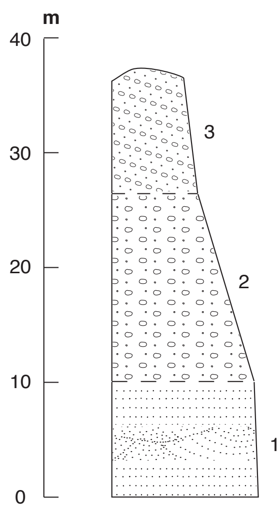
The silt becomes increasingly stony below 26 m height, and rounded to subrounded clasts up to 46 cm diameter mantle the face of the bluff. The stones possibly were deposited as dropstones or turbidites in an ice-proximal lake.

Exposure Nk-11

A south-facing 70-m bluff 5.5 km below the mouth of Douglas Creek is situated within the moraine belt of Itkillik II age. The bluff intersects an irregular surface that contains numerous kettles and several river-terrace remnants that formed as drainage became reestablished during glacier retreat from the Itkillik II end moraine (Hamilton and others, 1987). The lowest stratigraphic unit (unit 1), which forms vertical-sided buttresses near the base of the section, consists of compact pebble-small cobble gravel in a silty sand matrix (fig. 14). The upper part of the deposit is structureless, but overturned folds and one near-vertical 30-cm bed of deformed peaty silt are present at greater depth. The peaty silt bed has an apparent age of 34,990 ± 230 yr B.P. Unit 1 probably is stream gravel with associated floodplain deposits that subsequently was deformed by overriding glacier ice.

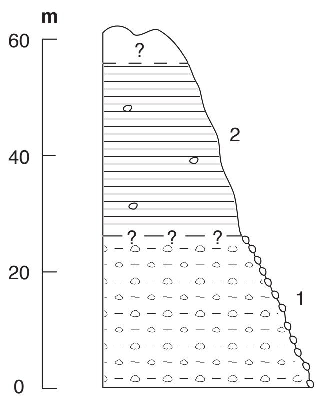
Overlying alluvium (unit 2) consists of parallel-bedded to crossbedded sand, pebbly sand, and pebble-small-cobble gravel. Beds of oxidized organic silt with rootlets in growth position 4 m and 2 m below the top of the alluvium are dated

Figure 12. Exposure Nk-9. Southeast side Noatak River 1.5 km downstream from mouth of Douglas Creek.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	ca.10	**Sand and fine gravel.** Inclined beds of fine sand and pebble-small-cobble gravel, with some drapes of gray clayey silt. **Deltaic deposit.**
2	ca.16.5	**Coarse gravel.** Rounded to subrounded clasts up to large cobble size, with some very small boulders. **Alluvium.**
1	ca.10	**Sand.** Fine sand and silty fine sand; commonly in parallel beds and laminae. Ripple cross-laminae, planar and tangential crossbeds, silt drapes, and flame structures also present. **Ice-contact deposit?**

Figure 13. Exposure Nk-10. North side Noatak River 3.5 km west of mouth of Douglas Creek.



Note compressed scale

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	ca.30	**Silt.** Poorly exposed. Contains rythmites consisting of alternating coarse silt and slightly clayey fine silt, with sparse dropstones. Beds are tilted, faulted, and folded, with deformation increasing downward. **Distal glaciolacustrine deposit.**
1	ca.26	**Stony silt.** No primary exposures. Rounded to subrounded stones to 47 cm diameter mantle bluff face. **Ice-proximal glaciolacustrine deposit.**

at 34,840 ±950 yr B.P. and 30,070 ±470 yr B.P., respectively. Gravel beds at greater depth dip upvalley at angles up to 12°-34°, then level out and fine laterally to form a paleobasin floor composed of muddy sand. This closed depression within the gravel may have resulted from continued melt of buried glacier ice during deposition of unit 2.

The upper diamict (unit 3) is interpreted as massive till with basal sediments consisting largely of redeposited river gravel. Unsorted, rounded to subrounded, striated clasts up to boulder size dispersed in a compact, gray, silty matrix grade downward at about 3.5 m depth into compact rounded pebbles and small cobbles that resemble the diamict of unit 1. Like unit 1, this deposit exhibits faint, highly deformed size stratification. Clasts of peaty silt incorporated in the diamict 70 cm above its base are dated at 34,010 ± 350 yr B.P.; they must have been redeposited from unit 2.

Unit 4 consists of rounded to subrounded alluvial pebbles and cobbles in a poorly sorted matrix of sand with phyllite chips. The alluvium contains several near-horizontal sand beds 10-30 cm thick that are continuous laterally for at least 20 m. A lag concentration of boulders up to 60 cm diameter occurs at the base of the alluvium and on the upper surface of the underlying diamict.

Exposure Nk-12

An unusually unstable bluff extends along the north bank of the Noatak River at the head of the Itkillik II outwash train (see fig. 5). The moraine front here is irregular and has been eroded by both glacial meltwater and by ice-marginal drainage derived from Douglas Creek. The outwash head is kettled, indicating that outwash overlapped the stagnating glacier terminus. Much of the basal unit in the bluff has deformed plastically, extruding toward the river edge and causing grabens and other tension features to form in the overlying gravel. The bluff's irregular upper surface contains many steep (up to 34°), unstable, unvegetated fault scarps indicative of continued tensional deformation.

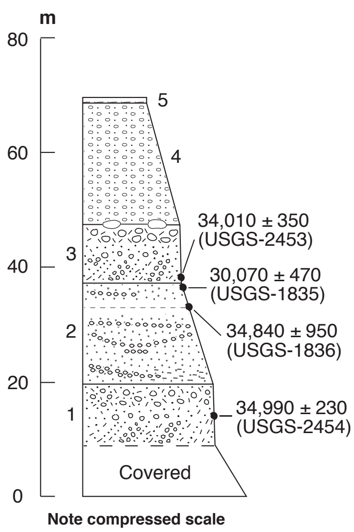


Figure 14. Exposure Nk-11. North side Noatak River 5.5 km west of mouth of Douglas Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	0.7	**Peat and silt.** Peat above frost-mixed silty peat; grades downward into silty gravel. **Bluff cap.**
4	22	**Coarse gravel.** Pebbles and cobbles in matrix of poorly sorted sand with phyllite chips. Some sand interbeds. **Alluvium.**
3	10.1	**Upper diamict.** Clasts up to boulder size dispersed in compact gray silt. Grades downward into compact, deformed, pebbles and small cobbles in silty matrix. **Till and tectonized proglacial deposit.**
2	18	**Sand and fine gravel.** Fine to medium sand, pebbly sand, and pebble-small-cobble gravel. Contains beds of oxidized organic silt near upper contact. **Alluvium.**
1	10.5	**Lower diamict.** Rounded pebbles and small cobbles in matrix of compact silty sand to sandy silt. Structureless near top; faintly bedded and deformed near base. **Till and tectonized alluvium.**
--	9.7	**Debris apron.**

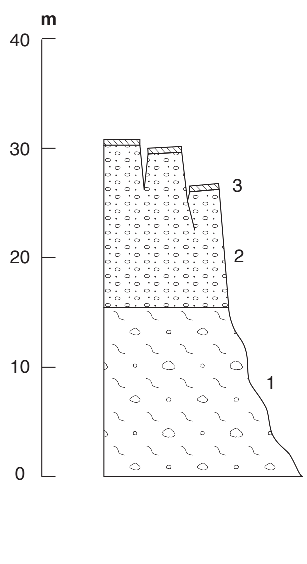


Figure 15. Exposure Nk-12. North side Noatak River 10 km west of mouth of Douglas Creek. Upvalley (east) end.

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.3	**Sand and soil.** Silty fine sand with some frost-mixed pebbles and cobbles. Bears Arctic Brown Soil profile, with solum 19 cm thick. **Bluff cap.**
2	15	**Gravel.** Stones up to large cobbles, with some very small boulders, in matrix of course sand and granules. **Outwash.**
1	16	**Diamict.** Stones to very small boulder size (40 cm diameter) in matrix of dark greenish gray stony silt to clayey silt. Wedges out downvalley. **Till or glaciolacustrine deposit.**

Diamict comprises the basal half of the bluff (unit 1) at its upvalley end (fig. 15) but it wedges out downvalley, and overlying outwash gravel thickens correspondingly. Diamict and gravel have been mixed together through much of the lower part of the bluff, and the original character of the basal diamict has been obscured.

The outwash (unit 2) consists dominantly of rounded to subrounded stones to large cobble size with some very small boulders (30-35 cm diameter) in a matrix of coarse sand and granules. The underlying diamict consists of clasts of similar size, shape, and lithologies in a matrix of dark gray stony clayey sandy silt. Clasts on the exposed face of the diamict may largely be derived from overlying outwash, but the high clay content (about 5-10 percent) and extreme instability of the diamict suggest a separate, possibly glaciolacustrine, origin.

Exposure Nk-13

An exposure into the Itkillik II outwash terrace 3 km downvalley from the moraine front stands about 31.5 m high. The terrace surface is planar for about 1 km upvalley from that exposure, then it degenerates into kame-and-kettle topography that probably marks the downvalley limit of Itkillik II glacier ice. Other kettle fields downvalley from the exposure probably developed from melting of older glacial ice of Itkillik I age after overriding by the Itkillik II outwash train.

The section at exposure Nk-13 consists of alluvium which coarsens progressively upward into outwash, with no evident erosion surfaces or unconformities (fig. 16). In the basal 8 m of the exposure, beds of medium to coarse sand up to 25 cm thick alternate with thicker beds of sandy pebble-small-cobble gravel. The central 8 m of the section consists of faintly bedded rounded pebbles, small cobbles, and sparse medium cobbles with some 10-cm interbeds of coarse sand and pebbles. Pebbles, small to medium cobbles, and sparse larger cobbles in a matrix of nonoxidized medium to coarse sand and granules dominate the upper 8 m of the deposit. A bed of dark gray clayey silt and gray silty fine sand 8.5 m above river level contains sparse rootlets and organic detritus that are dated at 30,160 ±410 yr B.P.

Progressive changes in clast lithology reflect increasing dominance of upvalley sources as sediment size increases upward through the section. The percentage of locally derived carbonate rocks decreases upward from 30 to about 10; whereas granitic rocks from glacial source areas near the valley head increase upward from less than 1 percent of all clasts to about 10 percent.

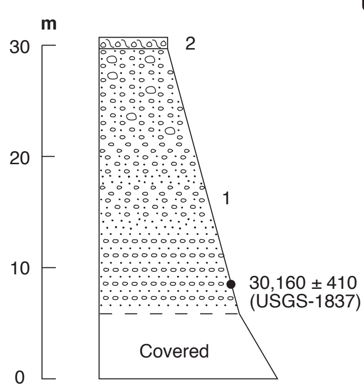
Discussion

The 11 exposures from the upper Noatak River valley provide a complete cross section through the Itkillik II moraine belt and through the lacustrine and slackwater deposits that formed during glacier retreat (fig. 17). Radiocarbon ages from five of the bluffs (appendix 1) provide a direct age bracket for the advance and retreat of the Itkillik II glacier (Hamilton and others, 1987), and provide limiting ages on the subsequent lake stage.

Nk-9 through Nk-13 provide exposures 30-70 m deep into the Itkillik II moraine belt and its associated outwash apron. Radiocarbon dates show that deposition of fine interstadial alluvium began sometime before 35 ka and continued until at least 30 ka. Subsequent glacier expansion is recorded by coarsening-upward sediment with increasing upvalley lithologies at Nk-13 and by deposition of the upper diamict at Nk-11. The glacier initially eroded and redeposited interstadial alluvium along the valley center, then later deposited massive, bouldery, silt-rich till.

The basal diamicts at exposures Nk-12 and Nk-11 are puzzling. Geologic relations at the moraine front indicate that the diamict at Nk-12 should be a till, but its unstable, plastic character and high silt content suggest that it may be glaciolacustrine in part. Perhaps the Itkillik II glacier advanced past the site, retreated, and then readvanced into moraine-dammed lake deposits to form the basal diamict. The lower diamict of Nk-11 has an apparent radiocarbon age of 34,990 ±230 yr B.P., which approaches the limit of accurate radiocarbon dating. The lower diamict most likely is a subglacial deposit that consists of till above ice-thrust alluvium, but its radiocarbon determination may be a minimum age that does not closely

Figure 16. Exposure Nk-13. North side Noatak River 13 km west of mouth of Douglas Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	1.1	**Sod, peat, and silt.** Sod and brown peat above stony silt. Many stones vertical. **Bluff cap.**
1	±24.5	**Gravel.** Interbedded sand and pebble-small-cobble gravel at base. Grades upward into pebble-small-cobble gravel with some sand and pebble beds, then into weakly stratified pebbles and cobbles in matrix of medium to coarse sand and granules. **Alluvium, grading upward into outwash.**
--	6.0	**Debris apron.**

date the glacial advance. However, subsidence features in the overlying alluvium indicate that stagnant glacier ice must still have been present during deposition of the interstadial alluvium, and kettles in Itkillik II outwash downvalley from Nk-13 likewise indicate persistence of underlying glacial ice until late Wisconsin time (Hamilton and Van Etten, 1984).

Exposures Nk-10 and Nk-9 exhibit glaciolacustrine sediments to heights as great as 56 m above modern river level and deformation structures formed by melting of buried glacial ice. These deposits may represent an early ice-contact stage of a lake that formed behind the moraine dam shortly after deposition of the upper diamict and high-level (48-69 m) recessional outwash at Nk-11.

As the Itkillik II glacier continued to retreat upvalley, an elongate lake formed within the basin that developed behind its moraine belt. The lake extended upvalley at least 11 km, as indicated by the basal lacustrine and deltaic units at Nk-8 through Nk-6, and it filled with dominantly deltaic sediments to a height of 11-15 m above modern stream level before probable breaching of the moraine dam allowed reestablishment of the Noatak River through this stretch of its valley. Radiocarbon ages from Nk-8 show that the lake was in existence by 15 ka and that the river had become established across the former lake floor by about 9.3 ka.

Exposures Nk-5 and Nk-4 show that the elevated base level provided by the moraine-dammed lake caused the Noatak River to aggrade by about 10 m farther upvalley, depositing slackwater sediments upstream to at least the Lake Matcharak area (see fig. 5). Alluviation of fine gravel upvalley from Lake Matcharak also may be related to this base-level rise, because its minimum age limit of 10.0 ka at Nk-3 is close to the age limit of 9.3 ka on lacustrine deposits at Nk-8.

Subsequent alluviation formed a conspicuous 17- to 18-m terrace that is widespread around Lake Matcharak and traceable downvalley through the Douglas Creek area. Alluviation of terrace gravel ended sometime between 9.3 and 2.7 ka, based on bracketing radiocarbon ages from Nk-8 and Nk-7, respectively.

Schist, vein quartz, and granitic rocks dominate the lithologies of all diamicts and gravel units in the upper Noatak valley. Quartzite and carbonate rocks generally are present but less abundant. Granitic rocks commonly are the major component of the largest size fractions, and they are particularly abundant in glacial till and outwash. Especially during times of aggradation, when little sediment by-passing occurs, interstadial deposits derived largely from adjoining tributary valleys are distinguished readily from glacial deposits, which typically were dominated by sediments eroded from the rugged granitic highlands at the valley head.

Aniuk River Area

Introduction

For about 9 km downvalley from the Itkillik II moraine front, the Noatak River occupies a narrow (0.5 km) Holocene floodplain flanked by the 30-m terraces of the continuous outwash apron that originates at that moraine. Beyond this point, the floodplain abruptly widens to about 3 km and is bordered by more fragmentary remnants of the outwash (fig. 18). These outwash remnants commonly are flanked by younger terraces composed dominantly of sand. Both outwash and sand are heavily kettled, indicating that numerous stagnant ice masses of Itkillik I age must have persisted through the Itkillik II ice advance.

The Itkillik I end-moraine complex crosses the valley center in a 9-km-wide belt 22-32 km downvalley from the Itkillik II moraine front. The Holocene floodplain of the Noatak River narrows to 1.0-1.5 km through this stretch, and is bordered by remnants of Itkillik II outwash incised within till and ice-stagnation deposits of the Itkillik I glacial advance.

Downvalley from the Itkillik I moraine front, the Noatak basin floor becomes a broad plain of low relief that is underlain by glaciolacustrine deposits of Itkillik I and Itkillik II

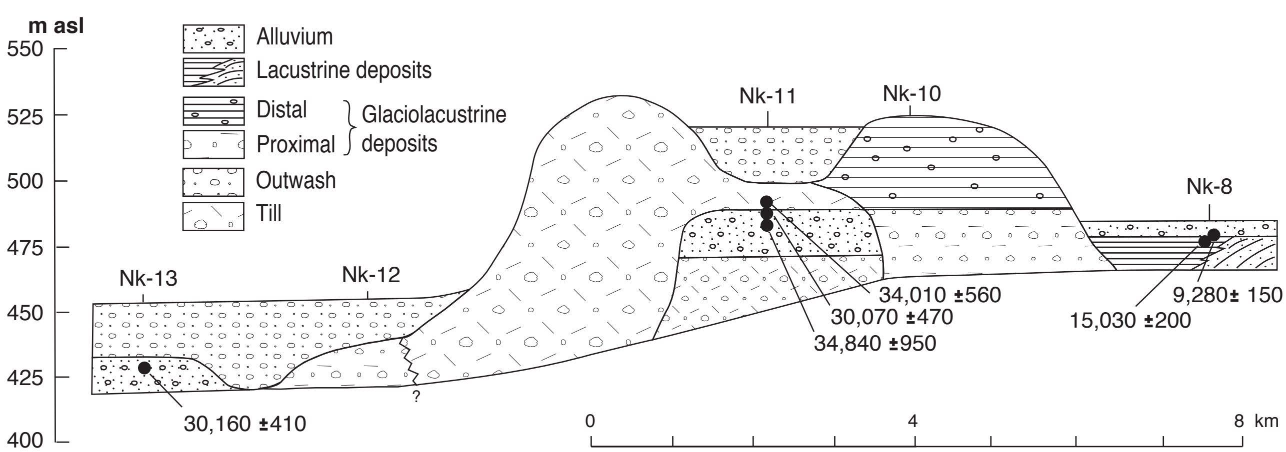


Figure 17. Section through Itkillik II (late Wisconsin) moraine belt, upper Noatak River valley, showing interrelations of exposures Nk-8 through Nk-13. Vertical scale shows altitude (meters above sea level). Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

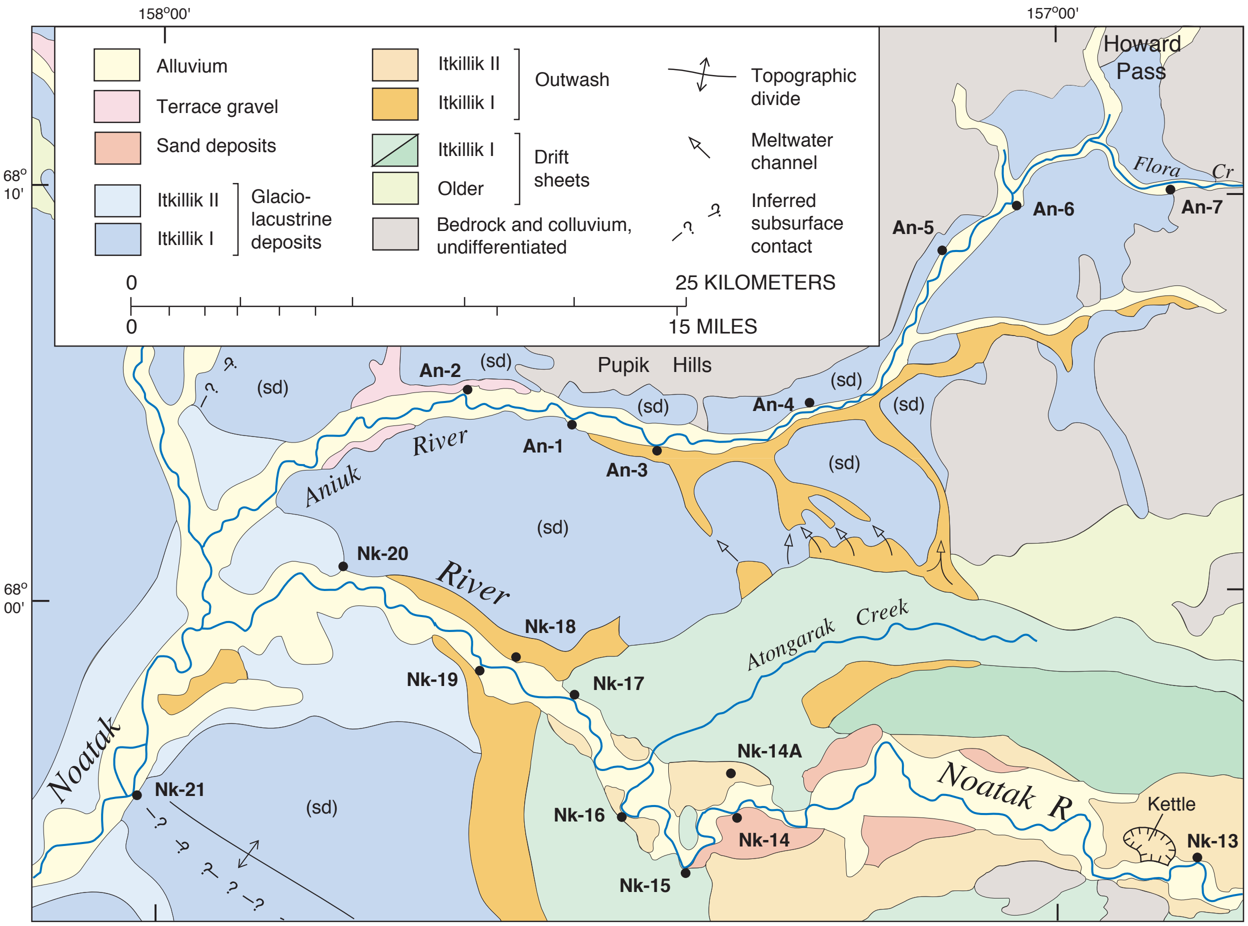


Figure 18. Generalized geologic map, Aniuk River area, north-central upper Noatak basin. Outer and inner Itkillik I drifts are correlated with Itkillik IA and IB advances elsewhere in Brooks Range. Unit (sd) designates glacial deposits of probable middle Pleistocene age that are concealed beneath glaciolacustrine sediments.

ages (fig. 18) and locally by concealed older deposits. The lacustrine plain is incised deeply by the Aniuk River as well as the Noatak River, and bluff exposures along both drainages provide good stratigraphic records of alternating glacial and alluvial episodes.

The upper reaches of Aniuk River were largely fed by eastern tributaries that originated as outwash trains of Itkillik age (fig. 18; Hamilton, 1984a, 1984b). Exposures generally are limited to late Pleistocene and Holocene alluvium.

Exposure Nk-14

A bluff with a severely slumped face extends along the south bank of the Noatak River 5 km upvalley from the mouth of Atongarak Creek. The exposed part of the bluff face stands 17 m high and consists of a younger sandy terrace deposit that is incised within the outwash terrace of Itkillik II age (see fig. 18). A vegetated slope rises inland from the bluff crest to the terrace-like surface of the sand deposit that stands 21.5 m above river level.

A partial section excavated 11-14 m above the river exposed about one meter of bedded sand with willow-cored peaty sand mounds above tundra soil (fig. 19). The buried tundra soil consists of layers of black humic fine sand up to about 20 cm thick alternating with thinner beds of dark gray fine sand. The humic sand contains abundant rootlets. Beds are deformed by overturned folds of probable solifluction origin and by collapse into a wedge-like depression. A thick peaty bed at 11.5 m height is dated at 4,220 ±110 yr B.P.

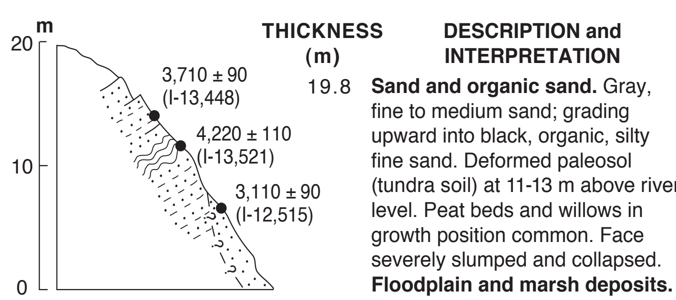


Figure 19. Exposure Nk-14. South side Noatak River 27 km east-southeast of mouth of Aniuk River. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

The tundra soil is overlain by brownish gray medium and fine sand that alternate in beds 1-2 cm thick. Peaty interbeds and abundant rootlets in growth position are present within the sand, and willow stems up to 5 cm diameter commonly form the cores of peaty lenses. Beds typically are undulating at the base of the unit, reflecting the surface of the underlying buried soil, and become more planar upward. Willow in growth position at 13 m height is dated at 3,710 ± 90 yr B.P.

Willow in growth position also was sampled 6.4 m above the river during an earlier visit to this site. Its radiocarbon age of 3,110 ± 90 yr B.P. is too young for its position in the bluff face. The willow may have been in a slump block that was not recognized during that visit.

Exposure Nk-14A (not illustrated)

A partly vegetated bluff face on the north shore of a kettle lake 1.5 km north of the Noatak River opposite Nk-14 (see fig. 18) intersects probable outwash of Itkillik II age. The weathered face of the bluff stands 30 m above river level and exhibits rounded pebbles and small to medium cobbles (up to 16 cm long) in a sandy matrix. The upper 1.1 m of the deposit is a light gray (5Y 6/2), frost-churned, silty sandy gravel with many stones oriented vertically.

The kettle at the base of the bluff intersects an abandoned channel network of the Noatak River that probably is of late Holocene age (Hamilton, 1984a). The kettle clearly has enlarged into these deposits, and shows no evidence of sediment filling from the river. It evidently has continued to develop into late Holocene time, and may still be active today.

Exposure Nk-15

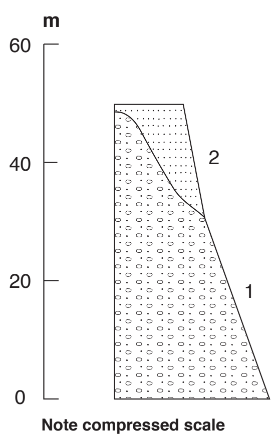
The north-facing cutbank of a large-amplitude meander bend of the Noatak River intersects deposits of Itkillik I age about 5.5 km south-southeast of the mouth of Atongarak Creek (see fig. 18). The valley floor here is a kettled surface of low relief that probably formed during or after ice wastage from the Itkillik I moraine belt.

The bluff face stands 50 m high and exposes gravel overlain by sand (fig. 20). The contact between these units is hummocky in profile, with relief up to about 15 m. The gravel consists of rounded to subrounded pebbles and cobbles in a sandy matrix, and includes some small boulders up to about 70 cm long. The overlying sand deposit has a planar upper surface which masks the relief on the underlying gravel.

Exposure Nk-16

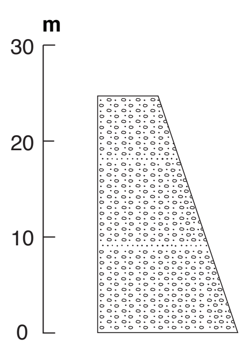
A cutbank on the south side of the Noatak River 3 km above the mouth of Atongarak Creek stands 24.8 m high and exposes probable outwash gravel (fig. 21). Pebbles and cobbles up to about 30 cm diameter, with sparse boulders, occur in a sandy matrix. Some sand layers are interbedded within the gravel.

From the bluff crest, the surface rises inland 15 m more to a flat-topped surface of pebble-cobble gravel with sparse small boulders in a matrix of oxidized dark yellowish brown (10YR 4/4) sand. The oxidized matrix of this deposit contrasts strongly with the virtually unweathered matrix of the younger gravel unit in the cutbank.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	0-15	**Sand.** Very well sorted fine sand to silty fine sand. Gently undulating upper surface. **Slackwater or lacustrine deposit.**
1	50-35	**Gravel.** Rounded to subrounded pebbles, cobbles, and some small boulders in sandy matrix. Irregular (kame-like) upper surface. **Outwash.**

Figure 20. Exposure Nk-15. South side Noatak River 25.5 km east-southeast of mouth of Aniuk River.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
24.8	**Gravel.** Stones to cobble size, with sparse large boulders, in oxidized dark yellowish brown sandy matrix. Some sand layers. **Outwash.**

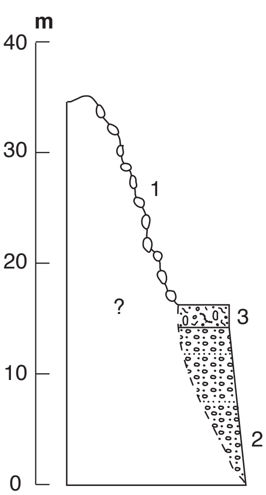
Figure 21. Exposure Nk-16. South side Noatak River 22 km east-southeast of mouth of Aniuk River.

Exposure Nk-17

A cutbank exposure on the north side of the Noatak River 5 km northwest of Atongarak Creek intersects a probable outwash terrace inset within the outermost end moraine of Itkillik I age (see fig. 18). The moraine here is represented by hummocky coarse gravel, which stands 35 m above the river. Unvegetated scarps and sag ponds suggest lateral flow toward the river; they expose poorly sorted stones up to 65 cm long in a muddy matrix.

The river-cut face of the moraine is obscured entirely by slides and flows (unit 1; fig. 22). Exposed clasts are subrounded pebbles, cobbles, and very small boulders of upvalley lithologies (granite, gneiss, vein quartz, schist, and carbonate rocks). Matrix material is sand and silt, but may have been mixed on the bluff face, and original matrix composition is uncertain.

A 16.5 m gravel terrace (unit 2) is inset within the moraine (fig. 22). Weakly stratified, subrounded, pebble-small cobble gravel in a matrix of well washed coarse sand coarsens upward slightly into the middle part of the unit, where sparse medium cobbles occur. Gravel beds 50 cm thick alternate with 10-cm beds of pebbly medium sand. Clasts are of upvalley lithologies, dominantly schist, vein quartz, and carbonate rocks. The gravel is capped by 1.8 m of gray, frost-mixed silty sandy gravel (unit 3) that locally overlies fissile gray stony clayey silt with sand interbeds.

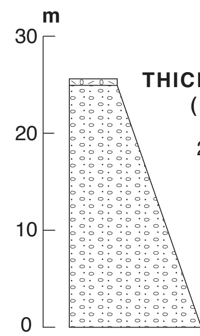


UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	1.8	**Stony silt.** Gray, frost-mixed stony silt to silty sandy gravel; many stones vertical. Contains some lenses and clots of deformedpeat. Locally overlies fissile, gray stony clayey silt with sand interbeds. **Pond deposit.**
2	14.7	**Gravel.** Weakly stratified, subrounded pebbles, small cobbles, and sparse larger cobbles in matrix of coarse sand and granules. Some 10-cm beds of coarse sand and pebbly medium sand. **Outwash.**
1	35	**Diamict.** Rounded to subroundedpebbles, cobbles, and very small boulders in sandy to muddy matrix. Mixed by slides and flows on bluff face. **Till and ice-contact gravel?**

Figure 22. Exposure Nk-17. North side Noatak River 17.5 km east of mouth of Aniuk River.

Exposure Nk-18

A weathered bluff face north of the Noatak River 2 km downvalley from the outermost Itkillik moraine front interesects the outwash apron associated with that moraine (fig. 18). The outwash terrace here stands 25 m high; its face exposes rounded pebbles and small cobbles up to 15 cm long in a sandy matrix (fig. 23). Rock types include granite, vein quartz, greenstone, schist, quartzite, and limestone. Many stones are carbonate-encrusted and (or) discolored by iron and manganese oxides. A trench at the crest of the bluff exposes 0.4 m dark grayish brown stony sandy silt above yellowish brown sandy gravel.

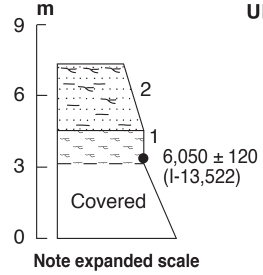


THICKNESS (m)	DESCRIPTION and INTERPRETATION
25	**Gravel.** Rounded pebbles and small cobbles in sandy matrix, oxidized yellowish brown (10YR 5/4) near top. Capped by 0.4 m dark grayish brown (10YR 4/2) stony sandy silt. **Outwash.**

Figure 23. Exposure Nk-18. North side Noatak River 15.5 km east of mouth of Aniuk River.

Exposure Nk-19

A cutbank exposure into a Holocene alluvial terrace of the Noatak River 3 km downvalley from the Itkillik I moraine front (see fig. 18) stands 7.3 m high. The lowest exposed deposit (unit 1) is a bed of massive peat 3.3-4.5 m above river level (fig. 24). Overlying floodplain deposits (unit 2) consist of bedded sand, organic silty fine sand, and sandy peat. A sample of the lowest exposed peat is dated at 6050 ±120 yr B.P.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	2.8	**Sand and peat.** Sand, sandy peat, and organic silty fine sand, in parallel near-horizontal beds. Base not exposed. **Floodplain deposit.**
1	1.2	**Peat.** Massive peat bed. **Bog or marsh deposit.**
--	3.3	**Debris apron.**

Figure 24. Exposure Nk-19. South side Noatak River 13.5 km east of mouth of Aniuk River. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure Nk-20

A cutbank exposure on the north side of the Noatak River 6.5 km east-northeast of the mouth of Aniuk River stands 26 m high and has a nearly horizontal, planar upper surface. It stands near the contact between Itkillik II and Itkillik I glaciolacustrine deposits on the Noatak basin floor (see fig. 18). Two silty and clayey stony units of probable glaciolacustrine origin are present (units 1 and 3; fig. 25). The lower of the two units is a poorly sorted stony clay that contains abundant faceted and striated clasts of upvalley lithologies. Overlying alluvium (unit 2) was deposited on an erosional unconformity that contains lag boulders up to 1.2 m long. In the upper glaciolacustrine unit (unit 3), an early shallow-water phase of stone-free fine sediment grades upward into clayey silt with dropstones that formed when the water deepened and icebergs were able to reach the site. Dropstones dominantly are rounded pebbles and small cobbles, with some larger clasts up to small boulder size.

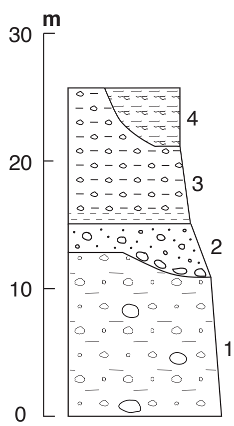
Fragments of a small tree about 13-15 cm diameter occur up to 9.4 m height in a gulley on the bluff, but their original location on the bluff face could not be determined. The wood was identified as probably spruce or possibly larch (USDA/FPL, date uncertain).

Exposure Nk-21

A prominent bluff along the southeast side of the Noatak River 8 km below the mouth of Aniuk River intersects an unusually high-standing and hummocky part of the Noatak basin floor. The bluff face stands as high as 74.5 m, but the ground surface rises inland, forming a broad, hummocky, southeast-trending topographic divide about 150 m above river level (see fig. 18).

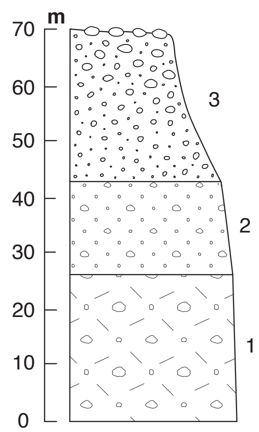
The basal unit in the bluff is a compact stony silt with scattered striated stones up to 1.2 m diameter (fig. 26). Clasts are upvalley lithologies: limestone, dolomite, and marble; with lesser granite, gneiss, and a dark aphanitic igneous rock. This glacial diamict probably is a till, but its well sorted silt matrix suggests that the glacier probably had advanced into a glacial lake and may have deposited its load in contact with lake water.

The glacial diamict is transitional upward into interbedded sand and sandy fine gravel (unit 2), with maximum clast size about 7 cm. This unit may be a slackwater deposit that formed when the Noatak River was still partly blocked by glacier ice farther downvalley. The uppermost unit (unit 3) is best exposed in a promontory at the west end of the bluff, where pebble-small-cobble gravel coarsens upward into gravel that contains cobbles and small boulders up to about 45 cm diameter.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	0-4.5	**Peat and organic silt. Bog deposit.**
3	11-6.5	**Stony silt.** Stones to very small boulder size, commonly striated, in matrix of dark gray clayey silt. Stone-free silt, sandy silt, and silty clay at base. Upper contact commonly channeled, with gravel, peat, and organic silt fillings. **Upper glaciolacustrine unit.**
2	2-6	**Gravel.** Pebbles, cobbles, and sparse small boulders in sandy matrix. **Alluvium.**
1	11-13	**Stony clay.** Rounded pebbles, cobbles, and some small boulders with random fabric,dispersed in dark greenish gray (5GY 4/1)sandy silty clay. Many clasts faceted and striated. Erosional upper contact, with lag boulders. **Lower glaciolacustrine unit.**

Figure 25. Exposure Nk-20. North side Noatak River 6.5 km east-northeast of mouth of Aniuk River.



Note compressed scale

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	30.5	**Gravel.** Pebbles and small cobbles in sandy matrix; coarsens upward into cobble-small boulder gravel. Surface is littered with boulders and boulder fragments up to ca. 68 cm length. **Alluvium.**
2	17	**Stony and sandy fine gravel.** Interbedded in beds 10-50 cm thick. Sand is dark grayish brown (10YR 4/2), well sorted, fine to medium sand with lenses of gray silty fine sand. Gravel is dominantly pebbles with coarse sand matrix. Transitional contact with unit 3. **Fluvial bar and overbank deposits.**
1	27	**Stony silt.** Striated stones scattered in matrix of dark olive gray (5YR 3/2), well sorted, nonbedded silt. **Till?**

Figure 26. Exposure Nk-21. Southeast side Noatak River 8 km south-southwest of mouth of Aniuk River. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Pebble-small-cobble gravel is dominant along the bluff's crest, with scattered larger cobbles and boulders up to a maximum length of 68 cm. Boulder lithologies include typical upvalley types—granite, gneiss, quartzite, and vein quartz—with pyroxenite also present. A test pit exposes subrounded pebbles and small cobbles in a matrix of yellowish brown (10YR 5/4) silt with granules that probably was mixed into the gravel by frost activity.

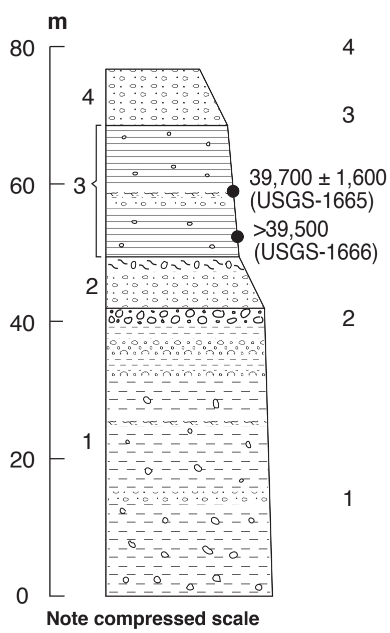
Exposure An-1

A prominent bluff on the south side of Aniuk River 12 km above its mouth stands about 80 m high. Although this feature is only 13 km northeast of Nk-20, it contains a much older stratigraphic record that may correlate more closely with that of Nk-21. The bluff is well beyond the limit of Itkillik II glaciolacustrine deposition in the basin (see fig. 18), therefore all exposed glaciolacustrine units must be of Itkillik I age or older.

The lower glaciolacustrine unit (unit 1) is a thick (43 m) stony gray clay that contains dispersed pebble and cobble dropstones. The clay generally is unstratified, but a gravel bed is evident at about 15 m height and a peat bed at 25 m height (fig. 27). The dispersed clasts decrease in abundance upward, whereas layers and lenses of pebble-cobble gravel become more abundant in that direction. One gravel layer near the upper contact of unit 1 contains boulders to nearly 1 m length; another nearby gravel layer is capped by a 2-cm-thick peat bed.

The overlying alluvium (unit 2) is a coarse (cobble-small boulder) gravel that contains highly oxidized sand beds. The upper 1.2 m of the alluvium has been subjected to severe frost action; it has been mixed with the overlying silt and clay, and many stones are oriented vertically. A contorted peat bed about 10 cm thick is present at 1 m depth at one locality along the bluff face.

The upper glaciolacustrine unit (unit 3) consists of gray clay and brown silt, which generally are laminated. Stones are rare, and none exceed cobble size. Silty peat 2 m above the base of the unit is dated at >39,500 yr B.P. A 1.5-m bed of pebble-small- cobble gravel in the middle part of the unit is capped by a thin (0.5 cm) peat bed with an apparent age of 39,700 ±1,600 yr B.P., which is beyond the limit of accurate radiocarbon dating at other sites in northern and central Alaska (for example, Hamilton and others, 1988; Hamilton and Ashley, 1993). A pollen assemblage from this peat is typical of low shrub-herb tundra with some alder thickets (T.A. Ager and E. Shaw, U.S. Geological Survey, written commun., 2/8/83). The bluff is capped by about 8 m of alluvial gravel (unit 4).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	8.2	**Gravel.** Rounded pebbles and cobbles in sandy matrix. **Alluvium.**
3	20	**Slightly stony clay and silt.** Gray clay and brown silt, generally laminated. Contains sparse pebbles and cobbles. Layer of pebble-small-cobble gravel capped by thin peat bed occurs 7.5-9.0 m above base. **Upper glaciolacustrine unit.**
2	8	**Gravel.** Pebbles, cobbles, and small boulders, with interbeds of highly oxidixed brown (7.5Y 5/4) sand. Upper 1.2 m mixed with gray silty clay and contorted peat beds, with many stones vertical. **Alluvium.**
1	43	**Stony clay.** Rounded to subrounded pebbles and cobbles in matrix of nonstratified gray clay. Stones lack fabric and many are steeply inclined. Lenses and layers of pebble-cobble gravel increase upward. Contains peat beds at 25 m height and within gravel near upper contact. **Lower glaciolacustrine unit.**

Figure 27. Exposure An-1. South side Aniuk River 31 km southwest of Howard Pass. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure An-2

A cutbank on the north side of Aniuk River 5 km west of An-1 intersects a 20-m terrace that is widespread along this stretch of the river (fig. 18). A probable glaciolacustrine stony clay at the base of the exposure (fig. 28) is overlain by oxidized sand that grades upward into alluvial gravel. A 5-cm peat bed at the top of the gravel, dated at >48,000 yr B.P., contains pollen typical of herbaceous tundra with sparse willows and dwarf birch (T.A. Ager and E. Shaw, U.S. Geological Survey, written commun., 2/8/83). The topmost unit, which consists of clasts dispersed in a brown silty matrix, in part may be a solifluction deposit derived from the adjoining valley side.

Exposure An-3

A cutbank on the south side of Aniuk River 4.5 km upvalley from exposure An-1 intersects a 20-m terrace that contains outwash derived from the Itkillik I moraine front overlain by glaciolacustrine deposits (fig. 18). Coarse gravel at the base of the section (fig. 29) consists of typical upper Noatak drainage lithologies (schist, vein quartz, quartzite, and granite). The gravel fines upward into gravelly sand at about 7 m height and then into lacustrine sandy silt with sparse pebbles at about 12 m. The top 4 m of the bluff face is covered largely by peat, which has draped downward over ice-rich stony silt.

Exposure An-4 (not illustrated)

A prominent moraine-like ridge along the north side of Aniuk River 22 km southwest of Howard Pass (see fig. 18) is vegetated, and its poorly exposed face therefore is not illustrated. Remnants of the 20-m outwash terrace are inset along its southeast flank, and an apparent kame terrace near its southwest end has a probable ice-contact face 25 m high. The ice-contact face consists of a mixture of (1) subangular pebbles and small cobbles of local sandstone and shale mixed with (2) rounded cobbles and small boulders up to 45 cm diameter of granite and quartzite. Excavations into the weathered bluff face exposed fine sand near river level and, midway up the bluff face, rounded pebbles in an abundant matrix of platy coarse sand and granules. Cobbles and small boulders are most abundant near the top of the bluff. The upper surface of the deposit is continuous with paired terrace remnants that are traceable northward along an underfit stream channel into the Pupik Hills (see fig. 18).

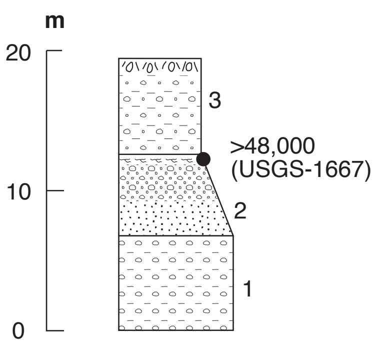


Figure 28. Exposure An-2. North side Aniuk River 29.5 km southeast of Feniak Lake. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	ca.7	**Stony silt.** Pebbles and cobbles dispersed in brown sandy silt. Upper 1.5 m frost-deformed with many stones vertical. **Origin uncertain.**
2	ca.6	**Sand and gravel.** Fine to medium sand, grading upward into pebble-small-cobble gravel in abundant sandy matrix. Peat bed at upper contact. **Alluvium.**
1	ca.7	**Stony gray clay.** No description available. **Glaciolacustrine deposit?**

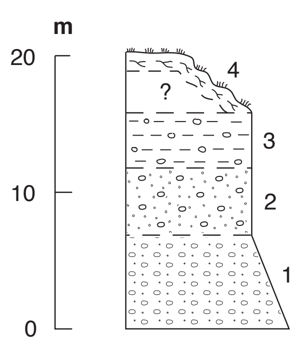


Figure 29. Exposure An-3. South side Aniuk River 28 km southwest of Howard Pass.

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	4	**Largely covered.** Probably peat above stony silt. **Bluff cap over glaciolacustrine deposit.**
3	4	**Stony silt.** Sandy silt with sparse pebbles. **Glaciolacustrine deposit.**
2	5	**Gravelly sand.** Transitional contact with unit 1. **Slackwater deposit?**
1	7	**Gravel.** Rounded to subrounded pebbles, cobbles, and sparse very small boulders in sandy matrix. **Outwash.**

Exposure An-5

A 5-m cutbank on the northwest side of Aniuk River 12 km southwest of Howard Pass exposes Holocene alluvial gravel and floodplain deposits (fig. 30). Pebbles and small cobbles of mostly local platy quartzite and sandstone occur in a matrix of gray platy granules and medium to coarse sand. Some sandy lenses of similar composition also occur within the gravel. At one locality, a channel in the gravel surface dips to within 1 m of the river. Large fragments of willow (*Salix*) up to 6 cm diameter in a matrix of organic silty fine sand 3.8 m above river level within this channel-filling deposit are dated at 8,210 ± 130 yr B.P.

The gravel elsewhere is overlain by 2-3 m of peat that grades upward into silty to sandy peat and fine gravel. Fragments of willow (*Salix*) wood from the base of the peat unit are dated at 8,530 ± 140 yr B.P.

Exposure An-6

An 8-m cutbank exposure along the east side of Aniuk River 8 km southwest of Howard Pass exposes mainly alluvial gravel (fig. 31). Rounded clasts are up to cobble size, with a few very small boulders also present. Quartzite is dominant, but granite also is common in the cobble fraction. The uppermost meter of the deposit has been frost churned and mixed with brown silt.

Exposure An-7

A cutbank of Flora Creek 4.5 km above its mouth intersects a flat-topped gravel deposit 15 m high (fig. 32). Pebbles and small cobbles predominate, with small quartz pebbles especially abundant. Sparse larger cobbles of granite, quartzite, and vein quartz also are present. The gravel has an unusually sandy matrix, and may be underlain by sand. It grades upward into a coarser cobble gravel with some very small boulders up to about 45 cm long.

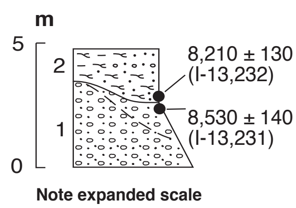


Figure 30. Exposure An-5. Northwest side Aniuk River 12 km southwest of Howard Pass. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	2-3	**Peat and sand.** Massive peat overlain by silty to sandy peat and fine gravel. Grades laterally into organic silty fine sand. **Floodplain deposit.**
1	3-2	**Gravel.** Pebbles and small cobbles of mostly local lithologies in abundant matrix of gray, platy granules and medium to coarse sand. Contains large wood fragments (6 cm diameter) in lens of organic silty fine sand. **Alluvium.**

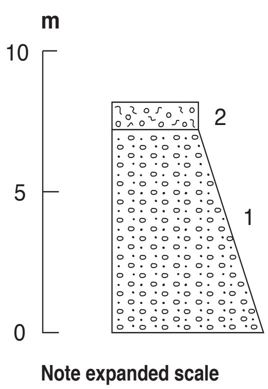


Figure 31. Exposure An-6. East side Aniuk River 8 km southwest of Howard Pass.

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	1.0	**Silty gravel.** Gravel clasts mixed with brown silt. **Frost-churned deposit.**
1	7.2	**Gravel.** Rounded pebbles, cobbles, and some very small boulders in sandy matrix. **Outwash.**

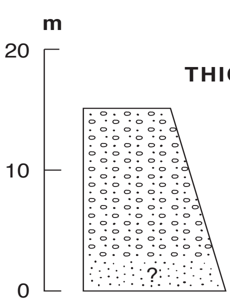


Figure 32. Exposure An-7. South side Flora Creek 4.5 km above its mouth.

THICKNESS (m)	DESCRIPTION and INTERPRETATION
15	**Gravel.** Pebbles, small cobbles, and some larger cobbles in very sandy matrix. Sand may underlie gravel near base of section. **Alluvium above deltaic(?) deposit.**

Discussion

Two unusually high bluffs, Nk-21 and An-1, lie well beyond the limit of recognized Itkillik I glaciation (see fig. 18); they expose very long records that appear to include pre-Itkillik glacial and interglacial phases. Nk-21, which intersects a possible buried arcuate end moraine, contains an apparent basal till that either was water-laid or incorporated proglacial lacustrine sediments. Clast lithologies indicate that the glacier originated in the upper Noatak River valley. An apparent arcuate limit of hummocky drift-like topography beneath glaciolacustrine sediments north of the Aniuk River (Hamilton, 1984b) may define the corresponding north flank of this large glacial lobe. The diamict is overlain by probable slackwater deposits that may have formed while the Noatak River valley was still partly blocked by wasting glacier ice. The basal diamict at An-1 may be a basin-margin equivalent of the two lowermost units at Nk-21. It appears to be largely of glaciolacustrine origin, but includes gravel beds that increase upward in the section, perhaps as the thinning of a glacier farther down the Noatak drainage system permitted temporary or partial releases of an ice-dammed lake. The granite-bearing ice-contact sediments in the bluff at An-4 may have been deposited by the same large Noatak ice lobe.

At exposure An-1, the strongly oxidized peat-capped alluvium at 43-51 m height at An-1 probably was deposited during a subsequent interglaciation, and it may correlate with the pebble-small-cobble channel gravel of lower unit 3 that occurs at a comparable height in Nk-21. Terrace remnants composed of comparable pebble-small-cobble gravel are widely present in this sector of the Noatak River valley, and may represent a major interglacial deposit. The overlying coarser gravel at Nk-21 may represent lag deposits of ice-rafted clasts from younger glaciolacustrine-sediment cover that later was eroded by the Noatak River when it flowed about 70 m above its present level. The clasts include pyroxenite boulders, which are not present in the upper Noatak River valley. This eroded deposit may correlate with the distal glaciolacustrine deposits (unit 3) at An-1, which are overlain by alluvium deposited about 71-79 m above modern river level. Two radiocarbon ages on the upper glaciolacustrine unit at An-1 are considered to be non-finite and indicate an age greater than 39.5 ka.

Exposure Nk-20, between the moraine belts of the Itkillik I and older glaciations, contains two glaciolacustrine units separated by alluvium. The lower glaciolacustrine unit contains only clasts of upvalley lithologies and probably correlates with the Itkillik I ice advance. The upper glaciolacustrine unit, which contains stone-free sediments at its base, is correlated with deposits of Itkillik II age downvalley. Alluvium between the two glaciolacustrine units may be the source of the spruce or larch wood found on the bluff. If so, it may demonstrate that a full interglacial interval separated deposits of Itkillik I and Itkillik II ages.

A terrace of about 20 m height, exposed at sites An-2 and An-3, represents the partial filling of a trough that was eroded by the Aniuk River, probably during the interglaciation that preceded the Itkillik I ice advance. The trough later filled with distal glaciolacustrine deposits of probable Itkillik I age and with outwash from valley trains that extended northwest from the Itkillik I glacial terminus (fig. 18). The sediment succession at both exposures seems to indicate that glaciolacustrine sedimentation preceded and followed outwash deposition from the outermost Itkillik I ice advance in the upper Noatak River valley. Exposure Nk-7, on Flora Creek, also may contain Itkillik I outwash above possible glaciolacustrine sediments. A radiocarbon determination from inferred outwash at An-2 is non-finite at >48 ka.

Two exposures, Nk-17 and Nk-18, provide information on the outermost end moraine of Itkillik I age and its associated outwash apron, respectively. The moraine stands about 35 m high where cut by the Noatak River at Nk-17, and its lithologies are typical of glacial source areas in the upper Noatak River valley. The general instability of the glacial diamict, its evident muddy matrix, and its geologic setting (see fig. 18) indicate that the glacier at its maximum extent may have terminated in standing water of glacial lake Noatak. Clasts in the outwash apron at Nk-18 are stained by oxides and encrusted by carbonates, and matrix material near the top of the section is discolored by precipitated oxides. These weathering features contrast with the unweathered gravel of the 16.5-m terrace of probable Itkillik II age that is inset within the moraine at Nk-17.

The depositional basin upvalley from the moraine belt is flanked by lateral moraines of Itkillik I age. Closer to the valley center, drift with an irregular hummocky surface is overlain by a blanket of sand, which masks much of the underlying relief. Terrace remnants 25-30 m high of unweathered Itkillik II outwash are inset within the drift (fig. 33). The outwash generally is finer than that exposed close to the Itkillik II moraine front, but locally (as at Nk-16) it is coarser and probably includes clasts reworked from the adjoining drift sheet. A sand deposit inset within the outwash stands at least 17 m high, but has Holocene radiocarbon ages (as discussed below). Recent alluvial surfaces close to modern river level are intersected by kettle lakes, which evidently have continued to grow after the alluvium was deposited. Relict glacier ice of Itkillik I age may still underlie this part of the Aniuk Lowland.

Three measured sections (An-5, Nk-14, and Nk-19) provide radiocarbon ages (appendix 1) that are compatible with a mid-Holocene warm interval in this part of the Noatak drainage system. The base of a massive peat unit at An-5 is dated at 8.5 ka, and large willows grew about 8.2 ka in a channel that evidently was cut into the peat. Massive peat at Nk-19 was accumulating by 6.0 ka. Mid-Holocene peat accumulation at Nk-14 and perhaps at the other sites may have terminated shortly before 3.7 ka, and in each case likely was due to renewed river alluviation, increased wind activity, decreased vegetation cover, or some combination of those factors.

Cutler River Area

To facilitate discussion of the geology of the large and complex Cutler River drainage basin, the bluff exposures in this sector of the Noatak River valley are divided into six sets. Bluffs along or adjoining the Noatak River near the mouth of Cutler River (Nk-22 through Nk-25, Cu-1; fig. 34) are discussed first, followed by the set of bluffs that cluster closely together along the lower courses of Cutler River and Kaluich Creek (Cu-2 through Cu-6; fig. 34). The more diverse and widely scattered bluffs along the upper courses of Cutler River and Kaluich Creek, and along Natmotirak Creek and Imelyak River, are then presented in that sequence.

Noatak River Bluffs

Introduction

In the vicinity of its confluence with the Cutler River, the Noatak River intersects the Cutler moraine, an arcuate end moraine 3-4 km wide that was deposited by a glacier that flowed eastward into the upper Noatak basin (Aniuk Lowland) from a source in the DeLong Mountains (see fig. 2 and Hamilton,

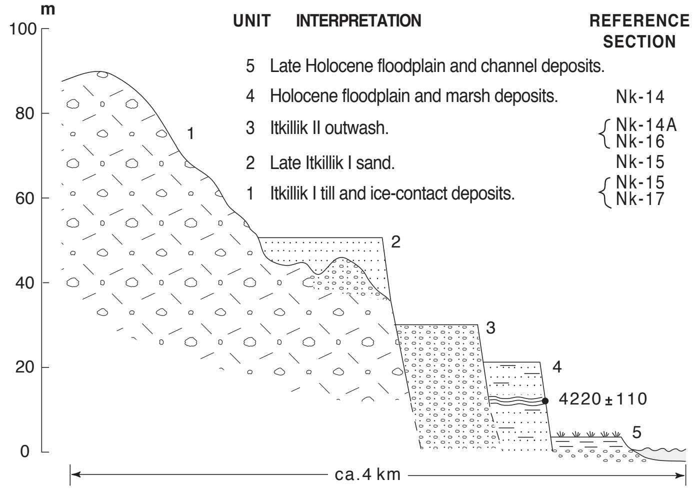


Figure 33. Schematic cross-profile of Noatak River valley above Itkillik I (Atongarak Creek) moraine belt. Profile extends from modern river channel to crest of lateral moraine. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

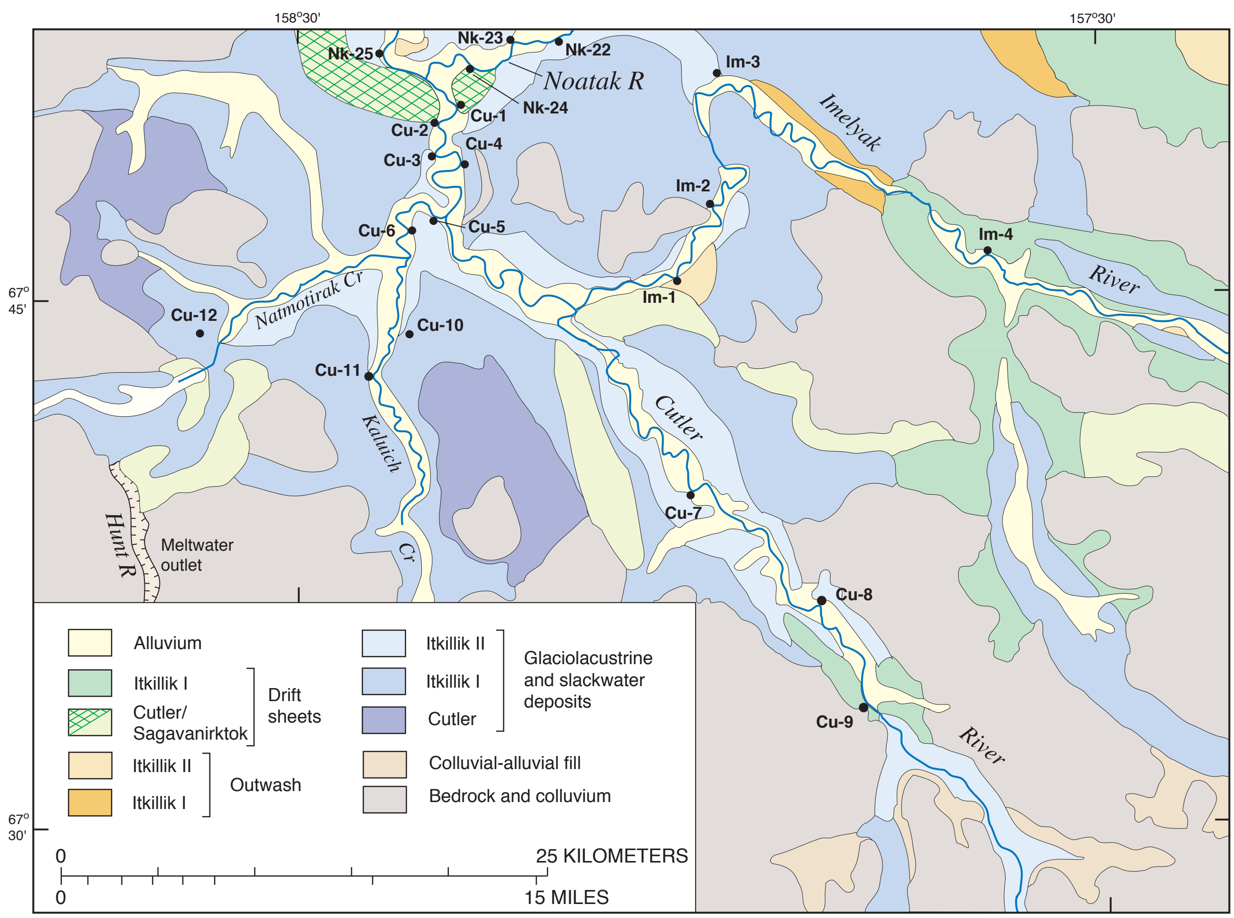


Figure 34. Generalized geologic map, Cutler River area, south-central upper Noatak basin.

2001). Associated lateral moraines are sharply defined, but their extension into the valley center is more diffuse because the glacier probably terminated in a lake dammed by its advance (Hamilton, 2001 and in press). Lacustrine deposits correlated with subsequent glacial advances are enclosed within the end moraine and extend beyond it (Hamilton, 2001); and they probably overlap the moraine as well.

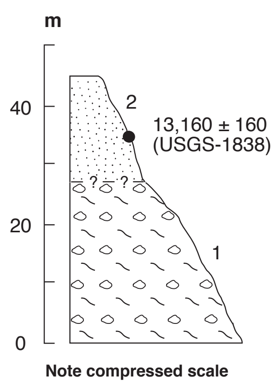
Five very similar bluff exposures occur near the Cutler River confluence. Exposures Nk-22 through Nk-25 have been cut by the Noatak River; Cu-1 is on the Cutler River 2 km above its mouth (fig. 34). Each bluff contains a stony silt unit, generally disturbed by flowage, overlain by vegetated sandy sediment.

Bluff Exposures (Nk-22 through Nk-25 and Cu-1)

Exposure Nk-22 is located on the south side of the Noatak River 8.5 km above the mouth of Cutler River and upvalley from the mapped end-moraine limit; it intersects a nearly level surface underlain by glaciolacustrine deposits (Hamilton, 1984a). The basal deposit in the bluff is highly plastic, stony clayey silt (fig. 35) that is nearly identical to the basal deposits of exposures Nk-23, Nk-24, and Cu-1 (discussed below). However, this deposit is only 26 m thick at Nk-22, and the associated lacustrine plain stands only 43 m above modern river level. Clast lithologies are similar to those in the three other exposures, but appear to include a larger component of granite and other rock types derived from the upper Noatak River valley (listed in appendix 2). Limited exposures of the overlying unit (unit 2) show well sorted, horizontally bedded, fine and medium sand that contains rootlets dated at 13,160 ± 160 yr B.P.

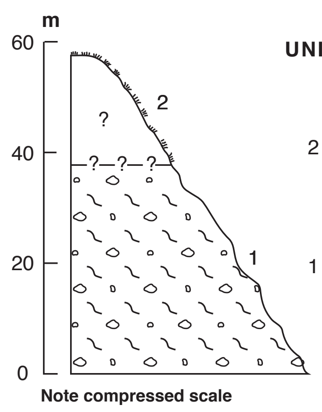
Three nearly identical bluffs (Nk-23, Nk-24, and Cu-1), which span a distance of only 5 km, intersect a gently undulating upland surface 54-59 m high that probably is underlain by the Cutler end-moraine complex (see fig. 34). In each bluff, 38-46 m of clayey silt with abundant striated stones is overlain by poorly exposed sandy sediments in which stones are rare or absent (figs. 36 and 37). The clayey silt is plastic when moistened, and flows readily on all bluff faces; it contains subangular to subrounded pebbles, cobbles, and sparse small boulders. Clast lithologies include rare granites, but are dominated by gabbros and quartzites, with abundant cherts in the pebble fraction (appendix 2). The overlying stone-free unit is generally poorly exposed; but well sorted, stratified, fine sand with some medium sand is evident in one locality.

Exposure Nk-25, 3 km below the mouth of the Cutler River, is situated inside the arcuate end-moraine belt. This river bluff contains the same basal stony silt and overlying sand(?) as the four neighboring exposures, but the stony silt is more compact and less subject to flowage than correlative units farther upvalley (fig. 38*A*). Undisturbed exposures are strongly jointed. An excavation just above the upper contact of the stony silt (fig. 38*B*) exposed alluvial fine gravel, sand, and silt that contains a black humic paleosol.



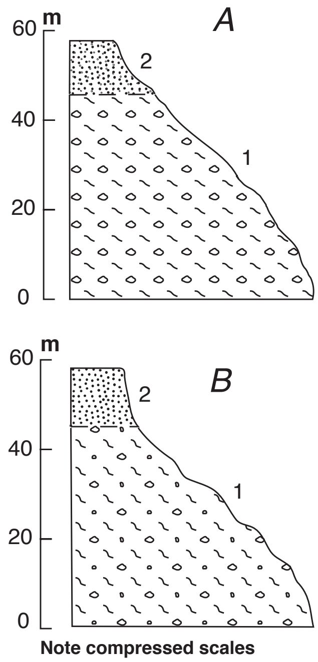
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	17	**Sand.** Poorly exposed sandy deposit with no stones evident. Limited exposure near middle of unit shows olive (5Y 5/3) to olive gray (5Y 4/2) fine and medium sand in beds 5-10 cm thick containing *in situ* rootlets. **Floodplain deposit?**
1	26	**Stony silt.** Dark gray (5Y 4/1) clayey silt with abundant subrounded to angular clasts; some clasts striated. Highly plastic, flowing readily on slopes. **Glaciolacustrine deposit.**

Figure 35. Exposure Nk-22. South side Noatak River 8.5 km east-northeast of mouth of Cutler River. Poorly exposed, with abundant debris flows. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	21	**Vegetated.** Unstable and poorly drained deposit, entirely obscured by vegetation. **Unknown deposit.**
1	38	**Stony silt.** Subangular to subrounded, commonly striated, pebbles, cobbles, and some small boulders in matrix of very dark gray (5Y 3/1) clayey silt. Exposed only in debris flow. **Glaciolacustrine deposit.**

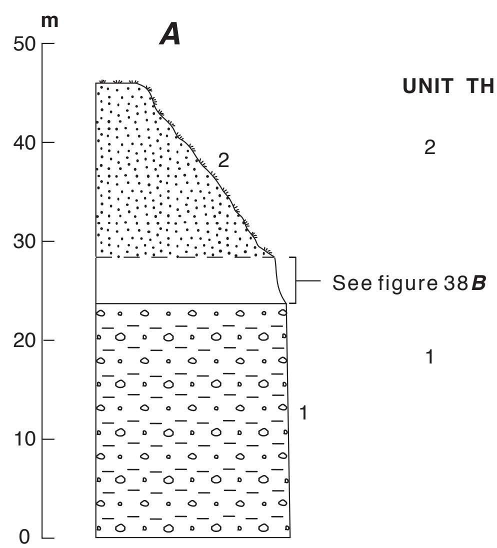
Figure 36. Exposure Nk-23. North side Noatak River 5 km east-northeast of mouth of Cutler River.



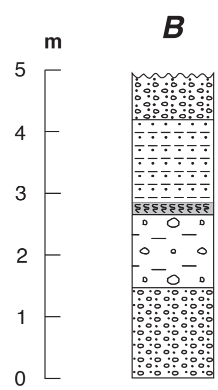
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	12	**Sand.** Mostly covered. Upper 2 m is structureless, well sorted, silty very fine sand that grades downward into weakly bedded fine sand with thin (ca. 1 cm) layers and lenses of medium sand. **Origin uncertain.**
1	46	**Stony silt.** Subangular to subrounded, commonly striated, stones up to boulder size in matrix of very dark gray (5Y 3/1), plastic, clayey silt. Exposed only in debris flow. **Glaciolacustrine deposit.**

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	12.5	**Sand.** Poorly exposed. **Origin uncertain.**
1	42	**Stony silt.** Abundant pebbles and cobbles and very sparse small boulders in matrix of dark olive gray (5Y 3/2) clayey silt. Stones commonly striated. **Glaciolacustrine deposit.**

Figure 37. Exposures Nk-24 and Cu-1. Nearly identical bluff exposures near mouth of Cutler River. (*A*) Exposure Nk-24, south side Noatak River 3 km east of mouth of Cutler River. (*B*) Exposure Cu-1, east side Cutler River 2.4 km above its mouth.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	23	**Sand?** Well sorted silty very fine sand near top. Vegetated face with only exposures at base. **Origin uncertain.**
1	24	**Stony silt.** Subangular to subrounded, commonly striated, pebbles, cobbles and sparse very small boulders in matrix of dark olive gray (5Y 3/2) slightly clayey silt. Strongly jointed, with joint planes passing through stones. **Glaciolacustrine deposit.**



THICKNESS (m)	DESCRIPTION and INTERPRETATION
0.3+	**Fine gravel.** Granules and pebbles in matrix of poorly sorted fine to coarse sand. Top not exposed.
1.4	**Sand with silt.** Well sorted olive brown (2.5Y 4/4) silty very fine sand. Contains layers 1-4 cm thick of gray clayey silt.
0-0.2	**Paleosol.** Black, pebbly, humic silt and silty humus, alternating in layers 1-2 cm thick.
1.2	**Stony silt.** Subangular to subrounded stones up to small boulders in matrix of very dark gray (5Y 3/1) slightly clayey silt.
2.1	**Fine gravel.** Subangular to subrounded pebbles and small cobbles in abundant matrix of poorly sorted medium to coarse sand and granules. Directly overlies unit 1.

Figure 38. Exposure Nk-25. West side Noatak River 3 km below mouth of Cutler River.(*A*) Bluff profile. (*B*) Detail of base of unit 2, from excavation 24-29 m above river level. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Discussion

Because of its noncompacted nature and its association with a probable water-laid end moraine, the basal stony silt at exposures Nk-22, Nk-23, Nk-24, and Cu-1 is considered to be an ice-proximal glaciolacustrine deposit. This sediment differs from normal basal tills, which generally are compact and form resistant units in river bluffs (see fig. 4 and table 2). The basal unit in all four bluffs probably lacked primary compaction and had a high moisture content that later became frozen into ice-rich permafrost. These properties, together with its clayey matrix, would account for the ubiquitous flowage of this unit on the bluff faces. In contrast, the basal unit at exposure Nk-25, which probably was deposited subglacially, is more compact and more resistant to flowage. The stony silt unit at all five exposures contains abundant chert pebbles and gabbro or pyroxenite clasts which were derived from sources to the north and northwest in the DeLong Mountains, as discussed in the appendix 2.

The mostly covered unit that overlies the stony silt appears to be primarily sandy alluvium that may have formed as a slack-water deposit when the Aniuk Lowland was blocked by a later, less extensive glacial advance that terminated farther downvalley (Hamilton, 2001 and in press). The presence of alluvium and peat at the sand-silt contact at Nk-25 demonstrates that a nonglacial interval separated those two units, and that the sand therefore must have formed during a separate glacial advance. A radiocarbon age of about 13.2 ka from the middle of the sand unit at exposure Nk-22 would seem to provide a representative date for the blockage of the Aniuk Lowland by the younger glacial advance. However, the basal stony silt unit at this exposure is 15-20 m thinner than at the three exposures clustered around the Cutler River confluence, and the upland surface also is 15-20 m lower. Exposure Nk-22 might therefore represent a late-glacial readvance and renewed blockage of the Aniuk Lowland that could have followed an initial cycle of glaciation, ice wastage, and river downcutting.

Lower Cutler River

Introduction

For about 16 km above its mouth, the Cutler River is incised within an extensive lacustrine plain about 55 m high that extends south and east from the Cutler moraine front (see fig. 34). Discontinuous remnants of a younger surface that stands about 30 m above the river are inset within the lacustrine plain. Five exposures (Cu-2 through Cu-6) are clustered closely together along the lower Cutler River and Kaluich Creek within 5.5 km of the outer margin of the Cutler moraine. The highest exposure (Cu-4) appears to exhibit the longest stratigraphic record.

Exposure Cu-4

A west-facing bluff along the Cutler River 5.5 km above its mouth stands 45 m high and rounds back to an upland surface 53 m above modern river level. The bluff documents at least two major episodes of glaciolacustrine deposition separated by an interval of river activity (fig. 39*A*). Poorly exposed organic-rich silt at the base of the section may have developed on a poorly drained river floodplain or alternatively may represent initial ponding by glacier ice advancing eastward up the Noatak River valley (as shown in fig. 2). The channeled upper surface of the basal silt unit has been incised to a depth of at least 2 m. Overlying stony silt contains deformed peat and gyttja lenses near its base. Some lenses dip at angles as great as 85° and appear sheared, as if overridden and deformed by glacier ice. Alluvium above the stony silt contains a possible floodplain deposit (fig. 39*B*) dated at >50,000 yr B.P. Clay rhythmites, which mark the beginning of a younger episode of glaciolacustrine sedimentation, are succeeded upward by a thick deposit of silty clay that contains abundant striated tillstones. Mafic igneous rocks and several varieties of chert are the dominant pebble-sized clasts (appendix 2). The uppermost unit is dominantly sand and silt that has been severely deformed by slumping and flowage. Permafrost has aggraded into the deformed sediment, preventing any excavations through it.

Exposures Cu-5 and Cu-6

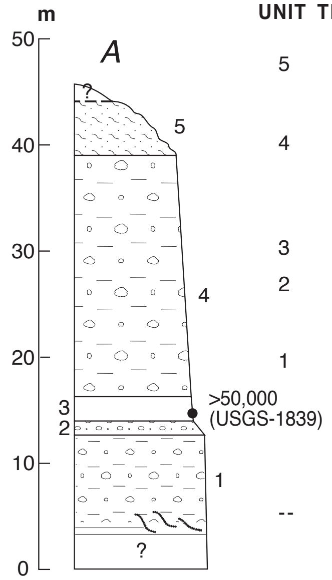
Two bluffs along Kaluich Creek near its confluence with the Cutler River (see fig. 34) are only 1.5 km apart and of comparable height (figs. 40 and 41). They intersect the northeast and west margins of a narrow erosion remnant bounded by the floodplains of Cutler River and Kaluich Creek.

Exposure Cu-5 contains flow deposits of clayey silt that contain abundant striated clasts up to boulder size. Overlying faintly bedded, fine to medium sand contains some organic-rich zones. Wood fragments from a slump block that may have originated 3-6 m below the top of the bluff are dated as >40,000 yr B.P. A mammoth tusk also was found within the sand deposit.

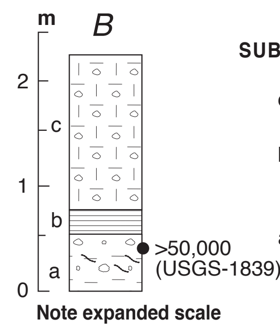
In exposure Cu-6, a basal deposit of oxidized fine sand is overlain by rhythmically bedded clay with dropstones. The clay has an erosional upper contact with up to 2 m relief, and is overlain by a 26-m-thick deposit of stony clayey silt that contains dispersed clasts up to small boulder size. Pyroxenite cobbles are common, and black chert is abundant in the pebble fraction.

Exposures Cu-2 and Cu-3

Two east-facing cutbanks of the Cutler River 3 and 4.5 km above its mouth intersect sloping surfaces that are inset within uplands of Itkillik I age (see fig. 34). Both bluffs contain a basal stony clay unit with abundant polished and striated stones up to small boulder size (figs. 42 and 43). The clay has been eroded close to river level, and is overlain by alluvial gravel containing clasts up to small cobble size. Cu-2, a low bluff about 13 m high, contains only Holocene sand and peat above the gravel. Willow wood 0.4 m above the base of the sand is dated at 7,280 ±120 yr B.P. Cu-3 stands about

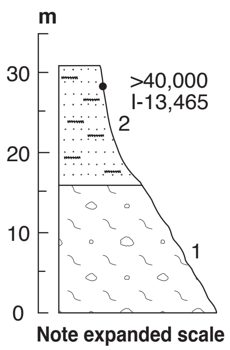


UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	5	**Sand and silt.** Dark gray (5Y 4/1) humic silt, silty fine sand, and stony fine sand. Deformed by slumping and flowage; no original bedding evident. **Origin uncertain.**
4	24	**Stony clay.** Subangular to rounded, commonly striated, pebbles, cobbles, and sparse boulders up to 1.6 m length in matrix of very dark gray (5Y 3/1) silty clay. **Proximal glaciolacustrine deposit.**
3	2.3	**Silt and clay. Glaciolacustrine deposits. (**See fig. 39*B*.)
2	1.3	**Gravel.** Rounded to subrounded pebbles, small cobbles and sparse larger cobbles in sparse matrix of poorly sorted sand and granules. **Alluvium.**
1	9	**Stony silt.** Subrounded to subangular, commonly striated, pebbles, small cobbles, and sparse larger cobbles in matrix of dark gray (5Y 4/1) clayey silt. No obvious sorting or bedding, and stones lack fabric. Contains deformed lenses of woody peat and gyttja 4-5 m above river level. **Glaciolacustrine deposit.**
--	?	**Organic silt.** Well-bedded, organic-rich deposit, incised to at least 2 m depth at contact with unit 1. Poorly exposed. **Pond deposit?**



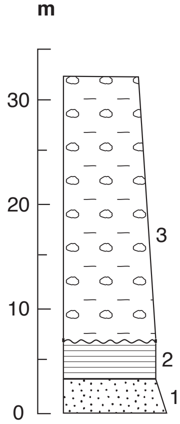
SUBUNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
c	1.5	**Silty clay.** Blocky silty clay with sparse pebbles. **Glaciolacustrine deposit.**
b	0.25	**Clay rythmites.** Rhythmically bedded clay and silty clay. Couplets thicken downward from 3-5 mm at top to ca. 1 cm at base. **Distal glaciolacustrine deposit.**
a	0.55	**Stony silt.** Faintly bedded silt and clayey silt with sparse dropstones up to large cobbles. Contains contorted thin peat beds and sparse wood fragments. **Floodplain and initial glaciolacustrine deposit(?)**

Figure 39. Exposure Cu-4. East side Cutler River 5.5 km south-southeast of its mouth. (*A*) Bluff profile. (*B*) Detail of unit 3. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	15	**Sand.** Well sorted, pale olive (5Y 6/4), fine to medium sand. Contains faintly bedded organic-rich zones 1-15 cm thick. **Slackwater (floodplain?) deposit.**
1	16.5	**Stony silt.** Rounded to subrounded, commonly striated stones up to 1 m diameter in matrix of very dark gray (5Y 3/4) clayey silt. Subject to flowage along bluff face. **Glaciolacustrine deposit.**

Figure 40. Exposure Cu-5. South side Kaluich Creek 1 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	26	**Stony silt.** Subangular to subrounded, commonly striated, pebbles, cobbles, and sparse small boulders in matrix of slightly plastic, dark greenish gray (5G 4/1), sandy clayey silt. Erosional basal contact. **Procimal glaciolacustrine deposit.**
2	3.7	**Clay.** Rythmically bedded dark gray clay and silty clay, forming couplets 2-6 mm thick. Fines upward, with basal layer relatively silty. Sparse dropstones of sand, granules, and small pebbles. Lebenspurren along some bedding planes. **Distal glaciolacustrine deposit**
1	3.3	**Sand.** Well sorted, oxidized fine sand and gray silty very fine sand. Contains climbing ripples and silty to clayey drapes. **Deltaic deposit?**

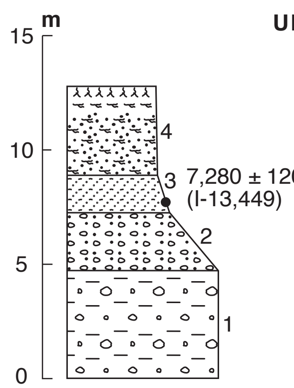
Figure 41. Exposure Cu-6. East side Kaluich Creek 2.5 km west-southwest of its mouth.

10 m higher, with its upper surface rising inland. This bluff contains a thicker alluvial deposit that is overlain by sand, silt, and clay that may have been deposited during an episode of impeded drainage. A thick deposit of organic silt at the top of the section is cut by an ice wedge about 3 m high and up to 1.5 m wide.

Discussion

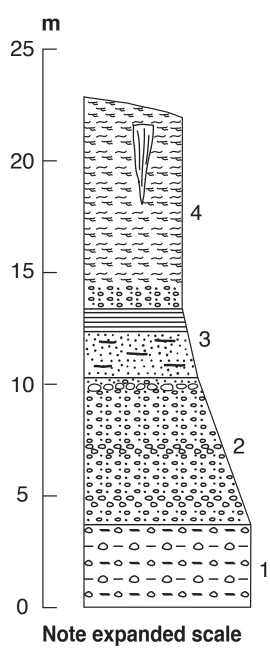
The upper glaciolacustrine unit at Cu-4 is comparable in height and lithology to the basal stony clayey silt of Itkillik I age that occurs in the five bluffs (exposures Nk-22 through Nk-25 and Cu-1) close to the Noatak-Cutler Rivers confluence. The overlying sand and silt, which is associated with an upland surface 53 m high, may be a facies equivalent to the poorly exposed, sandy, slackwater deposits along the Noatak River that underlie an aggradational surface 54-59 m high that formed during Itkillik II time. The basal glaciolacustrine deposit at Cu-4 may represent an earlier glacial advance that possibly overrode that locality before the glacier withdrew sufficiently for an ice-dammed lake to form.

Exposures Cu-5 and Cu-6 intersect an erosion surface about 30 m high that extends southeastward up the Cutler River. Cu-6, on the Kaluich Creek side of the erosion remnant, was freshly undercut by the creek when visited in 1983. A basal exposure of strongly oxidized sand probably predates the last glaciation. Rhythmically bedded clay above the sand probably marks the onset of glacial damming, as at Cu-4. The overlying diamict resembles the basal stony clayey silt that is widespread around the Noatak-Cutler Rivers confluence, where it is associated closely with the ice front of Cutler age. Cu-5, on the Cutler River side of the erosion remnant, contains a similar stony clayey silt that was truncated erosionally at about 16 m height and then buried by a sand deposit that resembles the slackwater deposits of inferred Itkillik II age elsewhere around the Noatak-Cutler Rivers confluence. Wood was found at only one location in the sand, and its non-finite age indicates that it may have been redeposited from older sediments.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	4	**Sod, peat, and peaty sand.** Not examined closely. **Bluff cap.**
3	1.5	**Sand.** Fine sand with ripples, detrital organic mats, ball-and-pillow structures, and silt laminations. Some interbeds of medium sand and silty fine sand. Near-horizontal bedding. **Floodplain deposit.**
2	2.6	**Sandy gravel.** Subrounded to rounded pebbles and sparse small cobbles in abundant, poorly sorted matrix of medium sand to granules. **Channel alluvium.**
1	4.8	**Stony clay.** Dark greenish gray (5GY 4/1) silty clay. Contains rounded to subrounded pebbles, cobbles and sparse boulders. **Glaciolacustrine deposit.**

Figure 42. Exposure Cu-2. West side Cutler River 3 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	8.3	**Peat and organic silt.** Contains ice wedge. Sand and pebble gravel locally present at base. **Loess with peat?**
3	3.1	**Sand and clay.** Rythmically bedded grayish brown to gray silt and clay above well sorted fine to medium sand with climbing ripples, drapes, and detrital organic mats. **Glaciolacustrine?**
2	7.0	**Sand and gravel.** Pebbly sand and sandy fine gravel, with local sand-free layers of small pebbles and of pebbles to small cobbles. Lag deposit of coarse cobbles and very small boulders near top. **Alluvium.**
1	3.5	**Stony clay.** Dark blue-gray (5B 4/1), stiff, plastic, silty clay. Contains abundant polished and striated stones. **Glaciolacustrine deposit.**

Figure 43. Exposure Cu-3. West side Cutler River 4.5 km above its mouth.

Exposures Cu-2 and Cu-3 contain identical basal units of stony, silty clay that probably correlate with the other basal glaciolacustrine deposits around the Cutler River mouth that are related to the ice advance of Cutler age. Both glaciolacustrine deposits have been erosionally truncated close to river level and are overlain by channel gravel of the Cutler River. A Holocene section above the gravel at Cu-2 probably represents floodplain accretion about 7.0-7.5 ka, followed by river downcutting that allowed the overlying peat and peaty sand to form. The sedimentary section above the gravel at Cu-3 is thicker (11.4 m) than corresponding deposits at Cu-2, and it is more complex. Rhythmically bedded silt and clay above sand with climbing ripples probably represents deltaic deposition followed by submergence, perhaps due to rising water levels in the upper Noatak basin during the Itkillik II ice advance. The thick, overlying organic-rich silt may represent loess, which may have been retransported by solifluction to the base of the hillslope that overlooks Cu-3. This deposit could represent a significant time interval, perhaps during all or part of the late Wisconsin glaciation.

Upper Cutler River Valley

The valley floor of the Cutler River broadens into a marshy lowland with little relief 3 km above the Imelyak River confluence. A relatively undissected deposit that fills the valley center within this area appears to have transgressed across an erosionally dissected, older lacustrine plain (see fig. 34). These two landscape units have been mapped as Itkillik II and Itkillik I glaciolacustrine deposits, respectively (Hamilton, 1984a). The younger unit is intersected by exposure Cu-7. Farther up the Cutler River, deposits on the valley floor become more varied. At exposures Cu-8 and Cu-9, the river flows past the subdued end moraine of a glacier that may have terminated in standing water during Itkillik I time. Headward parts of the valley are mostly underlain by generally shallow, stony, colluvial and alluvial deposits.

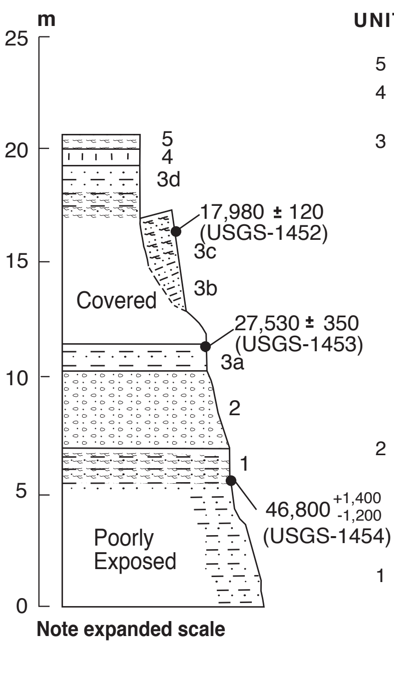
Three additional exposures were measured along or near Kaluich and Natmotirak Creeks, two western tributaries to the Cutler River (fig. 34). All three exposures are within a poorly drained landscape of gentle relief in which a blanket of glaciolacustrine deposits of inferred Cutler age (Hamilton, 2001) overlies older glacial deposits and bedrock.

Exposures Cu-7 through Cu-12

Exposure Cu-7, on the west side of Cutler River 12 km above the Imelyak River confluence, stands about 21 m high and intersects a marshy planar surface. Two sandy deposits with peaty interbeds are separated by alluvial gravel (fig. 44). The basal unit (unit 1) consists of subhorizontal beds 3-8 cm thick of dark gray to olive gray silt, silty fine sand, and fine sand. Silty fine sand is dominant in the lower part of the unit; interbeds 1-2 cm thick of woody bryophytic peat occur through the upper part. Wood and peat 1 m below the upper contact is dated at $46{,}800\,^{+1{,}400}_{-1{,}200}$ yr B.P. Overlying alluvium (unit 2) contains clasts to about 10 cm length of marble, schist, vein quartz, and other lithologies that are common near the valley head.

The upper sandy unit (unit 3) of Cu-7 is partly obscured by slumping. Basal deposits range from interbedded dark greenish gray sand and clayey silt to interbedded silty very fine sand to medium sand; these represent probable overbank alluvial facies. These sediments grade upward into laterally continuous organic silt and fine sand, and then into silty very fine sand with interbedded bryophytic peat. A peat bed 1 m above the base of the upper sandy unit is dated at 27,530 ± 350 yr B.P.; peat 1.5 m

Figure 44. Exposure Cu-7. West side Cutler River 27 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	0.4	**Peat and silt. Holocene bluff cap.**
4	0.8	**Sand and silt.** Faintly bedded very fine sand, grading upward into nonbedded silt. **Loess.**
3		**Sand, silt, and peat (overbank and marsh deposits)**
d	2.0+ (base covered)	**Sand with peat.** Silty very fine sand and fine sand in beds 0.5-6 cm thick. Very dark gray humic fine sand at 0.4-0.9 m depth. Basal 0.8 m contains 1-3 cm beds of sandy bryophytic peat and abundant rootlets.
c	2.1+ (top missing)	**Peat and sand.** Silty very fine sand and sandy peat in beds 1-5 cm thick. Sedge and grass peat dominant near top; mats of bryophytic peat below 60 cm depth.
b	2.0+ (base covered)	**Sand and silt.** Organic silt with vertical stems and rootlets, grading upward into silty very fine sand and fine sand in beds 1-3 cm thick.
a	1.1+ (top covered)	**Silt and sand.** Silty very fine sand and medium sand in beds and lenses 4-10 cm thick. Upper 0.6 m is olive gray silt to very fine sand with some organic beds.
2	3.4	**Sandy gravel.** Subrounded to rounded pebbles and small cobbles in sandy matrix. Generally subhorizontally bedded, with some trough crossbedding. Some interbeds up to 20 cm thick of slightly oxidized, light brown (7.5YR 6/4) fine to medium sand. Sparse lenticular swale fillings of gray silty fine sand. **Alluvium.**
1	6.6	**Sand and silt.** Silt, silty fine sand, and fine sand in subhorizontal beds 3-8 cm thick. Silty fine sand dominant in lower half of unit; well sorted fine sand in topmost 0.7 m. Peaty interbeds 1-2 cm thick throughout upper half of unit. **Slackwater and marsh deposit.**

below the unit's top is dated at 17,980 ±120 yr B.P. The bluff is capped by sandy to silty eolian deposits (unit 4) overlain by silty peat (unit 5).

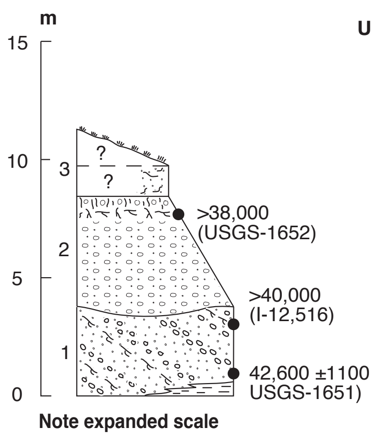
Exposure Cu-8 is situated on the northeast side of the Cutler River near the mouth of a tributary stream and close to the severely eroded front of a poorly defined drift sheet (see fig. 34). The exposure stands about 10 m high, rounding back into the base of a hillslope. Despite its low height, Cu-8 contains a surprisingly old depositional record. Interbedded sand, fine gravel, and organic-rich silty fine sand overlie lacustrine clayey silt near the base of the exposure (fig. 45). The sand and gravel beds dip southwest at about 20°; they probably were deposited on a fan delta that was built into standing water by the tributary stream that adjoins the bluff. Two radiocarbon determinations on willow wood and peat from the inclined beds indicate a non-finite age of >40,000 yr B.P. for the deposit. The channeled upper surface of the fan-delta deposit is overlain by alluvial gravel which contains clasts of upvalley lithologies (dominantly schist, vein quartz, quartzite, and marble). The upper 0.7 m of the gravel is oxidized, and rooted willow from a peat lens 0.1 m below the oxidized zone has a non-finite age of >38,000 yr B.P. The overlying sandy unit contains deformed beds of eolian(?) fine sand and silt that may have been displaced by solifluction. Alternatively, this unit may represent a former bluff cap that has slumped into its present position.

Pollen assemblages from two horizons in exposure Cu-8 have been identified and interpreted by T.A. Ager and Effie Shaw (U.S. Geological Survey, written commun., 2/9/83). A pollen subsample of USGS-1651 (fig. 45), taken near the base of the exposure, is dominated by sedge and willow, with birch, grass, and sage (*Artemesia*) also common. This assemblage is characteristic of an herb-shrub tundra that contains abundant willow thickets and wet meadows. A pollen subsample of USGS-1652, from near the top of the gravel unit, contains very high (91 percent) sedge. This assemblage represents a wet sedge meadow within a regional tundra environment.

Exposure Cu-9 intersects the drift sheet in the upper bedrock valley of Cutler River (see fig. 34). The river's bed here is choked with boulders up to 2.4 m long of typical upvalley lithologies (schist, quartzite, and marble). The entire exposure has been disrupted by flowage (fig. 46). Fresh river cuts along its base show unsorted, glacially shaped stones to boulder size in a muddy sand matrix. The overlying vegetated, hummocky flow surface rises inland to a moraine crest at about 25 m height.

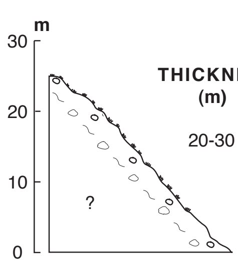
Exposure Cu-10 occurs 1.5 km above the mouth of an unnamed eastern tributary to Kaluich Creek (see fig. 34). Vegetated flows entirely obscure the bluff face (fig. 47), but boulders of schist and marble protrude from the flows and are abundant in the stream bed. Quartz dominates the pebble fraction, with no black chert or granite evident. Although severely mixed by flowage, the sediment matrix appears to be dominantly sandy.

Exposure Cu-11, an east-facing cutbank on the west side of Kaluich Creek, stands 9.5 m high. Stiff, plastic, stony clay, which protrudes just above river level at the base of the



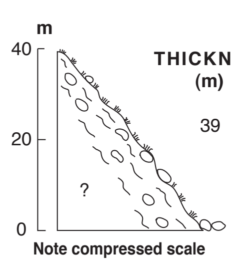
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	1.1+	**Sand with silt.** Very dark gray (10YR 3/1) silty very fine sand; interbedded with dark brown (10YR 4/3) fine sand. Beds are deformed, and interpenetrate in places. Contains deformed lenses of dark grayish brown (10YR 4/2) silt. Basal 10-12 cm consists of faintly bedded medium sand overlain by thin organic horizon. **Eolian(?) deposit above alluvium with paleosol.**
2	4.7	**Gravel.** Subrounded to rounded pebbles and small cobbles in matrix of coarse to medium sand. Upper 0.7 m oxidized yellowish brown (10YR 5/8); overlies peat lens with rooted willow. **Alluvium.**
1	3.8	**Sand and fine gravel.** Interbedded fine to medium sand, sandy pebble gravel, and organic-rich silty fine sand. Strikes N75°E; dips 20°SW. Contains matted plant material along bedding planes. Grades downward and laterally into dark gray clayey silt with some beds of fine sand. **Deltaic and lacustrine deposits.**

Figure 45. Exposure Cu-8. Northeast side Cutler River 36 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



THICKNESS (m)	DESCRIPTION and INTERPRETATION
20-30	**Stony sand.** Rounded to subangular, faceted and striated stones up to boulder size in matrix of gray muddy sand. Exposed only in debris flows. **Till or glaciolacustrine deposit.**

Figure 46. Exposure Cu-9. West side Cutler River 41 km above its mouth.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
39	**Diamict.** Face obscured by vegetated flows. Boulders up to 1.6 m diameter exposed on bluff face and in streambed. **Till or glaciolacustrine deposit.**

Figure 47. Exposure Cu-10. North side unnamed eastern tributary to Kaluich Creek 1.5 km above tributary's mouth.

bank (fig. 48), probably is glaciolacustrine. Overlying alluvial gravel has a cap of silty fine sand that may be either a channel filling or a floodplain deposit. The topmost unit is poorly exposed, interstratified stony silt and peat that may represent a shallow, intermittent lake.

Exposure Cu-12 is the headwall of a tundra earthflow about a kilometer northwest of Natmotirak Creek near the west flank of the Cutler River lowland (see fig. 34). The headwall, which stands about 6 m high, exposes laminated clayey, sandy silt with dropstones up to about 30 cm diameter that decrease upward in abundance but remain unchanged in size (fig. 49). Overlying gray silt contains peat layers and lenses that have been deformed by ice-wedge growth. Deformation increases upward to the top of the unit, where an unconformity separates the peaty silt from about 0.5 m of surface sod. An ice wedge 3 m wide at its top extends downward from the base of the surface sod to below the base of the headwall.

Peat from the base of the peaty silt unit has a non-finite age of >48,500 yr B.P. Its pollen assemblage is dominated by sedge (55 percent) and willow (24 percent), indicating a wet sedge meadow with willow thickets within treeless herb tundra (T.A. Ager and Effie Shaw, U.S. Geological Survey, written commun., 2/8/83). Peat from the middle of the unit probably also is non-finite in age (>43,600 yr B.P.) despite its reported age of 43,600 ±1300 yr B.P. Its pollen is almost entirely (94 percent) sedge, with grasses and herbs present in small amounts but willow absent (T.A. Ager and Effie Shaw, U.S. Geological Survey, written commun., 2/8/83). Ager and Shaw conclude that this assemblage probably represents a wet sedge meadow within treeless tundra.

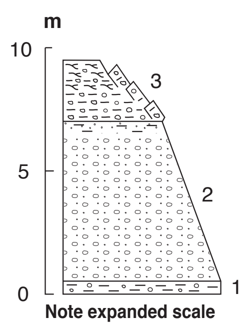
Discussion

Six exposures along the upper Cutler River and its western tributaries reveal a complex record of middle(?) and late Pleistocene glacial, glaciolacustrine, and alluvial episodes in this part of the upper Noatak basin.

Fan-delta deposits at exposure Cu-8 document standing water at the Itkillik I moraine front at some time prior to 40 ka and probably before 42.6 ka. Because the small tributary stream that adjoins this site probably was inadequate to build an extensive fan-delta complex, it may have been augmented by meltwater and detritus from wasting glacier ice in the adjoining drainage of Imelyak River. Detailed mapping of this relationship should allow direct correlation of the fan delta and its contemporaneous lake with either the Itkillik I glacial advance or a preceding more extensive glacial expansion in the Imelyak drainage system (see fig. 34). The basal slackwater deposit at Cu-7 may be correlative with the fan-delta deposit at Cu-8 because both units are overlain by similar fluvial gravel deposits that alluviated to about the same height (8.5-9.0 m) above the modern river. Laminated lacustrine sediments at Cu-12 document a glacial-lake stage that could be correlative with the basal deposits at Cu-7 and Cu-8, but the probable non-finite radiocarbon ages at all three exposures alternatively would permit the overlying silt with peat at Cu-12 to be older than the alluvial gravel at the other two sites. Cu-11 also contains a probable succession of glaciolacustrine and slackwater deposits separated by alluvial gravel. The basal stony clay deposit may be correlative with the clayey silt at Cu-12, and alluviation along the valley center at Cu-11 could have been synchronous with peat accumulation on the higher-standing wet sedge meadow at Cu-12.

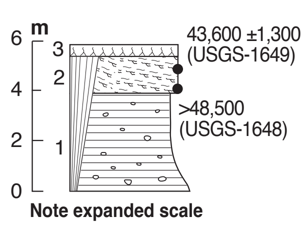
Late Wisconsin (Itkillik II) glacial damming of the upper Noatak basin is documented by overbank and marsh deposits at Cu-7; these underlie a 21-m surface, and are bracketed by radiocarbon ages of about 28 ka and 18 ka. Poorly exposed bluff-top deposits at Cu-8 and Cu-11 may be correlative with this stage of alluviation in the Cutler River area. At Cu-12, which stands higher above the modern floodplain, the Itkillik II phase may be

Figure 48. Exposure Cu-11. West side Kaluich Creek 7 km above its confluence with Natmotirak Creek.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	2.5	**Stony silt and peat.** Dark gray stony silt, interstratified with and capped by black to dark reddish brown peat. Severely slumped. **Glaciolacustrine and postglacial deposits.**
2	6.5	**Gravel.** Rounded to subangular pebbles and small cobbles in matrix of poorly sorted fine to coarse sand with some silt and platy granules. Capped by 0.3 m dark olive brown silty fine sand. **Alluvium.**
1	0.5	**Clay.** Stiff, plastic, stony gray clay. **Glaciolacustrine deposit?**

Figure 49. Exposure Cu-12. North side Natmotirak Creek 12 km above its mouth. Headwall of earthflow. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.5	**Surface sod.** Unconformably overlies unit 2.
2	1.5	**Silt with peat.** Gray silt with layers and lenses of deformed peat. Deformation increases upward. Cut by ice wedges. **Loess.**
1	4	**Stony silt.** Laminated clayey silt, containing dropstones that decrease upward in abundance. Cut by ice wedges that extend below base of exposure. **Glaciolacustrine deposit.**

marked only by an unconformity that separates Holocene sod from underlying deformed silt with peat and large ice wedges.

The bouldery flow deposits at Cu-9 and Cu-10 are severely mixed and poorly exposed. Both deposits contain assemblages of clasts derived exclusively from the headwaters of the Cutler River; they lack Noatak valley lithologies, such as chert, gabbro, pyroxenite, and granite, that are common around the Cutler River mouth. Because Cu-9 intersects a morainal ridge, this flow deposit probably is redeposited till from the glacier tongue that appears to have terminated in the glacial lake of Itkillik I age. Cu-10, which cuts the base of a long hillslope, probably intersects a glacial deposit that predates the widespread veneer of Itkillik I glaciolacustrine sediments.

Imelyak River Valley

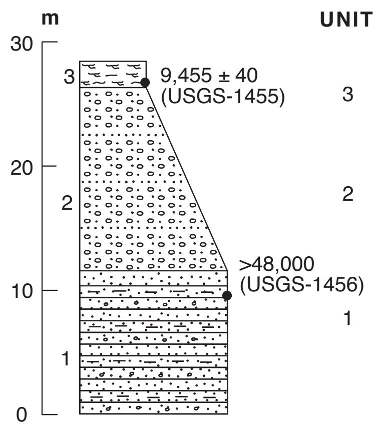
The lower course of Imelyak River extends through an area of moderate relief that is underlain by an arcuate end moraine near the Imelyak-Cutler Rivers confluence, by a bedrock upland north of the moraine, and by glaciolacustrine deposits, outwash, and alluvium farther upstream (see fig. 34). About 15 km above its mouth, the Imelyak River approaches to within 6 km of the Noatak River, and a low north-northwest-trending trough on the basin floor indicates that the two drainages formerly must have been connected at this locality. Three exposures (Im-1 through Im-3) in the lower Imelyak River valley contain assemblages of deposits that can be correlated with sequences of events along the Cutler and Noatak Rivers.

The upper valley of Imelyak River is dominated by drift sheets of inferred Itkillik I and Itkillik II age and their associated outwash trains (see figs. 5 and 34). Three exposures (Im-4 through Im-6) in this sector of the valley consist dominantly of glacial deposits.

Exposures Im-1 through Im-7

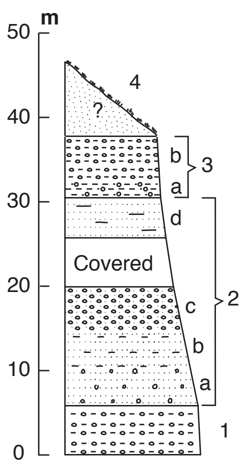
Exposure Im-1 is a north-facing cutbank on Imelyak River just upstream from the moraine at the Imelyak-Cutler Rivers confluence (fig. 34) The cutbank intersects an alluvial terrace 28.5 m high that probably is underlain by outwash from the adjoining moraine (Hamilton, 1984a). The basal unit exposed here is horizontally bedded sandy sediment that contains some clayey silt beds (fig. 50). Detrital wood 2 m below the upper contact has a non-finite age of >48,000 yr B.P. Overlying coarse gravel consists of upvalley lithologies (schist, vein quartz, and marble). The gravel is capped by peat and peaty silt that has a basal radiocarbon age of about 9450 yr B.P.

Exposure Im-2, situated 4.5 km farther up Imelyak River, is a bluff face 37 m high that contains two glaciolacustrine deposits separated by a thick alluvial sequence (fig. 51). The basal glaciolacustrine unit consists of silty clay with drop-



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	2.1	**Peat and silt.** Peat, silty peat, and peaty silt. Willow stems up to 3 cm diameter present through upper 1.4 m. **Floodplain deposit.**
2	14.9	**Gravel.** Subrounded stones to large cobble size, with some small boulders, in matrix of coarse sand and granules. Some interbeds of sand and fine gravel. **Outwash.**
1	11.5	**Sand.** Olive gray (5Y 5/2) fine sand, silty fine sand, and medium sand to granules; in horizontal beds ca. 20 cm thick. Contains sparse beds of clayey silt 5-7 cm thick. **Basin fill.**

Figure 50. Exposure Im-1. South side Imelyak River 5.5 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	10+	**Uncertain.** Generally vegetated, sloping surface. Appears to be largely or wholly sand.
3	ca. 8	**Stony silt and silty gravel.** Sandy clayey silt with striated dropstones (a), overlain by silty gravel (b). **Glaciolacustrine deposit.**
2	ca. 23	**Sand and gravel.** Pebbly medium sand (a), overlain successively by interbedded medium sand and silty fine sand (b), sandy pebble-small-cobble gravel (c), and faintly bedded sand with partings of micaceous fine sand (d). **Alluvium.**
1	6	**Stony clay.** Gray silty clay with faceted and striated dropstones. **Glaciolacustrine deposit.**

Figure 51. Exposure Im-2. West side Imelyak River 9 km above its mouth.

stones. It is overlain by an interstadial or interglacial complex of fluvial sand and fine gravel. The upper glaciolacustrine unit consists of sandy, clayey silt with striated dropstones overlain by silty gravel. The bluff rises an additional 10 m inland as a vegetated surface that may be underlain entirely by sand.

Exposure Im-3 (not illustrated) is a stabilized and largely vegetated bluff face that rises about 30 m above an abandoned channel segment of the Imelyak River that is now an oxbow lake. Sparse exposures show a "brown gravel" consisting of weathered pebbles and small cobbles up to about 16 cm diameter in an oxidized sandy matrix. Clasts include quartzites, vein quartz, limestone, and schist, with rare granite. The deposit fines upward into an oxidized pebble gravel of the same composition.

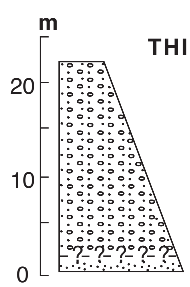
Exposure Im-4, a south-facing cutbank within the Itkillik I moraine belt on the Imelyak River, stands 22.5 m high and exhibits only alluvium (fig. 52). Although diamict and outwash of Itkillik II age occur a short distance upvalley from this locality (see figs. 5 and 34), the weathered nature of the gravel at Im-3 suggests that it is older. The deposit may represent recessional outwash of the Itkillik I glacier.

Exposures Im-5 and Im-6 are two cutbanks near the head of Imelyak River that intersect an end moraine of probable Itkillik II age (shown in southwest corner of fig. 5). Both cutbanks expose abundant striated stones up to boulder size (fig. 53). Im-5, which contains unsorted till-like sediment, intersects a hummocky morainal surface that stands about 21 m above the river. Im-6, slightly farther upvalley from the moraine front, contains gravel above a till-like diamict that has a somewhat water-washed sandy matrix.

Discussion

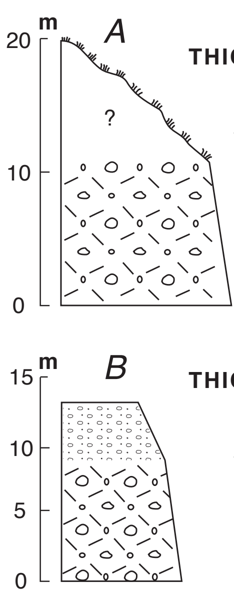
The strongly oxidized gravel at exposure Im-3 resembles the gravel sheet around exposure Nk-21, 8 km to the north along the Noatak River. Knolls of similar-appearing gravel were noted along the northeast side of Imelyak River between Im-3 and the Itkillik I moraine front (Hamilton, 1982, 1992). Stratigraphic relations at Nk-21 and regional extent of the oxidized gravel indicate that the oxidized gravel probably is a widespread interglacial deposit of pre-Itkillik age.

The sediment succession at exposure Im-1 is interpreted as largely related to the glacial advance down Cutler River valley that formed the end moraine near the Cutler-Imelyak Rivers confluence. Although this exposure stands only 28.5 m high, its upper units may have been eroded by the Imelyak River, which is confined narrowly here between the end moraine to the south and bedrock uplands to the north. The basal sandy unit is largely a slackwater deposit formed by partial damming of the river; clayey silt beds indicate intermittent episodes of more effective local or regional blockage of drainage. The overlying gravel compositionally resembles other gravel units along the Cutler River and its tributaries,



THICKNESS (m)	DESCRIPTION and INTERPRETATION
22.5	**Gravel.** Rounded to subrounded stones to small boulder size (0.7 m) in weakly oxidized (light yellowish brown 10YR 6/4) sandy matrix. Stones near top weathered and carbonate encrusted. May overlie beds of fine sand. **Alluvium.**

Figure 52. Exposure Im-4. North side Imelyak River 2 km below mouth of Amakomanak Creek.



A

THICKNESS (m)	DESCRIPTION and INTERPRETATION
10.8+	**Diamict.** Unsorted, nonstratified, striated stones up to boulder size (0.8 m) in unsorted, calcareous, muddy matrix. **Till.**

B

THICKNESS (m)	DESCRIPTION and INTERPRETATION
13.2	**Diamict.** Rounded to subangular, striated stones up to boulder size (1.5 m) in unsorted to weakly sorted sandy matrix.Overlain by pebble-small-cobble gravel with light yellowish brown (10YR 6/4) sandy matrix. **Till and ice-contact gravel.**

Figure 53. Exposures Im-5 and Im-6 near head of Imelyak River. (*A*) Exposure Im-5, north side unnamed eastern tributary to Imelyak River 21 km above Amakomanak Creek confluence. (*B*) Exposure Im-6, east side Imelyak River 24 km above Amakomanak Creek confluence.

but it is much coarser than the pebble-small-cobble gravel that predominates at the other exposures and texturally is more like the proximal outwash deposits along the Noatak River. It is interpreted as outwash derived from the adjoining ice front. The outwash gravel is overlain unconformably by a peat cap of Holocene age. Any former weathering profile at the top of the gravel and any younger Pleistocene-age deposits must have been eradicated by erosion.

The poorly exposed sandy capping unit at exposure Im-2 is comparable in character and height to the slackwater(?) sand deposits that overlie glaciolacustrine sediments 11.5-14.5 km farther to the northwest near the Cutler River mouth. The succession of sediments beneath the upper sandy unit at Im-2 (see fig. 51) represents a complex series of events that may include blockage of lower Imelyak River valley by advance of the Cutler valley glacier (unit 1), then progressive wastage of the glacier (units 2a and 2b?), followed by (3) development of interglacial conditions (unit 2c). Subsequent advance of a glacier from the DeLong Mountains into the Noatak River valley caused impeded drainage (unit 2d) followed by standing-water conditions (unit 3a). Glacial recession (unit 3b) was followed by the advance during which the inferred capping sand (unit 4) was deposited.

Exposures Im-4 through Im-6 represent local glacial and fluvial events in the upper valley of Imelyak River. All three deposits are inorganic and hence undated by radiocarbon. However, the extent and physical appearance of the drift sheet that is intersected by Im-5 and Im-6 are compatible with those of the drift sheet of Itkillik II age in the upper Noatak River valley (see fig. 5), and glacial limits can be traced directly through mountain valleys that connect the two drift complexes. The drift sheet at Im-5 and Im-6 therefore is assigned confidently to the Itkillik II glaciation.

Aniuk Lowland Below Cutler River—Noatak River Bluffs

Introduction

Downriver from the Cutler River confluence, the Noatak River flows north-northwest for 18 km within a trough about 7-10 km wide that is confined between lateral moraines of the Cutler moraine complex (fig. 54). Along the floor of the trough, a Holocene floodplain 2-3 km wide is inset within a planar surface that stands 25-40 m above the Holocene deposits. This terrace-like surface is nearly level near the valley center, but rises at gentle gradients as it

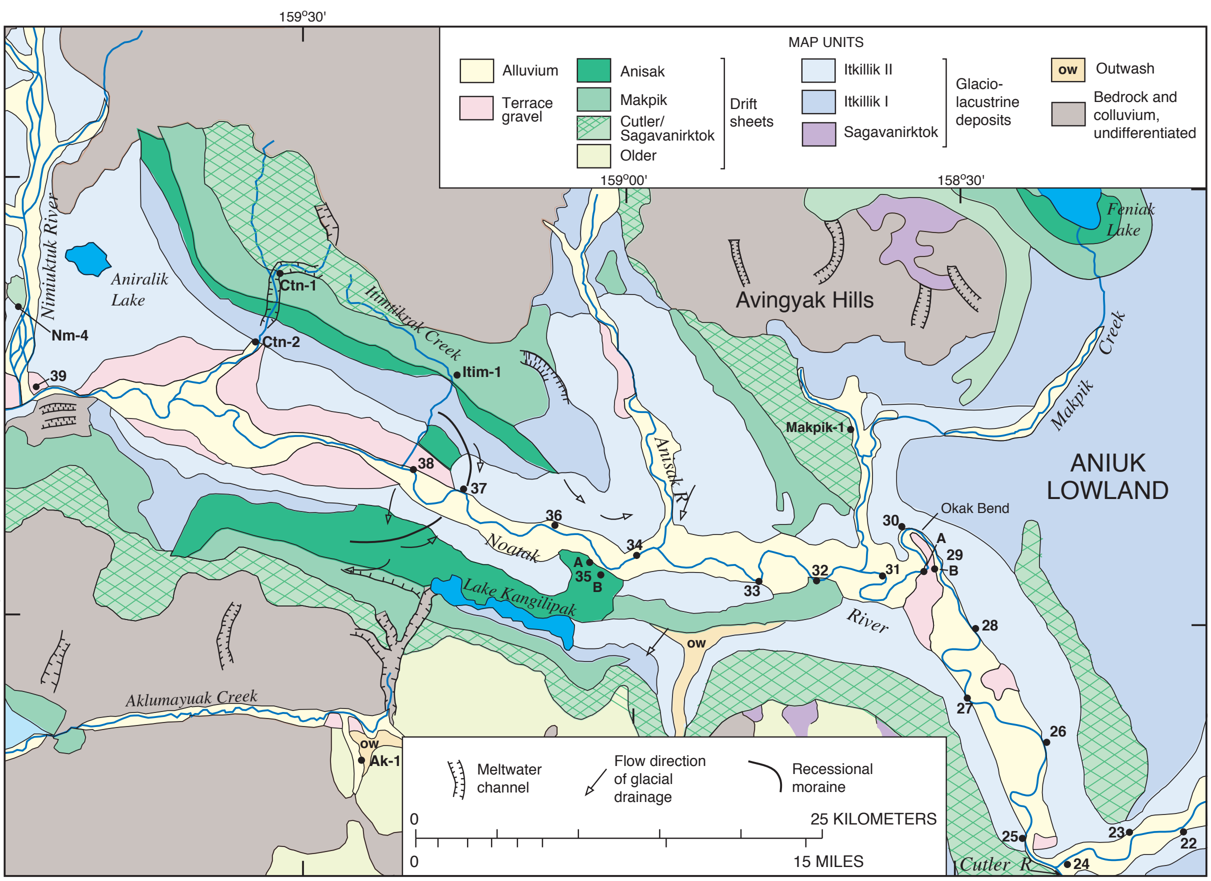


Figure 54. Generalized geologic map, Noatak River valley between mouth of Cutler River and lower Nimiuktuk River. Ctn, exposures along New Cottonwood Creek. Numbers without prefixes refer to Noatak River bluffs (designated Nk in text).

approaches the lateral moraines and wedges out against their inner flanks. The surface appears continuous with the sandy deposits (for example,, exposures Nk-23, Nk-24, and Cu-1, discussed previously) that surround and overlap the Cutler moraine along the lower Cutler River and around its mouth. Three exposures (Nk-26 through Nk-28) intersect the sandy unit and underlying glaciolacustrine and alluvial sediments along this stretch of the valley.

Near Okak Bend, the Noatak River flows through several involuted large meanders, then straightens out into a general westward course that begins near Makpik Creek. The meanders probably are controlled by bouldery erosion remnants of the Makpik drift sheet (Hamilton, 2001 and in press), which extends from the De Long Mountains eastward up the Noatak valley, terminating in an end moraine that intersects the valley center just west of Makpik Creek (fig. 54). Four closely spaced exposures (Nk-29A through Nk-31) provide information on glacial and alluvial history in the Okak Bend area.

Below Makpik Creek, the Noatak River flows westward for about 17 km through a stretch that is confined between lateral moraines of the Makpik drift sheet. It then intersects the Anisak end moraine (Hamilton, 2001 and in press), the eastern terminus of the Anisak drift sheet, near the mouth of Anisak River (fig. 54). A prominent line of south-facing river bluffs begins at the Anisak moraine front and continues down the Noatak River valley for 12 km, yielding exposures Nk-34, Nk-36, and Nk-37. Downvalley from Nk-37, the Noatak River meanders through a broad basin that is enclosed within the Anisak moraine. Only two exposures (Nk-38 and Nk-39) within this stretch were informative enough to be measured and recorded.

Exposures along the Noatak River downstream from the Cutler River differ from those farther upvalley in several important respects. The discharge of the Noatak River is significantly larger below the Cutler River confluence owing to the water contributed by this large tributary. Meander wavelength along the Noatak below the Cutler confluence consequently is much larger than that farther upvalley, and informative bluff exposures commonly extend for a kilometer or more along river bends. Erosive ability of the Noatak also is much greater below the Cutler confluence, and the Noatak River commonly has cut through late Pleistocene deposits to expose older sediments near river level. Deep erosion also has resulted in large-scale, fluvial cut-and-fill relations that greatly complicate bluff stratigraphy. In some places, downcutting by the Noatak River has intersected plastic clay-rich sediments that normally occur below river level. These deposits commonly appear as diapiric extrusions near the ends of river bluffs, where confining overburden has been removed by Holocene river erosion (Hamilton, 1995). Finally, the bluffs along this stretch of the Noatak River were examined in 1983 and again in 1993. Striking changes occured during the 10-year interval between visits: new exposures were cut by the river, and some former exposures were obscured by flowage, vegetation growth, and other surface processes.

Exposure Nk-26

A prominent bluff exposure 8 km north of the Cutler River confluence extends for 0.5 km along the east bank of the Noatak River. The bluff's exposed face stands 30-35 m high, and extends upward into a vegetated slope that rises to a nearly level surface at about 37-40 m height. An overview of the bluff face (fig. 55) shows two glaciolacustrine (stony mud) units separated by river gravel and floodplain deposits that fill a deeply scoured surface on the older stony mud. Deposition of the younger stony mud was followed by alluviation of sand. Two stratigraphic sections were measured near the south

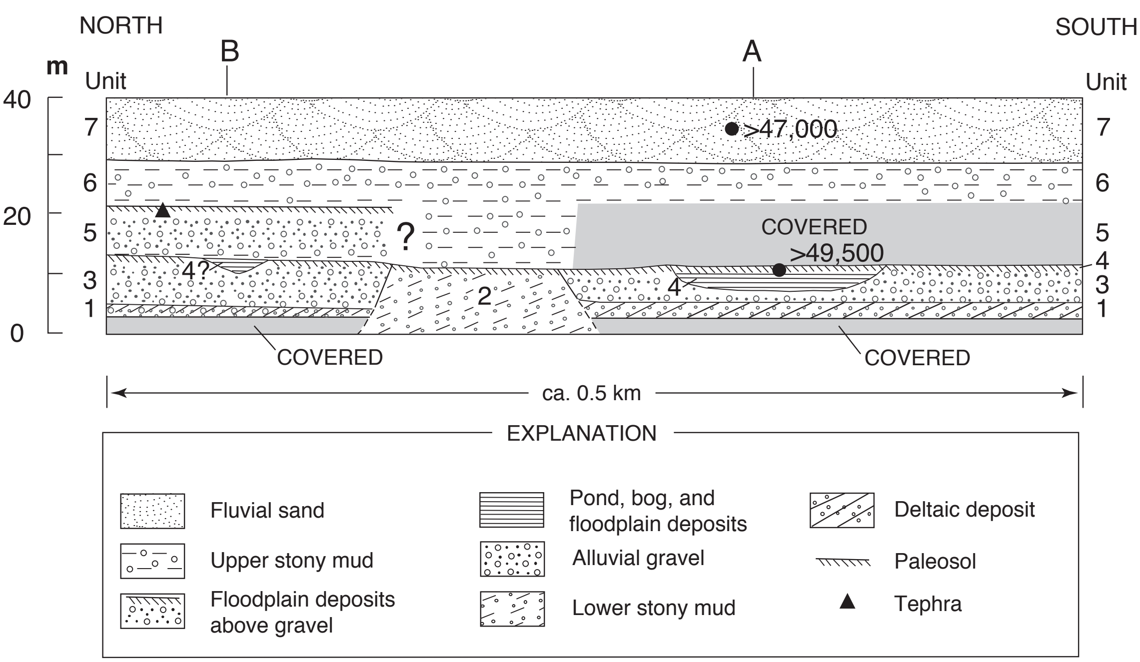
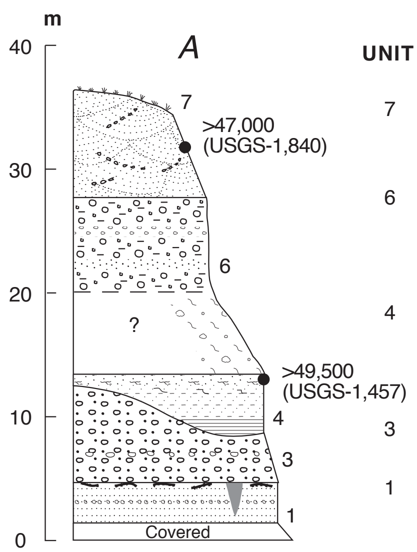


Figure 55. Stratigraphic relations along face of exposure Nk-26. East side Noatak River 8 km north of Cutler River mouth. From Elias and others, 1999, fig. 5. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

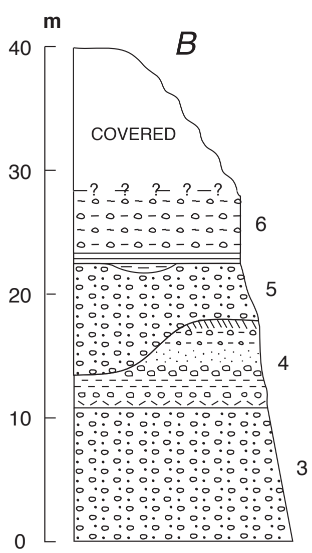
and north ends of the bluff (figs. 56*A* and 56*B*, respectively). The depositional sequence in the intervening area was partly obscured by widespread flowage of the lower stony mud.

The basal unit (unit 1) consists of about 2.3 m of finely laminated fine sand and organic fine sand that contains climbing ripples and probably formed as deltaic foreset beds. The sand is underlain by a probable floodplain complex that is dominated by fluvial deposits (ripple-bedded sand, oxidized fine sand, and oxide-impregnated fine gravel) in one locality and probable pond deposits (deformed wavy beds of well sorted fine sand and dark-colored sapropel) at another locality. A peat bed near the top of the unit is 5 cm thick, but has been deformed through a vertical range of 35 cm. An ice-wedge cast that originates at the peat horizon penetrates 120 cm into the underlying sand.

The lower stony mud (unit 2) forms an erosion remnant just downstream from the middle of the bluff. Flows obscure much of the bluff face here, but limited exposures show about 0.5 m of probable floodplain deposits (sand and silty fine sand) about 10 m above river level capping the lower stony mud and separating it from a younger glaciolacustrine unit. The lower stony mud consists of striated clasts up to cobble size, with some small boulders, dispersed in dark gray slightly clayey silt. The deposit contains several beds of well sorted very fine sand and laminated silty clay that have apparent dips downriver of 2-3°. These beds are about 0.5 m thick, but they thicken to about 1 m to fill depressions in the underlying stony mud. Cobble lithologies are dominantly quartzite, limestone, chert, and ultramafic rock types (appendix 2). One unusual rounded clast is conifer wood, which was identified as *Pinus* (white pine group) (USDA-FPL; 11/83). The coarse lag deposit that lines the river's edge along this section of the bluff is more heterogeneous and more bouldery than lag deposits



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
7	6.5	**Sand.** Crossbedded silty very fine sand to coarse sand with sparse granules and small pebbles. Some drapes of clayey silt. Contains wedge sets with tangential cross bedding. **Alluvium.**
6	15.8	**Stony mud.** Very dark gray clayey silt to silty clay, containing abundant striated pebbles and small cobbles and rare coarser stones. Stony mud and muddy gravel alternate through upper 9.7 m; basal 6.1 m obscured by debris flows. **Glaciolacustrine deposit.**
4	4.2	**Sand and silt.** Couplets of fine sand and clayey silt, overlain by horizontally bedded silt and very fine sand. Grades upward into horizontally bedded silt with wood fragments. Capped by compressed black woody peat. **Pond, bog, and marsh deposit.**
3	3.7	**Gravel.** Rounded pebbles, small cobbles, and sparse larger stones in matrix of poorly sorted sand. **Alluvium.**
1	4.7+	**Sand.** Finely laminated well sorted fine sand with climbing ripples. Deformed peat bed at top of unit. Pebble gravel in middle of unit contains ice-wedge cast. **Deltaic deposit.**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
6	5.7+	**Stony silt.** Rounded to subrounded pebbles, small cobbles, and some larger cobbles, mixed with subangular clasts to boulder size in clayey silt matrix. Some stones faceted and striated. Overlies 0.6 m of gray silty clay with some thin (2-10 mm) silt beds. Upper contact obscured. **Glaciolacustrine deposit.**
5	4.3+	**Gravel.** Pebbles, small cobbles, and sparse larger clasts in matrix of poorly sorted sand with abundant rock chips. Brown silt and black organic silt with sparse pebbles fill channel-like depression at upper contact. **Alluvium.**
4	6.5	**Silt, sand, and fine gravel.** Horizontally bedded silt, laminated silt, ripple-bedded sand, and fine gravel; overlain by dark gray clayey silt with dispersed pebbles and thin beds of oxidized fine sand. **Floodplain deposit.**
3	11.0	**Gravel.** Rounded to subrounded pebbles, small cobbles, and sparse larger cobbles in sandy matrix. Many clasts iron-stained. **Alluvium.**

Figure 56. Exposure Nk-26 (continued). Measured sections (see fig. 55 for locations). Modified from Elias and others, 1999, fig. 6. (*A*) Section *A*, measured near south end of bluff face. (*B*) Section *B*, measured ca. 120 m from north end of exposure. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

elsewhere along the bluff face; and it contains numerous ultramafic rocks derived from sources farther downvalley.

The gravel (unit 3) consists of rounded pebbles, small cobbles, and sparse larger clasts in a sandy matrix. Many stones through the upper 3 m of the deposit have reddish coatings of iron oxides, and clasts in the most permeable beds have oxide coatings through the upper 5 m of unit 3. Through the southern part of the bluff (fig. 56*A*), subangular boulders up to 65 cm long occur near the base of the gravel, and several “stone lines” of subrounded large cobbles and very small boulders occur at higher levels. These deposits probably resulted from downcutting and later lateral erosion by the Noatak River into the stony silt of the lower glaciolacustrine unit. Through the northern part of the bluff (fig. 56*B*), the gravel is better stratified and sorted, with no boulders and with a matrix generally washed free of clay and silt.

An interglacial floodplain complex is expressed by channel-filling deposits (unit 4) and peaty beds at heights between 11 and 17 m along the bluff face. Near the south end of the bluff (figs. 55 and 56*A*), a thick sequence of pond, bog, and marsh sediments fills a deep channel-like depression. Laminated sand, silt, and clayey silt are overlain by beds of sandy silt and black humic silt with flattened wood fragments. One large piece of wood was identified as *Picea* or *Larix* (USDA-FPL, 11/83). Peaty beds 11.0-11.6 m above river level in the central part of the bluff contain wood identified as *Salix* (USDA-FPL, 11/93), and wood from peat near this locality was dated as >49,500 yr B.P. A second probable channel fillng of sand, silt, and fine gravel near the north end of the bluff (fig. 56B) contains twigs and small wood fragments identified as *Picea* or *Larix* (USDA-FPL, 10/93).

Floodplain deposits containing the Old Crow tephra (Elias and others, 1999), which was deposited about 140,000 yr ago (Berger, 2003), cap a higher alluvial gravel deposit (unit 5; fig. 56*B*) through the north part of the bluff. Pollen and insect remains from organic deposits associated with the tephra suggest tundra vegetation with local dominance of sedge (Elias and others, 1999)

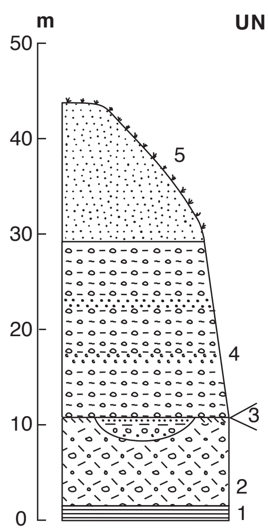
The upper stony mud (unit 6) contains unsorted, commonly striated, rounded to subrounded pebbles, small cobbles, and sparse larger cobbles, which are mixed with subangular clasts up to about 1 m diameter. Lithologies are dominantly quartzite and a gabbro-like dark crystalline rock, with other fine-grained igneous rocks also present (appendix 2). In at least one locality, the deposit consists of five subunits, each 1-3 m thick. Stone content remains fairly constant in each subunit, but matrix alternates between unsorted clayey silt and water-washed muddy sand and granules. The water-washed beds may represent intervals of sudden drainage of the lake, most likely due to breaching of its glacial dam. The basal 0.6 m of unit 6 consists of silty clay with some thin silt beds. This stone-free deposit may have formed during an initial shallow-lake stage in the upper Noatak basin or when glacier ice was too distant to contribute dropstones to the site.

The sandy deposit (unit 7) that caps the section generally is eroded back from the bluff face, and is poorly exposed. However, one exposure clearly indicates a fluvial origin for the deposit. Cross-bedded sand occurs with sparse fine gravel and some drapes of clayey silt, with thin lenses of fine organic detritus along some bedding planes. Migrating bedforms and ripples indicate paleocurrent directions parallel to the modern valley. Detrital wood collected 2.4-2.6 m below the exposed top of the unit is dated as >47,000 yr B.P.

Exposure Nk-27

An east-facing river bluff 5.5 km downvalley from exposure Nk-26 stands 44.5 m high and exhibits two diamicts (fig. 57). The upper one-third of the bluff is covered, but sand locally is exposed at the base of the covered unit. The contact between the two diamicts rises in height from 5.2 m above the river near the south end of the bluff to 10.7 m near the center.

Rhythmically laminated silt and clay above a paleosol developed on stony silt (unit 1) occurs along a 10-m stretch at river level near the center of the bluff. The paleosol surface strikes north and dips 10-12° E; it bears polygons 40-50 cm



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	ca. 14.5	**Sand.** Well sorted fine sand. Generally slumped and vegetated. **Alluvium?**
4	ca. 25	**Upper diamict.** Rounded to subrounded, striated pebbles and cobbles in matrix of gray muddy sand. Grades upward into rounded to subangular pebbles and cobbles in matrix of dark gray slightly clayey silt.Faintly bedded. **Glaciolacustrine deposit.**
3	0-3.6	**Sand, silt and fine gravel.** Variable laterally; intermittently present. **Floodplain deposit.**
2	3.5-9	**Lower diamict.** Rounded to subrounded, striated stones dispersed in highly compact dark gray sandy clayey silt. Platy stones parallel near-horizontal fissility. Cut by near-vertical joint planes. **Till.**
1	1.5	**Silt and clay.** Faintly laminated stony sandy silt, capped by paleosol. Overlain by rhythmically laminated silt and clay. **Pond and lake deposits.**

Figure 57. Exposure Nk-27. West side Noatak River 12.5 km north-northwest of Cutler River mouth.

diameter with marginal troughs about 5 cm deep. In part, the dip could be due to undercutting by the river, but part also appears to follow the downvalley dip of the upper contact of unit 1.

The lower diamict (unit 2) consists of striated stones dispersed in a well mixed matrix of sandy clayey silt. Clasts include downvalley lithologies (appendix 2). This deposit is highly compact, and maintains vertical faces along the bluff. It has a general fissile structure, with near-horizontal zones about 0.5 m thick of intense fissility associated with oriented platy stones; these probably represent shear zones. Oxides are concentrated along near-vertical joint planes and for 0.7 m below the upper contact. The lower diamict probably is a true till rather than a glaciolacustrine deposit.

The upper diamict (unit 4) is faintly bedded, with beds of stony mud alternating with better-washed layers of stony muddy sand and some beds of matrix-free pebbles. Striated pebbles and cobbles are common throughout the deposit. Chert, schist, and igneous rocks dominate the pebble fraction (appendix 2). Like the upper diamict at exposure Nk-26, unit 4 probably is glaciolacustrine in origin, and its deposition was interrupted periodically by breaching of a glacier dam farther downvalley.

Two localities near the center of the bluff exhibit lenses of probable fluvial overbank deposits up to 3.6 m thick (unit 3) that separate the lower and upper diamicts. Sand and fine gravel are overlain by interbedded sand and silt with sparse granules and pebbles. No organic remains were recognized in this alluvial unit.

The gravel bar on the east side of the Noatak River opposite exposure Nk-27 contains large detrital wood fragments of two types. Conifer wood, which is impregnated with iron oxides, includes large fragments up to 18 cm width that were identified as *Pinus* (USDA-FPL; 10/93). The source of this detritus is unknown. Angiosperm wood, identified in the field as *Populus* on the basis of bark and morphology, is present as somewhat smaller but more intact logs and branches. This detritus was traced upstream to a low Holocene terrace, where buried logs up to 11 cm diameter and dated at 1,570 ±90 yr B.P. (USGS-3401) are eroding from a cutbank. The *Populus*(?) wood has been identified as *Salix* (willow; USDA-FPL, 10/93), but this identification is suspect.

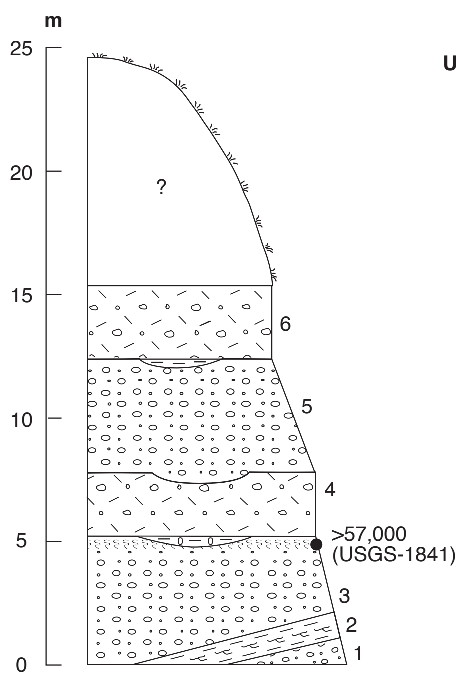
Exposure Nk-28

A southwest-facing river bluff 9 km downriver from Nk-26 has an exposed face 16 m high but rises inland 10 m more at a gentler angle to the edge of the broad undulating surface of a former valley floor. Nk-28 contains two well-exposed diamicts, with channel and floodplain alluvium separating and locally underlying them (fig. 58).

The lowest alluvial sequence is best exposed near the north end of the bluff. It declines in height southward, and can be traced upriver for only 120 m along the base of the bluff. A limited exposure of pebble-small-cobble gravel (unit 1) at the north end of the bluff is oxidized to about 0.5 m depth. Through this interval, admixed silt and numerous vertical stones attest to vigorous frost churning, probably within an active layer above a former permafrost table. Silt and peat (unit 2) cap the gravel. Gray silt and black organic silt, which form the top and base of the unit, are separated by 20-35 cm of black to dark reddish brown peat. Sparse flattened willow twigs up to 1 cm diameter have been identified as *Salix* (USDA-FPL, 11/30/93). Both the upper and lower silt beds thicken into channel-like depressions in the peat and gravel deposits that underlie them.

A younger alluvial gravel unit (unit 3) occurs throughout the bluff. Clasts up to large cobble size occur in an unusually

Figure 58. Exposure Nk-28. East side Noatak River 16.5 km north-northwest of mouth of Cutler River. Section measured near downriver end of bluff. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
--	10.0	**Covered.** Vegetated surface, rising inland.
6	3.0	**Upper diamict.** Striated clasts to small boulder size in matrix of dark grayish brown sandy silt. **Till?**
5	4.8	**Gravel.** Pebbles and cobbles in matrix of coarse to medium sand. Alternating cobble-and-pebble-rich layers, and some beds of stratified sand and granules. Upper 0.7 m oxidized. **Alluvium.**
4	2.6	**Lower diamict.** Pebbles, small cobbles, and sparse larger clasts in matrix of very compact, dark gray, clayey sandy silt. Near-horizontal fissility and stone fabric. Upper contact erosional, with slight oxide tint. **Till.**
3	5.4	**Gravel.** Pebbles and cobbles in matrix of coarse sand and granules. Upper 0.7 m oxidized dark yellowish brown. Local caps of black humic silt. **Alluvium.**
2	1.0	**Silt and Peat.** Gray silt and black organic silt above and below black to dark reddish brown peat with flattened twigs. **Floodplain bog and marsh deposit.**
1	0.7+	**Gravel.** Pebble-small-cobble gravel. Upper 0.5 m oxidized with vertical stones. **Alluvium.**

coarse-grained matrix of coarse sand and granules. The topmost 1 m of the gravel unit has been oxidized, and the upper part of the oxidized zone has been further modified by frost churning, downward migration of silt particles, and translocation of carbonates. In the central part of the bluff, the gravel locally is capped by 25 cm of stony brown sandy silt and black organic silt that has a non-finite age of >57,000 yr B.P. Many of the stones in this deposit have vertical orientations, and were incorporated within the silt by frost action.

The lower diamict (unit 4), a strongly jointed, extremely compact deposit that stands in near-vertical faces, probably formed as till. Rounded to subangular pebbles, small cobbles, and sparse larger clasts up to small boulder size (about 55 cm diameter) occur in a matrix of dark gray (N4), fissile, slightly clayey, sandy silt. The near-horizontal fissility lacks obvious grain-size sorting, but platy stones are aligned generally parallel to it. Only a very slight oxide tinge occurs at the upper contact of this unit.

The upper alluvial gravel (unit 5) is a weakly bedded deposit of rounded to subrounded clasts to large cobble size in a matrix of well sorted coarse to medium sand. It is unoxidized except for its upper 0.7 m, which has been altered to a yellowish brown (10YR 5/6) color and commonly has vertically oriented clasts. The gravel is capped locally by silty floodplain deposits. In the central part of the bluff, black to dark brown organic silt is up to 30 cm thick and contains algal (*Chara*?) laminations characteristic of a shallow pond deposit. At the upriver end of the bluff, black organic silt is interbedded with red (2.5YR 4.6) fine sand.

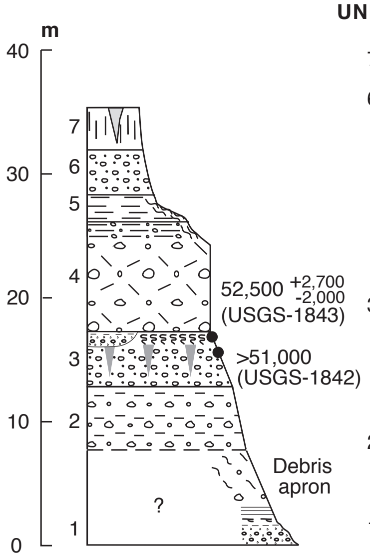
The upper diamict (unit 6), a possible till, generally is poorly exposed. It contains striated clasts up to small boulder size in a matrix that may consist of very dark grayish brown sandy silt.

Exposure Nk-29A

A pair of cutbank exposures on opposite sides of the narrow neck of Okak Bend stand only 450 m apart and intersect the same nearly level upland surface (see fig. 54). The northwest-facing cutbank on the west side of Okak Bend contains excellent exposures. Its face stands 25.5 m high, rounding back to a nearly level upland surface 37 m above the river. Two diamicts are separated and underlain by alluvial gravel and floodplain deposits (fig. 59).

The basal alluvium (unit 1) is exposed only at the downstream end of the bluff and near the bluff center. At the downstream exposure, northeast-dipping beds of dark gray to olive gray silt predominate. Interbeds of black peat with willow wood (*Salix*; USDA-FPL, 12/13/83) occur through the basal 65 cm of the deposit; beds of calcareous algae occur through the upper 95 cm. Although the base of the silt is not exposed, a concentration of boulders in the river begins at the point downriver where the lower contact of this dipping bed should emerge at the surface. A trench near the bluff center exposed alluvium, peat, and silt below the basal contact of the lower diamict, which here occurs 3 m above river level and rises toward the northeast. Alluvial fine gravel at the base of the trench grades upward into sand with detrital fragments of *Populus* wood (USDA-FPL, 10/93). Overlying floodplain deposits consist of oxidized peat, organic silt, sandy silt, and silty fine sand; they contain an insect fauna characteristic of a mesic tundra with woody shrubs (S.A. Elias, University of Colorado, written commun., 4/27/94).

The lower diamict (unit 2) has an exposed thickness of 5 m, but probably extends close to river level beneath the basal debris apron along much of the bluff. Pebbles, small to medium



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
7	3.1	Structureless silt and organic silt with ice wedges. **Loess.**
6	4.6	Poorly sorted, weakly bedded, medium to very coarse sand with sparse granules and small pebbles. Oxidized brownish yellow. **Alluvium.**
5	ca. 2	Plastic, dark gray silty clay. Flows readily. **Lacustrine deposit.**
4	ca. 9.2	**Upper diamict.** Abundant stones up to 1 m diameter in highly compact very dark grayish brown gritty silt. Near-horizontal shear planes and stone fabric. Strongly jointed, with yellowish red oxidation along joint planes. Grades upward into clayey silt with dispersed pebbles and cobbles. **Glaciolacustrine deposit above till.**
3	4.5	**Sand and gravel.** Rounded to subrounded pebbles, small cobbles, and sparse larger stones in matrix of poorly sorted,immature, medium to coarse sand. Some sand interbeds. Capped by 0.5 m dark gray silt above oxidized gravel with ice-wedge casts. Fine gravel, sand, silt, and peat fill channel-like surface depressions. **Alluvial and floodplain deposit.**
2	5+	**Lower diamict.** Dark, slightly bluish gray clayey silt, with dispersed clasts to medium cobble size and sparse larger stones. Lacks fabric. Base generally covered, but sticky, plastic, stone-free, silty clay exposed locally. **Glaciolacustrine deposit.**
1	2.2+	**Gravel, sand, silt, and peat.** Fine gravel grading upward into fine sand with detrital wood and into silt with peat. **Floodplain deposits with paleosol.**

Figure 59. Exposure Nk-29A. Southeast side Noatak River on west side of neck of Okak Bend, 21.5 km north-northwest of mouth of Cutler River. From Elias and others, 1999. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1). An additional radiocarbon age on the floodplain deposit in upper unit 3 (>46,400: AA20752) is not shown here.

cobbles, and sparse larger stones are dispersed in a dark, slightly bluish clayey silt. This unit is less compact than the upper diamict, and does not support vertical faces. Where exposed by trenching near the center of the bluff, the base of the lower diamict consists of a sticky, plastic, fissile, stone-free silty clay. Strong brown oxide concentrations occur along the fissile partings.

The overlying sand and gravel (unit 3) consists of rounded to subrounded pebbles, small cobbles, and sparse larger cobbles in a matrix of poorly sorted, angular, lithologically immature, medium to coarse sand. The gravel contains interbeds of sand and pebbly sand, and locally exhibits large-scale cross-bedding typical of bar foresets (G.M. Ashley, Rutgers University, oral commun., 7/27/83). The upper 75 cm of the gravel commonly is oxidized yellowish red (5YR 5/6), and is capped by 0.5 m of dark gray silt overlain by a thin (1-2 cm) black humic horizon. Ice-wedge casts up to 1.5 m wide and 3.2 m deep originate at the top of the gravel. Deformed peat within one ice-wedge cast has a non-finite radiocarbon age of >51,000 yr B.P.

Channel-like depressions up to about 1.5 m deep incised into gravel near the top of unit 3 are filled by sandy fine gravel, sand, silt, and peat. Slightly oxidized sand and fine gravel at the base of these deposits typically grades upward into peaty and silty floodplain deposits that commonly contain lenses of sandy fine gravel or pebbly silt. Shards of volcanic glass from the floodplain deposits have been identified as the ca. 140,000-year-old Old Crow tephra (Elias and others, 1999; Berger, 2003). Humic silt from a buried organic soil (Histosol) near the northeast end of the bluff has a radiocarbon age of $52{,}500^{+2{,}700}_{-2{,}000}$ yr B.P. This should be considered a minimum age limit on the paleosol. Black peat near the base of a channel filling near the center of the bluff contains pollen spectra and an insect fauna characteristic of a mesic tundra with woody shrubs (Elias and others, 1999).

The upper diamict (unit 4) contains abundant pebbles and cobbles, together with sparse boulders up to slightly more than 1 m diameter, in a matrix of extremely compact dark greyish brown sandy silt. This unit maintains nearly vertical, strongly jointed faces, with yellowish red oxidation along all joint planes. Sparse near-horizontal shear planes also are present, and platy stones generally parallel the fissility. The top of this unit is covered, but a test pit into the vegetated slope above its highest exposure uncovered a stony sandy silt that appeared identical to the upper diamict.

Exposure Nk-29B

The southeast-facing cutbank on the east side of the narrow neck of Okak Bend stands about 23 m high. It rounds back to an upland surface at about 29 m height that is identical to the 37-m surface measured at exposure Nk-29A. Although they are situated less than 0.5 km apart, the Noatak River between the two exposures flows 8 km around Okak Bend and declines about 6 m in altitude over this distance. The higher river surface at Nk-29B accounts for most of the discrepancy between the measured heights of the upland.

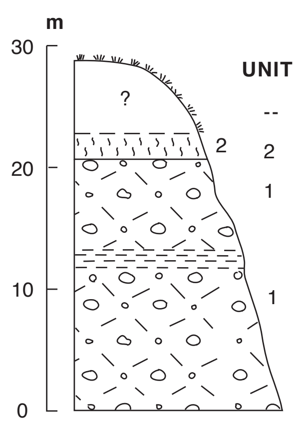
The face of Nk-29B lacks fresh exposures (fig. 60), but may contain the same sequence of diamicts and interstadial beds that is displayed at Nk-29A. Because of its proximity to that bluff face, the poorly exposed Nk-29B will not be discussed further.

Exposure Nk-30

An extensive bluff at the apex of Okak Bend is situated close to the inner flank of the Cutler River moraine (see fig. 54) and intersects a solifluction slope that extends southward from the moraine. The bluff face stands 41 m high, rounding back to a gently inclined upland surface at 48 m height. It exhibits two diamicts that are separated by alluvial sand and gravel and underlain by silt and clay (fig. 61).

Deposits beneath the lower diamict are poorly exposed. Dark gray silty clay (unit 1) is extruding plastically near the river's edge, and a trench near the downstream end of the bluff exposed 2.7 m of deformed, slightly oxidized silt and pebbly sandy silt that locally form discrete beds up to 30 cm thick. No organic matter was evident in any of these deposits.

The lower diamict (unit 2) is a very thick (21 m) deposit of probable till. It consists of dark gray, compact clayey silt with dispersed rounded to subrounded pebbles, small cobbles, and sparse larger stones. Black and green chert, dark green igneous rocks, and gray quartzite dominate the pebble fraction (appendix 2). This deposit is strongly jointed, and breaks down



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
--	9	**Covered.**
2	2	**Silt.** Poorly exposed gray silt. **Loess?**
1	21	**Diamict.** Striated stones up to >1 m diameter in black (5Y 2.5/2) sandy clayey silt. Compact and strongly jointed. Most platy stones have horizontal fabric. Contains poorly exposed layer of black humic silt. **Till with interstadial beds.**

Figure 60. Exposure Nk-29B. West side Noatak River on east side of neck of Okak Bend, 21 km north-northwest of mouth of Cutler River.

into angular fragments about 4 cm diameter. Oxide concentrations occur along some joint planes. Unit 2 also is cut by sets of subhorizontal shear planes that occur in zones 10-12 cm thick. Platy stones are aligned parallel to these shear planes.

The alluvium (unit 3) between the two diamicts consists of subrounded to subangular pebbles, small cobbles, and very sparse larger cobbles in a matrix of dark gray, poorly sorted, silty sand and granules. Black chert is abundant in the pebble range. The sand grains consist mainly of rock chips. Cross-bedded medium sand, silty fine sand, and pebbly fine sand occur as lenses 30-40 cm thick within the gravel, and cross-bedded sand, granules, and muddy small-pebble gravel occurs as a channel filling at least 1.3 m thick near the downriver end of the bluff. Unit 3 is capped by 75 cm of ripple cross-bedded, slightly oxidized, well sorted fine sand.

The upper diamict (unit 4), a probable glaciolacustrine deposit, has been entirely disturbed by flowage and no primary structures are present. Subangular to rounded pebbles, cobbles, and sparse boulders up to 1.5 m diameter, many faceted and striated, occur in a matrix of olive gray sandy silt. The boulders are predominantly igneous rocks, with quartzites also abundant (appendix 2). The top of this unit is not exposed.

Limited exposures above the upper diamict contain stone-free, loosely packed, yellowish brown silt that is interpreted as loess. It may be 4 m or more thick, but relations to units above and below are unclear.

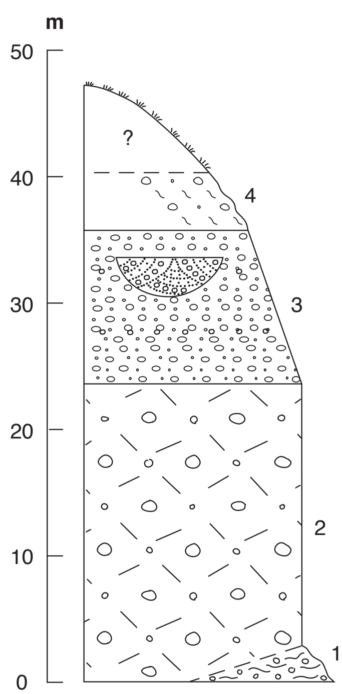
Exposure Nk-31

This southwest-facing river bluff occurs 1.5 km above Makpik Creek about where the Makpik moraine must formerly have intersected the center of the Noatak River valley (see fig. 54). The exposed face of the bluff is 27 m high, and meets the planar upper surface of a river-terrace remnant at a sharp angle. A single diamict occurs beneath alluvial sand and gravel that is capped by a probable floodplain complex (fig. 62*A*).

The base of the diamict is exposed only at the upstream end of the bluff, where it rises eastward from 1.5 m above river level to 1.9 m above the river and overlies a possible diapiric structure. The diamict is underlain here by strongly oxidized pebble gravel capped by 0.8 m of interbedded oxidized silt and fine sand. The upper 0.5 m of the silt-sand interbeds has especially strong oxide coloration (reddish brown; 5YR 3/2), and bedding is involuted through this interval. Detrital wood from bedding planes 5 cm above the base of the silt-sand unit has been identified as spruce (*Picea*; USDA-FPL, 10/93) and dated at >49,000 yr B.P.

The diamict (unit 1) consists of a dark gray clayey silt that contains dispersed, striated pebbles, cobbles, and some small boulders. It is moderately compact, but lacks fissility or stone fabric. Where exposed at the upstream end of the bluff, the basal 6 cm of the diamict is a gray, stone-free, slightly silty clay. The upper part of the diamict typically has a sandy silt matrix, and it tends to maintain steeper faces than the lower part of this deposit. Glaciolacustrine sediment may grade upward into basal till. The sharp and nearly horizontal upper contact of the diamict can be traced visually along the entire face of the bluff.

The overlying alluvium (unit 2) consists of sandy pebble-small-cobble gravel and pebbly sand that alternate in parallel beds about 30 cm thick. Both sand and pebbles are moderately mature, containing about 50 percent quartz. The basal 1.1 m of unit 2, at least locally, is a pebble gravel that consists dominantly



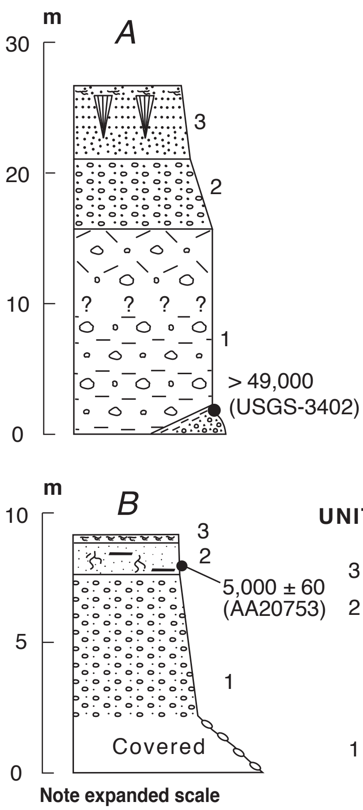
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
--	7	**Covered.** Includes at least 4 m of loosely packed, yellowish brown silt **Loess?**
4	4.5+	**Upper diamict.** Subangular to rounded pebbles, cobbles, and sparse boulders in matrix of olive gray sandy silt. Deformed by flowage. Top not exposed. **Glaciolacustrine deposit.**
3	12.5	**Sand and gravel.** Subrounded to subangular pebbles and small cobbles in matrix of dark gray silty sand and granules. Some beds of sand, pebbly sand, and muddy fine gravel. **Alluvium.**
2	21	**Lower diamict.** Dark gray, compact, clayey silt with dispersed rounded to subrounded, striated pebbles, small cobbles, and sparse larger stones. Strongly jointed, with oxides along some joint planes. Contains subhorizontal shear planes with aligned platy stones. **Till.**
1	2.7	**Silt and silty clay.** Highly deformed. Dark gray silty clay with rounded pebbles squeezing out along base of bluff; silt and pebbly sandy silt near downstream end of bluff. **Lacustrine or glaciolacustrine deposit.**

Figure 61. Exposure Nk-30. Northwest side Noatak River at apex of Okak Bend, 24 km north-northwest of mouth of Cutler River.

(60 percent) of subangular black chert. It contrasts with the subrounded pebble-small-cobble gravel deposited by the Noatak River, and may have been transported by Makpik Creek. The top of unit 2 interfingers with the base of the overlying sand unit.

The uppermost unit (unit 3) in the bluff is exposed only locally. It typically is a well sorted fine sand that is cut by ice wedges. Where exposed, the basal 1 m of this deposit is horizontally bedded gray to grayish brown fine sand and silty very fine sand that contains lenses of well washed medium sand up to 7 cm thick and also some thin beds of brown organic silt. Some beds exhibit internal sigmoidal cross-bedding. The upper part of the sand unit (up to 1.7 m exposed) consists of dark grayish brown (2.5Y 4/2), faintly bedded, fine sand, very fine sand, and organic fine sand. Strong brown (7.5YR 5/6) oxide concentrations occur along former vertical rootlets, and some actual rootlet remains also are present. Sod, peat, and humic sand cap the deposit, and the upper 0.6 m of the sand beneath this cap has been frost churned and oxidized to a strong brown (7.5YR 4/6) color.

A 9-m river terrace near the upstream end of exposure Nk-31 contains alluvial gravel capped by sandy floodplain deposits (fig. 62*B*). A small log identified as *Populus* (FPL, 11/17/95) within the floodplain deposits 47 cm above their base has been dated at 5,000 ±60 yr B.P.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	5.5	**Sand.** Well sorted fine sand with ice wedges. Medium sand lenses near base. Oxide concentrations along rootlets through upper 1.7 m. Frost churned beneath 0.6 m cap of peat and humic sand. **Floodplain and eolian(?) deposit.**
2	5.5	**Sand and gravel.** Pebble-small cobble gravel and pebbly sand in parallel beds 30 cm thick. Interfingering contact with overlying unit 3. **Alluvium.**
1	16.0	**Diamict.** Dark gray clayey silt with dispersed pebbles, cobbles, and some small boulders. Moderately compact, no obvious fissility or clast fabric. Thin layer of stone-free silty clay at base. **Till above glaciolacustrine deposit?**
0	<1.9	**Silt and fine gravel.** Oxidized silt and fine sand above oxidized pebble gravel. **Alluvium.**

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.2	**Sod mat.**
2	1.25	**Sand.** Brownish gray silty fine sand and colorless fine to medium sand, in subhorizontal beds 0.5-15 cm thick. Contains sparse detrital wood and willow(?) roots. Small *Populus* log occurs along bedding plane near unit base. **Alluvium.**
1	5.7+	**Gravel.** Subrounded to rounded pebbles and small cobbles in abundant sandy matrix. **Alluvium.**

Figure 62. Exposure Nk-31. North side Noatak River 1.5 km above Makpik Creek. (*A*) Bluff exposure. (*B*) River terrace immediately above bluff exposure. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure Nk-32

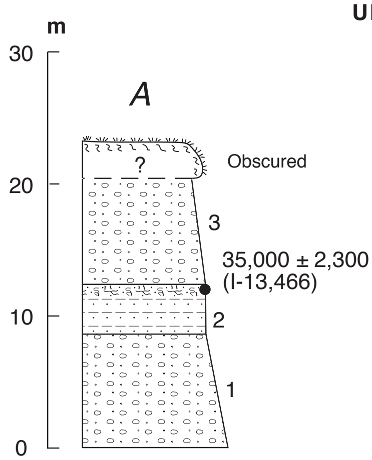
A north-facing river bluff 2.8 km downriver from the mouth of Makpik Creek was visited in 1983 and examined again in 1995. The bluff face is largely obscured by vegetation and debris. The bluff is highest (29.5 m) at its east end, where it intersects the inner flank of the Makpik Creek end moraine; it declines westward to form a 14-m alluvial terrace. The basal unit in the bluff, which generally is obscured by flowage, appears to be a glaciolacustrine deposit that consists of striated clasts dispersed in gray clayey silt. The clasts range in size up to small boulders, but pebbles and small to medium cobbles predominate.

A measured section in the east-central part of the bluff, where it stands 23 m high, consists of two alluvial gravel units separated by floodplain deposits (fig. 63*A*). The basal gravel (unit 1) consists of pebbles and sparse small cobbles in a matrix of poorly sorted sand and granules that are dominantly rock fragments. Overlying horizontally layered sand and silt (unit 2) is capped by black humic silt with abundant roots, which locally thickens to 0.6 m and becomes more peaty At that locality, the peat overlies 0.5 m of oxidized yellowish brown (10YR 5/8) medium sand with shrub roots. A radiocarbon age of 35,000 ± 2,300 yr B.P. on the paleosol could be finite, but the large counting error indicates that it may provide only a minimum limiting age on the deposit. The upper gravel (unit 3) contains somewhat coarser clasts in a matrix similar to that of unit 1. The uppermost 2.4 m of the section is obscured by slumping.

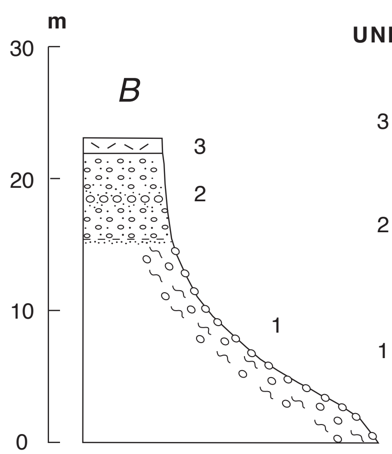
The bluff was revisited in 1995 in an attempt to collect additional organic samples for radiocarbon dating. However, erosional recession of its face by that time had exposed a glaciolacustrine deposit about 16 m thick which was actively flowing toward and into the river (fig. 63*B*). The only remaining undisturbed deposit was a 7-m section of gravel capped by floodplain deposits that formed the headwall of the debris flow. The gravel appeared identical to the alluvium of unit 3 that had been examined in 1983 (fig. 63*A*).

A 14-m terrace near the upstream end of the bluff consists of floodplain deposits and thick peat beds above alluvial sand and gravel. The floodplain deposits generally are sandy, with near-horizontal bedding, abundant rootlets, and locally thick peat deposits. An exposure close to Nk-32 intersects a deep channel eroded into the alluvium of unit 1 that later filled with peat and sand (fig. 64*A*). A thick bed of peat near the channel base formed between about 10.2 and 10.1 ka, and a silty peat higher in the section began forming about 9.6 ka. A short distance farther upstream, another terrace exposure yielded an age of 11,310 ± 85 yr B.P. near the base of floodplain deposits that overlie alluvial gravel and 4610 ±60 yr B.P. for the base of a 2-m peat unit that caps the section (fig. 64*B*).

A floodplain surface 4.5 m above river level at the downstream end of the bluff (fig. 64*C*) may be active only during times of infrequent severe flooding. The upper 1.9 m of exposed sediment consists of a thin cap of peat and sod above a floodplain sequence of oxidized fine sand and organic silty fine sand to sandy silt; some medium sand beds occur below 80 cm depth. The floodplain deposit contains abundant vertical stems and rootlets which, together with mosses, become concentrated into near-horizontal peat-like beds below 155 cm depth. Peaty material from 155 cm depth has a radiocarbon age of 930 ±60 B.P.

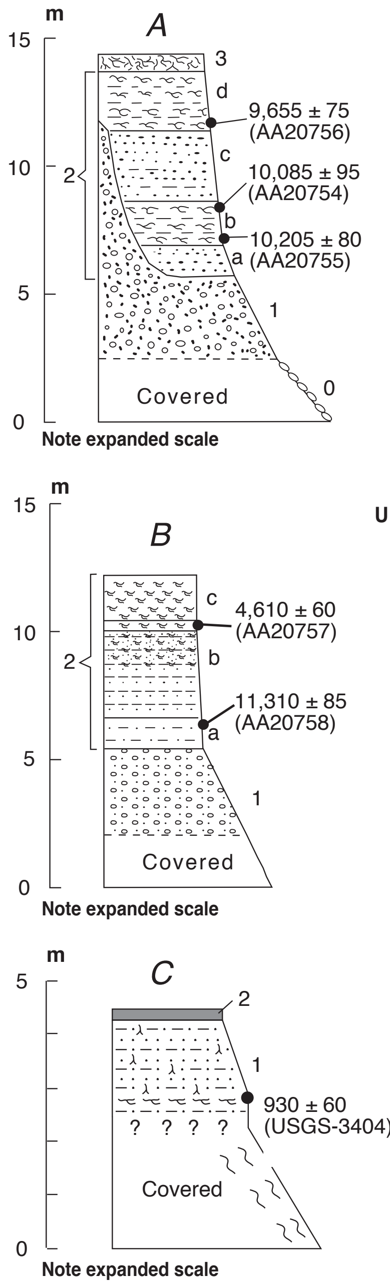


UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	8.0	**Gravel.** Weakly stratified pebbles and cobbles in matrix of poorly sorted sand and granules. **Alluvium.**
2	3.7	**Sand and silt.** Dark gray silt, fine sand, and some medium sand in near-horizontal layers 1-8 cm thick. Capped by paleosol up to 1.1 m thick that consists of peat, humic silt, and oxidized sand with abundant shrub roots. **Floodplain deposit.**
1	8.8	**Gravel.** Rounded pebbles and some small cobbles in matrix of poorly sorted, dark gray, immature sand and granules. **Alluvium.**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	0.75	**Bluff cap.** Sod (12 m) above structureless silt (38 m). Basal 25 cm is oxidized (yellowish) structureless medium sand with vertical pebbles.
2	6.3	**Gravel.** Pebble-small-cobble gravel, with layer of larger cobbles near center. Upper 30 cm is pebble gravel with admixed silt and vertical stones. Sand beds at base. **Alluvium.**
1	16	**Stony silt.** Rounded to subrounded pebbles, small cobbles, and sparse larger cobbles, many striated, in matrix of dark gray (10YR 1/4) silt. **Glaciolacustrine deposit.**

Figure 63. Exposure Nk-32. South side Noatak River 2.8 km below Makpik Creek. (*A*) Section measured in 1983 at east-central part of bluff. (*B*) Section measured in same general area during revisit in 1995. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT		THICKNESS (m)	DESCRIPTION and INTERPRETATION
3		0.6	**Bluff cap.** Modern vegetation mat above densely matted plant roots.
2			**Channel fill.**
	d	2.5	**Peat and silt.** Black peat and very dark gray organic silt containing abundant rootlets. Rooted shrubs common.
	c	2.8	**Sand.** Subhorizontally bedded fine to medium sand, generally oxidized (as in unit 2). Lenses of fine organic detritus along some bedding planes.
	b	1.7	**Peat and silt.** Black peat and very dark gray (N3) organic silt in weakly defined beds up to 15 cm thick. Abundant small (<1 cm diameter) twigs and roots.
	a	1.2	**Sand.** Oxidized (reddish yellow: 7.5 YR 6/6) and gray (N5) fine sand and some medium sand in subhorizontal beds 1-5 cm thick.
1		3.3+	**Gravel.** Rounded to subrounded pebbles and granules in beds 4-6 cm thick. Foreset beds dip westward. Base not exposed. **Alluvium.**
0		2.4	**Lag deposit.** Along river edge.

UNIT		THICKNESS (m)	DESCRIPTION and INTERPRETATION
2			**Floodplain complex.**
	c	1.9	**Peat.** Matted grasses and sedges with abundant wood fragments.
	b	3.8	**Peaty silt and sand.** Bedded silt and fine to medium sand with bryophytic peat interbeds that become thicker and more woody upward.
	a	1.1	**Sand.** Faintly bedded fine sand with some medium sand and silt beds. Coarser beds are weakly oxidized. Some cryoturbation. Upper 25 cm contains root mottles.
1		3.3+	**Gravel.** Rounded pebbles, granules, and sparse very small cobbles. Finer and coarser clasts alternate in beds 5-10 cm thick. Tangential cross-bedding. Base concealed beneath lag apron. **Alluvium.**

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	0.1	**Peat and sod. Bluff cap.**
1	1.8+	**Sand and silt.** Oxidized fine sand and organic silty fine sand to sandy silt; interbedded. Abundant vertical stems and rootlets, concentrated into peatlike beds at depth. Base not exposed. **Floodplain deposit.**

Figure 64. Terrace exposures adjoining Nk-32. (*A*) Deep bog exposed on face of 14.5-m terrace just upstream from Nk-32. (*B*) Terrace face about 150 m upstream from Nk-32. (*C*) Face of 4.5-m inactive(?) floodplain surface just beyond west end of Nk-32. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure Nk-33

A north-facing cutbank 7 km east-southeast of the mouth of Anisak River intersects the 14-m alluvial terrace where it is inset within the inner flank of the Makpik Creek moraine (see fig. 54). The terrace is 14 m high near the center of the exposure, but rises slightly upriver and may stand 15 m high at its eastern end. Most of the terrace face exposes only alluvial gravel overlain by floodplain deposits (fig. 65). However, a plastic stony gray clay locally is extruded from below river level along the base of the bluff. Abundant striated stones indicate that the clay probably is a glaciolacustrine deposit.

Alluvial gravel (unit 1) consists generally of rounded pebbles and small cobbles in parallel beds 10-30 cm thick. The thicker beds have a matrix of uncolored, poorly sorted silty sand and granules; the thinner beds commonly are openwork, with partial filling by sandy silt. Near its upper contact, unit 1 contains some beds 10-20 cm thick of matrix-free, silty pea gravel and gray fine sand interbedded with silty very fine sand.

The floodplain deposits (unit 2) dominantly are well sorted, olive gray (5Y 5/2) very fine sand. Beds of medium sand and pebbly sand 1-5 cm thick occur near base of the floodplain sequence, and beds of dark gray organic silty fine sand 0.5-1 cm thick are common near its top. Vertical rootlets are common. Peat lenses and detrital twigs 50 cm above the base of the unit are dated at 12,890 ±190 and 13,620 ±95 yr B.P., respectively. The upper 0.5-1 m of the sandy unit is mottled brownish yellow (10YR 6/8) to olive brown (2.5Y 4/4) by oxides.

The bluff is capped by about 1 m of sod, black to very dark brown peat, very dark gray silt and very fine sand that thickens to as much as 3 m in depressions within the underlying sand. Peat from the base of a 3-m depression filling dates 12,970 ±280 yr B.P.

Exposure Nk-34

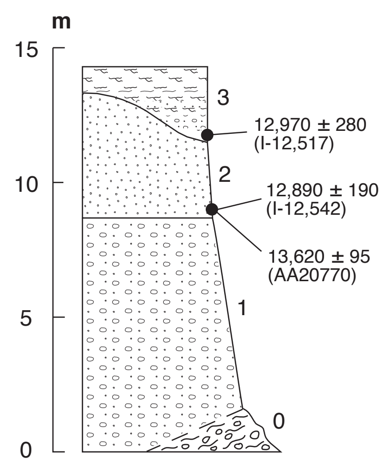
A short distance (1.5 km) below the mouth of Anisak River, a prominent bluff along the north side of the Noatak River marks the outer limit of the Anisak moraine (see fig. 54). River bars and channel margins here contain abundant boulders up to 1 m long (50-75 cm intermediate diameter). The bluff face stands about 55 m high, but the upper surface of the bluff rises inland at a gentler angle into a complex of gravel knolls and terracelike benches as much as 77 m above the river (fig. 66).

The bluff face is heavily vegetated, with exposures limited to recently active flows of diamict (unit 1). Subangular to rounded, commonly striated, pebbles, cobbles, and small boulders (up to 70 cm intermediate diameter) occur in a matrix of slightly sticky, dark gray (5Y 4/1), gritty, slightly clayey silt. Pebble lithologies are dominantly black chert, with igneous rocks and quartzites also common (appendix 2). The diamict probably is a proximal glaciolacustrine deposit.

The gravel knolls and benches are underlain by rounded to subrounded pebbles up to about 7 cm in an oxidized matrix of dark yellowish brown (10YR 4/6) silty sand. They may have been formed by meltwater flowing along the north margin of the glacier tongue.

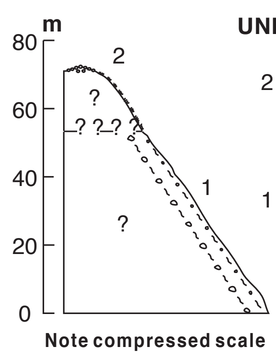
Exposure Nk-35

A complex exposure on the south side of the Noatak River 4 km below the mouth of Anisak River is situated within the Anisak moraine about 1.5 km from its outer limit (see fig. 54). Lag boulders along the river edge at this locality include several lithologies that are rare or absent upriver. These include graywackes, conglomerates, chert breccias, fossiliferous limestone, siltstone, and slate. Exposure Nk-35 has two separate components (figs. 54*A* and 54*B*) which are separated by a kettle depression that has been breached by the river. The northwestern section (bluff *A*) highest and most complex, but its face is



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	1-3	**Peat.** Black sedge-grass peat with sparse interbeds of silt, sand, and sandy fine gravel. **Depression filling.**
2	4.5-2	**Sand.** Olive gray (5Y 5/2) very fine sand with interbeds of dark gray, organic, silty fine sand. Upper 0.5-1 m oxidized olive brown (2.5Y 44). **Floodplain deposit.**
1	8.8-7.3	**Gravel.** Rounded pebbles, small cobbles, and sparse larger cobbles in variable matrix (sandy silt to poorly sorted silty sand and granules). Some thin lenses of fine to medium sand near top. **Alluvium.**
0	1-1.5	**Stony clay.** Dark gray, plastic clay with abundant striated stones. Extruded locally along base of bluff. **Glaciolacustrine.**

Figure 65. Exposure Nk-33. Postglacial terrace, south side Noatak River 7 km east-southeast of mouth of Anisak River. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	?	**Fine gravel.** Pebbles in matrix of dark yellowish brown (10YR 4/6) silty sand. Exposed on crests of knobs and terrace-like benches. **Ice-contact deposit?**
1	54+	**Diamict.** Subangular to rounded, commonly striated, pebbles, cobbles, and small boulders in matrix of dark gray (5Y 4/1) clayey sandy silt. Exposed only in debris flows. **Glaciolacustrine deposit?**

Figure 66. Exposure Nk-34. North side Noatak River 1.5 km below mouth of Anisak River.

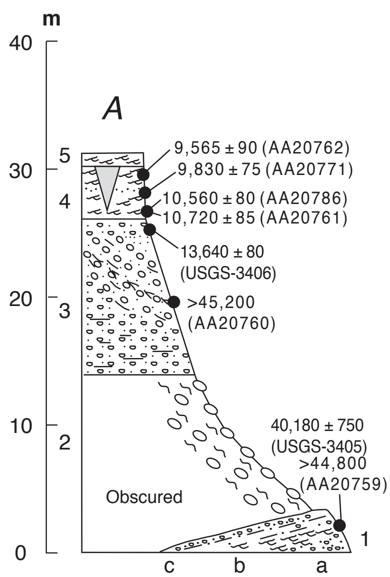
partly obscured by slumps and debris flows. The southeastern section (bluff *B*) is lower and is dominantly alluvium.

Bluff *A* stands as much as 32 m high. It exposes a diamict and alluvium, with organic-rich floodplain deposits at its base and crest (fig. 67*A*). A basal deposit that includes organic silt to silty fine sand and peat (unit 1) is exposed only in small diapiric extrusions that have been elevated to 3.6-1.6 m above river level at the extreme northwest end of the bluff. The organic deposits are underlain by alluvial sand and gravel, which extends below river level. Peat 55 cm above the base of the silt unit was initially dated at 40,180 ±750 yr B.P., but a later accelerator mass spectrometer (AMS) age of >44,800 yr B.P. on wood fragments is considered more reliable.

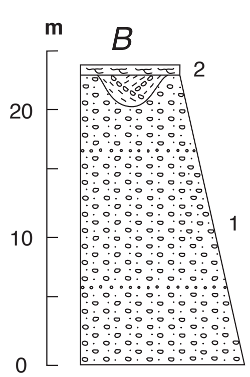
The lower part of bluff *A* generally is obscured by a debris apron 6.5 m or more thick. The lowest deposit exposed above the debris apron is very sandy pebble-small- cobble gravel (upper part of unit 1). The overlying diamict (unit 2) consists of pebbles and granules dispersed in a matrix of very dark gray silty clay. Partings define near-horizontal beds 5-8 cm thick. A thin (0.8 m) horizon of rhythmically laminated dark gray clay and dark greenish gray silt occurs at the base of the diamict. Some bedding planes within the rhythmites contain trace fossils (lebensspuren).

Sandy pebble-small-cobble gravel and medium sand with dispersed small pebbles (unit 3), which overlie the diamict, alternate in subparallel, horizontal to gently dipping beds 5-20 cm thick. Some thin beds of openwork small pebbles with silt coatings are present locally. Steeply dipping deformed beds at one locality reflect collapse into a steep-sided depression that probably resulted from meltout of a mass of residual glacier ice. Wood fragments near the base of this kettle fill are dated as >45,200 yr B.P.; they probably were redeposited from older sediments. Where exposed by excavating, the uppermost part of unit 3 consists of at least 1.6 m of silty very fine sand and oxidized (yellowish red: 5YR 5/6) fine sand. The sand is faintly laminated, with bryophyte mats along some bedding planes. A bryophyte mat 1.4 m below the upper contact of unit 3 has a radiocarbon age of 13,640 ±80 yr B.P.

The upper part of bluff *A* has been largely obscured by thawing of ice wedges and slumping of large blocks of coherent peat from the bluff crest, but several exposures show a thick (4-5 m) accumulation of peat and organic silt (unit 4). Radiocarbon ages range from about 10.7 ka near its base to 9.6 ka near its upper surface. The lower part of unit 4 contains lenses of silt, sand, and granule-small-pebble gravel, and probably accumulated on a floodplain.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	0.9	**Sod.** Overlies brown silt with rootlets. **Bluff cap.**
4	3.7	**Peat and organic silt.** Very dark gray organic silt and black silty peat, in beds 5-40 cm thick, with ice wedges. Abundant wood fragments up to 3-4 cm diameter in peat beds. Basal 24 cm contains vertical stones elevated from underlying gravel. **Floodplain deposit.**
3	12.2	**Gravel .** Subrounded to rounded clasts in poorly sorted sand-granule matrix. Generally in subparallel, near-horizontal beds 5-20 cm thick, but collapse structures also present. **Ice-contace alluvium.**
2	12.6	**Diamict.** Dark gray gritty clayey silt with abundant striated and faceted pebbles, small cobbles, and sparse larger clasts. Severely deformed by flowage. **Glaciolacustrine deposit.**
1 c	0.9	**Sand and gravel.** Sandy pebble-small-cobble gravel. Grades upward into gray, well sorted, faintly bedded fine sand. **Alluvium.**
b	1.6	**Organic silt.** Organic matter, including rootlets, abundant near top and base. Middle 0.6 m less organic, with well sorted fine sand interbeds. **Floodplain deposit.**
a	0.7+	**Gravel and sand.** Sandy granule-small pebble gravel, overlain by interbedded fine to medium sand and silty fine sand. Base covered. **Channel filling?**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	0.7	**Sandy sod, pebbly silt and sod, and sandy peat.** Rootlets abundant. **Bluff cap.**
1	23	**Gravel.** Rounded to subrounded pebbles and cobbles in matrix of dark gray, poorly sorted, silty sand and granules. Sparse beds of medium sand to silty fine sand. **Alluvium.**

Figure 67. Exposure Nk-35. South side Noatak River 4 km below mouth of Anisak River. (*A*) Measured section at downstream end of exposure. (*B*) Measured section at upstream (southeast) part of bluff. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

The southeast part of the bluff complex (bluff B) stands 24 m high and consists almost entirely of alluvium (fig. 67*B*). Rounded to subrounded pebbles and cobbles up to about 20 cm long occur in a matrix of dark gray (10YR 4/1), poorly sorted silty sand and granules. The matrix material is angular to subangular, and consists mostly of rock chips. Some thin (5-15 cm) sets of medium sand to silty fine sand are present within the gravel. Steeply dipping beds of silt, pebbly silt and sand, and granule-small-pebble gravel fill a steep-sided depression in the gravel surface. The steepness and poor sorting of the beds suggest that deposition could have been contemporaneous with meltout of underlying glacier ice. Bluff B is capped by about 70 cm of sandy sod above silt, sand, and sandy peat. The alluvium of bluff B is highly deformed at its east end, where beds drape over and become nearly vertical. The gravel also may have been collapsing above melting glacier ice at this locality.

A low terrace just east of bluff B stands 6.4 m above river level. An erosion remnant of diamict forms a resistant bench up to 2 m thick at the base of the terrace face. The diamict consists of striated pebbles, small cobbles, and sparse larger clasts dispersed in a matrix of gray gritty silt. It is overlain by 3.4 m of pebble-small-cobble gravel which is capped by 0.6 m of silt and fine sand.

Exposure Nk-36

About 5.5 km downvalley from the outer limit of the Anisak drift belt, a steep-sided (18°), narrow-crested (2-5 m) moraine ridge intersects the line of bluffs north of the Noatak River. A debris flow on the bluff face at this site is 0.5 km distant from the Noatak River at the north edge of its floodplain (see fig. 54). The bluff rises 46.5 m above the floodplain at the flow locality, and the debris flow exposes only diamict throughout this interval (fig. 68). Clasts in the flow deposit are rounded to subangular, and commonly striated; matrix is very dark gray, gritty, slightly clayey silt. Pebbles and cobbles are abundant, very small boulders (30-50 cm diameter) are moderately common, and larger boulders up to 1.4 m diameter are sparse. The boulders dominately are coarse-grained igneous rocks, gray quartzites, and carbonate rocks; pebbles primarily are coarse-grained and aphanatic igneous rocks, chert, and quartz (appendix 2). The diamict probably was orginally a till rather than a glaciolacustrine deposit because (1) it occurs in the core of a moraine, (2) its matrix has more sand and less clay than in typical glaciolacustrine deposits of the upper Noatak basin, (3) boulders are as large as 1.4 m diameter, and (4) clast abundance shows a smooth decrease with increasing size through the cobble and boulder range.

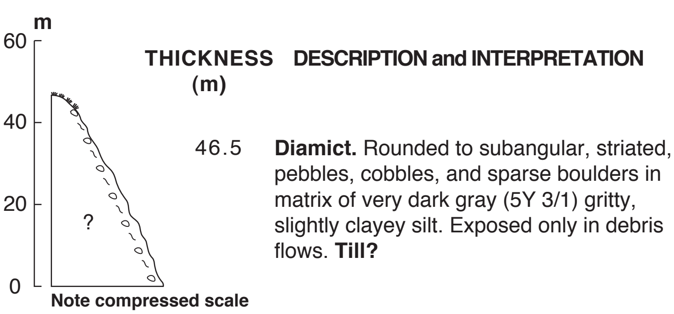


Figure 68. Exposure Nk-36. North side Noatak River 7 km downvalley from mouth of Anisak River.

Exposure Nk-37

A south-facing bluff that stands as high as 57 m begins 12.5 km downvalley from the mouth of Anisak River and extends for more than a kilometer farther west along the Noatak River. An apparent recessional moraine of the Anisak drift complex crosses the valley center here (see fig. 54), and the Noatak is deflected strongly northward into the glacial deposits that comprise the northern flank of its valley. The bluff exposes a complex glacial, fluvial, and lacustrine record that may span three separate glacial advances (fig. 69*A*; Hamilton, 2001; Edwards and others, 2003). The eastern part of the exposure contains two diamicts overlain by a thick sequence of lacustrine sediments. The western part contains a higher-standing pair of diamicts overlain by a thinner cover of silt and peat. The central part of the bluff, which is mostly concealed by massive slumps and flows, contains a wedge-like sediment complex that tapers westward and probably formed as a debris apron at the face of an ancient river-cut bluff.

Through the eastern one-third of the bluff, two diamicts are underlain and separated by alluvial gravel and are capped by a thick but largely concealed sequence of probable lacustrine sediments (fig. 69*B*). The gravel at the base of the section is divisible into two units that differ markedly in oxidation and probably are separated by a significant time interval. The lowest gravel (unit 1), which is exposed only in the extreme eastern and east-central parts of the bluff, is cemented strongly by iron oxides and stands in vertical faces. Rounded to subrounded pebbles and some small cobbles occur in a brownish yellow (10YR 6/8) sandy matrix. The deposit contains some thin sand lenses, and locally is capped by horizontally bedded, strongly oxidized (strong brown: 7.5YR 5/6) medium sand. Near the central part of the bluff, the gravel contains detrital logs up to about 18 cm diameter of spruce or larch (*Picea* or *Larix*; USDA-FPL, 10/93).

The overlying gravel (unit 2) consists of imbricated pebbles, small cobbles, and some larger cobbles in a sandy matrix. Some beds of silt, sand, and sandy fine gravel also are present. Yellowish brown (10YR 5/8) oxide-stained quartz is abundant (30-40percent) in the pebble fraction, and dominates the sand fraction. Sparse detrital wood fragments include spruce or larch (*Picea* or *Larix*; USDA-FPL, 11/83) and have a non-finite age of >46,000 yr B.P. The basal contact locally is a stone line of large cobbles and very small boulders.

The lower diamict (unit 3), a probable till, consists of striated pebbles, small cobbles, and sparse larger stones dispersed in a matrix of dark gray, indurated sandy silt to silty sand. This unit stands in vertical faces, with prominent jointing parallel to the bluff face. Strong brown to dark brown oxides (10YR 5/6 to 3/2) are concentrated along joint planes and on stone surfaces. The diamict has a sharp basal contact, which lacks the laminated clayey layer that commonly occurs at the base of glaciolacustrine diamicts in the upper Noatak basin.

The gravel between the diamicts (unit 4) commonly consists of subrounded pebbles and some small cobbles that transition upward into the overlying diamict through a 70-cm zone of compact gravel with a silty matrix in which many stones are inclined. Elsewhere in the bluff, the gravel consists of rounded pebbles, small cobbles, and some medium cobbles in a matrix of dark gray, poorly sorted sand and granules. It commonly is oxidized to a depth of 20 cm, and locally is capped by 20 cm of black, highly compact stony peat with some flattened wood fragments. The wood has been identified as spruce or larch (*Picea* or *Larix*; USDA-FPL, 11/83), and was originally dated at 36,610 ± 400 yr B.P. (USGS-3287). On a later visit, separate samples of detrital wood and peat were taken from this horizon and submitted for AMS radiocarbon dating. Both samples yielded non-finite ages greater than about 48,500 yr B.P.

The upper diamict (unit 5) consists of striated pebbles, cobbles, and sparse small boulders dispersed in gray, sandy, slightly clayey silt. This deposit is very compact and stands in vertical faces. It locally is oxidized strong yellowish red by ground-water seepage.

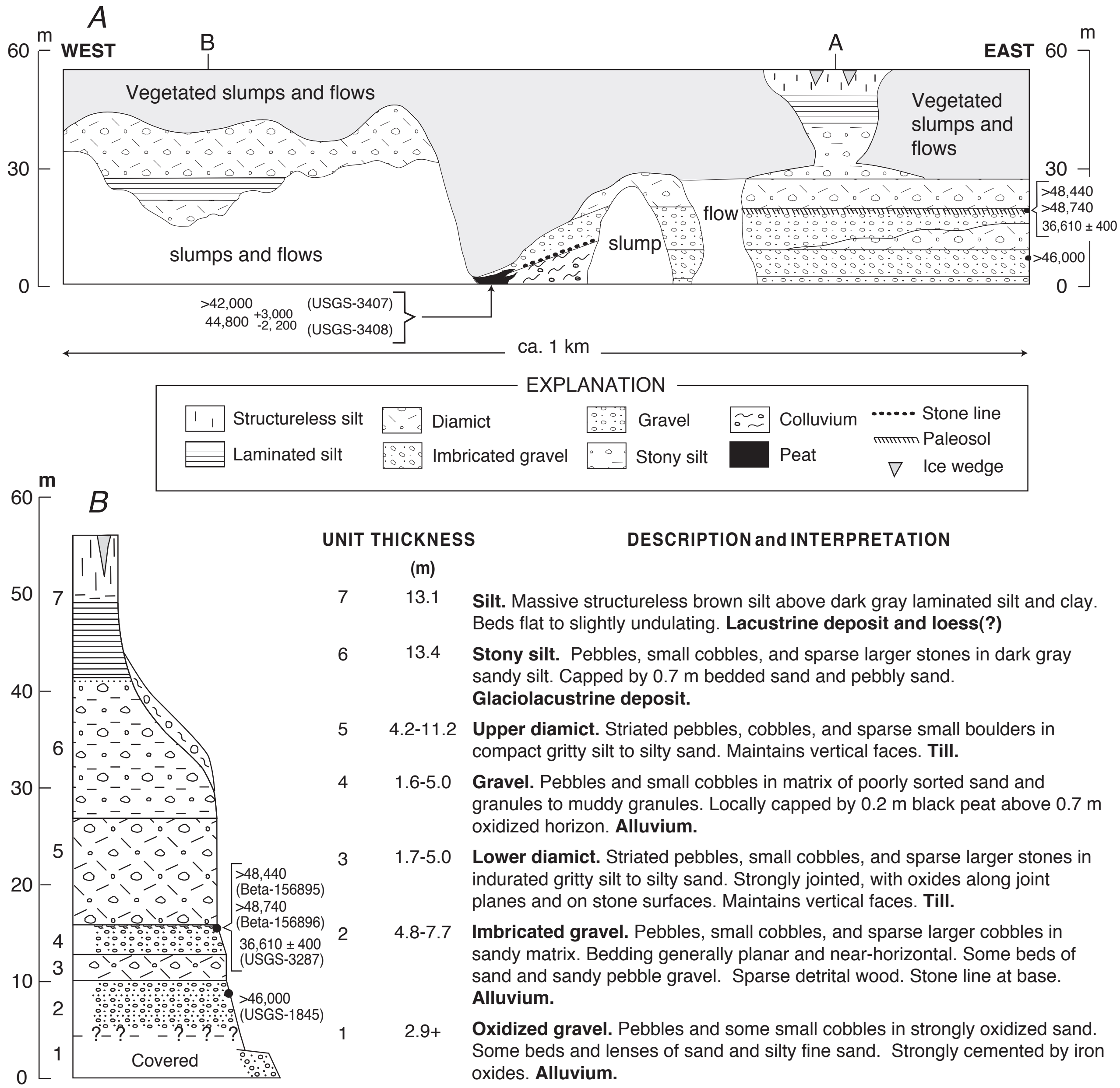


Figure 69. Exposure Nk-37. North side Noatak River 12 km west-northwest of Anisak River. (*A*) Stratigraphic relations in bluff face (from a field sketch). From Edwards and others, 2003, fig. 3. (*B*) Measured section A, with radiocarbon ages, eastern part of bluff. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Silty sediments above the upper diamict generally are displaced by flowage and slumping and further obscured by revegetation of the disturbed surfaces. Rare exposures show about 10-14 m of stony silt overlain by a nearly equal thickness of stone-free silt and clay. The dark gray stony silt (unit 6) contains clasts up to 40-50 cm diameter and is capped by a thin (0.7 m) deposit of fine alluvium. The overlying laminated dark gray silt and clay (unit 7) is capped by brown to gray loess-like silt that contains abundant ice wedges.

Much of the western part of the bluff is obscured by slumps and flows, but limited exposures exhibit two thick (11-24 m) diamicts separated by glaciolacustrine deposits (fig. 69*C*). The lower diamict (unit 1) contains striated clasts to small boulder size dispersed in a matrix of very dark grayish brown sandy silt. This deposit is strongly jointed, with dark grayish brown oxides concentrated along joint planes. Overlying silt and fine sand (unit 2) is rhythmically laminated in places, but elsewhere contains diamicts and turbidite layers. It appears to be entirely inorganic, and may represent a brief glacial fluctuation with the ice front remaining within the upper Noatak basin. The upper diamict (unit 3) is disturbed by flowage in all exposures. Clasts similar to those of the lower diamict occur in a matrix of dark gray clayey silt to very sandy silt. Slumped and vegetated deposits above the upper diamict appear to be largely stone-free silt and peat. These deposits rise to an upper surface that is accordant with the crests of slump headwalls along the eastern part of the bluff.

The upper part of the central segment of the bluff has been destroyed entirely by flowage, but a wedge of highly indurated gravel provides near-vertical basal exposures about 5-10 m high (fig. 69*D*). The sediment wedge is thickest to the east; it tapers westward and incorporates increasing amounts

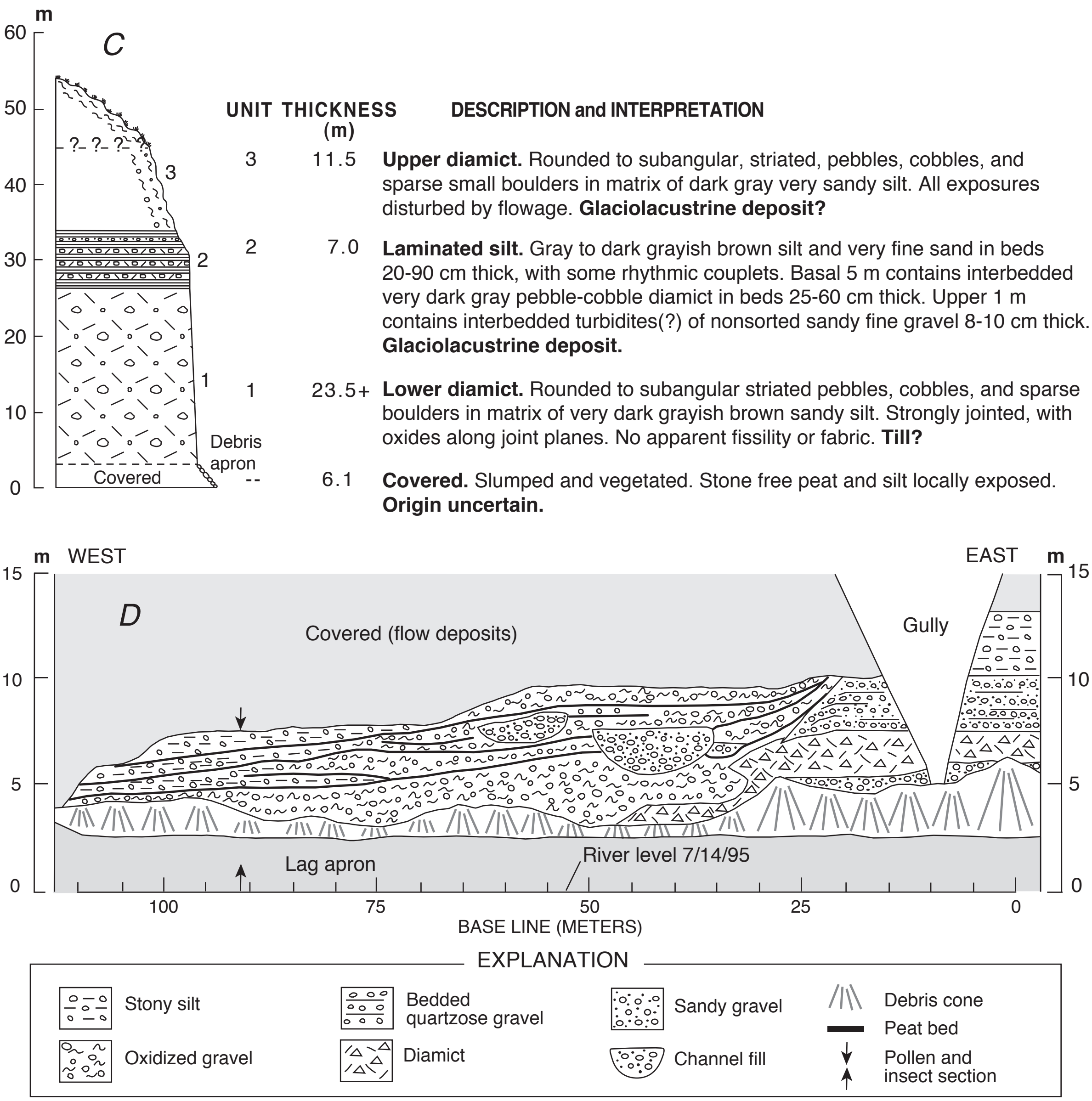


Figure 69. Exposure Nk-37 (continued). (*C*) Measured section B, western part of bluff.(*D*) Detail of debris wedge near river level in central part of bluff. From Edwards and others, 2003.

of fine-grained and organic deposits in that direction. Oxidized gravel and diamict, which are identical to units 2 and 3 farther east in the bluff (fig. 69*B*), occur locally beneath the sediment wedge. The thickest part of the wedge consists of subangular to subrounded pebbles, cobbles, and very small boulders in beds up to 1 m thick that are separated by thinner (5-10 cm) undulating beds of stony sand, pebbly silty sand, and organic silt. The gravel layers are matrix-free in some places, and elsewhere have a compact silty sand matrix. The upper 4-4.5 m of the gravel is oxidized reddish yellow (5YR 6/8). This unit appears to be a slightly deformed and mixed variant of the imbricated gravel which occurs through the eastern part of the bluff. The gravel interfingers westward with unsorted to weakly sorted, subrounded, commonly fractured pebbles and cobbles in an oxidized and indurated sandy to silty matrix. Lenses of pebbles, silt, and peat within the deposit dip westward at 7-10°. This unit thins to the west, where it interfingers with peat and organic silt. Except for the absence of boulders, this unit resembles deposits that form along the base of this bluff today. Peat and organic silt overlie and interfinger with gravel through much of the colluvial wedge, but generally thicken toward its distal (west) end where woody peat in beds 10-15 cm thick is interbedded with thicker (10-50 cm) beds of stony sand and oxidized pebble-cobble gravel. The peat contains logs up to 10 cm diameter of spruce or larch (*Picea* or *Larix*; USDA-FPL, 11/83) that yield three erratic radiocarbon ages (appendix 1), but probably are non-finite (>42,000 yr B.P.). Pollen and insect records from the peat beds provide supporting evidence for an interglacial spruce forest (Edwards and others, 2003). Strongly jointed dark gray silt with pebble dropstones overlies the peat in one locality. Sediments overlying the colluvial wedge generally are obscured by flowage, but alluvial gravel with a stone line at its base appears to overlap the eastern part of the wedge. Diamict overlies stony silt above the toe of the wedge, but this deposit could be a flow lobe.

Exposure Nk-38

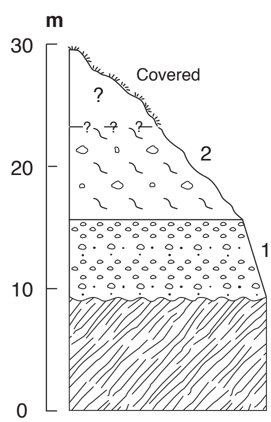
Near the mouth of Itimtikrak Creek, the Noatak River enters an unusually straight reach about 9 km long in which bedrock commonly is exposed near river level. At the east end of this reach, a south-facing river cutbank (fig. 70) stands 23 m high and rounds back to an undulating upland surface at about 40 m height.

Schist and quartzite bedrock at the base of the exposure stands about 10 m high and is overlain by alluvial gravel (unit 1). The gravel consists of alternating coarser and finer beds 10-20 cm thick. The coarser beds have a matrix of poorly sorted very dark gray sand; the finer beds lack any matrix. The upper 6 cm of the deposit are oxidized yellowish brown.

Overlying diamict (unit 2) has been modified by slumping and flowage. Striated and faceted clasts up to 65 cm long occur in a matrix of dark gray sandy, slightly clayey silt. The upper part of this unit is entirely vegetated, and any overlying deposits are not visible.

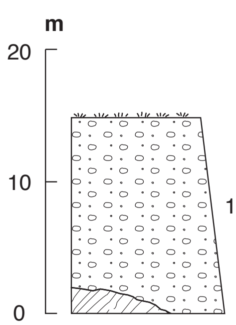
Exposure Nk-39

Near the mouth of Nimiuktuk River, a south-facing gravel cutbank (fig. 71) forms part of a 15-m terrace remnant with a near-level, poorly drained upper surface. Pebbles and



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	7.8+	**Diamict.** Rounded to subrounded pebbles, cobbles, and small boulders in matrix of dark gray, sandy, slightly clayey silt. Severely disturbed by slump and flowage. Top not exposed. **Glaciolacustrine deposit?**
1	6.2	**Gravel.** Coarse and fine gravel in beds 10-20 cm thick. Coarse beds are rounded pebbles and small cobbles in matrix of very dark gray poorly sorted sand. Fine beds are rounded small pebbles and granules without matrix. Stones in some beds are silt-coated. Upper 6 cm oxidized yellowish brown (10YR 4/4). **Alluvium.**
--	9.6	**Bedrock.** Schist and quartzite.

Figure 70. Exposure Nk-38. North side Noatak River 16.5 km west-northwest of Aniuk River.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	15-13	**Gravel.** Sandy pebble-small-cobble gravel with dispersed pyroxenite erratics up to 57 cm diameter. Probably capped by silt. **Alluvium.**
--	0-2	**Bedrock.** Intermittently exposed near river level.

Figure 71. Exposure Nk-39. North side Noatak River 1.5 km above mouth of Nimiuktuk River.

small cobbles dominantly consist of ferruginous sandstone; the dispersed larger stones primarily are pyroxenite. Because clast size and composition are similar to local river gravels, the deposit is interpreted to be a river deposit formed during postglacial downcutting. The larger stones were redeposited from local glacial sediments that were eroded by the downcutting river.

The height of the deposit is comparable to that of other local and regional 15-m terraces mapped previously as unit tg4 by Hamilton (2003).

Discussion

Direct correlation of stratigraphic units in the set of river bluffs between Cutler and Nimiuktuk Rivers is complicated by (1) facies changes related to former glacier terminal positions along the valley axis, (2) lateral facies changes between valley center and valley margins, (3) localized downcutting by the Noatak River during interglacial and interstadial phases, (4) glacial tectonism where grounded ice tongues advanced over deformable beds, (5) sediment input via major tributaries, and (6) recycling of older glacial, alluvial, and lacustrine sediments by advancing glaciers and the Noatak River. Assignment of bluff units to individual glacial advances and glacial-lake stages was attempted in a previous paper (Hamilton, 2001) and general relations are shown in figure 54.

Many of the higher bluff exposures contain glacial till and ice-contact gravel, glaciolacustrine sediments, and ancient river gravels. The till and glaciolacustrine deposits were differentiated by using the criteria listed in table 2. The alluvial gravel deposits generally are similar in clast size and composition to channel alluvium of the present-day Noatak River. They commonly fill channel-like or larger depressions that were deeply eroded following deglaciation and drainage of ice-dammed lakes. Probable interglacial deposition of the gravel is further indicated by (1) river downcutting close to modern level, (2) deep oxidation, (3) presence of conifer wood, (4) gravel clast size comparable to Holocene alluvium of the Noatak River, and (5) insect assemblages and pollen spectra reflecting climates comparable to or warmer than that of the present day (Elias and others, 1999; Edwards and others, 2003).

The Old Crow tephra, which formed during an early phase of the last interglaciation (Hamilton and Brigham-Grette, 1992) has been identified within floodplain deposits in Nk-26 and Nk-29A (Elias and others, 1999). Exposure Nk-26 exhibits dominantly glaciolacustrine deposits that formed in a succession of lakes that were dammed by glacial advances farther down the Noatak River valley. This bluff contains a thick glaciolacustrine deposit (unit 6; fig. 56*A*) that corresponds in height and in thickness to glaciolacustrine beds exposed at Nk-27. Exposure Nk-29A intersects a deeply buried end moraine (not shown in fig. 54) that separates the two arms of Okak Bend (Hamilton, 2001). The till assignable to that end moraine occurs between successions of river gravel and glaciolacustrine deposits.

Exposure Nk-30 is farther from the axis of the late Pleistocene Noatak valley than exposures Nk-26 through Nk-29, and consequently may differ stratigraphically from those bluffs because of its valley-side location. It also stands higher, hence has a probable subaerial capping deposit whereas alluvial or lacustrine sediments cap lower-standing bluffs. This exposure is near the toe of a conspicuous solifluction slope that extends southward from the moraine flank. Solifluction debris probably is a significant component of late Holocene deposits at this locality, and sediments derived from the valley sides may be included within older deposits as well.

At exposures Nk-31 and Nk-32, river gravel and floodplain deposits associated with an alluvial terrace about 23-26 m high unconformably overlie older till, lake sediments, and alluvium. Farther downvalley at Nk-35B, an alluvial terrace stands at a corresponding height (23 m). The nearby exposure Nk-35A forms a conspicuously higher 30-m terrace that is dated by a concordant set of four radiocarbon ages as forming between 13.6 ka and 9.5 ka. The early postglacial terraces at heights of 20-30 m provide a good analogue for the tephra-bearing floodplain deposits that stand about 20 m high at Nk-26 and Nk-29A. Those features probably formed early in the last interglacial interval based on pollen spectra and insect fauna (Elias and others, 1999) and on independent age assignments for the Old Crow tephra by Hamilton and Brigham-Grette (1992) and by Berger (2003).

Exposures Nk-32A, Nk-32B, and Nk-33 exhibit remnants of an alluvial terrace about 14-15 m high that also occurs widely through this sector of the valley. Radiocarbon ages from Nk-32B and Nk-33 indicate an age of about 13.5-11.3 ka for this feature. Dates on the channel fill at Nk-32A indicate a later episode of downcutting to about 6 m height took place at about 10 ka. These sets of radiocarbon ages overlap those at Nk-35A, indicating that postglacial downcutting by the Noatak River must have taken place very rapidly.

The remaining two exposures (Nk-34 and Nk-36) in this stretch of the Noatak River valley intersect portions of the Anisak moraine. The active debris flows that dominate Nk-34 indicate that this part of the moraine was built largely of glaciolacustrine deposits and that the Anisak glacier therefore terminated in a proglacial lake. The bluff face at Nk-36 is highly weathered but remains steep, suggesting that it may be underlain by till. The kettle-like collapse structures seen in the alluvium at Nk-35A indicate that stagnating ice of the Anisak glacier was still present during construction of the 30-m alluvial terrace.

The complex stratigraphic record of exposure Nk-37 extends back through the last interglacial and includes older glacial and interglacial deposits as well. The colluvial wedge in the central part of the exposure provides the key to relations between the glacial sequences of the eastern and western segments of the bluff (table 3). The eastern part of the wedge is dominated by clasts that probably were redeposited from the imbricated gravel and possibly also from the diamict that overlies that gravel. The wedge is then overlapped by younger alluvial gravel, which is overlain by till assignable to the

Anisak glacial advance. The till is covered by glaciolacustrine sediments, into which extended a body of till that formed during a readvance of the Anisak glacier (see fig. 54). A thick loess deposit caps the bluff. If correlations between the eastern, central, and western parts of the bluff are correct, the overall sediment record probably represents a sequence of 10 major depositional events (table 3).

The basal gravel at exposure Nk-38 contains fine as well as coarse beds and probably formed as interstadial alluvium. Its oxidized upper horizon indicates that a substantial interval of subaerial weathering followed deposition of the gravel and preceded formation of the glaciolacustrine unit. The glaciolacustrine deposit may have formed during the Avan advance, the last significant Pleistocene glacial event the western Noatak River valley (table 1).

Table 3. Correlation of depositional units in exposure Nk-37.

[--------, absent or obscured. From Hamilton, 2001]

Western section	Central section	Eastern section	Glacial event
←——	Massive silt (loess cap)	——→	
←——	Laminated silt + silt/clay rhythmites	——→	
Upper diamict	←—— Stony glaciolacustrine silt	——→	Anisak readvance
Laminated silt	--------------------	--------------------	
Lower diamict	←—— Upper till	——→	Anisak advance
--------------------	←—— Alluvial gravel	——→	
--------------------	Colluvial and peat wedge	--------------------	
--------------------	--------------------	Lower (oxidized) till	Cutler(?) advance
--------------------	--------------------	Imbricated gravel	
--------------------	←—— Oxidized gravel	——→	

Aniuk Lowland Below Cutler River—Tributary Drainages

Introduction

Ten additional bluffs were examined along tributaries to the Noatak River in this sector of its drainage system (fig. 54). Most are along south-flowing streams that drain the De Long Mountains. Single exposures were measured on Makpik Creek, Anisak River, and Itimtikrak Creek, and two exposures were measured along New Cottonwood Creek. Four bluffs are described along Nimiuktuk River, but three of these are beyond the north border of figure 54 and are shown only in figure 3. A single bluff measured south of the Noatak River is situated on Aklumayuak Creek.

Most of these tributary streams lack the erosive power of the Noatak River, and consequently many of their bluffs are relict features that have not been undercut recently. Their weathered faces reveal general sediment composition, but finer details such as bedding thickness and sediment structures are obscured. Some of the following bluff descriptions consequently contain little detail and are very brief.

Exposure Makpik-1

A gravel terrace remnant about 40 m high occurs on the west side of the west fork of Makpik Creek 9.5 km north of the Noatak River (see fig. 54). The gravel abuts the outer flank of the Cutler moraine, and may be a remnant of a formerly more extensive ice-marginal meltwater deposit.

The terrace face exposes subrounded to rounded pebbles and cobbles with sparse small boulders (55-75 cm diameter) in a matrix of coarse sand and granules (fig. 72). Silt is present near the top of the bluff as coatings on grain surfaces, but the actual depth to which silt was translocated could not be determined owing to the absence of fresh exposures along the bluff. A concentration of boulders up to about 75 cm diameter occurs in the upper part of the terrace exposure, and similar boulders are present along the inner edge of the terrace where it abuts the moraine. The boulders in the terrace face may be a lag

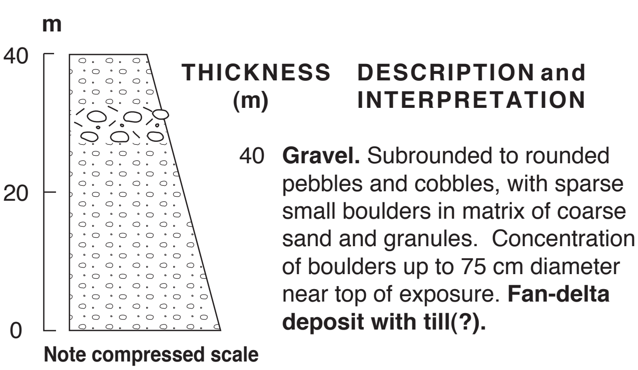


Figure 72. Exposure Makpik-1. West side of west fork Makpik Creek 9.5 km north of its confluence with Noatak River.

deposit that represents a brief advance of the fluctuating glacier front to the present position of Makpik Creek's west fork.

Fan-like deposits of pebble gravel on the east side of the west fork opposite the terrace remnant are part of an abandoned lower-level fluvial system that originated in the Avingyak Hills. These deposits may represent a fan-delta system that was graded to a proglacial lake that formed during a glacial advance that followed the Cutler event.

Exposure Anisak-1

A low bluff on a western tributary to Anisak River about 50 km above the mouth of that river is beyond the north margin of figure 54, but is shown in figure 2. The bluff is situated near the apparent northwestern limit of glacial-lake deposits of Makpik age (map-unit id1A in Hamilton, 2003). Thin glaciolacustrine sediments are exposed above stream gravel in an exposure that stands 14.5 m high (fig. 73).

The gravel (unit 1), which fines upward, contains an immature matrix characteristic of sluggish small tributary streams. Imbricated clasts indicate eastward flow direction like that of the modern stream. The overlying diamict (unit 2) contains glacier-modified stones in a matrix of mixed sand, silt, and clay.

The gravel was deposited by an aggrading and increasingly sluggish stream that may have been responding to rising base level resulting from glacier blockage and lake-level rise farther down the Anisak River. The overlying glaciolacustrine sediments would then have formed as the margin of the glacier-dammed lake expanded upvalley across this site.

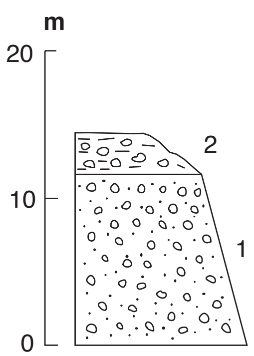
Exposure Itim-1

A northwest-facing bluff on the east side of Itimtikrak Creek stands 23.4 m high. It occurs within drift of the Makpik glacial advance (see fig. 54), but may be situated at the outer flank of a recessional moraine that formed during a readvance or stillstand of the Makpik glacier.

The bluff face has collapsed toward Itimtikrak Creek by slumping and flowage. Its highly disturbed surface exhibits glacier-modified stones to boulder size in a probably unsorted but silt-rich matrix (fig. 74). The largest clasts are pyroxenite and gray quartzite that originated in valley heads in the De Long Mountains. Black chert is prominent among pebble-sized clasts. Flowage of the bluff face suggests the presence of glaciolacustrine sediments, but the widespread slump blocks indicate that an additional unit such as till or gravel may be present also.

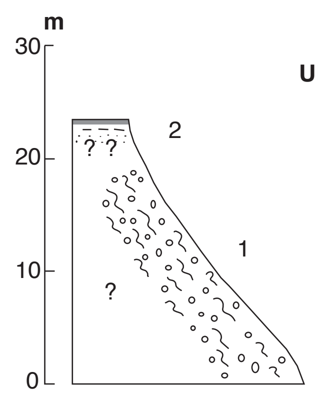
The exposure is capped by stony silt and silty peat that probably formed by frost mixing of eolian silt (loess) with sod and gravel. Silt-free gray sand below 70 cm depth probably reflects the former presence and upper limit of permafrost.

Figure 73. Exposure Anisak-1. North side unnamed western tributary to Anisak River 6.5 km above its confluence with Anisak River.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	2.8	**Stony silt.** Poorly sorted stones up to boulder size, many faceted, polished, and striated, in matrix of gritty clayey silt. **Glaciolacustrine deposit.**
1	11.7	**Gravel.** Pebbles and small cobbles in immature matrix of black sand and platy granules. Platy stones imbricated, with westward dips. Larger cobbles present at base. **Alluvium.**

Figure 74. Exposure Itim-1. East side Itimtikrak Creek 7 km above its mouth.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	>0.7	**Peat, silt, and sand.** Peat and silty peat overlie stony brown silt above gray-brown poorly sorted stony silty sand. Gray sand appears at 70 cm depth. Base not exposed. **Bluff cap.**
1	22.7	**Stony silt.** Subrounded clasts up to 80 cm length, many faceted and striated, in probable unsorted silty matrix. Largely obscured by slumps and flowage. **Glaciolacustrine deposit?**

Exposure Ctn-1 (New Cottonwood Creek)

A south-facing bluff stands 22.3 m high where eastern and western forks of New Cottonwood Creek converge just beyond the outer edge of the Makpik drift sheet (see fig. 54). The bluff exposes laminated lake sediments above fine alluvium (fig. 75).

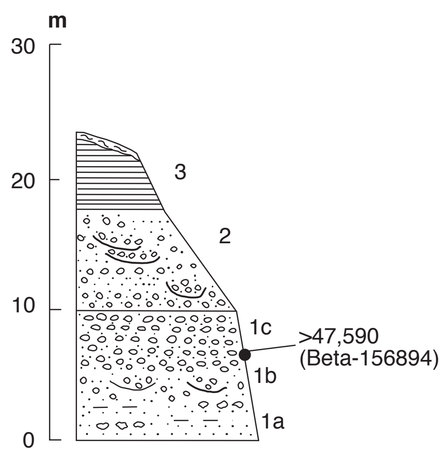
In the lower part of the section (unit 1), sand coarsens upward into channel-filling deposits of sandy pebbles and then into pebble-small-cobble gravel. Sandy gravel continues upward into overlying alluvium (unit 2). Both units 1 and 2 exhibit lenticular channel-fill structures characteristic of fluvial erosion and deposition. A large slab of detrital wood in gravel 6.8 m above creek level has a non-finite radiocarbon age of >47,590 yr B.P. The wood is similar in appearance to spruce, and a cone of *Picea glauca* (white spruce) was recovered at the same level.

The topmost deposit (unit 3) consists of rhythmically laminated silt, silty clay, and very fine sand that contains isolated stones up to very small cobble size. Beds and lenses 2-3 cm thick of sand with some granules occur near the top of the unit. The uppermost 70 cm of these sediments is frost-churned and filled with rootlets, indicating a former active layer associated with a permafrost table deeper than that of the present day.

Exposure Ctn-2

A high bluff with a terrace-like upper surface rises above New Cottonwood Creek where it intersects the northern lateral moraine of the Anisak (Itkillik Phase IB) advance (see fig. 54). The bluff face is largely stabilized and somewhat weathered. It exposes gravel above diamict, and water-washed gravel is exposed across the bluff's near-level upper surface (fig. 76).

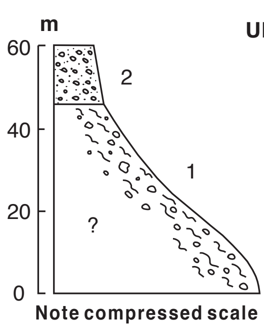
A recently active debris flow exposes unsorted, glacier-abraded clasts up to medium boulder size in a matrix of mixed sand to clay-sized grains (unit 1). Limestone is most abundant



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	4.7	**Sand to clay couplets.** Rhythmically laminated dark gray (7.5YR 4/0) silty clay to very dark grayish brown (10YR 3/2) well sorted very fine sand in couplets 5-10 cm thick. Bulk of each couplet is dark gray (10YR 4/1) silt with laminae 1-2 mm thick. Contains isolated stones to very small cobble size. Couplets thicker (10-20 cm) near base, with coarse silt to silty very fine sand dominant but clayey laminae 3-4 mm thick unchanged from higher in unit. **Lacustrine deposit.**
2	7.7	**Sandy gravel.** Subrounded pebbles and small cobbles in matrix of dark gray (7.5YR 4/0) poorly sorted sand and granules. Some channel-form crossbedding. Contains layers and lenses of gravelly sand 5-10 cm thick. **Alluvium.**
1	9.9	**Sand and fine gravel. Alluvium.**
c	5	Clast-supported pebble-small cobble gravel with near-horizontal bedding.
b	2	Sandy pebbles in lenticular (channel-filling) beds up to 0.5 m thick. Interstratified with sand in near-horizontal laminations a few millimeters thick that contain sparse granules and small pebbles. Some 10-cm sets of ripple crossbedded sand also present.
a	3	Near-horizontal to ripple cross-laminated sand with some lenses of silt and other lenses of detrital wood.

Figure 75. Exposure Ctn-1. New Cottonwood Creek at junction of forks 10 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Figure 76. Exposure Ctn-2. West side New Cottonwood Creek 5.5 km above its mouth.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	14.3	**Gravel.** Subrounded clasts to ca. 30 cm diameter in matrix of poorly sorted, dark, medium to coarse sand and granules. Clasts lack facets and striations; many have carbonate crusts. Matrix grains angular to subangular, with rock chips dominant. **Alluvium.**
1	46	**Diamict.** Unsorted, subangular to subrounded clasts in dark gray muddy matrix. About half of the clasts are striated and/or faceted. Pebbles to small cobbles dominant, but larger stones range up to 110 cm length. **Till and/or glaciolacustrine deposit.**

among the clasts, with quartzite, greenish conglomerate, diorite, pyroxenite, and ferrugineous sandstone also common. The unstable flow activity suggests the presence of glaciolacustrine sediments, but the bulky lateral moraine at this site indicates that glacial till should be present also. Perhaps flowing glaciolacustrine sediments have masked underlying till.

The overlying gravel (unit 2) contains subrounded clasts up to very small boulder size that lack any glacial overprint. Lithologies, which include gray quartzite, diorite, conglomerate, and angular fragments of black chert, are less diverse than in the underlying diamict. A test pit into the bluff's upper surface exposes frost-stirred and oxidized (dark yellowish brown: 10YR 3/6) silty gravel above very dark brown (10YR 2/2) unweathered sandy gravel at about 40 cm depth.

Exposure Nm-1 (Nimiuktuk River)

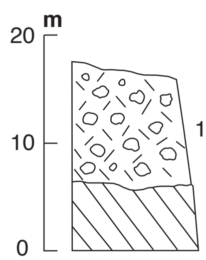
A north-facing bluff near the head of Nimiuktuk River lies beyond the north margin of figure 54 but is shown in figure 3. The bluff intersects a lateral moraine assigned to an unnamed glacial readvance of late Anisak age that is mapped as unit id_{1C} in Hamilton (2003). Till overlies a bedrock surface that stands about 6 m above river level (fig. 77). Unsorted glacier-modified clasts occur in a matrix of unsorted fine debris. Lithologies include crinoidal limestone, chert, ferruginous quartzite, and chert-rich conglomerate. Black chert is abundant in clasts up to very small boulder size; some large cobbles of green-gray and brown chert also are present. These lithologies crop out widely through local valley heads, indicating that the late Anisak readvance was a small, localized event.

Exposure Nm-2

A terrace exposure along the west side of Nimiuktuk River about 9 km below exposure Nm-1 (see fig. 3) occurs within probable outwash that issued from the late Aniuk moraine front. Many cobble-sized clasts in the terrace gravel (unit 1; fig. 78) are platy in shape; these commonly are imbricated, dipping upvalley. Black chert and gray quartzite are the dominant lithologies. The upper 80 cm of the exposure has been frost-churned and mixed with brown silt of probable eolian origin.

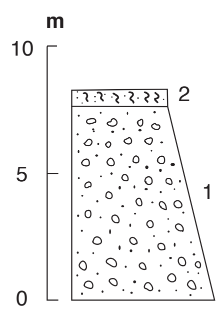
Exposure Nm-3

About 30 m of unsorted and unstratified till (fig. 79) is exposed in a north-facing bluff in a valley tributary to Seagull Creek, which flows southeastward into Nimiuktuk River (see fig. 3). At this site, tillstones range in size only up to small boulders and larger glacial boulders are rare in the stream bed. The relatively small size of these glacier-shaped clasts indicates that they probably were redeposited from alluvium along the center of Seagull Creek valley. Ice from the main valley of Seagull Creek probably flowed westward up the unglaciated tributary valley for a short distance beyond this site.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	10.1	**Diamict.** Clasts up to 80 cm length, many faceted and striated, in compact gray matrix. **Till.**
--	6.3	**Bedrock.** Lithology not recorded.

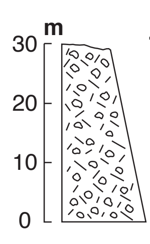
Figure 77. Exposure Nm-1. Southwest side Nimiuktuk River 13 km southeast of Thunder Mountain.



Note expanded scale

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	0.8	**Silty sand.** Black sand and granules frost-mixed with brown silt. **Bluff cap.**
1	7.7	**Gravel.** Subrounded pebbles and small to medium cobbles in subhorizontal beds 0.5-1 m thick. Some channel fillings present. Black chert and gray quartzite dominant. **Alluvium.**

Figure 78. Exposure Nm-2. West side Nimiuktuk River 9 km below Nm-1.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
29.5	**Diamict.** Subrounded pebbles, cobbles, and sparse small boulders in gray muddy matrix. Many stones faceted and striated. No sorting or stratification evident. **Till.**

Figure 79. Exposure Nm-3. South side unnamed western tributary to Seagull Creek 3 km above its confluence with Seagull Creek.

Exposure Nm-4

A bluff near the mouth of Nimiuktuk River exposes river gravel in an alluvial terrace that stands about 15 m high (fig. 80). Clasts range up to about 38 cm long in a poorly sorted sand-granule mixture. Rock types include pyroxenite, limestone, and gray quartzite. Terraces of comparable height are widespread in this part of the Noatak drainage system, and are mapped as terrace unit tg_3 (Hamilton, 2003; in press).

Exposure Ak-1 (Aklumayuak Creek)

A high-standing terrace near the head of Aklumayuak Creek 13 km southwest of Lake Kangilipak exposes gravel across its weathered face (fig. 81). Clasts through the lower part of the gravel section primarily are pebbles and small cobbles, with quartz abundant and other local lithologies such as schist, limestone or marble, and quartzite also common. Both clasts and matrix coarsen upward, with clasts ranging upward in diameter to about 30 cm. Lithologies change also, with ultramafic clasts derived from the DeLong Mountains becoming common. The base of the exposure is concealed by a lower gravel terrace, which rises 8.5 m above river level. A concentration of lag boulders on the creek's floodplain here contains many clasts in the 70-75 cm size range and a broken fragment of quartzite 82 cm long.

The coarsening-upward gravel with its increasing content of far-traveled lithologies indicates probable transition from a nonglacial stream deposit to glacial outwash at exposure Ak-1. The unweathered but strongly oxidized near-surface gravel supports field relations, which suggest an Anisak age (see fig. 54) for the outwash and its derivation from a glacier margin near the west end of Lake Kangilipak. The concentration of large boulders at the base of the bluff indicates that the terrace gravel alleviated following dissection of an older glacial deposit. Nearby erosion remnants of an ancient drift support this assumption.

Discussion

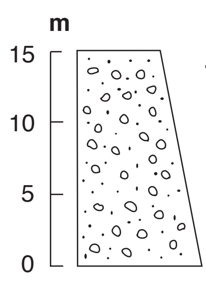
A highly weathered bluff along Makpik Creek exposes ice-contact gravel that may be related to the Cutler glacial advance. Bluffs along Anisak River and Itimtikrak and New Cottonwood Creeks contain glaciolacustrine deposits related to the Makpik and Anisak glacial advances. Together with wave-cut notches, beach ridges, and other geomorphic evidence, these bluff deposits demonstrate that extensive proglacial lakes inundated this part of the upper Noatak basin during those glacial events. At exposure Ctn-1, interglacial alluvium with spruce wood and a non-finite radiocarbon age is exposed beneath the glaciolacustrine sediments.

Exposures Nm-1 and Nm-2 contain till and probable outwash that were deposited near the head of Nimiuktuk River valley during a very late glacial readvance of Anisak age. The till at Nm-3 may have been formed at the same time by a glacier that issued from the same general highland source area and extended into the upper valley of Seagull Creek.

Exposure Nm-4, a 15-m terrace near the mouth of Nimiuktuk River, probably is correlative with Nk-39, an alluvial terrace of comparable height on a nearby stretch of the Noatak River. These terrace remnants are part of the widespread 15-m Noatak valley terrace system discussed previously.

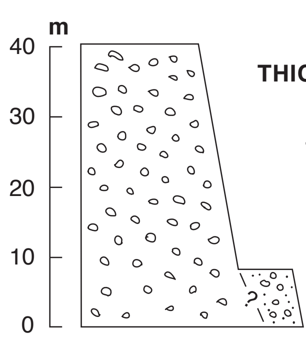
The Aklumayuak Creek exposure (Ak-1) is part of an outwash train deposited by meltwater that flowed south through a deep rock-walled gorge from an ice margin near Lake Kangilipak. The present-day creek is an underfit stream that occupies a deeply incised valley eroded by much larger meltwater streams associated with at least two separate glacial advances into the Lake Kangilipak area (Hamilton, 2003 and in press).

Figure 80. Exposure Nm-4. West side Nimiuktuk River 6 km above its mouth.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
15	**Gravel.** Pebbles, cobbles, and very small boulders in matrix of black poorly sorted medium sand to granules with abundant rock chips. **Alluvium.**

Figure 81. Exposure Ak-1. North side Aklumayuak Creek 31 km above its mouth.



Note compressed scale

THICKNESS (m)	DESCRIPTION and INTERPRETATION
41.5	**Gravel.** Subrounded pebbles and small cobbles in sandy matrix with platy phyllite granules. Coarsens upward into coarse-pebble to medium-cobble gravel, that also contains large cobbles and very small boulders in matrix of poorly sorted sand to small pebbles. Gravel at bluff crest strongly oxidized to >30 cm depth, but clasts are little weathered. **Alluvium and outwash.**

Nimiuktuk River to Aklumayuak Creek

Introduction

Through the 30-km reach between the mouths of Nimiuktuk River and Aklumayuak Creek, the Noatak River flows southward through a narrow valley only 5 km wide that crosses the topographic grain of the De Long Mountains (fig. 82). However, the river's gradient through this stretch, about 1.1 m/km, is nearly identical to gradients farther upvalley and downvalley. The end moraine correlated with the Anisak glacial advance crosses the Noatak valley floor 7 km above the mouth of Aklumayuak Creek, and some of the bluffs through this reach expose glacial-lake sediments relating to this advance. Drift of the preceding Makpik glaciation occurs locally in tributary valleys (Hamilton, 2003), but has been eroded or blanketed by glacial-lacustrine sediments along the floor and lower flanks of the main valley.

Nine river-bluff exposures (Nk-40 through Nk-48) were recorded through this sector of the Noatak River valley. Other bluff faces were fully vegetated, and their underlying materials could not be measured or identified.

Exposure Nk-40

A silt and gravel exposure 14 km below the mouth of Nimiuktuk River rises to a heavily vegetated terrace-like surface 44 m above river level, then steps up to a 52-m surface farther inland that has pebble gravel exposed along its outer edge (unit 1; fig. 83). The 44-m terrace may be inset within the higher surface through a cut-and-fill process.

The younger gravel (unit 2) consists dominantly of sedimentary and metamorphic rocks, with ultramafic rock types present but uncommon. The size range, rounding, and lithology of the clasts are characteristic of normal river gravels that include rock types transported from the upper Noatak River valley. The overlying stony silt, which may extend

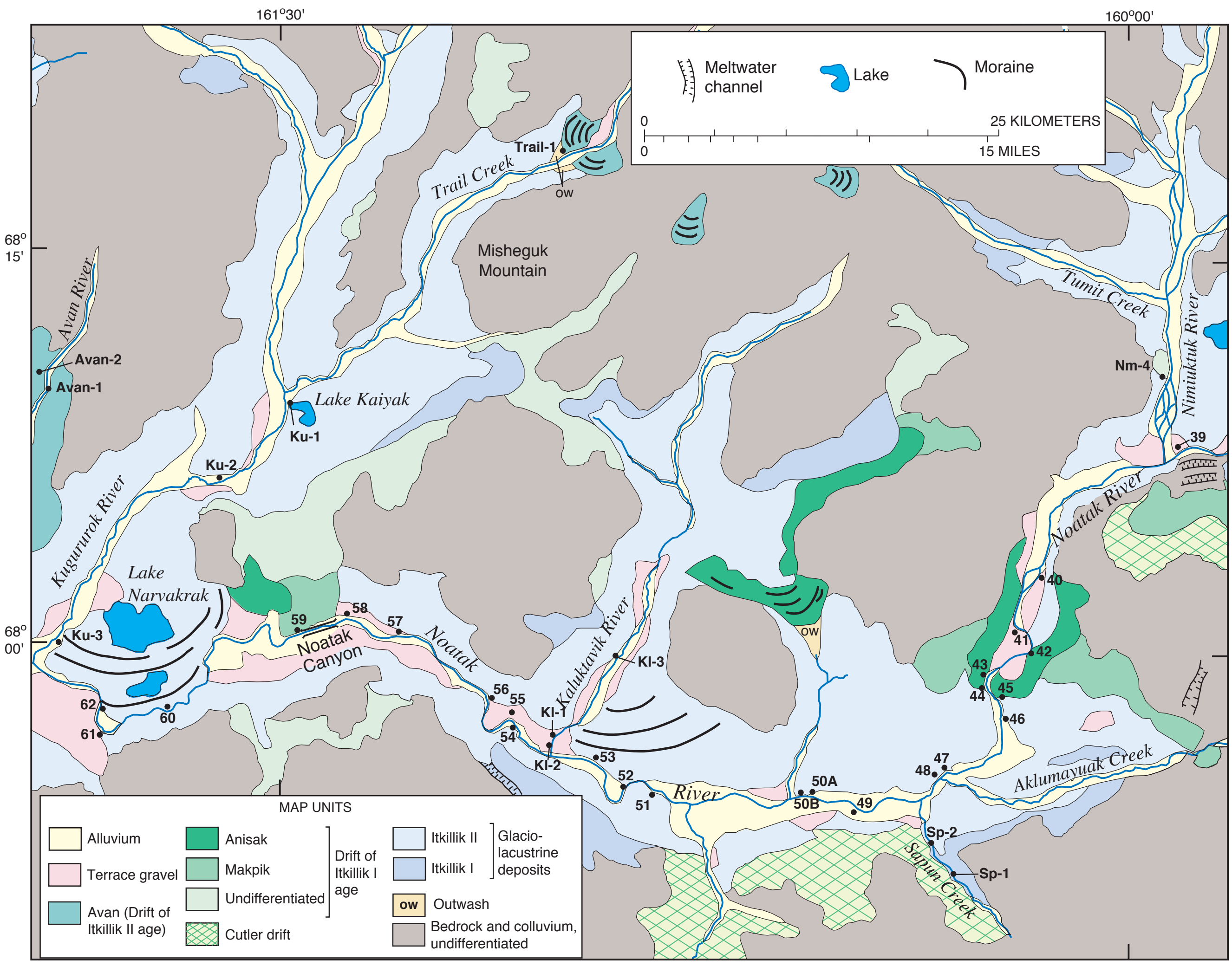


Figure 82. Generalized geologic map, Noatak River valley between Nimiuktuk River and Kugururok River. Numbers without prefixes refer to Noatak River bluffs (designated Nk in text).

entirely through the 22-m span of units 3 and 4, contains sparse clasts interpreted as dropstones; it is considered to be a distal rather than proximal glaciolacustrine deposit.

The inferred history of this deposit is (1) river flow at the 50-m level (regional terrace tg_1 of Hamilton, 2003 and in press), shortly after glacier retreat from the Anisak moraine, (2) downcutting through the older gravel, (3) either trimming of the older gravel to about 22 m height or renewed alluviation of younger gravel as base level rose due to renewed glaciation downvalley, (3) deposition of distal glaciolacustrine sediments as growing glaciers dammed a downvalley stretch of the Noatak River, and (4) downcutting to modern river level following deglaciation.

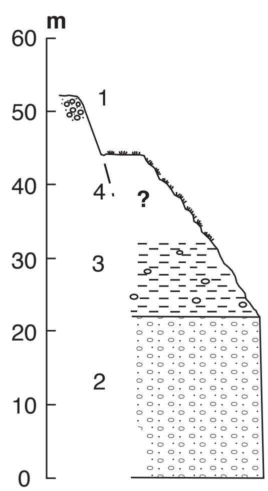
Exposure Nk-41

A prominent bluff along the west side of the Noatak River 17 km downstream from Nimiuktuk River rises 65 m to a terrace-like surface that is broken by kettle depressions (fig. 84). A hummocky, kettled end-moraine complex (see fig. 82) extends into the valley center from both valley sides at this locality; it rises upvalley into lateral moraines along both valley walls. The river's edge here is paved with medium to large cobbles and boulders up to 1.3 m diameter (even larger boulders occur beyond reach farther out in the river). Pyroxenites and other ophiolite complex rocks derived from the DeLong Mountains dominate boulder lithology.

Poorly exposed diamict (unit 1) comprises the central part of the bluff face. It is obscured by flowage, by mixture with overlying gravel, and by drapes of that gravel. Because of its extreme mobility, it is interpreted to be a glaciolacustrine deposit rather than till.

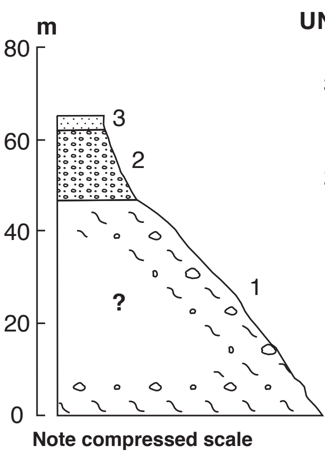
The overlying gravel (unit 2), which is composed dominantly of ultramafic igneous rocks and slate, forms near-vertical faces that rise to about 62 m above river level. It is capped by a probable floodplain deposit of silty very fine sand (unit 3).

Pebble-small-cobble gravel in a matrix of platy granules and coarse sand forms a basal exposure 34 m thick at the upstream end of the bluff. This deposit, which is not illustrated, probably formed by alluviation following river incision from the 65-m level.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	12	**Covered.** Heavily vegetated sediment, probably silt. **Glaciolacustrine deposit?**
3	10	**Stony silt.** Bedded, dark gray, fairly compact silt with sparse stones. Poorly exposed because of slumping. **Distal glaciolacustrine deposit.**
2	22	**Younger gravel.** Pebbles and small cobbles. Dominantly quartz, black chert, sandstone, quartzite, limestone, and phyllite. Some quartz clasts have schist adhesions. Ultramafic rock types present but uncommon. Clasts generally rounded; some well rounded. **Alluvium.**
1	8+	**Older gravel.** Poorly exposed pebble gravel. **Origin uncertain.**

Figure 83. Exposure Nk-40. East side Noatak River 14 km below Nimiuktuk River mouth.



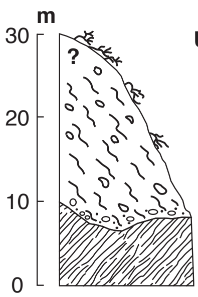
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	3	**Sand.** Grayish brown (2.5Y 5/2) silty very fine sand. Becomes increasingly organic and then peaty upward through topmost 60 cm. **Floodplain deposit.**
2	15	**Gravel.** Subrounded pebbles and cobbles in poorly sorted matrix of sand with slate chips. Ultramafic igneous rocks and slate dominate clast lithologies, with quartz, basalt, and sandstone also present. **Alluvium.**
1	47	**Diamict.** Contains boulders, some striated, up to 1.5 m diameter. Pyroxene and brown sandstone dominate the larger clasts. Poorly exposed. **Glaciolacustrine deposit?**

Figure 84. Exposure Nk-41. West side Noatak River 17 km below Nimiuktuk River mouth.

Exposure Nk-42

A partly vegetated west-facing bluff greater than 25 m high intersects probable glaciolacustrine deposits near the inner (north) flank of the Anisak end moraine (shown as Anisak Drift in fig. 82). Bedrock exposed close to river level is overlain directly by gravel that is mixed with diamict which has been severely deformed by slumps and flowage (fig. 85). Striated stones in a gritty silt matrix are exposed nearly continuously to about 20 m height, then intermittently up to 25.5 m. A dense alder thicket above this level reflects poorly drained, unstable sediments that probably are an upward continuation of the diamict.

A line of large erratic boulders that crosses the stream channel here may be perched on a bedrock ledge. Erratic boulders also are common along the river bank downriver from this locality.

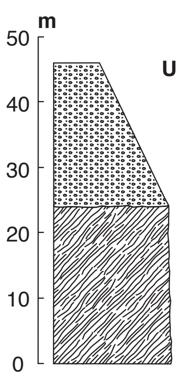


UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
_	>5	**Covered.** Dense alder growth.
1	>15	**Diamict.** Striated stones in gritty silt matrix. Contains admixed gravel at base.
_	6-10	**Bedrock.** Gray phyllite with vein quartz.

Figure 85. Exposure Nk-42. East side Noatak River 11 km above mouth of Aklumayuak Creek.

Exposure Nk-43

A bluff exposure along the west side of the Noatak River 10 km above Aklumayuak Creek exposes gravel over phyllite bedrock (fig. 86). The gravel consists of pebbles to medium cobbles, with some larger cobbles, in an immature sand and granule matrix. Mafic to ultramafic igneous rocks are abundant. This gravel forms part of a high-level (46-m) alluvial terrace that is inset within the Anisak end moraine (see fig. 82).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	22.0	**Gravel.** Rounded to subrounded pebbles, small to medium cobbles, and sparse larger cobbles in matrix of dark gray poorly sorted sand with phyllite chips. Mafic to ultramafic igneous rocks dominate cobble size range. **Alluvium.**
--	24.0	**Bedrock.** Gray phyllite, with wavy cleavage planes.

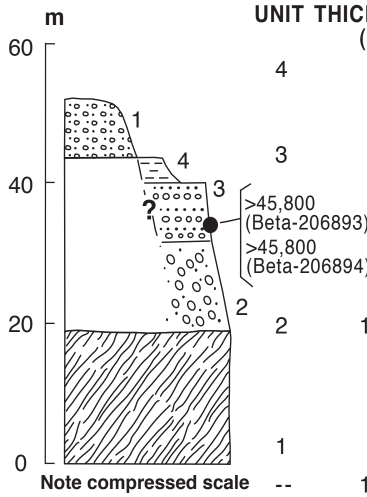
Figure 86. Exposure Nk-43. West side Noatak River 10 km above mouth of Aklumayuak Creek.

Exposure Nk-44

An east-facing river bluff a short distance below exposure Nk-43 stands at about the same height (44 m). From a narrow bench at this height, the surface rises inland to 52 m above river level, where slightly weathered, oxidized pebble-small-cobble gravel is exposed (unit 1; fig. 87). The 44-m terrace therefore is inset within a higher and conspicuously older gravel surface.

The lower half of the bluff face exposes gray phyllite bedrock; the upper half is dominantly gravel. The gravel (unit 2) consists of cobbles and some very small boulders (up to 40 cm diameter) in a matrix dominated by phyllite chips. The upper 8 m of this deposit (unit 3) stands in a steep face that exposes alternating cobbles and pebbly sand and granules in beds generally 30-50 cm thick. The overlying 3-4 m is covered, but flow amphitheaters suggest the presence of ice-rich silt.

Sand consisting dominantly of phyllite chips forms a 32-cm-thick deposit at the base of the 8-m bedded gravel unit. It contains a brownish gray silt bed 1-4 cm thick that locally is crossbedded. Fragments of detrital wood from the base of the silt bed have non-finite ages of >45,800 yr B.P.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	2	**Ice-rich silt?** Largely covered, with flow amphitheaters.
3	8	**Bedded gravel.** Weakly bedded cobble to pebbly sand-granule beds in matrix of platy (phyllite) granules and sand. **Alluvium.**
2	17	**Gravel.** Cobbles and sparse very small boulders in matrix dominantly of phyllite chips. **Outwash?**
1		**Oxidized gravel.**
--	19	**Bedrock.** Gray phyllite.

Figure 87. Exposure Nk-44. West side Noatak River 7 km northeast of mouth of Aklumayuak Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Exposure Nk-45

A gravel terrace 19 m high extends along the east side of the Noatak River just downstream from the outer flank of the Anisak moraine (fig. 82). The terrace face exposes less than a meter of silty floodplain sediments above unweathered, unoxidized sandy gravel (fig. 88).

The gravel (unit 1) consists of pebbles to medium cobbles, with some larger cobbles, in a matrix of poorly sorted sand with phyllite chips. Sand may predominate at the base of the section, but slumps obscure the primary sediments.

In contrast to the large boulders along the river channel and banks immediately upstream, the lag deposit along the river's edge at the base of Nk-45 consists of large cobbles with some very small boulders (up to about 40 cm diameter). Pyroxenites dominate the larger clasts. The absence of large boulders confirms that this locality lies beyond the limit of the Anisak glacial advance. The contrast between the lag deposit and the exposed gravels indicates that the terrace gravels were deposited after deposition and subsequent erosion of the outwash train from the Anisak glacier.

Exposure Nk-46

A gravel terrace with a nearly level, extensive upper surface 45 m above the river extends along the east side of the Noatak River 6 km above the mouth of Aklumayuak Creek (fig. 89). Phyllite bedrock along the base of the bluff has defended the overlying gravel from river erosion.

The gravel (unit 1) consists of pebbles and cobbles in a matrix of platy phyllite sand and granules. Small boulders are absent. It is capped by one meter or less of floodplain silt.

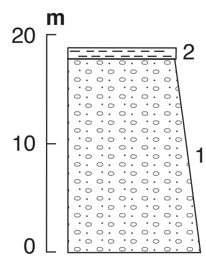
Terrace remnants at this height are present west of the river here, but they are not extensive. More extensive and continuous terraces are present at two lower levels—about 35 and 20 m above the river.

Exposure Nk-47

A low (25-m) terrace, along the south side of the Noatak River just above the Aklumayuak Creek confluence, lies at the west end of an extensive gravel terrace (see fig. 82) that separates the river from the creek. The terrace face exposes 18 m of gravel overlain by 6.5 m of sand that is capped by 0.5 m of peaty sand (fig. 90).

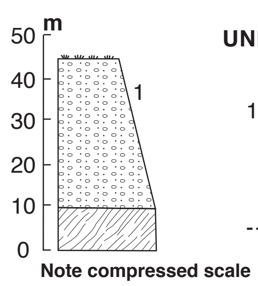
The gravel (unit 1) is dominantly pebbles and small cobbles, with dispersed larger clasts up to small boulder size. Quartz is abundant among the smaller clasts. The overlying deposit (unit 2) consists of well sorted, medium sand to brownish gray silty fine sand in near-horizontal beds that generally are 0.5 to 3 cm thick but locally are up to 12 cm thick. The sand is somewhat pebbly near its base, and contains a thin granule bed 2.3 m above its lower contact. Two samples from a small lens of woody detritus 2.0 m above the base of the sand had concordant radiocarbon ages

Figure 88. Exposure Nk-45. East side Noatak River 7.5 km above mouth of Aklumayuak Creek.



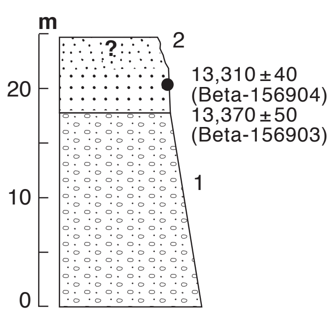
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	<1	**Silt. Floodplain deposit.**
1	18-18.5	**Gravel.** Rounded to subrounded pebbles and cobbles in abundant matrix of gray, poorly sorted sand mixed with phyllite chips. **Alluvium (reworked outwash?).**

Figure 89. Exposure Nk-46. East side Noatak River 6 km above of mouth of Aklumayuak Creek.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	35	**Gravel.** Pebbles and cobbles in matrix of platy phyllitic sand and granules. Capped by 1 m or less of silt. **Alluvium.**
--	10	**Bedrock.** Phyllite.

Figure 90. Exposure Nk-47. South side Noatak River 1.5 km above of mouth of Aklumayuak Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	7	**Sand.** Well sorted, bedded, nonoxidized medium sand to brownish gray silty fine sand; somewhat pebbly near base. Basal 4.5 m probable **flood-plain deposit**; upper 2.5 m poorly exposed, and may in part be **eolian.**
1	18	**Gravel.** Rounded to subrounded pebbles, small cobbles, and dispersed larger clasts to small boulder size. Quartz abundant (ca. 50%). **Alluvium.**

of 13,370 ± 50 yr B.P. and 13,310 ± 40 yr B.P. The basal two-thirds of the sand unit clearly is a floodplain deposit; the upper one-third is poorly exposed, and may in part be eolian.

Large cobbles and very small boulders (up to 30-40 cm diameter) dominate the lag deposit along the river edge at the terrace base. These clasts may be relict from an eroded outwash train associated with the Anisak end moraine.

Exposure Nk-48

The face of a 49-m terrace remnant directly opposite the mouth of Aklumayuak Creek exposes alluvium, till, and lacustrine silt above phyllite bedrock (fig. 91). The bedrock has an irregular upper surface with about 2 m relief that probably was created by river erosion.

Alluvial gravel (unit 1) is 4-6 m thick, being thickest over depressions on the bedrock surface. Near its base, beds of pebbly sand to pebble gravel are inclined downvalley at 10° to 12°. Higher in the unit, a lens of organic-rich sediment up to 33 cm thick contains detrital wood fragments interstratified with gray sand that overlie a compact layer of peat 1-2 cm thick. The wood fragments and the peat have identical nonfinite radiocarbon ages of >57,000 yr B.P. The wood has been identified as *Salix* (willow; USDA-FPL, 9/15/86). A pollen assemblage extracted from the peat is characteristic of "...a shrub-herb tundra composed of a mixture of dwarf birch, ericales…, willows, grasses, sedges, and herbs" (T.A. Ager, U.S. Geological Survey, written commun., 4/3/87). Interbedded coarse and fine sand near the upper contact of the gravel may represent a slackwater environment that developed as glaciers advanced into downvalley sectors of the Noatak valley.

The diamict (unit 2) has the attributes of a subglacially deposited till, as listed in table 2. It lacks sorting and stratification, contains abundant faceted and striated clasts, and has a compact matrix that allows it to stand in vertical bluffs. Ultramafic rocks like those noted in upvalley exposures are abundant among the coarser clasts. Some stones near the upper contact of the till are oxidized.

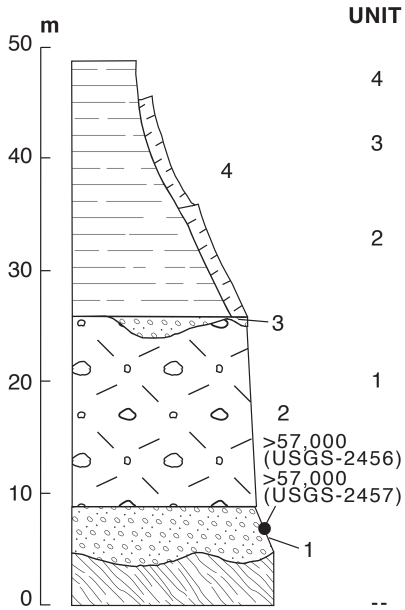
A second deposit of alluvial gravel (unit 3) is present locally above the till, being thickest where it fills a channel eroded into the till surface. Some clasts have oxidized surfaces. In most exposures, the gravel has been mixed with silt, which has slumped from above.

Well sorted stone-free silt 20-23 m thick forms the upper half of the bluff. This deposit has faint subhorizontal beds 0.5 to 3 cm thick, but all exposures are severely slumped and structures cannot be traced laterally.

Discussion

Bluffs along the Noatak River from Nimiuktuk River to just above Aklumayuak Creek expose glaciolacustrine deposits and postglacial fluvial sediments, but outcrops of glacial till and outwash are rare. Extensive erosion by the Noatak River through this narrow segment of its valley has removed most of the glacial record from the valley center and left only fragmentary remnants. Bluff exposures above the valley-crossing Anisak end moraine differ greatly from those within and below the end-moraine belt.

The three exposures (Nk-40 through Nk-42) above the end moraine contain glaciolacustrine sediments in exposures up to 45 m high, with higher gravel exposed at two locali-



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	2.3	**Silt.** Well sorted brown (10YR 5/3) silt. Faint subhorizontal bedding. Face severely slumped. **Lacustrine.**
3	0-3	**Gravel.** Pebbles and small cobbles, with quartz about 10 percent by volume and phyllite fragments abundant. About 10 percent of clasts have oxidized surfaces. **Alluvium.**
2	17-14	**Diamict.** Subangular to subrounded stones up to usual maximum diameter of 30 cm. Very sparse larger blocks up to 1 m length. Many clasts faceted and striated. No sorting or stratification. Some stones near upper contact oxidized. Stands in vertical faces. **Till.**
1	4-6	**Gravel.** Rounded to subrounded pebbles and cobbles, with some lines of large cobbles and some very small boulders. Matrix variable: silty coarse sand with granule chips in some beds; only partial silt filling between stones in others. Some 30-cm-thick beds consist of poorly sorted silty gray sand-sized rock chips with dispersed pebbles. Interbedded coarse and fine sand near upper contact. Irregular base fills depressions in underlying bedrock. **Alluvium.**
--	5-3	**Bedrock.** Gray phyllite with quartz veins. Irregular upper surface.

Figure 91. Exposure Nk-48. West side Noatak River opposite mouth of Aklumayuak Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

ties. No glacial deposits have been preserved in either of the bluffs (Nk-43 and Nk-44) within the end-moraine zone; however, both bluffs consist of postglacial river terraces at 40-46 m height that were inset within the end moraine. The two bluffs contain basal bedrock outcrops that have defended the terrace remnants from subsequent river erosion. Three bluff exposures (Nk-45 through Nk-47) below the Anisak moraine also are terrace faces that expose postglacial alluvial gravel at 44 m and about 18-22 m heights. The higher terrace level is correlative with the terrace remnants preserved within the end-moraine zone, and also coincides in height with some of the glaciolacustrine sediments exposed upvalley of the end moraine. The lower terrace level is part of a set of younger alluvial terraces.

The bluff (Nk-48) opposite Aklumayuak Creek intersects a terrace remnant that corresponds in height to high-level (45-50 m) terraces farther upvalley. The Noatak valley is wider here than the sector above Aklumayuak Creek and, consequently, a more complete glacial record has been preserved from subsequent river erosion. Compact till exposed at Nk-48 probably formed during the older glaciation of Makpik age because it lies well beyond the mapped limits of Anisak glaciation (Hamilton, 2003 and in press). Abundant pyroxenite clasts indicate that ice flowed southward from prominent ultramafic highlands in the De Long Mountains. Alluvial gravels above and below the till are of interglacial or interstadial character, and contain no discernable outwash. Oxidized stones within the upper gravel and near the top of the till indicate a significant hiatus between deposition of the till and the overlying lacustrine silt. This thick silt unit, which comprises the upper half of the exposure, represents a major episode of damming of the Noatak River. However, its well-sorted, stone-free character is unlike that of most glaciolacustrine deposits in the Noatak valley. The glacier dam must have been some distance downvalley, and the silt must have been carried into this locality by rivers rather than glaciers or icebergs.

Sapun Creek

Two high bluffs along the lower course of Sapun Creek are situated near patches of drift of uncertain age (see fig. 82) that probably represent a glacial lobe that extended south into the valley of Sapun Creek from the Noatak valley. Glaciolacustrine deposits of at least two ages also occur at lower altitudes along the creek and the adjoining south flank of the main valley.

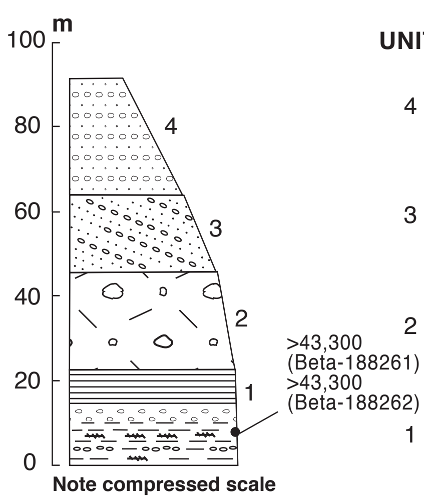
Exposure Sp-1

A weathered bluff face along the east side of Sapun Creek 6 km above its mouth stands 91.5 m high and exposes fluvial gravel above glacial and glaciolacustrine deposits (fig. 92).

Unit 1, at the base of the bluff, consists of horizontally bedded fine sand, silt, and clayey silt; with lenses of organic-rich sediment. Some beds 10-20 cm thick of pebble gravel in a matrix of platy granules also are present. Slightly cross-bedded sand to pebble-small-cobble gravel in the midpart of the unit forms a bed 2.5 m thick. Fine peaty lenses concordant with bedding occur 7.8 m above river level. Two separate lenses about 3 m apart horizontally along this horizon yield identical limiting ages of >43,300 yr B.P. The upper part of the unit consists of laminated silt and clayey silt. Unit 1 is interpreted as fluvial slackwater deposits that grade upward into lacustrine sediments.

Diamict consisting of unsorted and unstratified stones up to small boulder size (unit 2) overlies the laminated silty deposits, and is interpreted to be glacial till. Its matrix of platy phyllite granules and small pebbles indicates some water washing by Sapun Creek at the ice front. Unit 3, probable deltaic deposits that overlie the diamict, consists of phyllitic sand with lesser fine sandy gravel in parallel beds that generally dip downvalley.

The bluff is capped by a 38.2-m thick deposit of fluvial sand and gravel (unit 4). Pebbles and small cobbles, domi-



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	38.2	**Sand and gravel.** Pebbles and small cobbles in matrix of poorly sorted platy phyllite granules and small pebbles. **Alluvium.**
3	17.8	**Sand with fine gravel.** Phyllitic sand with some fine sandy gravel. Parallel beds, dominantly dipping downvalley. **Deltaic deposit.**
2	13	**Diamict.** Unsorted and unstratified stones up to small boulder size in matrix of platy phyllite granules and small pebbles. **Till?**
1	22.5	**Bedded fine sediment.** Horizontally bedded fine sand, silt, and clayey silt, with organic lenses. **Slackwater and lacustrine deposits.**

Figure 92. Exposure Sp-1. East side Sapun Creek 6 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

nantly of quartz and phyllite, occur in a matrix of poorly sorted platy phyllite granules and small pebbles. Sparse larger clasts dominantly are phyllite and quartz; and some rounded ultramafic rock types also are present.

Exposure Sp-2

A bluff farther down Sapun Creek near the south flank of the Noatak River valley provides excellent exposures of fluvial and glaciolacustrine deposits (fig. 93). The bluff face rises steeply to 40 m height, where a thaw ampitheater exposes an 11-m-thick section of stony silt. A vegetated surface above the amphitheater rises to a knob of slightly oxidized gravel that stands as high as 61 m above river level. The largest stones exposed on that feature are a partly buried quartz slab with exposed length of 72 cm and a large cobble of gray quartzite 22 cm in diameter. Both clasts are slightly weathered. Below the thaw amphitheater, the bluff face exposes a thick deposit of fine sandy gravel overlain by fluvial gravel.

The fine sandy gravel at the base of the exposure (unit 1) is a probable deltaic deposit. Beds of dark gray sand-size phyllite chips alternate with similar beds that contain granules and dispersed pebbles of phyllite and quartz. Some beds of coarser (pebble-small- cobble) gravel are present at the north end of the section. The beds dip southward up Sapun Creek at 11° to 18°. In a downdip (southward) direction, the gravel beds interfinger with sand, and sand beds thicken into a bed of poorly sorted muddy sand with widely dispersed pebbles. Flattened detrital twigs from a clayey lens 1 m below the top of unit 1 have a non-finite age of >48,280 yr B.P.

An isolated block (unit 1a) of slumped sediment extends from 8 to 11.5 m above river level near the north end of the bluff. It contains sand and gravel similar to sediments in units 1 and 2, but some fluvial cross-beds are present and some stones are imbricated. The imbrication suggests northward flow direction parallel to present-day Sapun Creek. Wood fragments and clasts of detrital peat are present in the slump block.

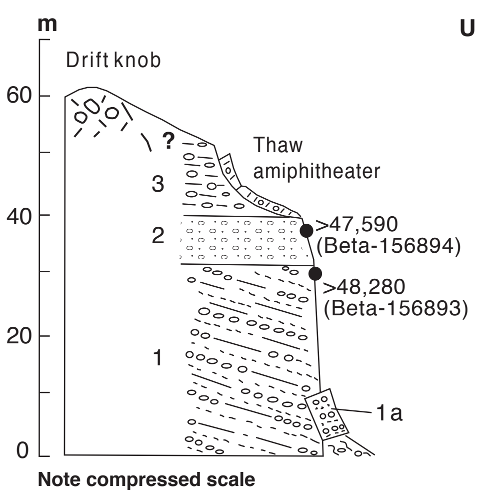
The alluvial gravel (unit 2) consists of subrounded pebbles and small cobbles in an abundant matrix of phyllite chips of granule to coarse sand size. Some large cobbles and rare small boulders up to 35 cm diameter are present, mainly concentrated in a single stone line. Most clasts are phyllite or quartz with phyllite adhesions. A 35-cm-thick bed of muddy pebble gravel is present 2 m below the gravel's upper contact. It could represent brief damming of the Noatak valley prior to the longer-lasting inundation represented by unit 3. At the south end of the bluff, the gravel extends lower; it dips southward at 15° to 18° and interfingers southward with phyllitic sand of unit 1. Clast lithology is the same as at the north end of the bluff, but some beds have a matrix of muddy phyllite chips. A lens of small detrital wood fragments from a probable channel-filling deposit 2 m below the top of the gravel near the north end of the bluff has a non-finite age of >47,590 yr B.P.

The thaw ampitheater exposes pebbles, small cobbles, and sparse larger clasts in a matrix of brown slightly clayey silt (unit 3). Larger clasts, up to 38 cm long, are subangular quartz with phyllite adhesions. Smaller, more rounded pebbles and small cobbles include ultramafic rock types, sandstone, and limestone. The stony silt of unit 3 is interpreted as a late-glacial or postglacial lake deposit that received some input from river gravels and erosion of local phyllitic bedrock.

The lag deposit at the base of the bluff includes striated pyroxenite boulders up to 39 cm diameter from the DeLong Mountains and large blocks of quartz with phyllite adhesions, which probably are derived locally.

Discussion

The sequence of sediments at exposure Sp-1 records the advance of a tongue of the Noatak valley glacier southward up Sapun Creek, followed by its recession. The fluvial slackwater fluvial deposits that grade upward into laminated lacustrine sediments reflect base-level rise as the advancing glacier progressively blocked the valley of Sapun Creek. The overly-



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	11	**Stony silt.** Pebbles, small cobbles, and sparse larger clasts in matrix of brown slightly clayey silt. **Glaciolacustrine deposit.**
2	7-10	**Gravel.** Subrounded pebbles and small cobbles, with sparse larger clasts, in matrix of phyllite chips. Bed of muddy pebble gravel 2 m below upper contact. Thickens southward. **Alluvium.**
1	29-33	**Sand and fine gravel.** Sand is dark gray, and dominantly phyllite chips. Gravel is granules and dispersed pebbles in sand matrix. some coarser (pebble-small-cobble) gravel present. Block of sediment near north end of bluff (unit 1a) contains wood fragments. **Deltaic deposit.**

Figure 93. Exposure Sp-2. East side Sapun Creek 3.3 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

ing diamict records glacial advance across the site, with some water-washing at its face by the still-flowing Sapun Creek. Probable deltaic beds above the diamict were formed in standing water by Sapun Creek as the glacier began receding from its valley. The overlying alluvium, which contains dominantly local rock types with minor admixture of reworked glacial clasts, occurs to the unusual height of 91.5 m above river level. It may have been deposited while the receding ice tongue was still close enough to form a high local base level for Sapun Creek.

Exposure Sp-2, at the south margin of the Noatak River valley, has been more severely eroded than Sp-1. It records a sequence of fluvial and lacustrine sediments that formed after recession of the glacier back into the Noatak valley. The basal sand and fine gravel comprises part of a deltaic deposit that formed while the receding ice front remained nearby and meltwater flowed south into the valley of Sapun Creek. The overlying gravel resembles nonglacial alluvium that was deposited along the Noatak River and its tributaries during interglacial and interstadial intervals (Hamilton, 2001). The glaciolacustrine stony silt exposed in the thaw amphitheater represents a later glacier advance that blocked the Noatak valley. This silt exposure occurs at the same height as the deltaic deposit (unit 3) at Sp-1, and very likely is contemporaneous with it.

Exposure Nk-48 is situated only a few kilometers north of the Sapun Creek exposures, but its relation to those deposits is unclear. If the diamicts at Nk-48 and Sp-1 are tills deposited during the same glacial advance, then much of the subsequent sediment record has been lost to erosion at Nk-48. Two radiocarbon age determinations were made on organic samples from each of the three bluffs (Nk-48, Sp-1, and Sp-2). All ages are non-finite, and confirm that most of the events recorded in the bluffs took place prior to the Avan (late Wisconsin) glaciation. However, these minimum age limits are of little value in correlating events and deposits between the three bluffs.

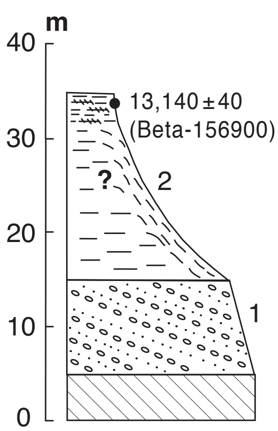
Sapun Creek to Kaluktavik River

Below Sapun Creek, the Noatak River flows generally westward for 28 km to the confluence of Kaluktuvik River. Its valley floor is wider here than above Aklumayuak Creek, and deposits of late Pleistocene age are more commonly preserved in river bluffs. However, deep cut-and-fill relations in some bluffs attest to the erosional power of the Noatak River through this stretch. Most of the river bluffs are heavily vegetated, but five of them (Nk-49 through Nk-53) contained exposures sufficient for at least partial measurement and description.

Exposure Nk-49

The poorly exposed face of a 35-m terrace a short distance below Sapun Creek exhibits bedrock near river level overlain by gravel beneath a thick silt deposit (fig. 94). The gravel (unit 1) is dominated by pebbles and small cobbles; larger cobbles are sparse and boulders are absent. Platy stones are faintly imbricated. Major lithologies are vein quartz (derived from schist), sandstone, quartzite, black chert, and green crystalline rock. Ultramafic rock types are rare. Matrix is poorly sorted sand and granules, with quartz grains abundant and few phyllite chips. The unit is faintly bedded into pebble- and granule-rich layers that are inclined downvalley. Clast size and composition are typical of nonglacial alluvium.

The overlying silt (unit 2) has slumped and flowed, and undisturbed exposures are limited to the headwalls of thaw amphitheaters. The upper 3 m of the deposit is faintly laminated, with black peaty beds, lenses, and layers parallel to bedding. Woody peat from 1.1 m below the surface is dated at 13,140 ±40 yr B.P. This part of unit 2 may have formed on a floodplain or in a thaw lake. Although lower-lying parts of unit 2 are covered or severely disturbed, only stone-free silt is exposed. The near-level upper surface of unit 2 and its absence from slightly higher bedrock outcrops indicates that it



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	20	**Silt.** Dark gray (5Y 4/1) silt, with black peaty lenses and layers through upper 3m. Lower 17 m obscured by slump blocks, but appears stone free. **Lacustrine?**
1	10	**Gravel.** Rounded to subrounded pebbles, small cobbles, and sparse medium cobbles. Faintly bedded into pebble- and granule-rich layers 10-40 cm thick that dip downvalley at 10^{o} to 13^{o}. **Deltaic deposit?**
--	5	**Bedrock.** Gray slate.

Figure 94. Exposure Nk-49. South side Noatak River 4.5 km downvalley from Sapun Creek. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

probably is a lacustrine rather than eolian (loess) deposit. The absence of stones suggests that the deposit was derived from nonglacial sources.

Exposures Nk-50A and Nk-50B

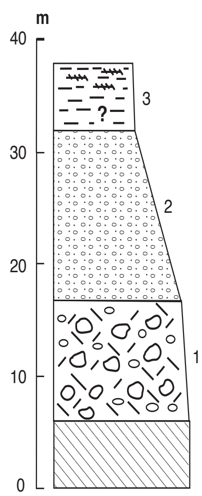
Two exposures, Nk-50A and Nk-50B were measured about 1 km apart along a long south-facing bluff that declines in height downvalley from about 38 m at Nk-50A to 28 m near its west end at Nk-50B.

At Nk-50A, bedrock is overlain by diamict, probably till, beneath gravel and capping silt (fig. 95). The diamict (unit 1) contains unsorted and unstratified, faceted and striated stones up to boulder size (1.2 m diameter) in a compact silty matrix that maintains a near-vertical bluff face. The clasts mainly are rounded pebbles and small cobbles that probably were derived from river gravels entrained and transported by a glacier that advanced westward down the Noatak valley. Gravel above the till consists of clasts to medium cobble size, with sparse larger cobbles, in a sandy matrix. Black chert is abundant in the pebble range, but the largest clasts are ultramafic rocks and quartzites. The bluff is capped by about 6 m of poorly exposed silt with peat lenses and layers visible through its upper 2 m.

Exposure Nk-50B, which is incised into the flank of an alluvial terrace that declines in height downvalley, stood 35 m high at the locality where measured in 1986 and 28 m where measured nearby in 2000 (only the most recent measured section is shown in fig. 96). In both measured sections, river gravel stands 23-24 m high and is capped by 5-10 m of silt. The alluvial gravel (unit 1) consists of pebbles to medium cobbles, with sparse large cobbles, in a gray sandy matrix. Ultramafic rocks and quartzites dominate the larger clasts. The silt (unit 2) is faintly laminated near its base, where it contains granules and fragments of detrital wood dated at 25,060 ±230 yr B.P. This deposit grades upward into an oxidized, structureless, probably eolian silt. It is interpreted as a floodplain deposit overlain by loess.

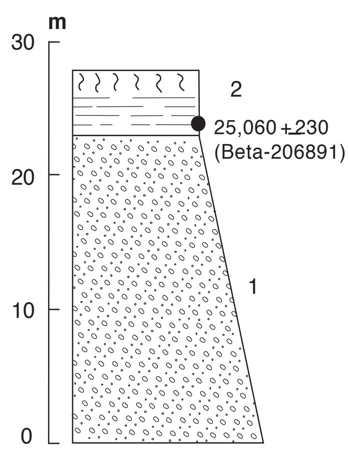
Exposures Nk-51A and Nk-51B

A heavily wooded bluff about 50 m high extends for greater than 2 km along the south side of the Noatak River about 7-9 km above the mouth of Kaluktavik River. The bluff intersects glaciolacustrine deposits which cover this sector of the valley floor (see fig. 82). Separate sections were measured in 1986 and 2000 where localized exposures present at those times provided some information on bluff composition.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	6	**Silt.** Brown to gray silt; poorly exposed. Peat layers and lenses through upper 2 m. **Floodplain deposit?**
2	16	**Gravel.** Rounded to subrounded pebbles, small to medium cobbles, and sparse larger cobbles; some beds extremely sandy. Largest clasts are ultramafic rocks and quartzites. **Alluvium.**
1	10-11	**Diamict.** Rounded pebbles and small cobbles, with sparse larger stones up to 1.2 m diameter, in matrix of compact olive gray (5Y 5/2) sandy silt. **Till.**
--	5-6	**Bedrock.** Gray slate.

Figure 95. Exposure Nk-50A. North side Noatak River 8.5 km below mouth of Sapun Creek.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	5	**Silt.** Grayish brown (10Y 5/2) and faintly laminated near base, with lenses of granules and detrital wood fragments. Grades upward into light yellowish brown structureless silt. Capped by about 0.5 m peat. **Floodplain deposit with loess cap.**
1	23	**Gravel.** Rounded to subrounded pebbles and small to medium cobbles, with sparse large cobbles, in matrix of poorly sorted sand and slate chips.Ultramafic rocks and quartzites dominate larger clasts. **Alluvium.**

Figure 96. Exposure Nk-50B. North side Noatak River; about 1 km farther west along face of same bluff as Nk-50A. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

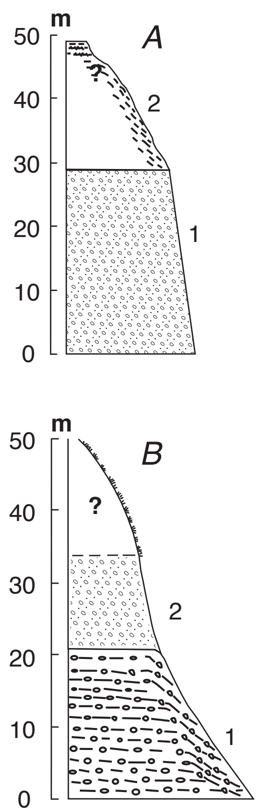
At Nk-51A, thick silt overlies gravel (fig. 97*A*). The gravel appears to be fairly well sorted and mature nonglacial alluvium. Its clasts dominantly are quartz, schist, and sandstone transported by southern tributaries, and only a small percentage (about 5 percent) of ultramafic rocks derived from glacial source areas in the DeLong Mountains. The overlying silt is severely slumped in all exposures, but it appears to contain few or no stones. The headwalls of thaw amphitheaters expose 2-3 m of brown silt containing lenses and layers of peat.

Exposure Nk-51B is completely covered above 30-35 m height, but debris flows below that level provide limited exposures of stony silt overlain by gravel (fig. 97*B*). Actively moving, unvegetated flow surfaces exhibit abundant stones, many of them faceted and striated, in a silt matrix. Ultramafic rocks and quartzites, abundant in the larger fractions, are derived from glacial source areas in the DeLong Mountains. The overlying gravel is nonglacial in character, with abundant quartz derived from southern tributaries to the Noatak River. Its upper contact is concealed.

Exposure Nk-52

A largely vegetated bluff along the north side of the Noatak River is situated at the downstream end of a 86-m-high river-cut bedrock face. A partial exposure of the bluff was examined in 1986, but 14 years later it was almost entirely concealed. Stony silt is overlain by probable stone-free brown silt (fig. 98).

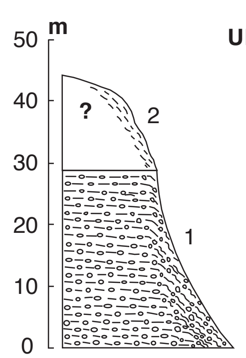
The stony silt (unit 1), which flows readily in all exposures, contains numerous rounded pebbles and small cobbles and larger subrounded stones up to small boulder size in abundant dark gray clayey silt. The boulders include mafic igneous rock types not noted farther upvalley. The overlying fine-grained sediment (unit 2) is slumped and nearly entirely vegetated, but stone-free brown silt is present in rare exposures.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	20	**Silt.** Dark reddish brown (5 YR 2.5/2), with peat layers and lenses, through upper 2-3 m. Largely concealed below this level. **Lacustrine or glaciolacustrine deposit?**
1	29	**Gravel.** Rounded to subrounded pebbles, small to medium cobbles, and sparse large cobbles in abundant matrix of gray subangular medium to coarse sand with slate chips. **Alluvium.**

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
--	16+	**Covered.**
2	13	**Gravel.** Rounded pebbles and small cobbles in sandy matrix that includes abundant phyllite chips. Quartz relatively abundant (30 percent of clasts). **Alluvium.**
1	21	**Stony silt.** Clasts to medium cobble size, with some larger clasts up to 40 cm diameter, in matrix of dark gray (7.5YR 4/0) gritty silt. Many clasts faceted and striated. Ultramafic rocks and quartzites are abundant in larger clast sizes. Quartz relatively rare (<5 percent). **Glaciolacustrine deposit.**

Figure 97. Exposure Nk-51. South bank Noatak River about 8 km upvalley from mouth of Kaluktavik River. (*A*) Section measured in 1986. (*B*) Section measured in 2000.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	12	**Silt?** Largely covered. Brown silt visible in rare exposures. **Lacustrine or glaciolacustrine deposit?**
1	29	**Stony silt.** Rounded pebbles and small cobbles, with some subrounded stones up to small boulder size (70 cm length), in matrix of slightly plastic dark gray (10YR 4/1) clayey silt. **Glaciolacustrine deposit.**

Figure 98. Exposure Nk-52. North side Noatak River 6 km upvalley from mouth of Kaluktavik River.

Exposure Nk-53

A vegetated bluff about 4 km above Kaluktavik River is covered by stabilized and largely vegetated debris flows. Where measured in 1986, a debris flow extended to a height of 36.5 m on the bluff face. Where measured in 2000, a flow exposed stony silt to a height of only 19 m, where it was overlain by gravel (fig. 99).

The stony silt (unit 1) consists of clasts up to small boulder size, commonly striated and faceted, in an abundant matrix of gray gritty silt. The lower part of the flow has abundant rounded pebbles and small cobbles; it may represent a gravel unit beneath the flow that perhaps formed prior to deposition of the stony silt. The overlying gravel (unit 2), which is only exposed to 2 m or less thickness, appears to be nonglacial alluvium. Lag boulders up to 1.6 m long along the river edge include ferruginous sandstone and diverse ultramafic rock types.

Discussion

The glaciolacustrine deposits that cover most of the Noatak valley floor between Sapun Creek and Kaluktavik River are draped over arcuate ridges (Hamilton, 2003 and in press) that resemble buried end moraines. The orientations of these features suggest that a glacier flowed south down the valley of Kaluktavik River into the Noatak valley, where it spread into a broader lobe that dammed the Noatak drainage. During part of this time, it may have contacted a separate glacier that flowed westward down the Noatak valley, or the two glacial advances may not have been in phase. Because outermost end moraines of probable Anisak age have been mapped farther north up Kaluktavik River valley and farther east up the Noatak valley, the subsurface moraines around the mouth of the Kaluktavik are inferred to date from the preceding Makpik glaciation.

The seven bluff exposures measured along the Noatak River between the Sapun and Kaluktavik drainages are obscured partly by flows and vegetation, and part of their record has been lost to erosion by the Noatak River. However, some consistent relations are evident: (1) sediments predominantly are either stone-free lacustrine silt, stony glaciolacustrine silt, or nonglacial river alluvium, (2) stone-free silt always occurs above the stony silt, and (3) alluvial gravel is never exposed above 34 m height. Compact till is exposed in bluffs near Sapun Creek but was not seen farther downvalley. Stony silt occurs to 20-30 m height in all three exposures within 8 km of the Kaluktavik River mouth, but was not recorded farther upvalley. Stone-free silt, the uppermost unit in most bluffs, occurs in deposits as thick as 20 m and to heights of 50 m above the river. Its thickness and faint laminations suggest lacustrine origin, but absence of dropstones indicates that it must have formed in a lake dammed by a glacier at a location sufficiently distant downvalley that no debris-carrying floating ice reached this sector of the Noatak River valley.

Exposure Nk-49 has unusual delta-like alluvium near its base that resembles the lower gravel at Nk-48. Peaty lenses at about 34 m height near the top of the stone-free silt unit are dated at 13.1 ka. The river evidently flowed at this level for some time after downcutting from the 50-m surface. This age is very close to the 13.3 ka and 13.4 ka ages on a probable floodplain deposit at about 20 m height at Nk-47, about 8 km farther upvalley. Perhaps the Noatak River at this time was still partly blocked by glacier ice downvalley and was flowing sluggishly at a gradient gentler than that of the present day. The three similar radiocarbon ages also may indicate that general revegetation of this sector of the Noatak River valley began at this time.

Exposure Nk-50A contains a compact till that may correlate with tills mapped at exposures Nk-48 and Sp-1. Overlying gravel and probable floodplain deposits are close in height to the silt deposits at Nk-49, suggesting that the Noatak River fluctuated near this level for some time after drainage of the lake. Both measured sections of exposure Nk-50B, farther along the same bluff, consist of postglacial alluvium inset into the older deposits.

Exposure Nk-51B contains glaciolacustrine stony silt at its base that is overlain by gravel exposed to a height of about 34 m above the river. Although the nearby bluff Nk-51A contains comparable gravel that rises to a somewhat similar height, no stony silt is evident beneath it. The Noatak River must have downcut and eradicated the stony silt here, then deposited gravel as it alleviated again. Both bluffs stand about 50 m high, and both may be capped by stone-free lacustrine silt, although exposures are limited.

Exposure Nk-52 rises inland to a near-level surface that may be close in height to the 50-m level noted in upvalley exposures. Like those other high bluffs, Nk-52 exposes stone-

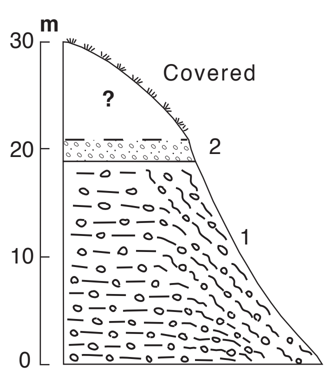


Figure 99. Exposure Nk-53. North side Noatak River 4.2 km upstream from mouth of Kaluktavik River.

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	>2	**Gravel.** Rounded pebbles and cobbles in sandy matrix. **Alluvium.**
1	19	**Stony silt.** Subangular to subrounded stones up to small boulder size, commonly faceted and striated, in matrix of gray (5Y 5/1) gritty silt. **Glaciolacustrine deposit.**

free silt above silty glaciolacustrine sediment, but any intervening alluvium has been lost to erosion. The glaciolacustrine silt contains boulders that are larger than those noted upvalley, and also rock types not found upvalley. These clasts indicate probable input of sediments derived from the Kaluktavik glacier.

A lower bluff close to the mouth of Kaluktavik River (Nk-53) may have been eroded down to about 30-m height during late-glacial downcutting. Large lag boulders at its base indicate that the Noatak River could have cut into and eroded till deposited directly by the Kaluktavik glacier at this locality.

Lower Kaluktavik River Valley

Two exposures near the mouth of Kaluktavik River intersect glacial and proglacial deposits associated with an end moraine of the glacier that flowed south down the valley of Kaluktavik River (see fig. 82).

Exposure Kl-1

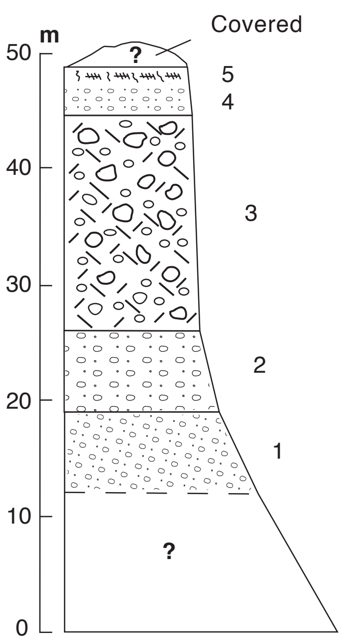
A prominent river bluff about a kilometer above the mouth of Kaluktavik River occurs where a probable end moraine, largely covered by younger glaciolacustrine deposits, crosses the valley center. The former moraine position is marked by a concentration of large boulders up to 1.5 m diameter in the river bed, by elongated boulder-littered knobs that stand about 60 m above the river, and by thick but poorly exposed diamict in the weathered bluff face (fig. 100). Basal debris aprons 15-19 m high obscure the lowermost sediments.

The lowest exposed deposit (unit 1) is fine gravel at least 7 m thick that includes some beds of silt-coated pebbles and others of pebble-small-cobble gravel in a silty matrix. These sediments may have been deposited in standing water or in sluggishly moving, very silty water. The overlying coarse gravel (unit 2) has abundant large cobbles and some very small boulders. It is crudely bedded, and exhibits some size sorting. Diamict up to about 18 m thick (unit 3) dominates the exposure. Where measured in 1986, it had all the attributes of a subglacial till—unsorted and unstratified, faceted and striated stones up to 1 m diameter in a compact matrix of sandy silt that locally maintained near-vertical faces. A section a short distance to the south, measured in 2000, contained coarse gravel like that seen previously, but the overlying compact diamict consisted of unstratified pebbles, small cobbles, and sparse larger stones in a muddy matrix. Striations were rare, and those few present were shallow and diffuse. The tillstones at this locality may have been reworked by meltwater or river water, which mixed them with river gravels and then deposited them in a muddy environment.

The gravel above the diamict (unit 4) appears to be nonglacial river alluvium. The section is capped by silt, which is up to 3.2 m thick locally but commonly is eroded.

Exposure Kl-2

At the mouth of Kaluktavik River, the poorly exposed face of a 33-m river terrace exposes pebble gravel beneath silt-capped cobble gravel (fig. 101). The terrace extends up the river about a kilometer to exposure Kl-1, where it merges with the outer face of the end moraine.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	0.4	**Bluff cap.** Sod and peat above frost-mixed stony brown silt.
4	4.0	**Gravel.** Rounded pebbles and cobbles in sandy matrix. **Alluvium.**
3	18	**Diamict.** Unstratified pebbles, small cobbles, and sparse larger stones up to 1 m diameter in sandy matrix. Few stones striated; some bear shallow and diffuse marks like those formed by scour of river ice. **Till.**
2	6-7	**Coarse gravel.** Large cobbles and some very small boulders. Crudely bedded, with 2 prominent cobble-rich horizons. **Advance outwash?**
1	≥7	**Fine gravel.** Pebble-small-cobble gravel with silty matrix and openwork silt-coated pebbles. Poorly exposed, with base covered. **Slackwater deposit?**
--	19	**Covered.** Shallow gullies expose fine sand or silt. **Slackwater or lacustrine deposit?**

Figure 100. Exposure Kl-1. West side Kaluktavik River 0.9 km above its mouth.

The gravel (unit 1) consists of rounded to subrounded pebbles, cobbles, and rare very small boulders that commonly are silt-coated. Most of the unit is pebble-rich, with an abundant matrix of poorly sorted silty sand with rock chips. The upper 3 m is coarser cobble gravel, with large cobbles and some small boulders concentrated near the top. Clasts include several igneous rock types not seen farther up the Noatak River valley that must be derived from the Kaluktavik drainage system. The overlying silt (unit 2) is variable in thickness, being deepest where it fills channels on the gravel surface. It is faintly bedded, with some sand and peat lenses present, and bears a peat cap about 0.2 m thick.

The poorly exposed gravel appears to be deltaic, with about 3 m of coarser topset beds above inclined foreset beds. The silt coatings on the clasts indicate probable deposition in a turbid body of standing water. The overlying silt appears water-laid, and may be a floodplain deposit.

Exposure Kl-3

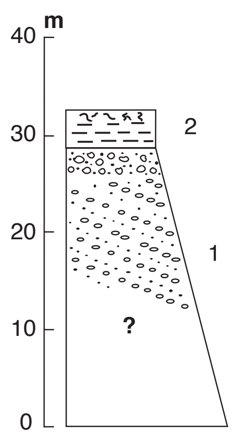
A gravel terrace 7.5 km up Kaluktavik River from exposure K-1 stands 15 m high and consists dominantly of imbricated cobble gravel capped by silt (fig. 102). Layers of pebbles and small cobbles alternate with cobble lenses within the gravel (unit 1), and a sand layer 15 cm thick occurs 5 m above its base. Dip directions of the imbricated stones are identical to that in the modern river bed, and the alternating gravel layers and lenses are like modern bar and channel deposits.

The gravel is overlain by 70 cm of stony silt that is capped by 40 cm of structureless silt (unit 2). Many stones in the stony silt stand vertically, indicating that they have been frost-heaved upward from the underlying gravel. Deformed lenses of brown peat also attest to frost action in the stony silt. The overlying structureless silt is stone-free, and probably formed as loess. A nearly continuous buried peat at the contact between the stony and stone-free silts is radiocarbon dated at 2760 ±40 yr B.P. It probably represents the ground surface at the time that influx of eolian silt began.

Discussion

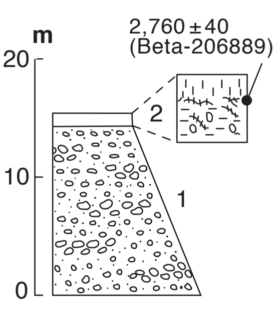
Exposures along the lower Kaluktavik River intersect the core and outer face of an end moraine at Kl-1 and its associated outwash train at Kl-2 (see fig. 103). Fine gravel beneath the till and outwash may be a slackwater deposit that grades downvalley into deltaic sediments. It may have been deposited as advancing glaciers farther down the Noatak valley crossed the valley floor and dammed the river. The till-outwash association represents full-glacial conditions in the Kaluktavik drainage. Distinctive clast lithologies confirm that ice flowed southward down the Kaluktavik valley and across the north part of the Noatak valley floor. The outwash gravel aggraded to a height of about 30 m, and may correlate with alluvial-terrace remnants of similar height farther up the Noatak River valley. Silt and nonglacial alluvium are present locally above the glacial deposits.

The 15-m terrace exposed farther upvalley at Kl-3 was formed by aggrading channel deposits of Kaluktavik River. The terrace surface then was subjected to intense frost mixing that was followed in late Holocene time by loess deposition.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	0.6-3.4	**Silt.** Dark gray (5Y 4.5/1), faintly bedded; contains some sand lenses. **Floodplain deposit.**
1	26-29	**Gravel.** Dominantly pebble-rich, with abundant poorly sorted silty sand matrix containing numerous rock chips. Clasts in some beds are silt coated. Upper 3 m is coarser (cobble gravel with very small boulders up to 37 cm long), and includes igneous rock types not seen farther up Noatak River valley. **Deltaic deposit?**

Figure 101. Exposure Kl-2. West side Kaluktavik River at its mouth.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	1.1	**Silt.** Structureless, stone-free, tan to gray silt (40 cm) above stony tan silt with deformed peat lenses (70 cm). **Loess above floodplain deposit.**
1	14.4	**Gravel.** Imbricated cobble gravel. Layers of pebbles and small cobbles alternate with cobble lenses. **Alluvium.**

Figure 102. Exposure Kl-3. West side Kaluktavik River 8.5 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

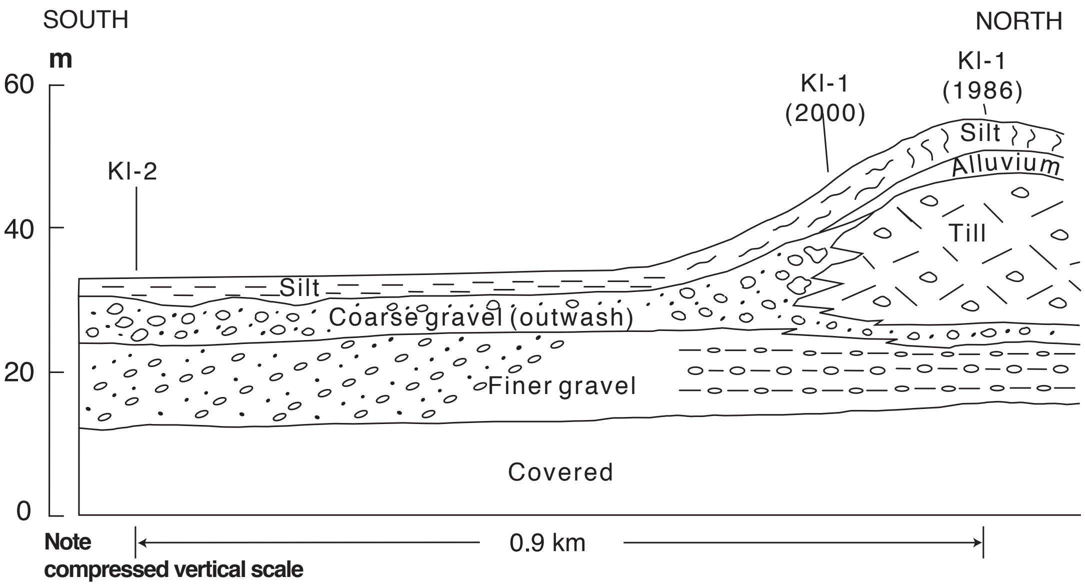


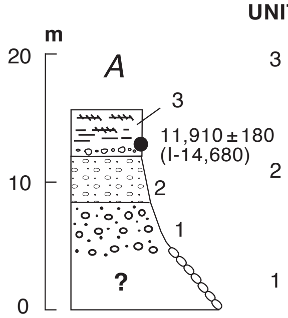
Figure 103. Sketch showing geologic relations of end moraine and outwash train near mouth of Kaluktavik River valley.

Kaluktavik River to Noatak Canyon

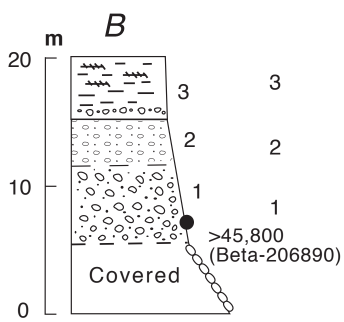
For 18 km downvalley from the Kaluktavik River confluence, the Noatak River meanders through glacial-lake deposits into which a series of postglacial river terraces have been incised. Beyond this stretch, the river intersects drift sheets and associated end moraines deposited by ice lobes that diverged from the southwest-trending Kugururok valley glacier; these flowed more directly southward across low divides and then into the Noatak valley (see fig. 82). Exposures upvalley from the end-moraine belt exhibit glaciolacustrine silt and stony silt, as well as alluvial gravel and floodplain deposits at multiple terrace levels. In the end-moraine zone, a large and complex river bluff exposes interfingering till and glaciolacustrine sediments bracketed by deposits of alluvial gravel.

Exposure Nk-54

A short distance below the Kaluktavik River confluence, exposure Nk-54 is located along the convex side of a meander bend. Because the Noatak River was downcutting as it eroded the meander laterally, it created an inclined floodplain surface (a “slip-off slope”) that declines in height northward toward the margin of the modern floodplain. Similar depositional sequences were measured at two localities that differ only in height: 15.5 m at Nk-54A and 20 m at Nk-54B (fig. 104).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	3.5	**Silt.** Gray to dark gray (10YR 5/1 to 4/1); faintly bedded. Contains peat layers up to 10 cm thick (most common near top) and detrital wood fragments (most common near base). Sand and gravel lenses through basal 0.6 m. **Floodplain deposit.**
2	3.3	**Oxidized gravel.** Rounded pebbles, small cobbles, and rare medium cobbles in sparse sandy matrix. Sand grains poorly sorted, subangular to subrounded, with quartz abundant (40% of all grains). All clasts oxide-coated. **Fluvial bar deposit.**
1	>2.1	**Coarse gravel.** Rounded to subrounded pebbles, cobbles, and rare very small boulders in sparse sand matrix. Some beds lack matrix, and their clasts are silt covered. Base not exposed. **Fluvial channel deposit.**
--	6.6	**Covered.** Lag pavement of coarse gravel.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	4.9	**Silt.** As described for Nk-54A, unit 3. Possibly thickened by slumping. **Floodplain deposit.**
2	2.9	**Pebble-small-cobble gravel.** As described for Nk-54A, unit 2. **Fluvial bar deposit.**
1	11.6	**Coarse gravel.** As described for Nk-54A, unit 1. Contains lenca. 1 m thick of bedded sand, silty fine sand, and sandy pebble gravel. Base not exposed. **Fluvial channel deposit.**

Figure 104. Exposure Nk-54. Slip-off slope, southwest side Noatak River 3 km below mouth of Kaluktavik River. (*A*) Exposure where sloping surface is 15.5 m high. (*B*) Exposure a short distance upstream from A, where surface is 20 m high. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

Coarse gravel at the base of each section probably is channel gravel of the postglacial Noatak River. At Nk-54B, it contains detrital wood that has a non-finite age of >45,800 yr B.P. This age is much too great for the postglacial gravel; the wood therefore must have been redeposited from older sediment. The channel gravel is overlain by finer gravel that may have been deposited on river bars. The probable floodplain deposit that caps the section contains detrital wood and lenses of sandy alluvium near its base and peaty layers at higher levels. A fragment of detrital willow (*Salix*) wood near the base of the floodplain silt at Nk-53A has a radiocarbon age of 11,910 ±180 yr B.P. At each locality, the sediment succession was deposited, and the floodplain later abandoned, as the Noatak River continued downcutting toward its modern level.

Exposure Nk-55 (not illustrated)

On the north side of the Noatak River about 4 km downstream from the mouth of Kaluktavik River, a prominent bedrock bluff rises 110 m above river level. A gravel bench at 96 m height on the flank of the bedrock (phyllite) bluff contains subrounded pebbles and cobbles with a few very small boulders. The stones are somewhat weathered, and some are fractured. The gravel can be traced downward to 55 m above river level, but part of its apparent thickness may be the result of draping over underlying bedrock.

Its geomorphic setting indicates that the gravel is part of a meltwater channelway that issued from the end moraine near the mouth of Kaluktavik River valley. The weathered state of the gravel is consistent with Makpik (Itkillik I) age, which is the assumed age of that end moraine based on regional mapping (Hamilton, 2003 and in press).

Exposure Nk-56

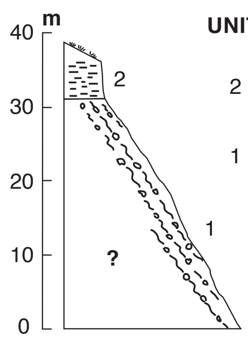
A fresh debris flow originates in a thaw ampitheater (fig. 105) along the east side of the Noatak River about 1.5 km below exposure Nk-55. This exposure was recorded for the first time in 2000 because no debris flow had yet taken place at this locality at the time of the 1986 traverse.

Stony fine-grained glaciolacustrine sediments (unit 1) are traceable from the river edge up to 32 m height. Clasts up to cobble size, with some small boulders, occur in a matrix of silt to clayey silt. Some water-washed beds up to 1 m thick within the deposit probably represent brief intervals of flowing water that followed drawdown of the glacial lake by breaching of its ice dam. Ice-rich gray silt (unit 2) is exposed in the amphitheater's headwall.

Formerly active but now vegetated flow ampitheaters occur higher on the valley side here. They indicate that glaciolacustrine sediments probably originally stood higher, and that those exposed at Nk-56 may have been truncated by river erosion.

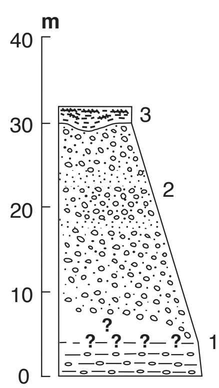
Exposure Nk-57

A bluff on the north side of the Noatak River is about equidistant between Kaluktavik River and Noatak Canyon, being 15 km downvalley from the river's mouth and 14 km upvalley from the canyon (see fig. 82). The bluff intersects an alluvial terrace that stands 32 m high (fig. 106).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	4	**Silt.** Ice-rich gray (N5) silt. **Lake or floodplain-pond deposit.**
1	32	**Stony silt.** Dark gray (N4) stony silt to clayey silt. Contains pebbles, cobbles, and sparse very small boulders up to 70 cm length. Some stones faintly striated. Contains several beds up to 1 m thick of faintly bedded, poorly sorted sand and granules with scattered pebbles and some thin (0.5-1.0 cm) silt beds. **Glaciolacustrine deposit.**

Figure 105. Exposure Nk-56. East side Noatak River 5.5 km downvalley from mouth of Kaluktavik River.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	1.8-2.8	**Peaty silt.** Brown to grayish brown silt, coarsening near base to medium to fine sand with faint parallel bedding. Peat lenses in upper 1 m; dipping to 1.5 m depth in channel fills. **Floodplain deposit.**
2	27-26	**Gravel.** Rounded pebbles, small to medium cobbles, and some larger cobbles in sparse sandy matrix. Some beds openwork, with small pebbles and granules the smallest fraction present. Other beds contain abundant gray rock chips of coarse sand size. **Alluvium.**
1	4+	**Stony silt.** Dark gray (5Y 4/1) stony, gritty silt. Some stones striated. **Glaciolacustrine deposit.**

Figure 106. Exposure Nk-57. North side Noatak River 14 km upvalley from Noatak Canyon.

Glaciolacustrine stony silt (unit 1) is exposed to 4 m above river level, the height to which the base of the bluff has been freshly eroded by spring floods. The silt probably rises higher, but its upper contact is obscured by gravel that has slumped downward. The overlying gravel (unit 2) is nonglacial alluvium consisting of rounded to subrounded clasts to medium cobble size, with some larger cobbles and a few very small boulders up to 36 cm long. Some beds of finer sediment are present. The bluff is capped by silt (unit 3), which is peaty in its upper parts and sandy near its base. The silt thickens downward where channels have incised the surface of the underlying gravel. It is interpreted to be a floodplain deposit.

A lower terrace 14 m high is inset into the 32-m terrace and extends downvalley from it. It continues at this level nearly to the active point bar that marks the apex of this river bend, suggesting that the river may have remained about 14 m above its present level for a significant period while it meandered laterally.

Exposure Nk-58

Exposures Nk-58 and Nk-57, which stand 5 km apart along the same bluff line that follows the north side of the Noatak River, are similar in composition. However, rather than forming part of a river terrace, the bluff at Nk-58 rounds back to a somewhat higher, undulating upper surface. Coarse alluvial gravel (unit 1; fig. 107) is exposed to about 33 m height, but its lower part is obscured by a younger alluvial terrace (fig. 107). Its upper contact is obscured by vegetated brown silt (unit 2) that drapes down over the upper bluff face.

The lower alluvial terrace, which stands about 15 m high, is composed of finer gravel, dominantly pebbles and small cobbles, in a matrix of dark gray sand and granules.

Exposure Nk-59

A very large bluff a short distance upvalley from Noatak Canyon intersects a complex assemblage of glacial deposits that formed when a south-flowing lobe of the Kugururok valley glacier advanced into the center of the Noatak valley (see fig. 82). The exposure, which stands 30-40 m high, extends about 850 m along the north side of the Noatak River. It was mapped during a 1-week period in 1986 by measuring a base line along the river edge and then describing stratigraphic sections measured vertically at 50-m intervals. The depositional record of the western half of the bluff is complex and was partly obscured by debris flows in 1986 (fig. 108*A*). The eastern half of the bluff was better exposed and had more consistent stratigraphy (fig.108*B*); this part of the bluff therefore is described first.

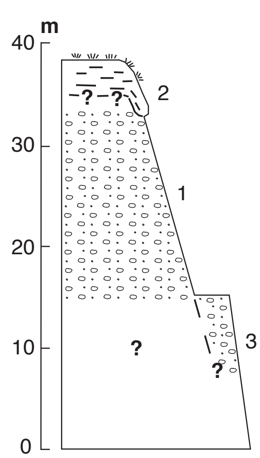
Eastern Sector

Through the eastern part of the exposure, preglacial gravel is overlain by till and ice-contact sediments that grade upvalley into deltaic and lacustrine sediments. These deposits were eroded to various levels by the Noatak River, which then deposited alluvial gravel above them. The section is capped by silt and peaty silt.

The basal gravel (unit 1; fig. 108*C*), which generally stands to heights of 15-16 m above the modern river, consists dominantly of pebbles and small cobbles in a sandy matrix. Some centimeter-scale beds of medium sand, sand with granules, and silt-covered openwork pebbles are present. The base of the gravel is obscured by debris aprons that originate 7-13 m above the river, rising in height eastward. The uppermost part of the gravel contains silt introduced from above, and it locally is oxidized to about 40 cm depth. The gravel is preglacial alluvium that locally was weathered prior to glaciation and later altered by silt penetrating downward from overlying glaciolacustrine sediments. Locally it is overlain by 0.1-0.3 m of floodplain and pond deposits that consist of compact brown to gray silt and clayey silt. At 150 m E (see fig.108*B*), silt and clay couplets form the lower part of a 3-m lacustrine section (unit 2; figs. 108*B* and 108*C*). The couplets probably are annual varves because the upward transition from silt to clay (which takes place during autumn freezeup) is transitional but that from clay to silt (spring breakup) is abrupt.

A highly compact diamict of nonsorted and nonbedded clasts in a matrix of silty sand (unit 3a) forms near-vertical faces 7-11 m high through the east-central part of the bluff

Figure 107. Exposure Nk-58. North side Noatak River 9 km upvalley from Noatak Canyon.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	15.3	**Gravel of lower terrace.** Rounded to subrounded pebbles, small cobbles, and some larger cobbles in abundant matrix of dark gray immature sand and granules. **Younger alluvium.**
2	5.5	**Silt.** Brown silt. Mostly covered by vegetation. **Origin uncertain.**
1	17.8+	**Gravel of upper terrace.** Subrounded to rounded pebbles, cobbles, and sparse very small boulders (up to 35 cm length) in matrix of immature coarse sand and granules. **Older alluvium.**

between base-line positions of about 25 m W and 150 m E. The clasts commonly are striated and faceted. Pebbles and cobbles predominate, with some small boulders also present. This deposit is interpreted as massive till, derived largely by reworking of river gravels, that interfingers eastward (upvalley) with probable deltaic deposits.

At 150 m E (fig. 108B), the diamict underlies and interfingers with beds of sand and gravel that dip upvalley at 11° to 18° (unit 3c; fig. 108C). The diamict, which forms vertical faces in the lower half of this unit, generally exhibits weakly defined size sorting and bedding; it generally contains clasts no larger than medium cobble size in a silty matrix. The gravel commonly is openwork pebbles and small cobbles, with silt partly filling interstices between the clasts. The sand commonly is cross-bedded, with medium to fine sand predominant. The basal till-like sediment may represent advance outwash that was deposited in a proglacial lake (unit 3b) and later overridden by advancing glacier ice. The sand and gravel beds form part of the proglacial deltaic complex.

The deltaic deposit (unit 2c) extends from about 150 m E to 250 m E. It dominantly consists of beds 15-45 cm thick of pebble and cobble gravel, and of parallel-bedded sand and silty fine sand. These beds dip upvalley and toward the Noatak valley center at angles from 15° to 20°. Some gravel beds consist of well-sorted silt-covered stones that lack any matrix. In some thicker (up to 1 m) structureless beds, pebbles and sparse small cobbles occur in an unsorted matrix of silt and sand. A channel-filling deposit of sand to fine gravel at about 200 m E is bordered by a diapiric structure in which underlying sand has risen about 2 m vertically. The steeply dipping beds are interpreted as deltaic foreset beds; where thick and structureless, they probably formed as mass-flow deposits down the delta front.

At the base of the deltaic complex, lacustrine sediments underlie and interfinger with deltaic bottomset beds. The lacustrine deposits are laminated dark gray (5Y 4/1) clay to fine sand. The bottomset beds are horizontal near their base, with silty fine sand dominant. They coarsen and steepen progressively upward, and thick (18-20 cm) beds of coarse sand with granules dipping upvalley from 5° to 15° are common in upper parts of the bottomset sequence.

The glaciolacustrine sediments (unit 3b), which are traceable through the eastern 150 m of the bluff, consist of unsorted, unstratified clasts dispersed in a matrix of compact gritty silt. The stones, some of which are striated, range up to small boulder size but dominantly are pebbles and small cobbles. In the upper and basal parts of the unit, beds 0.5-1.0 m thick of rounded small to medium cobbles in a sparse matrix of pebbles and granules are interbedded within the stony silt. These water-washed sediments probably formed when the proglacial lake filled to overflowing and eroded a channel through its ice dam. The lake would have remained drained for a short interval, enabling the Noatak River to flow briefly across the site; it then would have filled again as continuing flow of the glacier sealed its outlet channel.

Highly deformed, cohesive, stone-free clayey silt (see fig. 108*B*) is exposed between about 25 m E and 100 m E. This deposit reacted plastically to the weight of the overlying gravel, forming near-vertical squeezeup structures with heights as great as 7 m. It locally forms recognizable beds of laminated silt with thin (millimeter-scale) wavy laminae of gray clay spaced at intervals of 15-20 cm, but in most places its original structures have been deformed almost beyond recognition. Although lacustrine in origin, this deposit is separate from the glaciolacustrine stony silt of unit 3b. It may have formed in a moraine-enclosed lake during or after glacier recession.

The upper gravel (unit 4; figs. 108*B* and 108*C*) is 10-11 m thick in the east-central part of the bluff, where it rises to about 37 m above the modern river. Farther upvalley, it has been eroded during postglacial river downcutting, reducing its thickness. The gravel is parallel- to cross-bedded, and contains rounded (some subrounded) pebbles and small to medium cobbles, with sparse larger clasts up to small boulder size. It is weakly size-sorted, with some pebble- and cobble-rich layers. Clasts commonly have thin silt coatings, as on modern river bars. The matrix is sand and granules that consist mostly of rock chips and with very little quartz. Unlike most underlying units, the upper gravel is loosely consolidated and generally does not support slopes steeper than 45°. An ice-wedge cast bordered by stones with vertical orientations was noted at 200 m E. Lower parts of the gravel locally contain diapiric squeezeups of dark gray stony mud and fine sand, and a concentration of large cobbles and small boulders lies along its lower contact. At 50 m E, silty fine sand near the base of the gravel contains organic detritus with a non-finite radiocarbon age of >58,000 yr B.P. (fig. 108*B*) that includes wood identified as *Picea* (USDA FPL, 3/17/87). The gravel formed as postglacial river alluvium, with a lag deposit of coarser clasts at its base created by erosional winnowing of fine sediments from underlying till and glaciolacustrine deposits. The unexpected great age of the detritus, which includes spruce wood, indicates that interglacial sediments probably were eroded by the Noatak River and then redeposited at this site.

The bluff is capped by up to 6.5 m of silt, peaty silt, and locally sand (unit 5; fig. 108*C*). Faintly laminated silt predominates. It contains peat layers and lenses as thick as 10-20 cm, which are most abundant in upper parts of the unit. In some places, silt beneath the peat beds exhibits aggregate structure produced by repeated freeze-thaw. The ice-wedge cast at 200 m E originates near the base of the silt and penetrates 4.4 m downward into the underlying gravel. Near the wedge cast, peat 0.8 m above the base of unit 4 is dated at 7,540 ±130 yr B.P. At 350 m E, the silt is underlain by 0.5-0.7 m of fine sand. Fine sand also is present locally above the silt as cliff-head deposits. The silt formed in part as a floodplain deposit, and also may have been deposited in ponds on the floodplain surface. Some silt also may have been transported as loess to this site. Silt deposition continued into at least early Holocene time, as indicated by the radiocarbon age. The cliff-head deposits formed more recently where strong winds swept up the face of the modern bluff, entraining and redepositing sand.

Western Sector

Much of the western part of the bluff face is obscured by debris flows, which originate in an amphitheater whose headwall stood as high as 45 m above the river (fig. 108*A*). The headwall was actively receding in 1986 owing to thaw of massive ice and ice-rich silt, but had become largely stabilized and vegetated when seen again 14 years later. Available exposures in 1986 displayed diamicts of several types interspersed with lacustrine, fluvial, and colluvial sediments in deposits that varied laterally and vertically over short distances. This variability has resulted from river erosion and from collapse into and around cavities created by melting glacier ice.

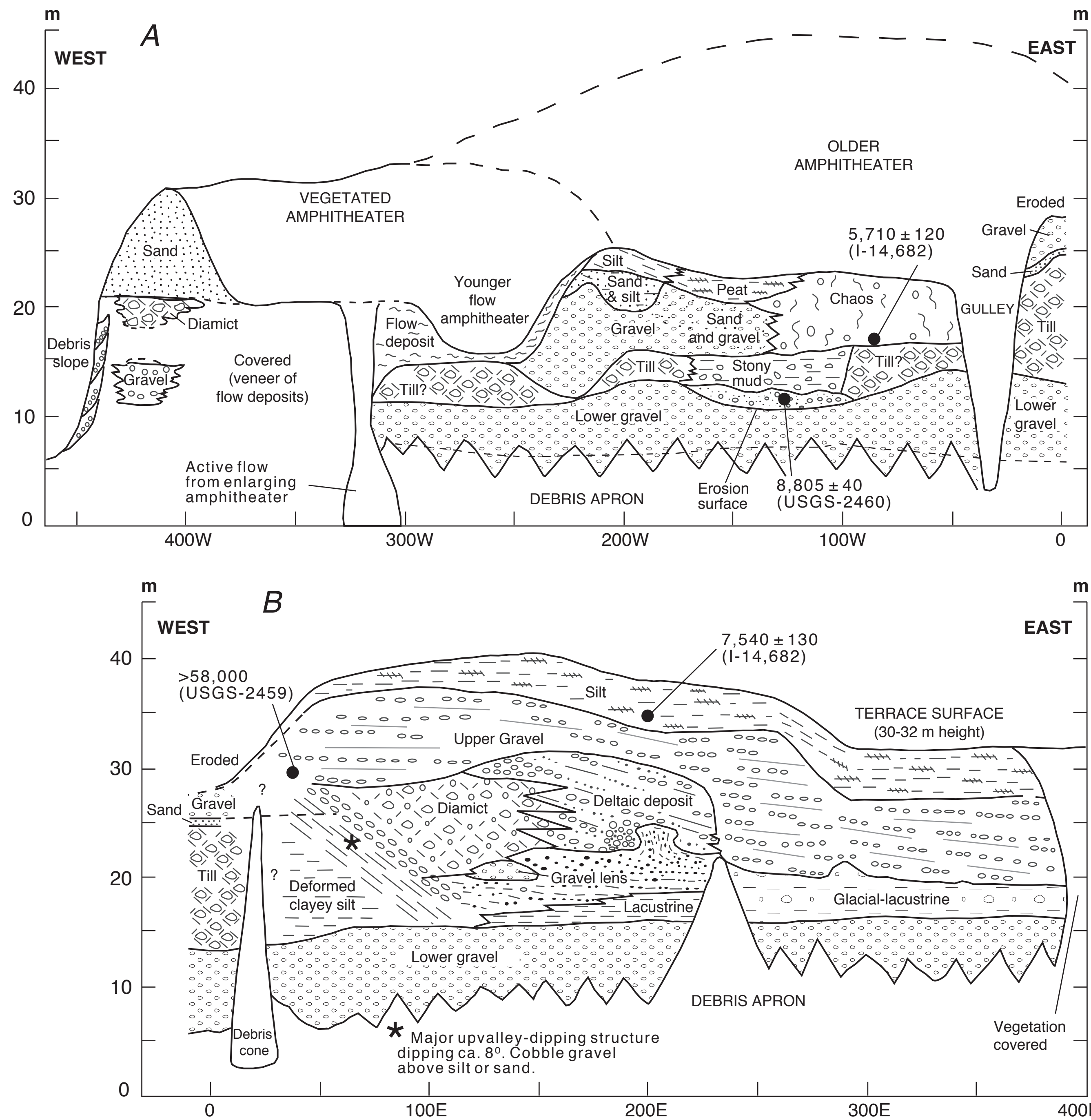
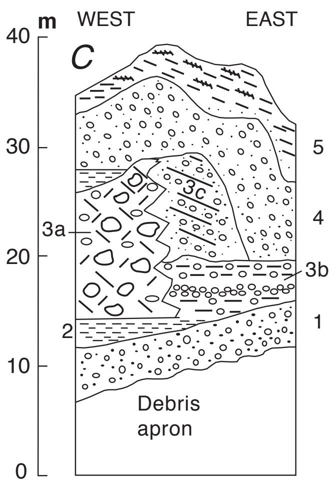


Figure 108. Exposure Nk-59. North side Noatak River 6 to 7 km upvalley from Noatak Canyon. Sketch of bluff face (1986). (*A*) West half of exposure. (*B*) East half of exposure. Bottom scales in meters west and east of bluff center. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

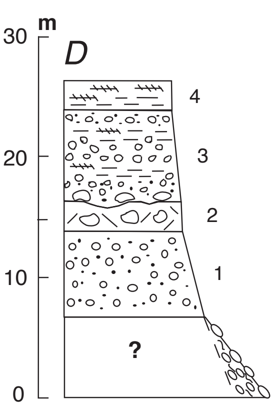
Basal gravel (unit 1; fig. 108*D*) forms a deposit that is continuous with the basal alluvium of the eastern sector of the bluff, and it generally is identical in composition. Its base is obscured by debris aprons 6.5-8.5 m high that generally are lower than those farther east. In common with the gravel farther east, the upper 0.5-1.5 m of this deposit is impregnated with silt introduced from above. Because of overriding by glacier ice, however, it typically is structureless and more compact than the gravel beneath it, generally standing in near-vertical faces. The gravel commonly is overlain by thin beds of compact, strongly laminated to faintly bedded silt to clayey silt that contains scattered stones at one locality. These sediments probably represent local ponding on the Noatak valley floor as the advancing glacier approached the valley center.

Till-like sediments similar to those of unit 3a farther east overlie the gravel through much of the bluff between 50 m W and 300 m W. These sediments commonly are unsorted and compact, with abundant striated stones. At 50 m W, the diamict contains a sequence of interbedded sand and pebbly mud that probably was generated during an outburst flood. In other places, the deposit is less compact and contains steeply dipping structures, sand lenses, or other attributes of till that was remobilized as mass-flow deposits. At 125 m W, cross-bedded fluvial sand and gravel lenses interstratified with the diamict contain peat dated at 8,805 ±40 yr B.P. Along much of its upper surface, lag boulders, gravel interbeds, and deep channeling demonstrate that an episode of river erosion followed deposition of the diamict. The early Holocene radiocarbon age indicates that some of the mass-flow deposits may have formed by remobilization of till at that time.

Stony mud that resembles the glaciolacustrine unit 3b in the eastern part of the bluff occurs between about 100 m W and 175 m W. Striated and faceted stones occur in a dark gray, slightly plastic matrix. Interstratified beds of silt-covered pebbles and sand with granules may represent minor outburst events. This glaciolacustrine deposit interfingers with till to the west, but may contact the eroded margin of a more continuous till body to the east. The glacial lake in which it formed probably was created during glacier recession, and it likely was a younger body that was separate from the more extensive lake farther east in which unit 3b formed. Its relation to the deformed clayey silt at 25-100 m E is obscure.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
5	1-5	**Peaty silt.** Faintly laminated dark grayish brown (2.5Y 4/2) silt with inter-bedded peat lenses that thicken and become more continuous upward. **Floodplain deposit.**
4	3-10	**Upper gravel.** Rounded pebbles and cobbles in parallel beds that dip downvalley at low angles. Dominantly cobble gravel, but contains some beds of crossbedded pebble gravel 10-30 cm thick. Matrix dark gray (N3 to N4), poorly sorted, immature sand and granules. **Alluvium.**
3c	7-9	**Sand and gravel.** Parallel bedded and well stratified. Forms upvalley-dipping beds interspersed with mass-flow deposts. **Deltaic deposit.**
3b	3-4	**Stony silt.** Pebbles, small cobbles, and sparse larger clasts dispersed in very dark gray (N3) gritty silt. **Glaciolacustrine deposit.**
3a	6-11	**Diamict.** Rounded to subrounded pebbles, cobbles, and sparse small boulders in highly compact matrix of dark gray (N4) silty sand. **Till.**
2	3.3	**Sand, silt, and clay.** Couplets 0.5-1 cm thick of alternating silt and clay. Transitional upward into beds of compact dark gray fine sand and silty fine sand with some dark gray (N3.5) clay interbeds. **Lacustrine deposit.**
1	3-9	**Basal gravel.** Subrounded to rounded pebbles, small cobbles, and sparse medium cobbles in poorly sorted sandy matrix. Contains beds of sand and granules 4-5 cm thick and beds of silt-covered openwork pebbles 5-10 cm thick. **Alluvium.**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	2.1	**Silt.** Laminated silt and peat, overlain by 0.3 m sod. **Floodplain deposit and bluff cap.**
3	7.4	**Sand and gravel.** Rounded to subrounded pebbles and small to medium cobbles in matrix of poorly sorted sand and granules. Contains interbeds of brown fine sand and light gray silt with some peaty beds; these commonly thicken into closed depressions on surfaces of the gravel beds. Lag boulders concentrated at contact with underlying diamict. **Alluvium.**
2	2.6	**Diamict.** Subrounded to rounded clasts, many striated, in compact matrix of dark gray, gritty, clayey silt. Several thin (ca. 5 cm) beds of openwork pebbles and granules near top. Irregular eroded upper surface. **Till.**
1	6.8+	**Gravel.** Rounded pebbles and small to medium cobbles in poorly sorted sandy matrix. Brown silt with scattered stones and faint horizontal bedding locally present at upper contact. Base not exposed. **Alluvium.**
--	6.9	**Debris apron.**

Figure 108. Exposure Nk-59 (continued). (*C*) Generalized section, eastern part of exposure. (*D*) Measured section at 190 m W (see fig. 108 *A*).

Alluvial gravel (unit 3; fig. 108*D*) is preserved above till and glaciolacustrine sediments along the bluff between about 125 m W and 250 m W. Clasts to medium cobble size occur in a matrix of poorly sorted sand and granules. Interbeds of sand and silt, with gravel lenses, typically are subhorizontal and thicken into depressions. However, in some places they are contorted, with dips up to 35°. These sediments may have been deformed by slumping into gravel-floored river channels or by subsidence into voids created by continued melt of nearby glacier ice. Although the gravel appears similar to the upper gravel farther east in the bluff, it is significantly lower in height than the gravel farther east (17-22 m versus 20-35 m). The deformation structures indicate that meltout of glacier ice likely was continuing while the downcutting Noatak River was flowing at a level about 20 m above that of the present.

Between about 50 m W and 150 m W, the gravel had been so highly deformed by slump and collapse that it was designated as “chaos.” Many stones in this sector are oriented vertically, and festoons and clasts of brown silt have intruded the gravel from above. The “chaos” directly overlies the eroded surface of till and stony mud, with a lag deposit of striated boulders marking the contact. At one site within the “chaos” horizon, bedded sand, silt, and peat containing lenses of pebble gravel directly overlie diamict. Peat at the base of this succession was radiocarbon-dated at 5,710 ±120 yr B.P. The “chaos” probably formed by collapse of river gravel over melting glacier ice. The bedded sand and silt with basal peat may have formed as a kettle fill that followed collapse of a vegetated surface during continued meltout of glacier ice in mid-Holocene time.

Between 50 m W and 225 m W, the exposed bluff face stands about 23-25 m high, with its crest forming the outer edge of the amphitheater floor. This section of the bluff is capped by silt and peat (unit 4; fig. 108*D*), which generally is 2.0-2.5 m thick. Gravel locally is intermixed with the silt at its base. Peat beds thicken and become more continuous upward, and peat also thickens into a broad swale that is centered at about 150 m W.

Flow deposits of muddy gravel are widespread near the western end of the bluff. Where exposed at 300 m W, aggregates of mud adhere to clasts and are incorporated within the matrix; and fragments of willow wood locally are present. The muddy gravel is structureless to faintly bedded, with beds dipping toward the river at about 10°. Farther west, flow deposits containing numerous striated stones are draped over the bluff face. Alluvial gravel like that of unit 1 farther east is exposed intermittently 11-15 m above the river through the veneer of flow deposits, and diamict similar to that of unit 3a in the eastern part of the bluff is exposed intermittently at about 18-21 m height.

Dark grayish brown (2.5Y 4/2), well sorted fine sand, a deposit found nowhere else in the bluff, occurs at 21-31 m height at the bluff’s extreme west end. The sand contains scattered rounded pebbles and small cobbles, but it is slumped severely in all exposures and the clasts may have been derived from another deposit when slumping took place. Similar deposits of fine sand form wind-built dunes that stand as high as 10 m on nearby parts of the present-day river floodplain. The dunes are most common on concave river banks (cutbanks) directly west of barren point bars across which strong downvalley winds can move freely and entrain sand. Their formation primarily may have been during winter months, when downvalley winds are common and the river which separates cutbank from point bar is frozen.

The headwall of the ampitheater stands 13 m high, and it is set back from the bluff face about 35 m. It was mostly vegetated in 1986, but rare exposures revealed peat, silt, ice wedges, and gravel above massive buried ice with exposed thickness as much as 7 m. Sharply defined foliation planes within the massive ice dipped about 21° in a general upvalley direction. Clasts frozen into the ice generally were widely dispersed, but were concentrated along the foliation planes. The ice was clear, with sparse bubbles and no evident dirt inclusions. It was directly overlain by poorly sorted gravel that contained boulders up to 70 cm diameter. This diamict may be ablation drift, a coarse water-washed deposit that commonly accumulates on top of downwasting glacier ice.

An older and completely vegetated thaw ampitheater farther back from the river between about 250 m W and 50 m E rises to 40-45 m height. No sediments were exposed on its headwall or floor.

When revisited in 2000, the bluff face and amphitheater headwall were obscured almost completely by flows that had become stabilized and vegetated. A conspicuous seepage line at about 15 m height along the central part of the bluff marked the probable upper surface of the basal gravel. Some gravel mixed with silt was extruding from part of the headwall, and striated stones were common at this locality and elsewhere across the amphitheater. Glacier ice no longer was visible.

Exposure Nk-60

Sediment deposits perched at high levels on a bedrock cliff near the western end of the north wall of Noatak Canyon were accessed by helicopter in 2003. The overall bluff profile stands 135 m high (fig. 109*A*); the distribution of the surficial deposits along the top of the bluff is sketched in figure 109*B*. The bedrock which forms most of the bluff is black slate with quartz veins. Along the bluff’s crest it is overlain by till and gravelly sand, and is capped by a loess blanket up to 2 m thick.

The till (unit 1) formed over an irregular bedrock surface. Its thickness is 8-12 m, but it follows bedrock topography (fig. 109*B*) so that its highest exposed occurrence is 31.5 m above its lowest exposed base The till is unsorted and nonstratified, and contains boulders up to at least 1.3 m diameter. Ultramafic lithologies dominate the larger clasts. Through its highest exposed position on the bluff, the upper 60 cm of the till is oxidized yellowish brown, and its clasts are oxide-stained and slightly weathered.

The sand (unit 2), which ranges in thickness up to 10 m or more, consists of black silty sand with platy granule-sized fragments of slate. All exposed faces are slumped, so primary bedding is not visible. The sand may have formed as a deltaic deposit in standing water.

The loess cap (unit 3) is sandy silt with slate chips and stands in near-vertical faces. It probably is a mixed eolian and colluvial deposit that formed during incision of Noatak Canyon.

Discussion

The stretch of the Noatak River valley from the mouth of Kaluktavik River to Noatak Canyon was affected strongly by the glacier that flowed southeastward from the DeLong Mountains through the Kugururok valley system to its mouth. The source of the high-level till at Sekuiak Bluff (at the west end of Noatak Canyon) was a broad glacial lobe that covered the floor of Kugururok valley and spread south across the Noatak valley floor (see fig. 82). Its near-surface weathered horizon indicates that the till probably was deposited during Makpik (Itkillik I) time. The till farther upvalley at exposure Nk-59 was deposited by a distributary glacier, probably of the same age, that diverged from the main Kugururok valley glacier and flowed directly south across low passes into the Noatak valley. When seen in 1986, Nk-59 exposed a complex record of preglacial river gravel, glacial-age till and proglacial lake sediments, late-glacial ice wastage and ponding, and postglacial river and eolian activity associated with continued meltout of glacier ice.

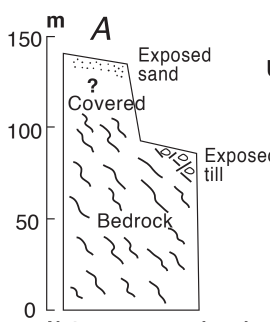
Farther east up the Noatak River valley the glaciolacustrine sediments at the base of Nk-56, as well as those farther upvalley at Nk-51B through Nk-53, probably were formerly continuous with the deposits of stony silt in the eastern sector of Nk-59. The glaciolacustrine sediments commonly are overlain by thick ice-rich silt, which probably also is lacustrine, but the silt generally is poorly exposed and its origin is uncertain.

Exposures Nk-57 and Nk-58 occupy the same bluff line north of the Noatak River. The exposed top of the alluvial gravel at each bluff stands 30-33 m above river level, and is overlain by silt. The silt clearly is a floodplain deposit at Nk-57, but at Nk-58 it is thicker, stands higher, and could be lacustrine in origin. These deposits probably are continuous with the upper gravel and overlying silt exposed in the eastern section of Nk-59, which are similar in height. They document a significant interval during which the Noatak River remained at a level about 30 m above that of the present day.

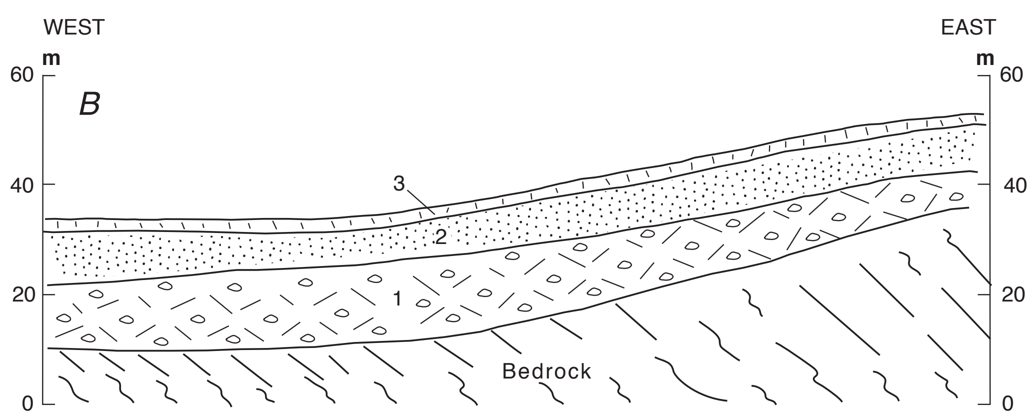
At Nk-57 and Nk-58, a lower terrace with measured heights of 14-15 m may have formed during a pause in regional downcutting. The radiocarbon date farther upriver at Nk-54A indicates that the Noatak River was flowing at about that height about 12 ka as it eroded downward toward its present level.

Noatak Canyon to Kugururok River

Below Noatak Canyon, the Noatak River flows into a broad lowland that widens progressively westward. Thick glaciolacustrone deposits cover the valley floor, draping over arcuate end moraines that were deposited by south-flowing



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	up to 2 m	**Silt.** Bluff cap. Silt with slate chips. Stands in steep faces. **Loess with colluvium.**
2	>10 m	**Sand.** Black (10YR 2/1) poorly sorted silty sand with platy slate granules. Base not exposed. **Deltaic deposit?**
1	8-12	**Diamict.** Unsorted and unstratified clasts up to boulder size. Matrix uncertain due to admixture of sand from overlying unit. Oxidized yellowish brown (10YR 5/4) near upper contact at east end of section. **Till.**



Note compressed scale. Zero point is about 70 meters above river level.

Figure 109. Exposure Nk-60. North side Noatak River at west end of Sekuiak Bluff, Noatak Canyon. (*A*) Overall bluff profile. (*B*) Upper bluff face (from a 2002 field sketch).

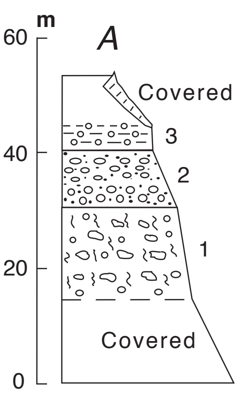
glaciers at and beyond the mouth of the Kugururok River (see fig. 82). Three bluff exposures were recorded along this stretch of the Noatak River.

Exposure Nk-61

An arcuate meander cutbank on the south side of the Noatak River forms a bluff line that originates in till bluffs at the downstream end of Noatak Canyon and extends west and then north for about 2.5 km. The bluff has a planar upper surface about 50 m high that extends along the cutbank and farther downvalley as a conspicuous alluvial terrace. Intermittent exposures reveal gravel above glaciolacustrine sediments except near Noatak Canyon, where gravel overlies till and bedrock. Bluff exposures were examined in 1986 and 2000, with different sections measured on each visit.

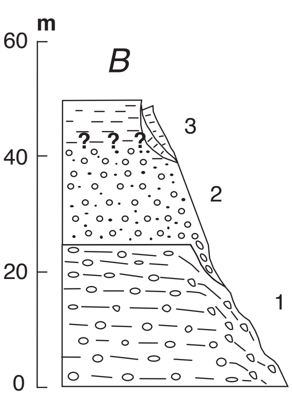
Exposure Nk-61A (fig. 110*A*) was measured near the west end of the bluff line near the mouth of a small unnamed tributary that enters the Noatak River from the south. The bluff face here stands 44 m high, with slump blocks creating a gentler slope that rises inland to a planar upper surface 53 m above the river. The base of the bluff face is covered with flow lobes, and the composition of underlying sediments is uncertain. The lowest exposed deposit (unit 1) is a strongly weathered diamict that contains rotted clasts in a matrix rich in clayey weathering products. The diamict probably was originally a till. The overlying gravel (unit 2) consists of platy immature gravel that grades downward into coarser gravel that contains abundant large cobbles. The clasts in the platy gravel are mostly of local derivation, whereas those of the coarser gravel contain far-traveled igneous rocks. The gravel unit probably represents a fan deposit built by the nearby tributary stream that overlaps glacial outwash. The topmost unit (unit 3) is largely obscured by slump blocks, but basal exposures reveal stony silt and silty gravel. The silt may be mostly eolian in origin; and the gravel may be an alluvial deposit of the tributary stream. These two components may have been intermixed in part by frost action and in part by colluvial activity.

Exposure Nk-61B (fig. 110*A*) was measured a short distance downvalley from Nk-61A. The bluff face here stands 50 m high, exposing gravel above glaciolacustrine stony silt. The glaciolacustrine deposit (unit 1) consists of clasts that range up to small boulder size embedded in a matrix of gritty (sand-rich) clayey silt. Much of this deposit is obscured by gravel, which drapes down from the overlying unit. Stiff clayey silt without stones, which is exposed near river level, may represent a basal facies of the glaciolacustrine deposit that formed when glaciers were advancing down tributary valleys but had



Note: compressed scale

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	>3.4	**Silt and gravel.** Stony silt (1.2 m thick) above silty gravel (2.2 m). Gravel in part consists of subrounded pebbles in immature silty sand matrix. Silt contains stones possibly admixed by frost action. **Loess and alluvium?**
2	10.0	**Gravel.** Subrounded pebbles and cobbles, many platy in shape, in poorly sorted sand-granule matrix. Clasts largely quartz and quartzite; few igneous rocks. Grades downward into coarser gravel containing numerous large rounded cobbles; many of igneous rock types. **Fan deposit above outwash.**
1	15.3	**Weathered diamict.** Intensely oxidized and weathered.Upper several meters oxidized strong brown (7.5YR 5/6). Underlying sediments are greenish to brownish and appear clay enriched. Numerous pebbles and cobbles; some intact, others entirely rotted. **Till?**
--	6.9	**Debris apron.** Largely flow lobes derived from unit 1.



Note: compressed scale

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	>10?	**Brown silt.** Exposed only in slump blocks. May be draped over gravel. **Origin uncertain.**
2	>15?	**Gravel.** Pebbles and cobbles, typically subrounded, in immature matrix of shale or phyllite chips, other rock chips, and angular quartz fragments. Weakly bedded, with some beds having muddy matrix. **Outwash?**
1	25	**Stony clayey silt.** Pebbles, cobbles, and some small boulders in matrix of dark gray (N4) gritty,clayey silt. Stiff clayey silt without stones is exposed near river level. **Glaciolacustrine deposit.**

Figure 110. Exposure Nk-61. Southwest side Noatak River at and below west end of Noatak Canyon. (*A*) Exposed face at west end of canyon. (*B*) Exposed face a short distance downstream from exposure *A*.

not yet reached their maximum size. The overlying gravel (unit 2) has an exposed thickness of 15 m, but its upper contact is obscured by slump blocks and it may rise higher than illustrated in figure 61*B*. The capping brown silt (unit 3) is exposed only in slump blocks. Its exact thickness, structure, and origin are uncertain.

Exposure Nk-62

A west-facing exposure on the east side of the Noatak River 2 km downstream from Nk-61 stands 32 m high, with a slump-covered slope leading farther upward to a near-horizontal terrace-like surface 45 m above river level (fig. 111). Most of the bluff face is debris-covered and vegetated, but limited exposures were obtained by trenching and also at places where the river is undercutting the base of the bluff.

A river-eroded basal exposure, measured in 2000, revealed highly weathered stony clay (unit 1). Clasts include brown sandstone and sheared quartz fragments—lithologies that are rare in Pleistocene-age glacial and glaciolacustrine deposits of the Noatak valley. This deposit could be a very old till, or possibly gouge along a fault zone. Overlying gravel (unit 2) is oxidized to 1 m depth, and locally to 2 m, but its degree of weathering is much less than that of unit 1. Stony silt (unit 3) that overlies the gravel is a typical glaciolacustrine deposit, but it is highly compacted and supports near-vertical faces.

A debris slope littered with pebbles and cobbles intermixed with brown silt rises more than 20 m above the exposed basal section. Absence of boulders indicates that fluvial gravel rather than till probably underlies the debris slope. The clasts may have been derived from outwash. The admixed brown silt may have been contributed by loess that formerly capped the gravel.

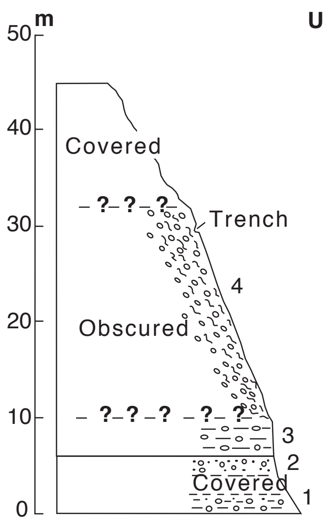
A few meters upstream from the measured section, reddish yellow (5YR 6/8) to pale yellow (2.5Y 8/4) to grayish green (5G 5/2) clayey saprolite is squeezing out near river level. This intensely weathered residual soil reflects a degree of alteration that is unknown among Pleistocene deposits in northern Alaska; it suggests that a relict soil of Tertiary age could be present at or below river level.

Discussion

The three exposures close to the west end of Noatak Canyon underlie an extensive terracelike surface about 50 m high that may decline in height downvalley. Each of these exposures contains alluvial gravel 10-20 m thick that probably formed during alluviation of the Noatak River during waning phases of the last regional glaciation. The gravel is overlain by a poorly exposed cap of sediment that largely may be brown silt of eolian (loess) origin. Where close to the mouth of a north-flowing tributary stream, the gravel and silt units contain fine gravel and platy fan deposits of local lithologies. Beneath the gravel, the section closest to Noatak Canyon (Nk-61A) contains a highly weathered diamict, whereas the other two exposures exhibit glaciolacustrine stony silt. The glaciolacustrine deposits may have formed in a broad lake that was dammed behind moraines of the Kugururok, Avan, and Kelly valley glaciers. Highly weathered deposits, provisionally identified as till and saprolite, occur at or near the bases of two of the bluff sections (exposures 61A and 62). Their high degree of chemical alteration indicates a probable Tertiary age for these units. With the possible inclusion of a lithified gravel at Avan-1 (see Avan River section), these are the oldest known surficial deposits in the Noatak River valley.

Kugururok River Valley

Three exposures along the lower course of Kugururok River intersect glaciolacustrine sediments of Avan (Itkillik Phase II) age that locally are draped over morainal ridges assigned to the preceding Anisak glacial advance (see fig. 82). An additional exposure along Trail Creek, a large east-



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	20	**Gravel.** Rounded to subrounded pebbles and cobbles mixed with brown silt. Exposed only on weathered debris slope. Base not exposed. **Outwash.**
3	>2	**Stony silt.** Unsorted pebbles and cobbles, many striated, in matrix of compact, very dark gray, gritty clayey silt. Stands in near-vertical faces. Base not exposed. **Glaciolacustrine deposit.**
2	>2	**Fine gravel.** Rounded to subrounded pebbles in sand-granule matrix, with some sand beds 10-15 cm thick. Quartz ca. 50 percent in pebble fraction and 60-70 percent in sand fraction. Moderately oxidized to 1 m depth, with some permeable beds oxidized 1 m deeper. Upper contact undeformed; lower contact not exposed. **Alluvium.**
1	>2	**Oxidized clay.** Reddish yellow (7.5YR 6/8) stony clay. Exposed only near river edge. Contains fractured and weathered clasts of lithologies that differ from those in younger tills and glaciolacus-trine deposits. Upper contact not exposed. **Till?**

Figure 111. Exposure Nk-62. East side Noatak River 6.4 km upstream from Kugururok River mouth.

ern tributary to Kugururok River, is a short distance from the Misheguk Mountain mafic and ultramafic complex (Boak and others, 1987). The Trail Creek exposure intersects an outwash apron just beyond a moraine front correlated with the Avan ice advance and near the upvalley margin of glaciolacustrine sediments of similar age.

Exposure Ku-1

Lake deposits of the last major (Avan) glaciation are well exposed along the east bank of Kugururok River 27 km above its mouth, where the river approaches Lake Kaiyak most closely. This river-cut bluff stands 30.8 m high, exposing a complex of lacustrine sediments (fig. 112). In the lowest exposed deposit (unit 1), pebbles, cobbles, and some small boulders up to about 40 cm diameter are dispersed in a matrix of dark gray sandy silt. Stone orientations range from horizontal to vertical, with no fabric evident. In the midpart of the unit, two beds of poorly sorted but water-washed sand and gravel are separated by 1.3 m of stony silt. The upper gravel bed is 1 m thick; the lower bed is 0.5 m thick. In the diamict above the gravel beds, boulders up to 40 cm diameter are more common than in the basal diamict, and the silt matrix is sandier.

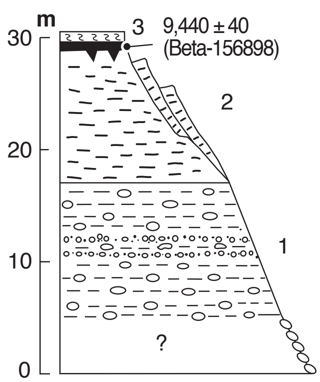
The stone-free silt above the diamict (unit 2) is concealed partly by slumping. It is capped by oxidized silt and by peat, which locally is deformed downward into wedge-like depressions. Peat sampled 1.0 m below the bluff crest has an early Holocene radiocarbon age of 9,440 ±40 yr B.P.

The stony glaciolacustrine sediments with interbeds of muddy gravel reflect two episodes of lake drainage owing to ice-dam failure and probably catastrophic outburst floods. The stone-free silt (unit 2) overlies the diamict without any evident weathering, soil formation, frost disturbance, or other indications of subaerial exposure. This probably reflects persistence of a lake in lower Kugururok valley as glaciers thinned and receded. The early Holocene radiocarbon age of the buried peat implies that lake recession took place near the close of the late Pleistocene, but the wedge-like peat protrusions indicate that an episode of subaerial ice-wedge formation probably preceded the peat accumulation.

Exposure Ku-2

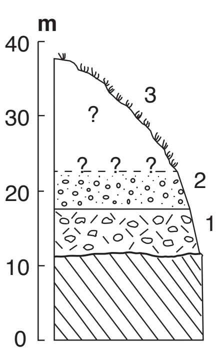
A south-facing bluff along Kugururok River southwest of Lake Kaiyak exposes glacial, alluvial, and possibly lacustrine sediments above bedrock. Where visible, the upper surface of the steeply dipping bedrock has been abraded by overriding glacier ice. The overlying diamict (unit 1; fig. 113) contains unsorted glacier-modified stones in a gritty silt and clay matrix. Much of the sand may have been washed down from the overlying gravel and mixed with the diamict on the bluff face. The gravel (unit 2), which is dominated by pebbles and small cobbles, appears to be river alluvium. It may extend about 1 m higher than shown in figure 113, but only 5 m thickness is exposed. The upper 15.7 m of the bluff face (unit 3) is vegetated and its composition is uncertain. However, no clasts are exposed

Figure 112. Exposure Ku-1. East side Kugururok River opposite northwest arm of Lake Kaiyak. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	1.2	**Silt and peat.** 0.8 m slighty oxidized brown silt above 0.4 m black peat to very dark grayish brown (10YR 3/2) silt. **Bluff cap.**
2	13.5	**Silt.** Dark gray (5Y 4/1), frozen, ice-rich clayey silt. No stones evident. Face massively slumped. **Lacustrine deposit.**
1	12.1+	**Diamict.** Unsorted, nonstratified clasts up to large cobble and rarely small boulder size; many faceted and striated. Matrix is dark gray (10YR 4/1) gritty silt. Contains 2 beds of poorly sorted sand and gravel separated by ca. 1.3 m of diamict. Base not exposed. **Glaciolacustrine deposit.**
--	5.2	**Covered. Debris apron.**

Figure 113. Exposure Ku-2. North side Kugururok River 7.5 km southwest of Lake Kaiyak.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
3	15.7	**Concealed.** Stabilized and vegetated slumps and flows. Polygon troughs common. No clasts exposed. **Lacustrine?**
2	5+	**Gravel.** Pebbles and small cobbles in very dark gray, poorly sorted, sandy matrix. Upper contact concealed. **Alluvium.**
1	6	**Diamict.** Clasts up to boulder size in gritty, clayey silt matrix. **Till.**
--	11.5	**Bedrock.** Interbedded shale and sandstone, steeply dipping. Upper surface polished, striated, and grooved.

across its surface, suggesting that it may be a fine-grained lacustrine or possibly eolian deposit. Troughs resulting from meltout of a polygonal ice-wedge network are common.

Lower river terraces here stand 7.8 m and 3.5 m above the modern river. At both terrace levels, alluvial gravel is exposed above the truncated surface of dipping bedrock.

Exposure Ku-3

An active thaw amphitheater along the Kugururok River near its mouth reveals poorly exposed sediments around its unstable headwall and mixed detritus across the flow lobe at its base. On the flow surface, faceted and striated stones up to small boulder size are dispersed in a matrix of clayey silt that contains little or no sand (unit 1; fig. 114).

Sediments with near-horizontal stratification (unit 2) are evident on the vertical amphitheater headwall, but access is difficult and ice-rich permafrost obscures their composition. Fine sand may overlie stony mud, but the position and nature of the contact between these two deposits are unclear. Vertical ice wedges penetrate the upper part of the amphitheater headwall. Subhorizontal sediments between the wedges contain black peaty mats at about 6.5 to 7.5 m depth. Peat taken from this interval has an apparent radiocarbon age of 43,480 ±1230 yr B.P., but its large counting error indicates that this may be a minimum rather than finite age. The active layer at the top of the headwall is estimated to be 30-60 cm deep and probably developed in fine sand.

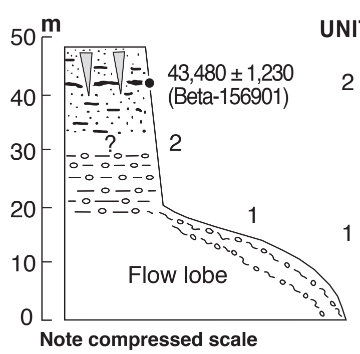
Exposure Trail-1 (Trail Creek)

A bulky end moraine assigned to the Avan (Itkillik Phase II) ice advance (see fig. 82) covers the floor of Trail Creek valley about 30 km above its confluence with Kugururok River. Outwash that issued from the moraine front formed a terrace that declines in height downvalley. At an exposure midway along its length, the terrace stands 15 m high and is underlain by unweathered gravel (fig. 115). Clasts up to 40 cm long occur in a matrix of immature (black; 10YR 2/1) sand and granules that contains abundant rock chips. A soil profile about 0.5 m thick caps the gravel. Dark grayish brown (10YR 4/2) structureless silt with abundant rootlets overlies oxidized and frost mixed silty gravel. The oxidized horizon is about 20 cm thick. It is dark yellowish brown (10YR 4/6), grading downward into dark brown (10YR 4/3).

Discussion

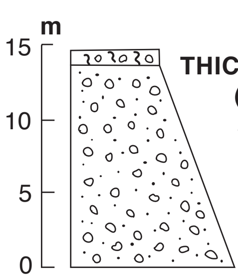
The three exposures along lower Kugururok River exhibit glacial, glaciolacustrine, alluvial, and other sediments that span two glacial advances followed by the Holocene interval. Exposure Ku-1 contains the youngest and least ambiguous record. The basal glaciolacustrine sediments at Ku-1 are part of the widespread glacial-lake deposits that formed behind an ice dam at the mouth of Avan River during the last major glacial advance of the Pleistocene. Interstratified gravel beds indicate that the ice dam failed at least twice, probably releasing outburst floods down the Noatak River. The overlying stone-free silt probably reflects diminishing glacier presence but continuing blockage of the Noatak River during late-glacial time. The radiocarbon age of 9.5 ka near its base clearly dates the bluff cap as Holocene. Several other similar peat dates in this region suggest that early Holocene climate may have been milder than at present.

Exposure Ku-2 is situated in line with several subsurface moraines of Anisak age that were buried beneath younger glaciolacustrine deposits. The diamict at Ku-2 overlies glacier-scoured bedrock, and probably was deposited as glacial till.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	29.5	**Obscure.** Ice-rich permafrost with near-horizontal layering. Composition uncertain, but stony mud may be overlain by fine sand. Penetrated by ice wedges. **Lacustrine?**
1	19	**Stony clayey silt.** Pebbles and small cobbles, with sparse larger cobbles and small boulders, in clayey silt matrix. **Glaciolacustrine deposit.**

Figure 114. Exposure Ku-3. Thaw ampitheater along east side Kugururok River 2 km above its mouth. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).



THICKNESS (m)	DESCRIPTION and INTERPRETATION
15	**Gravel.** Subrounded pebbles, small cobbles,and sparse larger clasts to small boulder size in black (10YR 2/1) sand-granule matrix. Capped by soil profile about 0.5 thick. **Outwash.**

Figure 115. Exposure Trail-1. North side Trail Creek 27 km northeast of Lake Kaiyak.

The overlying gravel may be interstadial in age, but it shows no evidence of weathering. The topmost unit appears stone-free, but its composition is otherwise unknown. It may consist wholly or largely of silt and organic deposits comparable to units 2 and 3 at exposure Ku-1.

Exposure Ku-3 exhibits a sediment succession similar to that of Ku-1, but it differs from that exposure in several important aspects. The basal glaciolacustrine deposit has a clayey silt matrix, which contrasts with the conspicuously gritty silt matrix of the youngest glaciolacustrine deposit at Ku-1 and other exposures. Much of the overlying unit is sandy rather than silty, and is penetrated by ice wedges much larger than the wedge-like features at Ku-1. Finally, airphotos of the lower Kugururok River valley clearly show that the valley floor near Ku-1 contains undisturbed glaciolacustrine sediments whereas the area around Ku-3 has been scoured by running water, probably when the Noatak River was flowing at the 50-m terrace level. Deposits dating from the last glaciation may have been truncated at this time, and the bluff section eroded down to a lower and older sediment succession. This truncation may explain the very old radiocarbon age (ca. 43.5 ka), which is much older than that of peat at similar stratigraphic positions at Ku-1 and other exposures. However, this radiocarbon age determination is suspect because of its large counting error, and it could be a minimum age limit instead.

The outwash exposure (Trail-1) on Trail Creek lies just below end moraines assigned to the Avan glacial advance and just above the upvalley limit of glaciolacustrine deposits of the same apparent age (see fig. 82). A soil profile on the outwash is similar to other soil profiles measured on glacial deposits of Itkillik II (late Wisconsin) age through the central Brooks Range (Hamilton, 1986). Rather than forming an elongate valley train, the outwash forms an apron that is truncated a short distance beyond the moraine front. Glacial meltwater may have flowed into the glacial lake at this location, and much of the “fan” deposits mapped there (Hamilton, 2003 and in press) could have formed as a thin veneer over deltaic sediments.

Kugururok River to Eli River

Introduction

Below the mouth of Kugururok River, the Noatak River flows westward for about 40 km to the western boundary of the Noatak National Preserve (fig. 116). It then curves south-

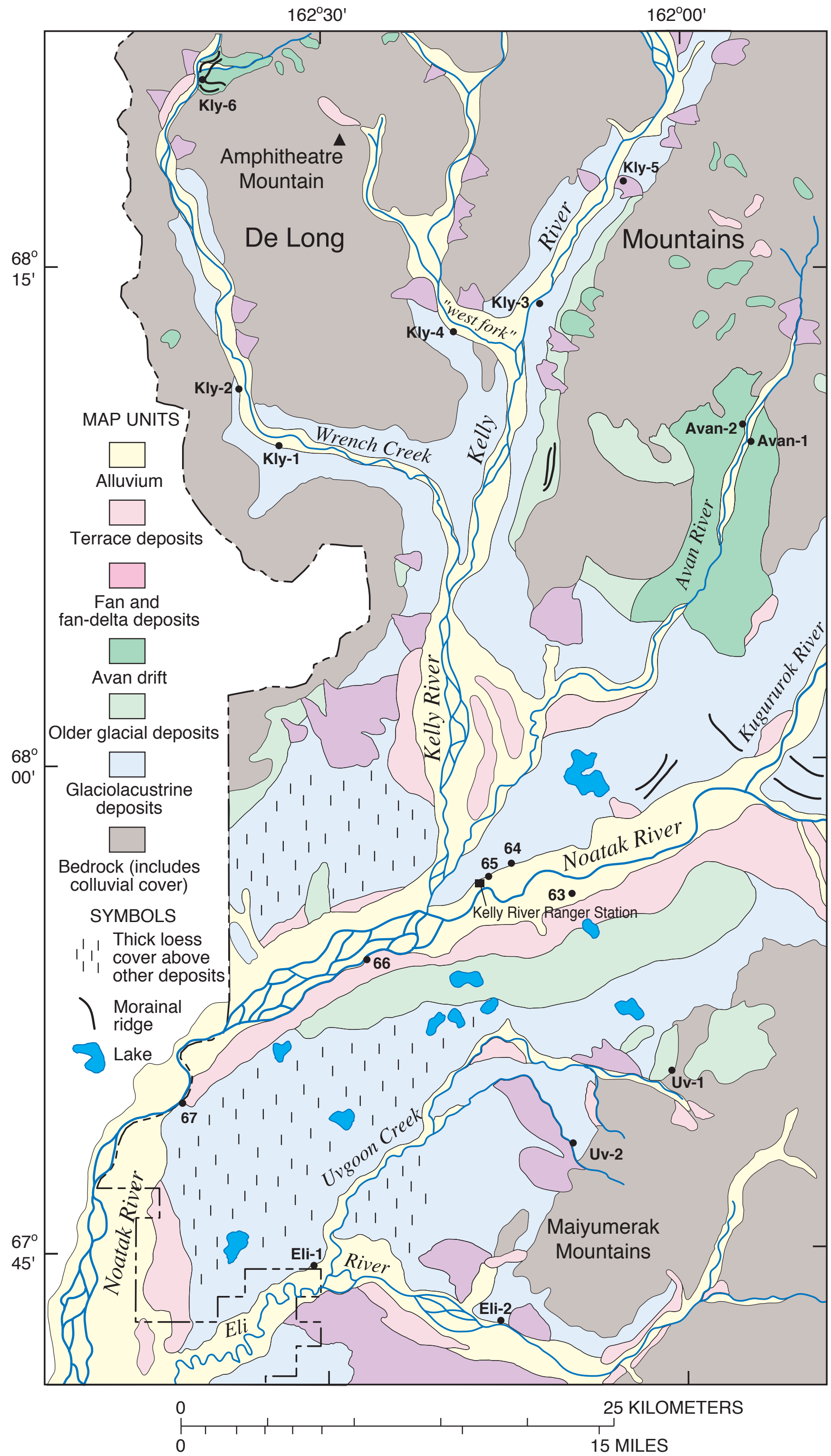


Figure 116. Generalized geologic map, Noatak River valley, Kugururok River to Eli River. Numbers without prefixes refer to Noatak River bluffs (designated Nk in text). West boundary of Noatak National Preserve shown by broken line.

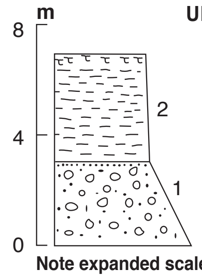
ward to flow through a broad lacustrine plain. Through its westward course, the river is confined to the south by an end moraine that was formed by south-flowing glaciers that issued from drainage systems now occupied by the Kugururok, Avan, and Kelly Rivers. The Noatak River flows through a single channel downstream to the mouth of Kelly River, where it becomes highly braided.

Five bluff exposures (Nk-63 through Nk-67) were measured through the west-flowing stretch of the Noatak River. These exposures reveal glacial tills, glaciolacustrine deposits, and fluvial gravels that are overlain in places by thick accumulations of silt.

Only low banks were seen along the Noatak River through the lacustrine plain that extends downvalley from Nk-67 (fig. 116). These banks lie beyond the western boundary of the Noatak National Preserve, and consequently were not examined closely.

Exposure Nk-63

The face of a low terrace along the south side of the Noatak River's active floodplain rises 7 m above the floodplain level (fig. 117). Basal gravel (unit 1) contains abundant gray quartzite and vein quartz, with black chert and ultramafic lithologies also common. The overlying silt (unit 2) is a typical Holocene floodplain deposit. It bears a sod cap that formed after the river cut down and abandoned its former floodplain.

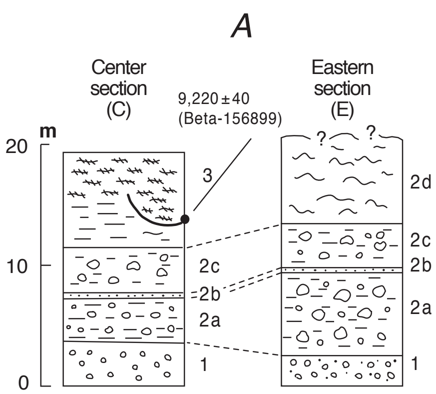


UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	4	**Silt.** Dark brown to dark gray waterlaid silt. Capped by sod 20-25 cm thick. **Floodplain deposit.**
1	3.1	**Gravel.** Subrounded stones up to medium cobble size in sandy matrix. Sand bed near upper contact. **Alluvium.**

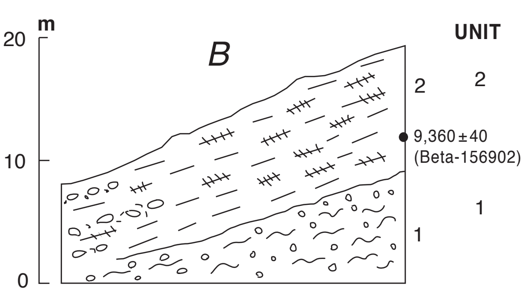
Figure 117. Exposure Nk-63. South side Noatak River floodplain 8.5 km above mouth of Kelly River. Measured heights are above active Noatak River floodplain.

Exposure Nk-64

A 20-m bluff at the north edge of the Noatak River's floodplain is partly concealed by vegetation but yielded three measured sections (figs. 118*A* and 118*B*). The easternmost section exposes a complex of glaciolacustrine sediments that overlies fluvial gravel. The gravel (unit 1; fig. 118*A*) is a mature fluvial deposit with quartz comprising 5-10 percent



UNIT	THICKNESS (m) C	THICKNESS (m) E	DESCRIPTION and INTERPRETATION
3	8	--	**Organic silt (center section only).** Dark reddish brown (5YR 3/2) peat to peaty silt, grading downward to dark grayish brown (2.5Y 4/2) silt with rare peaty lenses and wood fragments. Peat mass 4.7 m thick fills local depression in the silt.
2			**Glaciolacustrine deposits.**
d	--	?	**Slump and flow deposits (eastern section only).** Heavily vegetated surface rises inland into thaw amphitheater.
c	3.7	3.4	**Upper diamict.** Subrounded pebbles, sparse small cobbles, and rare large cobbles in unstratified matrix of very dark gray (10YR 3/1) muddy sand.
b	0.35	0.25	**Sand.** Nonbedded very fine sand, dark grayish brown (2.5Y 3/2), with thin layers and lenses of medium sand near upper contact.
a	3.6	<7.1	**Lower diamict.** Pebbles, small cobbles, and sparse larger clasts in matrix of dark gray (10YR 4/1) slightly gritty clayey silt.
1	3.9	>1.5	**Gravel.** Rounded pebbles and some small cobbles with quartz common (5-10 percent of total) in abundant sandy matrix. Sparse beds 4-14 cm thick of faintly bedded fine to very fine sand with some medium sand.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	14	**Silt.** Well sorted silt. Colors gray (10YR 6/1) to strong brown (7.5 YR 5/6) and black (5YR 2.5/1). Upper part deformed by slumping and flowage. Contains deformed clots of peat that include abundant rootlets and shrub twigs. Lower part contains west-dipping lenses of peat and locally more massive but highly contorted peat.
1	8.2	**Gravel.** Rounded to subrounded pebbles, with some small cobbles and rare larger cobbles, in matrix of very dark gray (10YR 3.1) sandy silt. Some clasts striated. Generally structureless, but contains some west-dipping beds of water-washed sandy gravel.

Figure 118. Exposure Nk-64. North side Noatak River 5 km upstream from Kelly River mouth (2 km above Kelly River Ranger Station). (*A*) Measured sections at central and eastern parts of bluff. (*B*) Exposed face at west end of bluff. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

of all stones and about 40 percent of the sand matrix. This unit may be thicker than shown because its upper contact is obscured by drapes of glaciolacustrine sediment on the bluff face. Striated clasts are common in both diamict deposits of unit 2. The lower diamict (unit 2a) appears to be undisturbed glaciolacustrine sediment, but the upper diamict (unit 2c) may have been remobilized as a flow. It probably extends upward through the slump and flow deposits that are obscured by vegetation. The thin sand bed (unit 2b) between the two diamicts probably formed during a brief interval of lake drainage.

Near its center, the bluff rises 19.5 m to a nearly level terrace-like surface. At the upper contact of the basal gravel (unit 1; fig. 118*A*), which is exposed here, a 10-cm-thick transition zone to the lower diamict contains interpenetrating tongues of stony silt and gravel in some places and mixed structureless silty sandy gravel elsewhere. The two diamicts and intervening thin sand bed (units 2a-2c) are nearly identical to the corresponding units farther east, but the upper of the two diamicts may have been truncated by river erosion because it is overlain at a height of only 11 m by probable floodplain silt (unit 3). Peat that fills a 4.7-m-deep depression in the silt has a basal radiocarbon age of 9,220 ±40 yr B.P. The depression may be the site of a thaw pond, or possibly a small stream channel, on the former floodplain.

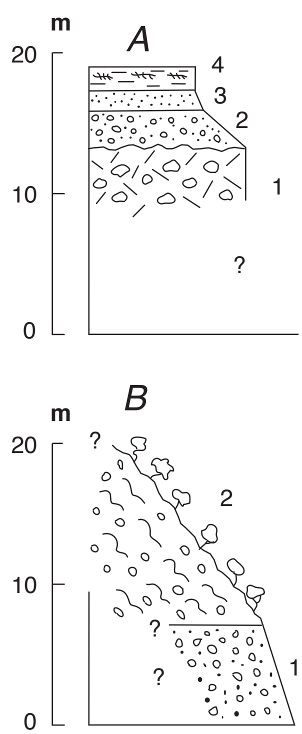
From the downstream (western) flank of the center exposure, the bluff slopes westward from the 20-m level down to a late Holocene terrace or floodplain level (fig. 118*B*). This section is dominated by westward-dipping beds of silty to sandy gravel that are overlain by silt, organic silt, and peat. These sediments comprised a detrital wedge of flow deposits that was shed from the face of the 20-m terrace during river downcutting. Although beds generally dip westward at low angles, some dip more steeply (up to 28°) toward the east and may have filled depressions created by thaw of ice-rich permafrost or relict glacial ice. Near the west end of the detrital wedge, silty fluvial gravel of unit 1 containing small boulders appears to be interbedded with the silt of unit 2. Twigs, root balls, and other wood fragments within unit 2 occur in peat beds and also are dispersed within the silt. Wood fragments from a possible thaw-lake deposit are dated at 9,360 ±40 yr B.P.

Exposure Nk-65

Two exposures were measured in different years short distances above the Kelly River Ranger Station (see fig. 116). Exposure Nk-65A was examined in 1986, but later became obscured. Consequently, a nearby partly vegetated exposure (Nk-65B) was the best exposure available for study in 1999.

Exposure Nk-65A (fig. 119*A*), an 18-m bluff with a terrace-like surface, exhibited an alluvial sequence above diamict. The diamict was compact and supported vertical faces; it probably formed as till rather than glaciolacustrine sediment. Its highly irregular stream-eroded upper surface had about 2 m relief. Above the till, a fining-upward succession of gravel, sand, and silt represented river-channel deposition followed by aggradation of organic-rich floodplain deposits.

Exposure Nk-65B (fig. 119*B*), measured a short distance above the Kelly River Ranger Station, yielded 8.5 m of gravel and stony silt exposed beneath 10 m or more of vegetated flow deposits. The gravel (unit 1) is similar to fluvial deposits of the modern Noatak River, with lenses of small boulders probably representing lag deposits on former channel floors. This



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
4	1.8	**Silt.** Silt and organic silt, becoming increasingly peaty near upper surface. **Floodplain deposit.**
3	1.3	**Sand.** Well sorted olive (5Y 4/4) silty fine sand. Some thin interbeds of organic silt. **Floodplain deposit.**
2	2.6	**Gravel.** Subrounded pebbles and small cobbles in sandy matrix. **Alluvium.**
1	3.5	**Diamict.** Rounded to subrounded pebbles and small cobbles with some less rounded larger clasts up to boulder size. Many faceted and striated. Matrix is very compact dark grayish brown (10Y 4/2) gritty silt. **Till.**

UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	>1.5	**Stony silt.** Mostly covered with dense shrubs. **Glaciolacustrine deposit.**
1	7	**Sandy gravel.** Pebbles and small cobbles with lenses of nested small boulders. Loosely packed. **Alluvium.**

Figure 119. Exposure Nk-65. North side Noatak River short distances above Kelly River Ranger Station (KRRS), 3 km above Kelly River mouth. (*A*) Section measured in 1986 a short (but unknown) distance above KRRS. (*B*) Section measured in 1999 about 150 m above KRRS.

alluvium is loosely packed and unweathered. It may predate glaciolacustrine deposition, but its fresh appearance suggests that it may be a Holocene-age river deposit that was covered by debris flows from a nearby glaciolacustrine exposure. The stony silt (unit 2) contains abundant polished and striated stones of glacial origin, and ultramafic lithologies from glacial source areas in the De Long Mountains dominate the larger clasts. This unit mostly is covered by dense shrub vegetation, but the headwall of a thaw amphitheater from which the flow issued is visible farther upslope.

Exposure Nk-66

A tall bluff with a measured height of about 55 m stands along the south side of the Noatak River below the Kelly River confluence. The bluff's face is largely obscured by vegetated slump blocks (fig. 120), but a near-vertical exposure at its base exhibits diamict in a highly compact matrix that contains little or no clay (unit 1). The diamict probably was deposited as till. Slump blocks above the till (unit 2a) have remained coherent although displaced downward on the bluff face. They expose horizontally bedded fine sand and silty fine sand that grades upward into probable loess.

Overlying deposits appear to be entirely silt, but are poorly exposed on the slumped and vegetated bluff face. Visible parts of units 2b and 2d appear to be nonbedded, and may have been deposited as loess. A possible thaw-pond deposit of irregularly bedded silt (unit 2c) is exposed in the upper part of the bluff face through a section that is steeper and more stable than deposits above and below it.

Exposure Nk-67

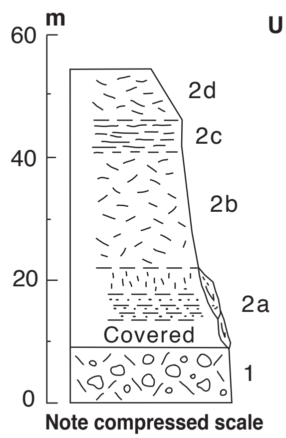
A 17-m silt exposure with a nearly level upper surface (fig. 121) stands along a northwest-facing cutbank of the Noatak River. A basal exposure of faintly bedded water-laid silt (unit 1) contains peaty beds and mollusk shells through a zone about 3.9-4.4 m above the river's spring-flood level. Some vivianite, a mineral that typically forms under water-logged conditions, also is present within this horizon. Peaty beds at 3.9 m height were dated at >43,100 yr B.P.

Silt-rich sediments (unit 2) that appear similar to those in the basal exposure extend upward nearly to the top of the bluff. These have slumped and flowed, then become revegetated, and consequently are poorly exposed. The section is capped by silty sod about 0.5 m thick.

Discussion

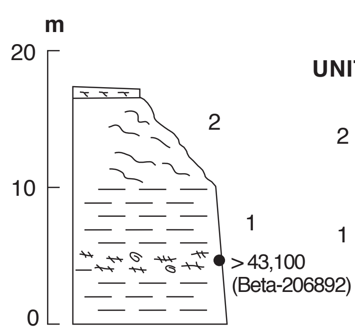
Till deposited directly by glacier ice is exposed at two localities along the stretch of the Noatak River near the Cutler River confluence. Exposure Nk-65A intersects till that probably is assignable to the Avan moraine (Hamilton, 2003 and in press). Farther downriver, the basal till deposit at Nk-66 probably is an eroded remnant of the north flank of the much larger end moraine that was built south of the present course of the Noatak River by south-flowing glaciers that issued from the De Long Mountains.

Glaciolacustrine deposits are common along the north side of the Noatak River above Kelly River. At Nk-64, two



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	45.4	**Silt. Fluvial, eolian, and lacustrine(?).**
d	?	Poorly exposed. Heavy vegetation cover.
c	5	Irregularly bedded. **Pond deposit?**
b	?	Poorly exposed.
a	12.5	Horizontally bedded fine sand and silty fine sand. Loosely packed and unstable, with all exposures displaced downward by slumping. Grades upward into structureless silt (loess). Basal 3.5 m covered.
1	9.3	**Diamict.** Unsorted stones, many striated, in matrix of unsorted silt to granules. **Till.**

Figure 120. Exposure Nk-66. South side Noatak River 4 km below mouth of Kelly River.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	ca. 10	**Silt.** Poorly exposed because of heavy vegetation cover. Appears similar to unit 1. **Origin uncertain.**
1	ca. 7	**Silt.** Compact, dark gray, faintly bedded. Contains mollusk shells, peaty beds, and vivianite through zone 0.5 m thick. **Pond deposit.**

Figure 121. Exposure Nk-67. South bank Noatak River 18 km below mouth of Kelly River. Heights measured above recent spring-flood level. Black dot, radiocarbon age determination (yr B.P.) with laboratory number in parentheses (see appendix 1).

glaciolacustrine units are separated by a thin sand deposit. As seen in bluff exposures farther upvalley, such brief interruptions in glaciolacustrine sedimentation are common in settings where glacier dams are breached and their lakes drain abruptly via outburst floods. Continued glacier flow can rapidly repair an ice dam, permitting the lake to refill soon after it drains.

A terrace at about 18-20 m height underlain by silty floodplain deposits is present at the center section of Nk-64 and at Nk-65A. Two similar radiocarbon ages indicate that downcutting from this terrace level was underway by early Holocene time.

The tall bluff at Nk-66 is difficult to interpret owing to displaced and vegetated slump blocks, but the 18-20 m river terrace may also be present here. The horizontally bedded fine sand seen at about 13-16 m height in displaced slump blocks resembles the eolian-dominated floodplain deposits described at Epiguruk, a bluff on the Kobuk River, by Ashley and Hamilton (1993) and Hamilton and Ashley (1993). Loess deposition would have commenced when the river abandoned this terrace level. If this interpretation is correct, then an astonishing body of loess about 37 m thick would have accumulated during Holocene time at Nk-66.

The 17-m bluff exposure at Nk-67 has a terrace-like surface that probably correlates with the 18- to 20-m terrace remnants farther upvalley. Rather than alluvium, however, exposed lower parts of the bluff face yielded pond and marsh deposits with abundant detrital wood and mollusk shells. A non-finite radiocarbon age (>43.1 ka) on the detrital wood is ambiguous. The wood may have been eroded from older sediments farther upvalley and transported downstream to this site. Alternatively, the lower part of the deposit truely may be this old, and would be separated from overlying much younger floodplain deposits by an unconformity concealed beneath vegetated slump and flow debris.

Kelly-Avan Drainage System

Introduction

The Avan River joins the Kelly River just 2 km above the Kelly River's mouth (see fig. 116). The narrow bedrock valley of the Avan River, which was scoured during the Avan (Itkillik II) ice advance, contrasts markedly with the Kelly River's broad valley floor, which is covered with glaciolacustrine deposits. Only two low exposures of alluvial gravel (Avan-1 and Avan-2) were measured along Avan River near the mouth of its bedrock valley.

The Kelly River system above the Avan confluence consists of the Kelly River trunk stream, it's informally named "west fork," and Wrench Creek (fig. 116). During the Avan glaciation, only very small glaciers advanced short distances from high-level cirques, and most valley floors below about 290 m (950 ft) altitude were inundated by a glacial lake. Five bluff exposures (Kly-1 through Kly-5) along Kelly River and the lower courses of its principal tributaries intersect glaciolacustrine deposits assignable to that lake stage. Because these deposits are similar in character and in age, their exposures are described together as a set. An additional exposure (Kly-6), described separately, intersects the outer flank of an end moraine in the upper valley of Wrench Creek.

Exposure Avan-1

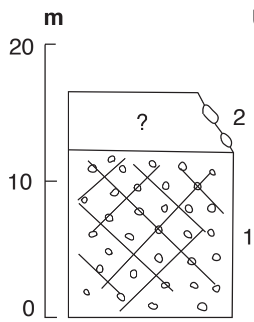
A terrace exposure along the east side of Avan River near the range front intersects possible drift of Avan (Itkillik Phase II) age (see fig. 116). Poorly exposed diamict overlies an unusual lithified gravel (fig. 122). The gravel (unit 1) is weakly bedded and indurated throughout. It locally contains veins of crystalline calcite. Resistant lithologies such as quartzite are little weathered, but probable mafic or ultramafic rock types have been reduced to a fine-grained mudlike substance. The gravel is heavily jointed, with joint planes passing through rather than around clasts. A block of sediment 2.5 m thick dips eastward at 5° to 6°, but beds elsewhere dip toward the northeast at about 12°.

The overlying diamict (unit 2) appears to be a poorly sorted, nonstratified, bouldery deposit. Its gray matrix generally is obscured by brown silt that drapes over the terrace face. The diamict probably is till, but alternatively it could be gravel with lag boulders which became intermixed on the bluff face.

Exposure Avan-2

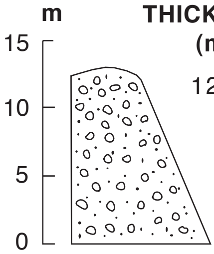
A short distance upvalley from Avan-1, an isolated elongated knob of gravel on the valley floor is an eroded remnant of a formerly more extensive valley-filling deposit. The knob's

Figure 122. Exposure Avan-1. East side Avan River 33 km above its mouth.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	4.2	**Diamict.** Poorly exposed. **Till or gravel.**
1	12.5	**Indurated gravel.** Rounded to subrounded pebbles and cobbles, with some sandy beds and lenses 10-20 cm thick and some cobble-rich lenses. Locally lithified, with joints and calcite veins. Some stones completely weathered. Dip angles up to 12°. **Tertiary(?) alluvium.**

river-cut flank exposes clasts up to cobble size, with no boulders present (fig. 123). All rock types are those common to the De Long Mountains.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
12.5	**Gravel.** Pebbles, small cobbles, and sparse larger cobbles in sandy matrix. Lithologies include black chert, quartzite, and pyroxenite. **Alluvium.**

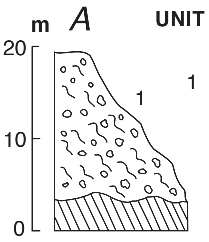
Figure 123. Exposure Avan-2. West side Avan River 1.5 km above Exposure Avan-1.

Exposures Kly-1 through Kly-5

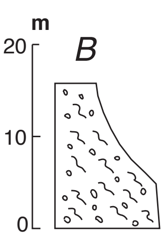
The five glaciolacustrine exposures (figs. 124*A* through *E*) exhibit stony silt that contains clasts up to small boulder size that commonly are striated. Lithologies vary slightly between the exposures, but quartzite, ultramafic rocks, and black chert generally are abundant at each site. Matrix material at exposures Kly-1 through Kly-3 is dark gray, gritty, slightly clayey silt. At Kly-4 and Kly-5, farther up the Kelly River and its "west fork," the matrix is mixed sand and silt which probably reflects sediment influx from tributary drainages into the lake. At all exposures, the glaciolacustrine deposits flow readily, with flows commonly originating at amphitheater-shaped headwalls. At Kly-1 and Kly-3, the glaciolacustrine units directly overlie bedrock. At Kly-4, a muddy well sorted gravel consisting of pebbles and small cobbles and lacking any larger stones underlies the glaciolacustrine unit. This may be deltaic sediment deposited by the "west fork" stream into the margin of the expanding glacial lake. Further lake rise would have overwhelmed the delta and flooded the site.

Exposure Kly-6

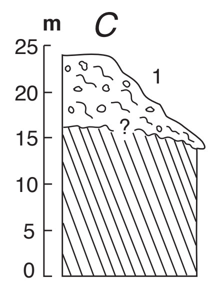
The stream-cut outer face of an end moraine at the headward forks of Wrench Creek stands 23 m high (fig. 125), but a vegetated slope rises inland an additional 17 m to the crest of a prominent boulder-littered morainal ridge. The bluff face exposes structureless limestone and chert rubble that reflects short transport distances from nearby sources.



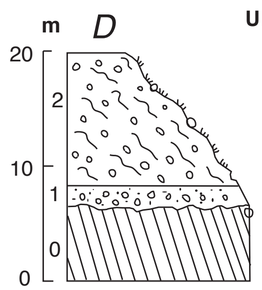
UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	17.5-16.5	**Stony silt.** Striated and faceted clasts up to 70 cm diameter in matrix of dark gray, gritty, slightly clayey silt. **Glaciolacustrine deposit.**
--	2-3	**Bedrock.** Black shale. Erosional upper surface.



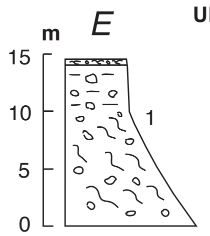
THICKNESS (m)	DESCRIPTION and INTERPRETATION
16	**Stony silt.** Slightly clayey, gritty silt, containing clasts to small boulder size. **Glaciolacustrine deposit.**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	8.5-10?	**Stony silt.** Stones to small boulder size, in matrix of clayey silt. **Glaciolacustrine deposit.**
--	14-15.5?	**Bedrock.** Black shale. Upper surface obscured by drapes of stony silt, and may stand higher than exposed height.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	11.7	**Stony mud.** Clasts up to 70 cm diameter in matrix of mixed sand and silt. **Glaciolacustrine deposit.**
1	1.6	**Muddy gravel?** Pebbles and small cobbles in muddy matrix. **Deltaic deposit?**
0	6.7	**Bedrock.** Quartzite interbedded with black shale. Erosional upper surface.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
1	14.5	**Stony silt.** Generally subangular pebblesand cobbles with some very small boulders in matrix of very gritty silt. Capped by 40 cm slightly stony, frost-mixed silt beneath thin sod mat. **Glaciolacustrine deposit.**

Figure 124. Exposures Kly-1 through Kly-5. Exposures of glaciolaustrine deposits in Kelly River drainage system. All bluff faces disturbed by flowage. (*A*) Exposure Kly-1. South bank Wrench Creek 15 km above its mouth. (*B*) Exposure Kly-2. West bank Wrench Creek 4 km above Kly-1. (*C*) Exposure Kly-3. East side Kelly River 3 km above "west fork" confluence. (*D*) Exposure Kly-4. South side "west fork" Kelly River 4 km above its mouth. (*E*) Exposure Kly-5. East side Kelly River 11.5 km upvalley from mouth of "west fork," near mouth of small west-flowing tributary stream.

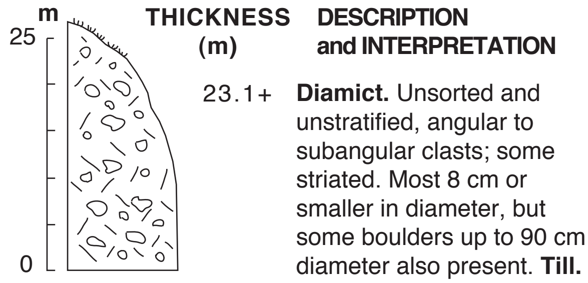


Figure 125. Exposure Kly-6. At headward forks of Wrench Creek 7.5 km northwest of Ampitheatre Mountain.

Discussion

The gravel exposed at Avan-1 is a highly altered deposit with an unusual degree of lithification, weathering, and structural deformation; and with crosscutting veins and joints. It probably is very old, indicating that the U-shaped trough occupied by Avan River may have been eroded by glaciers in early Pleistocene or perhaps late Tertiary time. Alternatively, its unusual degree of alteration may be due to faulting along the range front, which focused deformation here and allowed access of mineralizing fluids. The overlying diamict may be till dating from the glacial advance of Avan age, but it is poorly exposed and therefore both age and origin are uncertain. The gravel of exposure Avan-2 is part of an erosion remnant that stands to about the same height as the gravel unit at Avan-1. However, the two gravel deposits differ in composition and in postdepositional alteration, and therefore must have formed at different times. The highly indurated gravel at Avan-1 may have created a resistant barrier behind which valley-filling gravel (of which Avan-2 is a remnant) accumulated.

The glaciolacustrine deposits at exposures Kly-1 through Kly-5 probably were formed in a single water body that filled the lower valleys of Kelly River, its "west fork," and Wrench Creek. Unsorted clasts to boulder size within the lake deposits indicate the presence of a nearby calving glacier; most likely the glacier that filled Avan River valley, as indicated in fig. 116. Matrix material at the five glaciolacustrine exposures generally is similar, but contains more clay at downvalley sites and is sandier closer to the mouths of tributary streams farther upvalley.

The till exposed at Kly-6 was deposited by a short valley-head glacier that issued from relatively high-standing cirques along the north flank of Amphitheatre Mountain during Avan time. Similar short glaciers formed at this time near the heads of Kelly River and its "west fork." These lie beyond the north margin of fig. 116, but are shown elsewhere (Hamilton, in press).

Eli-Uvgoon Drainage System

The Eli River flows westward past the south flank of Maiyumerak Mountains, then crosses a broad lake-dotted basin before joining the Noatak River (see fig. 116). Uvgoon Creek, a northern tributary to the Eli, issues from several valleys along the northwest flank of Maiyumerak Mountains. Those channels then combine into a single stream that flows southwestward to join the Eli River.

Two exposures along Eli River intersect glaciolacustrine deposits within the broad basin floor (Eli-1) and at its eastern edge (Eli-2). The two exposures measured along Uvgoon Creek are more diverse. Exposure Uv-2 is a deltaic deposit along the east margin of the glacial lake, whereas Uv-1 is the stream-cut southeast flank of a high-standing morainal ridge.

Exposure Eli-1

A 6-m-high exposure along the west shore of an oxbow lake near the Eli River-Uvgoon Creek confluence consists of an amphitheater-headed flow deposit (fig. 126). Exposed in the headwall are unsorted clasts up to about 40 cm diameter in a matrix of clayey, sandy silt. Ultramafic rock types are abundant, with quartzite and black chert also common.

Beyond the flow headwall, an irregular surface rises 16 m higher to a level plain that stands 22 m above the oxbow lake. The sediment underlying this surface is silt-rich but generally concealed; it may be stone-free. Slumps rather than flows are the dominant form of deformation, further indicating that the silt could have been deposited as loess rather than glaciolacustrine sediment.

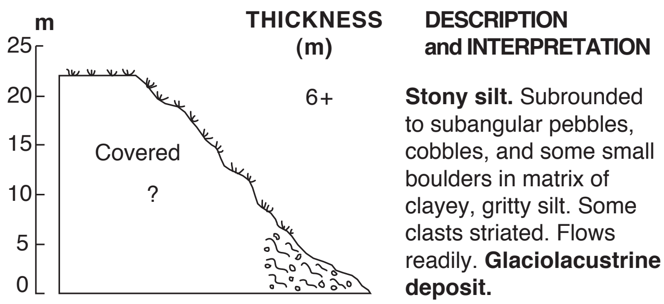
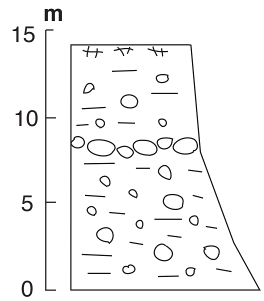


Figure 126. Exposure Eli-1. North side Eli River floodplain near mouth of Uvgoon Creek.

Exposure Eli-2

A south-facing 14-m bluff at the mouth of Eli River's bedrock valley exposes nonsorted clasts dispersed in a silty to sandy matrix that only locally contains traces of clay (fig. 127). Clast lithologies dominantly are ultramafic rock types, quartzite, limestone, and black chert derived from the De Long Mountains.

A boulder line across the midpart of the bluff contains the largest boulders visible along the bluff face, and these clasts perhaps were ice-rafted to this locality when the glacial lake stood briefly at its highest level. The boulders may have been concentrated into a lag deposit by fluvial scour during a subsequent episode of lake drainage.



THICKNESS (m)	DESCRIPTION and INTERPRETATION
14.2	**Stony silt.** Nonsorted and nonstratified clasts up to cobble and rarely boulder size in matrix that fines upward from silty sand at base to sandy silt near top. Some clasts striated. Largest boulders, up to 90 cm long, form line across midpart of exposure. Capped by 60 cm brown silt that is stony near base and peaty near top. **Glaciolacustrine deposit.**

Figure 127. Exposure Eli-2. North bank Eli River near south flank of Maiyumerak Mountains.

Exposure Uv-1

The southeast flank of a prominent ridge just north of Maiyumerak Mountains was steepened at some time in the past by stream erosion, forming a weathered face 31 m high (fig. 128). This surface is littered with pebbles, small cobbles, and less abundant larger clasts up to 1.5 m long. Lithologies are typical De Long Mountains rock types. Dunite, pyroxenite, and limestone containing black chert predominate, with gray quartzite also present.

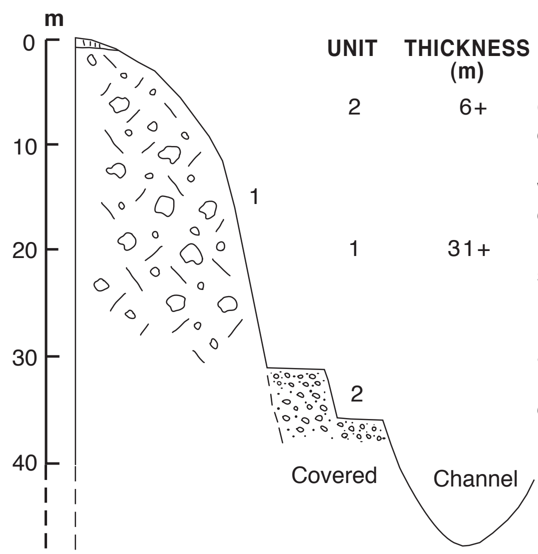
Two benches at the base of the ridge are apparent terraces of river-worked gravel that have an exposed thickness of 6 m. Clasts are better sorted and less weathered than those exposed along the ridge flank, and limestone is the dominant rock type.

Exposure Uv-2

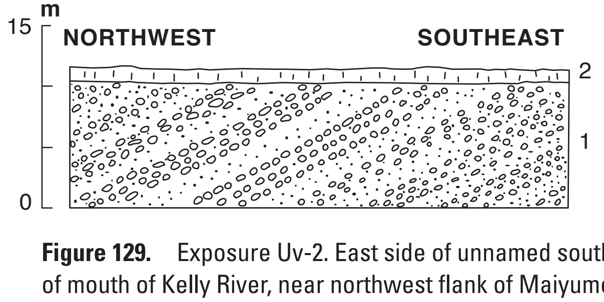
Deltaic gravel (fig. 129) is exposed along the east side of a tributary to Uvgoon Creek just beyond the northwest flank of Maiyumerak Mountains. This exposure, which stands 11.3 m high, is part of a terrace system created by stream incision into a fan-delta complex that had formed at the margin of a glacial lake (see fig. 116). The exposure consists of a nearly uniform set of foreset beds that strike N25°E to N50°E and dip northwest at 24°-28°. Pebble-small gravel predominates, with some sandy layers and lenses also present. Some layers are highly cemented by carbonates and stand in vertical faces. Stones, which include ultramafic lithologies, greenstones, quartz, limestones, and dark gray sandstone, commonly have carbonate crusts on their undersides. The terrace is capped by frost-mixed stony brown silt. Its upper surface is entirely vegetated, with frost hummocks common.

A set of lower (5- to 8-m) terraces on the opposite side of the stream from Uv-2 has gravelly surfaces covered with only patchy vegetation. These terraces must be significantly younger than the terrace at Uv-2.

Figure 128. Exposure Uv-1. Stream-cut flank of morainal ridge 0.8 km north of Uvgoon Creek 17 km southeast of mouth of Kelly River. Measured downslope from ridge crest.



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	6+	**Gravel.** Clasts well sorted with cobbles dominant. Limestone abundant in cobble range. Clasts retain original surfaces, with only minor surface etching. Base covered. **Alluvium.**
1	31+	**Diamict.** Rounded to subrounded pebble-small-cobble gravel with dispersed boulders up to 1.5 m length. Larger clasts poorly sorted to unsorted, rounded to subangular, with ultramafic lithologies common. Bears loess cap 1 m or less thick. Base covered. **Till.**



UNIT	THICKNESS (m)	DESCRIPTION and INTERPRETATION
2	≤1	**Silt.** Frost-mixed stony brown silt. **Loess.**
1	10.5	**Gravel.** Pebbles and small cobbles with some sandy layers and lenses. Beds dip northwest at 24° to 28°. Carbonate cement common. **Deltaic deposit.**

Figure 129. Exposure Uv-2. East side of unnamed southern tributary to Uvgoon Creek 21 km south-southeast of mouth of Kelly River, near northwest flank of Maiyumerak Mountains.

Discussion

Three of the four exposures described from the Eli-Uvgoon drainage system contain glaciolacustrine sediments. Exposures Eli-1 and Eli-2 exhibit unweathered sediment that must date from the youngest lake stage of probable Avan (Itkillik II) age. The clayey gritty silt matrix at Eli-1 is typical of offshore glacial-lake deposits, whereas the sandier matrix at Eli-2 reflects input of fluvial sediments into the glacial lake as part of a fan-delta complex near its margin. The altitude of Eli-2, about 90 m (300 ft), may be representative of at least part of the youngest lake stage that filed the lower Noatak basin and extended north into the Kelly River valley system. As at Nk-66, Eli-1 may contain a poorly exposed but substantial thickness of loess. Silt may have been scoured by strong upvalley (southerly) winds from the lower Noatak basin (Hamilton, in press) shortly after lake drainage and before the newly exposed fine-grained sediments became covered by vegetation. The silt then would have been deposited as loess across and beyond the northern part of the basin.

Uv-2 is a typical lake-margin delta deposit that formed at an altitude of about 210 m (700 ft) near the northwest flank of Maiyumerak Mountains. This lake margin stood about 120 m higher than the fan-delta deposits examined at Eli-2, and it could represent an older and higher lake stage. This inference is supported by the high degree of carbonate cementation in the deltaic exposure, and by its silt-covered, vegetated, frost-heaved upper surface.

Clasts exposed on the flank of the end moraine at Uv-1 are dominantly of De Long Mountains lithologies, indicating that the moraine probably was built by glaciers that originated in the valleys of Kugururok and Avan Rivers and flowed directly south across the Noatak valley floor. Previous mapping (Hamilton, 2003 and in press) suggested that the moraine probably is of Makpik (Itkillik I) age.

The weathered moraine flank at Uv-1 contrasts with the unweathered limestone clasts of the two stream terraces at its base, which retain their original depositional surfaces and show only minor solutional etching. A similar relation exists at Uv-2, where the silt-covered, vegetated, frost-heaved surface of the higher terrace contrasts with the largely barren gravelly surfaces of a set of lower terraces. The little-weathered terraces at these two sites may represent an interval of area-wide alluviation and downcutting that perhaps is correlative with glaciation and glacial-lake formation of Avan age.

Summary and Regional Relations

More than 100 bluffs along the Noatak River and its tributaries that were measured and examined during 1979-2005 have been illustrated and discussed in this report. Forty eight of those bluffs were dated by radiocarbon.

In the upper Noatak River valley, river-bluff exposures provide a cross-section through an end-moraine complex that correlates with the Itkillik II glaciation of the central Brooks Range on the basis of surface morphology, soil and weathering characteristics, and radiocarbon ages (Hamilton, 1986). Lacustrine and slackwater deposits that formed as the glacier receded from its end moraine were laid down between 15 ka and 9.3 ka.

Moraines and outwash correlated with two substages of Itkillik I glaciation in the central Brooks Range are exposed farther downvalley in the eastern part of the Noatak River's upper basin. These deposits locally are unstable and are being displaced laterally toward the river by underlying flows of clayey sediment. The terminus of the glacier of Itkillik I age must have extended into a lake dammed by contemporaneous ice advances farther downvalley. A large kettle, evident in outwash of Itkillik II age where it overlaps Itkillik I deposits, demonstrates that glacier ice persisting from the Itkillik I glaciation was still present at the time of the Itkillik II ice advance. Multiple terraces in the end-moraine zone reflect successive levels at which the Noatak River flowed during late Itkillik I time, during deposition of Itkillik II outwash, and during subsequent Holocene downcutting.

Two bluffs (An-1 and Nk-21) in the Aniuk area expose glacial and interglacial deposits of pre-Itkillik age. The 78-m-high bluff at An-1 contains multiple alluvial and glaciolacustrine units and deeply buried peat beds. This bluff and its organic record deserve further examination. Exposure Nk-21, which stands to 70 m height, has a water-scoured, terrace-like surface that was created by the Noatak River flowing at a very high level, probably during glacial recession from the Cutler advance. It therefore may record an early post-Cutler interglacial stage.

The Cutler River drainage system, in the south-central part of the Noatak River's upper basin, is the largest southern tributary to the Noatak River. The Cutler moraine was formed by a very large glacier that flowed southeastward out of the De Long Mountains; it covered the Noatak valley floor, and expanded eastward to the present mouth of the Cutler River. The glacier blocked the lower course of that river, deflecting it eastward to its present position. Although of middle Pleistocene age (Sagavanirktok River age in the central Brooks Range glacial succession), the Cutler advance has no exact equivalent in the central Brooks Range. It may be correlative with the very large glacier that built the Baldwin Peninsula moraine in the Kotzebue Sound region, perhaps about 500-600 ka (Huston and others, 1990).

Widespread flow deposits of Cutler age around the mouth of Cutler River have exposed thicknesses of about 40 m. They demonstrate that the Cutler advance terminated in a deep proglacial lake. Much of the Cutler drainage system remained unglaciated during Cutler and younger advances, but was filled with proglacial lakes assignable to Cutler and succeeding lake stages (Hamilton, 2001):

Makpik and Anisak	300 m asl (1,000 ft)
Okak	365 m asl (1,200 ft)
Cutler and older	520 m asl (1,700 ft)

Along the Cutler River, exposure Cu-7 exhibits peat and sand that span the last glacial maximum (the Itkillik II advance), as documented by radiocarbon dating. This demonstrates that marshy conditions with restricted drainage prevailed during Itkillik II time, probably promoted by rising base level due to glacier dams farther down the Noatak valley. This part of the Cutler drainage must have been a biologically rich environment during the last glacial maximum, a condition highly unusual within the Brooks Range at that time. An older succession of marsh deposits at Cu-7 may have accumulated until shortly after 46.8 ka, but this age determination needs to be confirmed by redating using the AMS method.

Through the western part of the upper Noatak basin or Aniuk Lowland (between Cutler River and New Cottonwood Creek) many of the higher bluffs along the Noatak River record the series of end moraines that were deposited by glaciers that flowed southeastward from the De Long Mountains subsequent to the Cutler advance. Those glaciers crossed the valley center and dammed a succession of proglacial lakes. Till of the oldest moraine (the Okak moraine) is not evident at the surface across the valley center, but forms the core of the prominent Okak Bend and is exposed at Nk-29. This till overlies the Old Crow tephra at that exposure, and therefore is younger than the last interglacial maximum (marine-isotope stage 5e). Successively younger moraines are the Makpik (broadly eroded in the valley center and not exposed in the bluffs), the Anisak (exposed at Nk-34), and Anisak recessional moraines (one of which is exposed at Nk-37). The moraines and their associated lake levels have been discussed and illustrated in a previous publication (Hamilton, 2001), which concluded that in the western Aniuk Lowland the Cutler water plane was at 425 m (1,400 ft) asl, the Okak at 325 m (1,100 ft) asl, and the Anisak at 300 m (1,000 ft) asl. These surfaces are 50-100 m lower than comparable lake stands in the eastern part of this lowland, where greater isostatic uplift took place owing to the more extensive glacier cover over the central Brooks Range.

Lower bluffs through the western part of the upper Noatak basin reflect alluvial-terrace formation through a series of downcutting stages beginning about 13 ka. Downcutting was rapid at first, yielding almost indistinguishable radiocarbon ages on successively lower terraces between about 30 m and 10 m height.

Downstream from Nimiuktuk River, the Noatak River was displaced southward by south-flowing glaciers that issued from higher parts of the De Long Mountains. Through the stretch between the Nimiuktuk and Kugururok Rivers, the Noatak occupies a generally narrow and rock-walled valley that is much more constricted than within the upper and lower basins. During Makpik and Anisak times, individual glaciers flowed southward out of the De Long Mountains through major valley systems. Glacier dams formed at the mouths of Kaluktavik, Kugururok, Avan, and Cutler River valleys during Makpik time, but only at the mouth of Avan River valley during the subsequent much more limited Avan (Itkillik II) glaciation. Glacial lakes at about 400 m (1,300 ft) asl are associated with the Makpik advance; lakes at about 300-350 m (1,000-1,150 ft) asl are correlated with the Avan advance. A spectacular exposure of relict glacier ice was examined in 1986 at Nk-59, but was no longer visible when that bluff was revisited 14 years later.

The final stretch of the Noatak River valley along which bluffs were examined extends from Kugururok River to Eli River and constitutes the northern part of the lower Noatak basin or Mission Lowland. An end moraine parallels the Noatak River to the south through much of this stretch. It probably is of Anisak age, but is buried and largely obscured beneath lacustrine sediments and loess and could not be examined directly. The Avan moraine, equated with the last glacial maximum (LGM) and the Itkillik II glaciation of the central Brooks Range, also is partly obscured by lake sediments, but is well exposed near the south flank of the De Long Mountains and in a bluff face (Nk-65A). Most exposures in the Kelly River drainage system exhibit glaciolacustrine sediments correlated with the LGM, which document filling of lower and middle valleys to about 290 m (950 ft) asl by elongate arms of a proglacial lake. Moraines of Avan age in the Kelly River system were restricted to heads of the larger valleys and to the mouths of short cirque-headed tributaries. During this and preceding lake stages, flow from the Eli River built a large fan-delta complex into standing water bodies that filled the Mission Lowland. Thick loess was generated from the barren mud-covered floor of this basin each time the lake drained. Loess blankets much of the Kugururok-Eli Rivers area, and may be as thick as 37 m at Nk-66.

Most of the radiocarbon ages from the higher and older bluffs along the Noatak River and its principal tributaries are non-finite, indicating that the glacial, glaciolacustrine, and interglacial alluvial deposits exposed there are all older than about 50 ka. (The few apparently finite ages are suspect because of large counting errors, and several of them have been demonstrated to be incorrect by later AMS radiocarbon dating.) These very old ages support recent mapping in the De Long Mountains, which has shown that the glacial advances of the LGM (Itkillik II) time were very limited in extent (Hamilton, in press). Similar very restricted glaciation of LGM age has been reported from parts of easternmost Russia by Gualtieri and others (2000) and by Brigham-Grette and others (2003). A few non-finite ages were obtained on detrital wood, commonly identified as spruce, found within terrace deposits that clearly are postglacial in age. Those wood pieces must have been redeposited from older sediments that date back to the maximum of the last interglacial, when spruce expanded into parts of the Noatak River valley, or to preceding interglacials.

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Appendix 1—Radiocarbon age determinations from river bluffs within Noatak National Preserve

Appendix 1. Radiocarbon age determinations from river bluffs within Noatak National Preserve.

[yr B.P., years before present; ht, height]

Bluff exposure no.	Age (yr B.P.)	Laboratory no. [1]	Material dated	Stratigraphic position [2] and prior publications [3]
Exposures Along Noatak River				
Nk-3	10,000 ±145	I-11,423	Peat	Base of floodplain deposit above gravel
Nk-4	>40,000	I-12,512	Wood	Small abraded detrital fragments; probably redeposited
Nk-7	2,660 ±80	I-12,511	Peat	Near base of bluff cap
Nk-8	9,280 ±150	I-13,396	Peat	At alluvial-deltaic contact (1)
Nk-8	15,030 ±200	I-12,514	Wood and rootlets	Near top of lacustrine beds (1)
Nk-11	34,010 ±350	USGS-2453	Peaty silt	Base of upper diamict; probably redeposited (1)
Nk-11	30,070 ±470	USGS-1835	Organic silt	2 m below top of fine alluvium (1)
Nk-11	34,840 ±950	USGS-1836	Organic silt	4 m below top of fine alluvium (1)
Nk-11	34,990 ±230	USGS-2454	Peaty silt	Within lower diamict (1)
Nk-13	30,160 ±410	USGS-1837	Rootlets and organic detritus	Alluvium 8.5 m above river (1)
Nk-14	3,710 ±90	I-13,448	Wood (*Salix*)	In growth position 13 m above river
Nk-14	4,220 ±110	I-13,521	Peat	Buried tundra soil
Nk-14	3,110 ±90	I-12,515	Wood (*Salix*)	In growth position; in slump block?
Nk-19	6,050 ±120	I-13,522	Peat	Near exposed base of massive peat 3.3 m above river
Nk-22	13,160 ±160	USGS-1838	Rootlets	In poorly exposed sand above glaciolacustrine deposit
Nk-26	>47,000	USGS-1840	Wood fragments	Within capping sand at 32 m ht (2) (3)
Nk-26	>49,500	USGS-1457	Wood fragments	Floodplain deposit at 9.5 m ht (2) (3)
Nk-27	1,570 ±90	USGS-3401	Wood (*Populus*)	Log in low terrace opposite exposure Nk-27
Nk-28	>57,000	USGS-1841	Organic silt	Floodplain deposit at base of lower diamict (3)
Nk-29A	>46,400	AA20752	Peat with wood	Floodplain deposit; 17.5 m ht (3)
Nk-29A	>51,000	USGS-1842	Peat	Ice-wedge cast in alluvium; 16m ht (2) (3)
Nk-29A	52,500 +2,700 /-2,000	USGS-1843	Humic silt	Channel fill in floodplain deposit; 17 m ht (2) (3)
Nk-31	>49,000	USGS-3402	Wood (*Picea*)	Floodplain deposit near river level (3)
Nk-31A	5,000 ±60	AA20753	Wood (*Populus*)	9 m terrace; near base of floodplain unit
Nk-32	35,000 ±2300	I-13,466	Peat	Paleosol within alluvium; 12.5 m ht (3)
Nk-32A	9,655 ±75	AA20756	Peat	14 m terrace; peaty channel fill; 3 m depth (3)
Nk-32A	10,085 ±95	AA20754	Woody peat	14 m terrace; peaty channel fill; 6 m depth (3)
Nk-32A	10,205 ±80	AA20755	Peat	14 m terrace; base of peaty channel fill (3)
Nk-32B	4,610 ±60	AA20757	Peat	14 m terrace; base of capping peat unit
Nk-32B	11,310 ±85	AA20758	Peat	12.5 m terrace; within overbank unit; 5.8 m depth (3)
Nk-32C	930 ±60	USGS-3404	Peat	4.5 m terrace; in floodplain deposit
Nk-33	12,890 ±190	I-12,542	Peat	14.5 m terrace; base of sandy floodplain deposit: 8.5 m ht (3)
Nk-33	12,970 ±280	I-12,517	Peat	14.5 m terrace; base of depression fill in flood-plain deposit: 10.5 m ht (3)

Appendix 1. Radiocarbon age determinations from river bluffs within Noatak National Preserve—Continued.

Bluff exposure no.	Age (yr B.P.)	Laboratory no.[1]	Material dated	Stratigraphic position [2] and prior publications [3]
Nk-33	13,620 ±95	AA20770	Detrital twigs	14.5 terrace; base of sandy floodplain deposit: 8.5 m ht (3)
Nk-35A	9,565 ±90	AA20762	Wood (*Salix*)	Near top of depression fill; 31.8 m ht (3)
Nk-35A	9,830 ±75	AA20771	Wood (*Salix*)	Log near top of silt and peat unit; 2.2 m depth (3)
Nk-35A	10,560 ±80	AA20786	Peat	Base of silt and peat unit; 3.9 m depth (3)
Nk-35A	10,720 ±85	AA20761	Wood (*Salix*)	Base of silt and peat unit; 28.1 m ht (3)
Nk-35A	13,640 ±80	USGS-3406	Peat	Bryophyte mat in eolian sand at 26 m ht (3)
Nk-35A	40,180 ±750	USGS-3405	Peat	Diapiric extrusion near river level at downstream end of bluff (3)
Nk-35A	>44,800	AA20759	Wood fragments	Diapiric extrusion near river level at downstream end of bluff (3)
Nk-35A	>45,200	AA20760	Wood fragments	Peaty layer in postglacial kettle fill at 23 m ht; probably redeposited (3)
Nk-37	33,690 ±300	USGS-1846	Wood (*Picea/Larix*)	Distal part of detrital wedge near bluff center (3) (4)
Nk-37	36,610 ±400	USGS-3287	Peat	Floodplain deposit below upper diamict; E sector of bluff (3) (4)
Nk-37	44,800 +3000/-2200	USGS-3408	Silty peat	Distal part of debris wedge near bluff center (3) (4)
Nk-37	>42,000	USGS-3407	Wood (*Salix*)	Distal part of debris wedge near bluff center (3) (4)
Nk-37	>46,000	USGS-1845	Wood (*Picea/Larix*)	Detrital wood in imbricated gravel unit; E sector of bluff (3) (4)
Nk-37	>48,440	Beta-156895	Wood	Floodplain deposit below upper diamict; E section of bluff (4)
Nk-37	>48,740	Beta-156896	Wood fragments in peat	Floodplain deposit below upper diamict; E section of bluff (4)
Nk-44	>45,800	Beta-206893	Detrital wood	Near base of alluvial gravel; 36 m ht
Nk-44	>45,800	Beta-206894	Detrital wood	Near base of alluvial gravel; 36 m ht
Nk-47	13,310 ±40	Beta-156904	Detrital wood	Near base of floodplain unit above gravel; 20 m ht (5)
Nk-47	13,370 ±50	Beta-156903	Rodent feces	Near base of floodplain unit above gravel; 20 m ht (5)
Nk-48	>57,000	USGS-2456	Detrital wood	Alluvium beneath till; ca. 6 m ht
Nk-48	>57,000	USGS-2457	Peat	Alluvium beneath till; ca. 6 m ht
Nk-49	13,140 ±40	Beta-156900	Woody peat	Silt with peat lenses near bluff crest (5)
Nk-50B	25,060 ±230	Beta-206891	Detrital wood	Near base of floodplain deposit above gravel; 24 m ht
Nk-54A	11,910 ±180	I-14,680	Detrital wood (*Salix*)	Near base of floodplain deposit above gravel; 3 m depth
Nk-54B	>45,800	Beta-206890	Detrital wood	Within fluvial gravel; 6 m ht
Nk-59	5,710 ±120	I-14,682	Peat	Base of "chaos" unit (kettle fill); 17 m ht
Nk-59	7,540 ±130	I-14,681	Peat	Near base of silt cap
Nk-59	8,805 ±40	USGS-2460	Peat	Alluvium interstratified with diamict; 12 m ht
Nk-59	>58,000	USGS-2459	Detrital wood (*Picea*)	In upper gravel; 29 m ht

Appendix 1. Radiocarbon age determinations from river bluffs within Noatak National Preserve—Continued.

Bluff exposure no.	Age (yr B.P.)	Laboratory no. [1]	Material dated	Stratigraphic position [2] and prior publications [3]
Nk-64	9,220 ±40	Beta-156899	Peat	Base of peat-filled depression; about 14 m ht (5)
Nk-64	9,360 ±40	Beta-156902	Wood	Organic silt unit in detrital wedge (5)
Nk-67	>43,100	Beta-206892	Peat	Pond deposit; 3.9 m ht
Exposures Along Aniuk River				
An-1	39,700 ±1600	USGS-1665	Peat	Mid part of upper glaciolacustrine unit
An-1	>39,500	USGS-1666	Silty peat	2 m above base of upper glaciolacustrine unit
An-2	>48,000	USGS-1667	Peat	Upper contact of alluvial gravel; 13 m ht
An-5	8,210 ±130	I-13,232	Wood (*Salix*)	In channel fill; 3.8 m ht
An-5	8,530 ±140	I-13,231	Wood (*Salix*)	Base of peaty channel fill; about 2.5 m ht
Exposures Along Cutler River				
Cu-2	7,280 ±120	I-13,449	Wood (*Salix*)	Near base of sand above gravel and diamict
Cu-4	>50,000	USGS-1839	Wood and plant remains	Near base of upper glaciolacustrine unit
Cu-5	>40,000	I-13,465	Wood (*Salix*)	In bedded sand that overlies diamict
Cu-7	17,980 ±120	USGS-1452	Peat	Peaty sand in slump block near top of bluff
Cu-7	27,530 ±350	USGS-1453	Peat	Near base of sand with peat beds; above gravel
Cu-7	46,800 +1,400 /-1,200	USGS-1454	Wood and peat	In fine sand and silt near bluff base
Cu-8	>38,000	USGS-1652	Wood (*Salix*)	Near top of gravel that overlies deltaic unit
Cu-8	>40,000	I-12,516	Peat and bark	Near top of deltaic and lacustrine unit
Cu-8	42,600 ±1,100	USGS-1651	Wood (*Salix*)	Near base of deltaic and lacustrine unit
Cu-12	43,600 ±1,300	USGS-1649	Peat	Within peaty silt above glaciolacustrine unit
Cu-12	>48,500	USGS-1648	Peat	Near base of peaty silt above glaciolacustrine unit
Exposures Along Imelyak River				
Im-1	9,455 ±40	USGS-1455	Peat	Base of peat cap above outwash gravel
Im-1	>48,000	USGS-1456	Detrital wood	Near top of bedded sand below outwash gravel
Exposures Along New Cottonwood Creek				
Ctn-1	>47,590	Beta-156894	Detrital wood (*Picea?*)	Alluvial gravel; 6.8 m ht
Exposures Along Kaluktavik River				
Kl-3	2,760 ±40	Beta-206889	Peat	Floodplain-loess contact; 70 cm depth
Exposures Along Kugururok River				
Ku-1	9,440 ±40	Beta-156898	Peat	Near base of peat above glaciolacustrine unit; 1.0 m depth
Ku-3	43,480 ±1,230	Beta-156901	Peat	Peat mat in ice-rich deposit; about 7 m depth
Exposures Along Sapun Creek				
Sp-1	>43,300	Beta-188261	Peat	Lacustrine or slackwater deposit beneath till; 7.8 m ht
Sp-1	>43,300	Beta-188262	Peat	Lacustrine or slackwater deposit beneath till; 7.8 m ht
Sp-2	>47,590	Beta-156894	Detrital wood	Channel fill near top of gravel; 40 m ht
Sp-2	>48,280	Beta-156893	Detrital wood	Near top of deltaic beds; 31 m ht

[a] Radiocarbon labs: AA, University of Arizona; Beta, Beta Analytic; I, Isotopes, Inc.; USGS, U.S. Geological Survey, Menlo Park, Calif.

[b] Heights are above river level; depths are below ground surface.

[c] (1) Hamilton and others, 1987; (2) Elias and others, 1999; (3) Hamilton, 2001; (4) Edwards and others, 2003; (5) Hamilton, 2003.

Appendix 2—Clast Lithologies of Tills and Glaciolacustrine Deposits, Central and Western Aniuk Lowland

Introduction

Highland source areas to the east, south, north, and northwest fed glacial sediments into the central and western Aniuk Lowland, where they are exposed in bluffs along the Noatak and lower Cutler rivers. Granitic rocks were derived from highlands to the east around the Noatak's headwaters; schist with abundant vein quartz and diverse metasedimentary rocks were transported via southern tributaries to the Noatak River, especially down the extensive Cutler River drainage system. Distinctive ultramafic rocks such as gabbros and pyroxenites (Nelson and Nelson, 1982) were carried southward from the Siniktanneyak Mountain area, and ultramafic rocks as well as chert and other sedimentary lithologies traveled southeastward from sources farther west in the De Long Mountains.

To assist in determining source areas for till deposits and glaciolacustrine sediments in this part of the Aniuk Lowland, clast lithologies were recorded from nine of the bluffs along the Noatak River between Nk-22 and Nk-36 and from two additional bluffs (Cu-1 and Cu-4) near the mouth of Cutler River. Although 50 clasts were counted in most cases, as few as 25 or as many as 100 were tabulated depending on their abundance and accessibility. These diverse stone counts were reduced to percentages to facilitate comparisons between stratigraphic units or between river bluffs. In several cases (for example, Nk-22), separate counts were made on clasts of different sizes from the same stratigraphic unit to investigate how size influences the rock types represented and their relative proportions.

Stone Counts

Exposure Nk-22
Clasts exposed on surface of debris flow (unit 1).

Cobbles; 28 counted	Percent
Quartzites	25
Pyroxenite	17
Aphanitic igneous rx	14
Misc. metamorphic rx	14
Granitic rx	11
Chloritized rx	11
Marble	8

Pebbles; 90 counted	Percent
Quartzites	28
Schist with vein quartz	22
Black chert	17
Pyroxenites	13
Miscellaneous	20

Exposure Nk-23
Clasts exposed on surface of debris flow (unit 1).

Large cobbles and boulders; 30 counted	Percent
Gabbros	30
Gray quartzites	27
Ferruginous quartzites	13
Limestone/marble	7
Granite	7
Chlorite schist	7
Black chert breccia	3
Gneiss	3
Slate	3

Pebbles; 100 counted	Percent
Pyroxenites	19
Gray-green quartzites	17
Ferruginous sandstone	15
Red, gray, & brown cherts	15
Black cherts	10
Green aphanitic igneous rx	10
Miscellaneous	6
Quartz and quartz w/ schist	4
Granitic rx	1

Exposure Nk-24
Clasts exposed on surface of debris flow (unit 1).

Boulders; 100 counted	Percent
Gabbros-syenites	48
Gray quartzites	24
Gray limestone	16
Ferruginous quartzites	8
Basalt	4

Pebbles; 98 counted	Percent
Black chert	44
Gabbro types	18
Ferruginous quartzites	12
Basalt	9
Red chert	9
Schist	4
Granite	2
Quartz	2

Exposure Cu-1
Clasts exposed on surface of debris flow (unit 1).

Large cobbles and small boulders (100)	Percent
Quartzites	48
Gabbros	28
Misc. igneous rx	12
Limestone	4
Quartz	4
Leucocratic granite	4

Pebbles; 34 counted	Percent
Quartzites	58
Black chert	24
Green chert	12
Gray chert	6

Exposure Cu-4
Pebbles from lower and upper glaciolacustrine units.

Lower Diamict (unit 1); 50 counted	Percent
Green porphyritic igneous rocks	22
Gray quartzites	14
Black chert	12
Gray limestone	10
White quartz	10
Leucocratic granite	6
Black phyllite	6
Green dike rx	6
Gray chert	4
Misc. (5 rx., 2percent each type)	10

Upper diamict (unit 4); 50 counted	Percent
Gabbro and gabbro-like rx	32
Black chert	18
Green chert	16
Green dike rx	14
Ferruginous quartzite	6
Gray limestone	4
Quartzite	4

Leucocratic granite	4
Chloritic schist	2

Exposure Nk-25

Pebbles from glaciolacustrine deposit (unit 1);

50 counted	Percent
Quartz and quartz w/ schist	44
Phyllitic schist	18
Limestone-dolomite-marble	16
Sandstone-mudstone	8
Misc. igneous rx	6
Quartzite	4
Gray chert	4

Exposure Nk-26

Stones from lower and upper glaciolacustrine units.

Lower stony mud (unit 2); 50 platy cobbles	Percent
Gray quartzite	30
Gray limestone	22
Black and gray chert	16
Dark, coarse crystalline rx	16
Dark, fine crystalline rx	16
Limestone	3

Upper stony mud (unit 6); 34 cobbles?	Percent
Gray quartzite	35
Gabbro-like dark crystalline rx	35
Basalts	15
Felsic igneous rx	6
White quartz	3
Chert breccia	3

Exposure Nk-27

Pebbles from lower and upper diamicts.

Lower diamict (unit 2); 50 counted	Percent
Porphyritic dark igneous rx	28
Aphanitic green igneous rx	24
Chert	22
Gray & ferruginous quartzites	22
Quartz and quartzose schist	4

Upper diamict (unit 4); 50 counted	Percent
Chert	28
Aphanitic green igneous rx	18
Quartz & quartzose schist	14
Dark porphyritic igneous rx	14
Quartzites	8
Graywackes	6
Chert breccia	2
Miscellaneous	10

Exposure Nk-30

Stones from lower and upper diamicts.

Lower diamict; 50 pebbles counted	Percent
Chert (equal amts black and green)	28
Dark green igneous rx	22
Gray quartzite	18
Aphanitic green igneous rx	12
Gray limestone	12
Quartz with schist	4
Siltstone	2
Ferrugineous quartzite	2

Upper diamict; 25 boulders counted	Percent
Igneous rx	68
Quartzites	28
Marble	4

Exposure Nk-34

Pebbles from debris flow; 50 counted	Percent
Chert (mostly black)	38
Coarse-grained igneous rx	16
Quartzites	16
Aphanitic igneous rx	12
Slates	8
Limestone-dolomite-marble	8
White quartz	2

Exposure Nk-36

Clasts exposed on surface of debris flow.

Boulders; 50 counted	Percent
Gray quartzite	30
Carbonate rx	30
Coarse-grained crystalline rx	28
Aphanitic igneous rx	6
Chert breccia	2
Conglomerate	2
Chert	2

Pebbles; 50 counted	Percent
Chert	32
Aphanitic igneous rx	22
Coarse-grained igneous rx	20
White quartz	12
Granite	4
Limestone	4
Miscellaneous	6

Discussion

Exposure Nk-22, about 3 km up the Noatak River valley from the Cutler moraine front, intersects a terracelike depositional surface 40-45 m high. Its diamict may be either a remnant of a Cutler-age proglacial deposit that has been truncated by erosion or a glaciolacustrine deposit that postdates the Cutler advance. The abundant cherts and quartzites in its pebble assemblage are comparable to clasts in deposits farther downvalley that were derived from the De Long Mountains. However, the assemblage also contains abundant schist derived from the southern Brooks Range. The cobble assemblage, which includes pyroxenite, granitic rocks, and several metamorphic rock types, also indicates derivation from multiple sources around the central and western Aniuk Lowland.

Three nearly identical bluff faces (Cu-1, Nk-24, and Nk-23) intersect the outer part of the Cutler moraine. Cu-1 and Nk-24 are situated only 2 km apart near the mouth of the Cutler River; Nk-23 stands 2.5 km northeast of Nk-24. All three bluffs contain a single basal unit of glaciolacustrine sediment about 40-45 m thick that largely is obscured by debris flows. Boulder samples from the three exposures are very similar, with gabbros and quartzites comprising 70-80 percent of the assemblage at each bluff. The gabbros were derived from Siniktanneyak Mountain (north of Feniak Lake), and were transported southward either by ice rafting or within a glacier tributary to the Cutler glacier. Granites derived from intrusions at the head of the Noatak valley are present at two of the localities. In contrast, pebble compositions of the three diamicts are very different. For example, quartzites are dominant at Cu-1, but much less abundant at Nk-23 and Nk-24; those at Nk-24 dominantly are ferruginous, whereas those at Nk-23 are a gray-green variety.

Exposure Cu-4, 3.7 km up the Cutler River from Cu-1, exposes two glaciolocustrine units. The lower diamict contains abundant limestone, quartz, granite, phyllite, and an aphanitic green igneous rock; lithologies derived from the southern Brooks Range and from intrusions near the Noatak headwaters. This assemblage differs significantly from those of the glaciolacustrine deposits around the mouth of the Cutler River. The upper diamict, in which cherts and gabbro-like rocks predominate, differs in important respects from the diamict at Cu-1. Black and green cherts are about equivalent in abundance at the two sites, but gabbro-like igneous pebbles predominate at Cu-4 whereas quartzites are dominant at Cu-1. However, lithologies of the mafic pebbles at Cu-4 resemble those of the gabbro boulders at Cu-1, Nk-23, and Nk-24, indicating that the four diamicts indeed could be correlative.

The thick glaciolacustrine deposits at exposure Nk-25, only 2.5 km downvalley from the Cutler River mouth, might be expected to correlate with the bluff deposits exposed around the Cutler moraine. However, Nk-25 intersects a terracelike surface about 45 m high which appears comparable to the surface at Nk-22 and the surfaces farther downriver at Nk-26 and Nk-27; its diamict also has a stratigraphic position similar to that of the upper glaciolacustrine deposits at Nk-26 and Nk-27. Pebble composition of the diamict at Nk-25 should be an ideal way to test these correlations, but its pebble assemblage is unique. Schist, vein quartz, and sedimentary and metasedimentary rock types predominate, indicating southerly sources and probable transport into the Noatak River via the Cutler River system. The De Long Mountains, primary source for the clasts farther downriver (as discussed below), were a negligible source for the pebbles at Nk-25.

Exposures Nk-26 and Nk-27, which are about 6 km apart, intersect a depositional surface about 40 m high that formed within the Cutler moraine following a nonglacial interval. Each exposure contains two diamicts separated by nonglacial alluvium and paleosols. The lower diamict appears to be a glaciolacustrine deposit at Nk-26 but a true till at Nk-27. These two deposits may represent maximum and recessional phases of the Cutler ice advance, or they could represent separate glaciations. Unfortunately, cobbles were sampled at Nk-26 (incidental to fabric studies), whereas a standard pebble count was carried out at Nk-27. The pebbles from Nk-27 dominantly are coarse- and fine-grained igneous rocks, chert, and quartzites, and are close in composition to other diamicts derived from the De Long Mountains. The lower diamict at Nk-26 also appears to show a characteristic De Long Mountains "signature." The upper diamict at each exposure, a glaciolacustrine deposit that rises to about 30 m height, should be correlative between the two sites. It may have formed in front of the Makpik moraine, derived from glacier sources in the De Long Mountains, which crosses the Noatak valley center a short distance downvalley. At Nk-27, the upper diamict contains abundant chert and igneous-rock pebbles, but schist also is abundant and graywackes are common. This assemblage indicates that DeLong Mountains lithologies may have been mixed with clasts derived from the southern Brooks Range. The upper diamict at Nk-26 should be equivalent to that of Nk-27, but the composition of its cobble assemblage is markedly different. Differing clast sizes may account for part of this contrast, but source areas also may differ between the two deposits.

Exposure Nk-30, at Okak Bend, probably intersects the north lateral moraine of the Cutler glacier, which flowed southeastward from the DeLong Mountains. Pebbles from the basal till unit are dominantly chert, igneous rocks, and quartzite, a characteristic DeLong Mountains assemblage that is common in exposures farther downvalley (for example, Nk-34 and Nk-36). Boulders from the upper diamict, a glaciolacustrine deposit probably associated with the Makpik moraine, also are primarily igneous rocks and quartzite of De Long Mountains derivation.

At exposures Nk-34 and Nk-36, pebble counts were taken from debris flows on diamicts interpreted to be proximal glaciolacustrine deposits associated with the Anisak moraine. Pebble assemblages from the two diamicts are nearly identical. Chert is dominant at both sites, followed by aphanitic and coarse-grained igneous rocks, which are about equal to each other in abundance. However, white quartz also is abundant at Nk-36 whereas quartzites are about equally numerous at Nk-34. These two similar lithologies possibly were not carefully differentiated during the pebble counts. A boulder count from Nk-36 shows some similarities to the pebble count, but also striking differences. For example, chert, the dominant pebble, is rare in the boulder range. It may occur only in thin beds where eroded from outcrop, or it may be so brittle or highly fractured that it is unable to survive transport as large clasts.

Conclusions

Clast lithologies from the westernmost sites, Nk-36, Nk-34, and Nk-30, have similar compositions that are compatible with a source area in the De Long Mountains northwest of the Aniuk Lowland. The progressive upvalley increase in limestone pebbles from Nk-36 (4percent) to Nk-34 (8percent) and Nk-30 (12percent), as well as the presence of quartz with schist at Nk-30, could reflect increased admixture of upvalley lithologies as glaciers advanced eastward up the Noatak valley. Diamicts from bluffs farther upvalley show more pronounced admixture of lithologies from other sources to the north (Siniktanneyak Mountain gabbros and pyroxenites), to the east (granitic rocks from the valley head), and south (schists, marbles, and other metamorphic rocks from the southern Brooks Range).

Near the mouth of the Cutler River the depositional record becomes extremely complex. Neighboring exposures of almost certainly correlative diamicts contain pebble assemblages that are strikingly different. However, boulder counts are more consistent. They confirm that the three exposures into the Cutler moraine contain correlative diamicts, and they indicate that the Cutler ice advance included a significant northern component—possibly a tributary glacier from Siniktanneyak Mountain.

The younger glaciolacustrine deposits inset within the Cutler moraine are more diverse, but they also appear to contain a characteristic signature—rock types derived from the upper Noatak River and from its southern tributaries. Whereas ice-proximal deposits of Cutler age contained sediments derived dominantly from the Cutler lobe, the younger glaciolacustrine deposits associated with more distant ice fronts were not dominated by a single source and therefore contain a more mixed assemblage of sediments.

The greater heterogeneity of pebbles relative to boulder-sized clasts at most sites probably is due to incorporation of interglacial alluvium, which fills the valley center today and is conspicuous in Pleistocene deposits exposed in river bluffs throughout the upper Noatak basin. This alluvium, generally pebble-to-small cobble gravel, must have been incorporated into glaciers advancing into the Aniuk Lowland and became a major component of their debris load at localities along the valley center. Reworked interglacial alluvium was even more important where glaciers from the DeLong Mountains flowed upvalley into the lowland. Those glaciers would have fronted in proglacial lakes, and therefore lacked the extensive outwash streams that transport alluvium away from an ice front.

The glaciolacustrine deposits in the Aniuk Lowland clearly are mixtures of sediments derived from multiple source areas. The dominance of individual source areas may have varied with time, being reflected in clast compositions that differ vertically within a deposit. Any such changes would be masked where sediments have been mixed by flowage down bluff faces as, for example, at Nk-22 through Nk-24. Many of these sediments also would have been recycled from one glaciation to the next rather than being flushed out of the basin through its narrow outlet. These complications make the rich Quaternary depositional record of the Aniuk Lowland difficult to interpret.

Glossary

Definitions of geologic terms used in this report were compiled by Julie A. Esdale from the American Geological Institute's Glossary of Geology (Jackson, 1997). The definitions were then edited to better reflect specific usage of those terms within this report.

A

abandoned channel A stream channel along which runoff no longer occurs.

ablation The wasting of glaciers by melting and evaporation.

active layer A surface layer of ground above permafrost that freezes each winter and thaws each summer. Its thickness ranges from several centimeters to a few meters.

aggradation Building upward of a stream bed by accumulation of sediments.

alluvial Pertaining to or composed of alluvium (sediment deposited by a stream or running water).

alluvial fan A low, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, with its apex pointing upstream. Deposited by a stream (a) where it issues from a narrow mountain valley and enters a plain or broad valley, or (b) where a tributary stream approaches or enters a main stream. It is steepest near the mouth of a mountain valley, and slopes outward with gradually decreasing gradient.

alluvium A general term for clay, silt, sand, gravel, or similar unconsolidated detritus that is deposited by a stream or other body of running water. Forms sorted or semisorted sediment in the stream bed or on its flood plain or delta, or as a fan at the base of a mountain slope.

angular Having sharp edges and corners. Indicates that a sedimentary particle has undergone little or no abrasion during transport.

aphanitic A fine-textured igneous rock in which the crystalline components are too small to be distinguishable by the unaided eye.

apparent dip The angle that a bedding or fault plane makes with the horizontal, measured in any random, vertical section rather than perpendicular to the strike. It can vary from nearly zero to nearly the true dip, depending on whether the vertical section is close to the direction of the strike or of the dip.

Arctic Brown soil A soil in which the surface organic horizon (A horizon) directly overlies a brown oxidized B horizon.

autochthonous Formed or produced in the place where now found. Applied to peat or other organic deposits that originated at the place where their constituent plants grew and died.

Avan A glacial advance down Avan valley in the western De Long Mountains that intersected and dammed the Noatak River Refers also to the time that advance took place (as in Avan time or Avan age).

B

ball and pillow structure A sedimentary structure that forms where a sandy bed overlies mud. A shock or other disturbance can cause the sandy layer to founder into the mud and to break up into hemispherical or kidney-shaped masses resembling balls and pillows.

basin A low-lying area with low relief. Also applied to the area drained by a river or stream (as in drainage basin or river basin).

bedding plane A planar or nearly planar bedding surface that visibly separates each successive layer of stratified sediment or rock from the preceding or following layer. It commonly marks a change in the environment or process of deposition, and may show a separation, a color difference, or both.

bench A long, narrow, relatively level or gently inclined strip or platform on a valley side or bluff face that is bounded by steeper slopes above and below. Appears as a terrace or steplike ledge breaking the continuity of a slope. Formed by differential erosion of sediments or rocks of varying resistance, or by a change in base level of erosion.

bluff A high bank with a steep face overlooking a river or its floodplain, or bodies of water such as lakes and seas. Especially common on the outside of stream meanders.

bottomset beds Horizontal or gently inclined layers of sediment deposited in front of the advancing foreset beds of a delta or of a bed form within a river channel.

boulder size Refers to rounded rock particles with diameters of 25.6 cm or more.

breccia A coarse-grained clastic rock composed of angular broken rock fragments. It differs from conglomerate in that the fragments have sharp edges and unworn corners. Commonly originates as a result of talus accumulation.

bryophyte A nonvascular plant that may have differentiated stems and leaves, but that has no true roots. Commonly refers to mosses.

C

calcareous algae A group of algae that remove calcium carbonate from the shallow water in which they live and secrete or deposit it as a more or less solid calcareous structure.

calcite A common rock-forming mineral composed of calcium carbonate ($CaCO_3$). It usually is white to colorless, but also may exhibit pale shades of gray or yellow. It is the principal constituent of limestone and speleothems (cave deposits), and also occurs in crystalline form in marble. Veins of calcite are abundant in metamorphic rocks of the Baird Mountains and south-central Brooks Range.

carbonate (a) A mineral compound that contains the negative ion CO_3^{-2}. Calcite and aragonite, $CaCO_3$, are common examples. (b) A sediment or sedimentary rock formed by precipitation from aqueous solution of carbonates of calcium, magnesium, or iron (for example, limestone and dolomite).

carbonate rock A sedimentary rock composed of more than 50 percent by weight of carbonate minerals, as described above.

cement Mineral material, usually chemically precipitated, that occurs in the spaces among the individual grains of a consolidated sedimentary rock, thereby binding the grains together as a rigid, coherent mass. The most common cements are silica (quartz, opal, chalcedony), carbonates (calcite, dolomite, siderite), and various iron oxides. Detrital clay minerals and other fine clastic particles also may serve as cements.

chert A hard, extremely dense or compact, dull to semivitreous microcrystalline or cryptocrystalline mineral that consists dominantly of interlocking minute crystals of quartz or masses of amorphous silica. It has a tough, splintery to concoidal fracture, and may be white or colored gray, green, red, yellow, brown, or black. Chert occurs principally as segregations (nodules) and less commonly as layered deposits (bedded chert) in limestones and dolomites. The term flint is sometimes used for the dark variety of chert.

clast An individual constituent, grain, or fragment of a sediment or rock, produced by the mechanical weathering (disintegration) of a larger rock mass. Generaly used in this report for particles larger than sand size.

clay size A term used in sedimentology for particles with diameters of 1/256 (0.004) mm or less.

climbing ripples A series of cross-laminae produced by superimposed migrating ripples, in which the crests of vertically succeeding laminae appear to be advancing upslope. Common in deltaic deposits.

cobble size Rounded to subangular rock particles with diameters between 6.4 cm and 25.6 cm.

colluvium A general term applied to any unconsolidated, heterogeneous mass of soil material and/or rock fragments deposited by rainwash, sheetwash, solifluction, or creep. Usually accumulates on lower parts of hillslopes. May include talus where closely intermixed with finer-grained deposits.

conglomerate A coarse-grained sedimentary rock, composed of rounded to subangular particles larger than 2 mm in diameter of varied size and composition set in a fine-grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay. Represents the consolidated equivalent of gravel both in size range and in the roundness and sorting of its constituent particles.

couplets Genetically related paired sedimentary laminae, generally occurring in repeating series as varves, but applied to other laminated sediments that do not form as annual paired deposits.

crinoidal limestone A limestone consisting almost entirely of the fossil skeletal parts of crinoids (cup-shaped organisms attached to the sea floor by long segmented stalks). The stalks are the component most commonly preserved.

cross bedding Cross-stratification (see below) in which the cross-beds are more than 1 cm in thickness.

cross-stratification Arrangement of strata inclined at an angle to the main stratification. Commonly subdivided into (a) cross-bedding, in which the cross-strata are thicker than 1 cm, and (b) cross-lamination, in which they are thinner than 1 cm. Probably most cross-stratification is produced by the migration of bed forms, particularly ripples (which form small-scale cross-lamination) and dunes or megaripples (which form medium- to large-scale cross-lamination or cross-bedding).

cryoturbation A collective term used to describe the stirring, churning, and all other disturbances of soil by frost action (for example, frost heaving, frost mixing, and solifluction). It produces hummocky terrain and/or patterned ground.

crystalline Applied to rocks consisting wholly of crystals or fragments of crystals, generally in the form of closely fitting or interlocking particles (many having crystal faces and boundaries). Characteristic of igneous rocks that developed through slow cooling from a molten state or of metamorphic rocks that have recrystallized as a result of temperature and pressure changes. The term also may be applied to certain sedimentary rocks (such as quartzite and some limestones) that are composed entirely of crystals.

cut and fill (a) A process of leveling whereby material eroded from one place is deposited nearby until the surfaces of erosion and deposition are continuous and uniformly graded. (b) A sedimentary structure characteristic of fluvial environments in which a channel eroded in older sediment is filled with younger sediment.

cutbank A steep bare slope formed by lateral erosion of a stream. Most commonly formed on the outside of meanders.

Cutler A glacial advance of middle Pleistocene age that issued from the De Long Mountains and filled the Noatak valley floor, extending upvalley as far as the mouth of the Cutler River (see fig. 54). Refers also to the time that advance took place (as in Cutler time or Cutler age).

D

debris flow A moving heterogeneous mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size.

delta A low-lying, nearly flat, alluvial tract of land at or near the mouth of a river. Generally forms a triangular or fan-shaped plain that is crossed by multiple distributaries of the main river. Extends beyond the general trend of the lakeshore or seacoast in cases where the sediment supplied by the river accumulates faster than it can be removed by tides, waves and currents.

deltaic Pertaining to or characterized by a delta.

detritus A collective term for loose rock and mineral material that is worn off or removed from older rocks by mechanical means (for example, disintegration or abrasion) and transported from its place of origin.

diamict A general term for a nonsorted or poorly sorted, nonstratified sediment or sedimentary rock that contains a wide range of particle sizes. Includes diamictite (lithified diamict) and diamicton (its nonlithified equivalent).

diapir A domelike upward squeezing of plastic core material which ruptures, upfolds, or othewise displaces overlying sediments or rocks. Common along the Noatak River where sand, gravel, or other clastic sediments overlie clay-rich lacustrine and glaciolacustrine deposits.

diorite A plutonic rock intermediate in composition between silicic (for example, granite) and mafic (for example, basalt). Dominantly composed of dark-colored amphibole (esp. hornblende), plagioclase, and pyroxene. Mafic minerals typically comprise less than 50 percent of the rock.

dip The angle that a structural surface such as a bedding or fault plane makes with the horizontal, measured perpendicular to the strike of the structure and in the vertical plane.

dolomite A carbonate sedimentary rock of which more than 50 percent consists of the mineral dolomite, or a variety of limestone or marble rich in magnesium carbonate. Dolomite is clearly associated and often interbedded with limestone, and usually represents a postdepositional replacement of limestone.

dropstone An oversized stone in laminated sediment that depresses the underlying laminae and may be covered by "draped" laminae. Most dropstones originate through ice-rafting.

dunite An ultratamafic plutonic rock that consists almost entirely of olivine, with accessory chromite generally present.

E

earthflow A mass-movement landform and process characterized by downslope translation of soil and weathered rock within well defined lateral boundaries. Initiates as a series of slump blocks that detach from a headwall scarp. The flow then moves downslope above a basal shear surface that is more or less parallel with the ground surface, and terminates as a lobe-like deposit. Common in ice-rich permafrost, where thaw generates abundant meltwater and the residual permafrost surface serves as a shear plane. Earthflows grade into mudflows through a continuous range in morphology associated with increasing fluidity.

end moraine A ridge-like accumulation of debris at the lower or outer end of a glacier.

eolian Pertaining to the wind. Can refer to (a) erosion and deposition accomplished by the wind, (b) wind-generated deposits such as loess and dune sand, and (c) sedimentary structures such as wind-formed ripple marks.

erosional unconformity A surface that separates older rocks that have been subjected to erosion from younger rocks that cover them.

erratic A rock fragment carried by glacial ice, or by floating ice, deposited at some distance from the outcrop from which it was derived, and generally resting on bedrock of different lithology. Size ranges from pebbles to house-size blocks.

extrusion Plastic sediment forced or pressed out from its initial position.

F

fabric The orientation in space of the elements (for example, clasts, crystals) that constitute a sediment or a sedimentary rock.

faceted boulder A boulder that has been ground flat on one or more sides by the action of natural agents, such as glacier ice, streams, or wind.

facies (a) The appearance and characteristics of a sediment or rock unit, usually reflecting the conditions of its origin and differentiating it from adjacent or associated rocks or sediments. (b) A mappable, areally restricted part of a deposit that differs in lithology or fossil content from adjoining beds deposited at the same time. (c) The environment or area in which a rock was formed (for example, eolian facies).

fan A gently sloping, fan-shaped mass of detritus forming a section of a very low cone, commonly at a place where there is a notable decrease in gradient. See alluvial fan.

fan delta A gently sloping alluvial deposit produced where a mountain stream flows into a lake or other water body. Normal fan sediment interfingers or intergrades downslope with deltaic sediments.

fault A fracture or zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture.

fault scarp A steep slope or cliff formed directly by movement along a fault and representing the exposed surface of the fault before modification by erosion and weathering.

ferruginеous Pertaining to or containing iron (for example, a sandstone that is cemented with iron oxide). Imparts a reddish or rusty color to the rock or sediment.

fining upward sequence A sediment succession that becomes progressively finer in grain size upward.

fissile Capable of being split easily along closely spaced planes.

flame structure A sedimentary structure consisting of wave- or flame-shaped plumes of mud that have been squeezed irregularly upward into an overlying layer. It probably is formed by overburden load accompanied by horizontal slip or drag.

floodplain (a) The flat or nearly flat lowland that borders a stream and that may be covered by its waters at flood stages. Constructed of generally fine-grained alluvium that is carried in suspension by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current. A river has a single floodplain, but may have one or more higher-standing terraces representing abandoned floodplains.

flow A mass movement of unconsolidated material that exhibits a continuity of motion and a plastic or semifluid behavior resembling that of a viscous fluid (for example, creep, solifluction, earthflow, mudflow, debris flow). Water usually is required for most types of flow movements.

flow amphitheater A bowl-shaped depression bordered on its upslope side by a crescentic scarp. Forms the headward portion of an earthflow or some types of debris flow.

fluvial Of or pertaining to a river or rivers.

fold A curve or bend of planar structures such as bedding planes or rock strata. Usually a product of deformation.

foliation A general term for a planar arrangement of textural or structural features in any type of rock. Most commonly applied to the planar structure that results from flattening of the constituent grains of a metamorphic rock.

foreset beds The inclined and systematically arranged layers within a cross-bedded unit. Generally refers to the set of inclined layers of sandy sediment deposited upon or along an advancing and relatively steep frontal slope, such as the outer margin of a delta or the lee side of a dune. Progressively covers the set of bottomset beds and in turn is covered or truncated by the topset beds. Foreset beds represent the greater part of the bulk of a delta.

fracture A general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fracture includes cracks, joints, and faults.

frost churning See cryoturbation.

G

gabbro A dark-colored, mafic intrusive igneous rock composed principally of plagioclase and clinopyroxene (augite), with apatite and magnetite or ilmenite as common accessory minerals. Gabbro is the approximate intrusive equivalent of basalt.

glacial (a) Of or relating to the presence and activities of ice or glaciers (for example, glacial erosion). (b) Pertaining to the distinctive features and materials produced by or derived from glaciers and ice sheets (for example, glacial lakes). (c) Pertaining to an episode of glaciation.

glacial lake (a) A lake that derives much or all of its water from the melting of glacier ice (for example, fed by meltwater), or lying on glacier ice and due to differential melting. (b) A lake occupying a basin produced by glacial deposition (for example, held in by a morainal dam). (c) A lake occupying a basin produced in bedrock by glacial erosion (for example, a cirque lake). (d) A lake occupying a basin produced by collapse of debris overlying or surrounding masses of stagnant ice (for example, a kettle lake).

glaciolacustrine Pertaining to, derived from, or deposited in glacial lakes. Most commonly refers to deposits and landforms formed by erosion and deposition around the margins of glacial lakes and to the sediments that accumulate on their floors.

glacier outburst flood A sudden release of meltwater from a glacier or glacier-dammed lake, sometimes resulting in a catastrophic flood. Generally results from melting of a drainage channel through the ice or from buoyant lifting of the ice by meltwater.

gneiss A foliated metamorphic rock in which bands or lenses of granular minerals alternate with bands or lenses dominated by flaky to elongate minerals. Commonly rich in feldspar and quartz, but mineral composition is not essential in its definition. Varieties are distinguished by texture (for example, augen gneiss), characteristic minerals (for example, hornblende gneiss), or general composition and/or origins (for example, granite gneiss).

gorge A narrow, deep stream incision with nearly vertical rocky walls.

gouge Soft, uncemented, clayey or clay-like material, commonly a mixture of minerals in finely divided form, found along some faults or between the walls of a fault. Formed by the crushing and grinding of rock material during fault movement, and by subsequent alteration by fluids that circulate along the fault.

graben An elongate depression bounded by faults along both sides.

granite An intrusive igneous rock in which conspicuous grains of quartz and alkali feldspars are dominant. Muscovite (white mica) generally is present also.

granitic Pertaining to or composed of granite.

granule size Refers to rock particles larger than very coarse sand and smaller than pebbles, having a diameter in the range of 2-4 mm. Grains are somewhat rounded or otherwise modified by abrasion during transport.

greenstone An informal term applied in the field to a compact dark green altered or metamorphosed basic igneous rock (for example, basalt or gabbro) that owes its color to the presence of green metamorphic minerals such as chlorite or epidote.

greywacke A dark gray, coarse-grained sandstone composed of poorly sorted angular to subangular grains of quartz and feldspar that are associated with abundant dark rock and mineral fragments.

gritty A textural term for soil or sediment that contains enough sand-sized particles to impart a roughness to the touch. The actual quantity of sand usually is small enough that sand cannot be seen by the unaided eye.

gyttja A dark, pulpy, freshwater mud characterized by abundant organic matter that is deposited in a marsh or lake whose waters are rich in nutrients and oxygen.

H

headwall (a) A steep slope at the head of a valley. Most commonly applied to the rock cliff at the head of a cirque. (b) The scarp at the upslope end of an earthflow or some debris flows.

Histosol A soil type in which the upper 80 cm or more of its profile consists of >50 percent organic materials. Most Histosols are saturated or nearly saturated with moisture, and are ice-rich when frozen.

Holocene An epoch of the Quaternary period, from the end of the Pleistocene, approximately 10,000 years ago, to the present time. Also the events and deposits assignable to that interval.

humic Pertaining to or derived from humus (finely divided and partly decomposed organic material).

hummock A small vegetated mound of earth or turf. Not diagnostic of permafrost, but most common in subpolar and alpine regions.

hummocky A landform with abundant hummocks.

humus The generally dark, more or less stable part of the organic matter of soil; so well decomposed that the original sources cannot be identified.

I

ice-contact deposit Stratified sediment deposited in contact with melting glacier ice. Characteristic landforms include eskers, kames, kame terraces, and drift surfaces with numerous kettles.

ice-dammed lake A lake held in place by the damming of natural drainage by a glacier (for example, advancing across a valley or crossing the mouth of a tributary valley).

ice-rafted Applied to detritus such as boulders or till which are deposited by the melting of debris-laden floating ice. A diagnostic component of glaciolacustrine sediments.

ice-stagnation deposit Deposited in contact with stagnating or stagnant glacier ice. Synonomous with ice-contact deposit.

ice wedge Wedge-shaped foliated ground ice produced in permafrost. Occurs as a vertical or inclined body that tapers downward; can be as much as 6 m wide and 30 m deep. Ice wedges originate by the growth of hoarfrost or by the freezing of water in a narrow crack or fissure produced by thermal contraction of permafrost.

igneous A term applied to rock or minerals that solidified from molten or partly molten material (magma). Also applied to the processes associated with the formation of such rocks.

imbricated Overlapping, as tiles on a roof. Common among platy pebbles and cobbles in stream sediments, where this feature serves as a flow-direction indicator.

in situ Formed in the place where now located (that is, not transported from elsewhere).

indurated A term applied to rocks or sediments hardened or consolidated by pressure or cementation.

interfingering The lateral termination of sedimentary units through splitting into many thin tongues, each of which pinches out independently. Results in the intergradation of markedly different sediments or rocks through a vertical succession of thin interlocking or overlapping wedge-shaped layers.

interglacial Pertaining to or formed during the time interval between two successive glacial epochs or between two glacial stages. The term implies both the melting of glaciers to about their present extent, and the maintenance of a warm climate for a sufficient length of time to permit revegetation to occur.

interstadial; interstade A warmer substage within a glacial stage, marked by a temporary retreat of the ice.

involution A highly irregular, aimlessly contorted sedimentary structure consisting of local folds and interpenetrations within fine-grained material. Developed by the formation, growth, and melting of ground ice in the active layer overlying permafrost.

Itkillik A general term used for glacial advances of late Pleistocene age in the central Brooks Range. Subdivided into Itkillik I, older advances of the late Pleistocene, and Itkillik II, advances of the last (late Wisconsin) glaciation.

J

joint A planar surface of fracture or parting in a rock or compact sediment along which no displacement has taken place. Commonly occurs as sets of parallel joints.

joint plane The surface of a joint.

K

kame A low mound, knob, hummock, or short irregular ridge, composed of stratified sand and gravel. Initially deposited by a subglacial stream as a fan or delta at the margin of a melting glacier, by a superglacial stream in a depression on the surface of the glacier; or as a ponded deposit on the surface or at the margin of stagnant ice. Its final form reflects partial collapse of the deposit as supporting ice walls melt away.

kame terrace A terracelike deposit consisting of stratified sand and gravel that formed between a melting glacier or a stagnant ice lobe and a higher valley wall or lateral moraine; and subsequently left standing after the disappearance of the ice. Commonly pitted with kettles and has an irregular ice-contact slope due to collapse as the supporting ice margin melts away.

kettle A steep-sided, usually basin- or bowl-shaped depression, commonly without surface drainage, in glacial deposits. Commonly contains a lake or marsh. Formed by the melting of a large, detached block of stagnant ice left behind by a retreating glacier, and wholly or partly buried in glacial drift. Kettles may range in depth up to tens of meters, and in diameter to 10 km or more.

L

lacustrine Pertaining to, produced by, or formed in a lake or around its margin.

lag A residual accumulation of coarse-grained sediment that remains on a surface or in a stream channel after the finer material has been blown away by winds or carried away by running water.

lag boulder A boulder-sized clast originally present within heterogeneous till or ice-rafted deposits. Remains at the site of deposition after the surrounding finer material has been eroded and transported away.

lamina The thinnest recognizable layer of original deposition in a sediment or sedimentary rock; differing from other layers in color, composition, or particle size. May be parallel or oblique to the general stratification. Generally restricted to sedimentary layers less than 1 cm in thickness. Several laminae may constitute a bed.

lamination Fine-scale stratification or bedding; typically exhibited by lacustrine and eolian deposits.

lateral moraine A low ridge-like mass of rock fragments carried on, or deposited at or near, the side margin of a mountain glacier. Composed chiefly of debris loosened from the valley walls by glacial abrasion and plucking, or fallen onto the ice from the bordering slopes.

lebensspuren Tracks or burrows of former living organisms evident on the bedding planes of fine-grained sediments.

lens A depositional unit bounded by converging surfaces that is thickest in the middle and thins toward the edges. Resembles a convex lens.

limestone A sedimentary rock composed chiefly of calcium carbonate, primarily in the form of the mineral calcite (that is, more than 95 percent calcite and less than 5 percent dolomite). Formed by either organic or inorganic processes, and may be detrital, chemical, oolitic, earthy, crystalline, or recrystallized. Many are highly fossiliferous, in some cases representing ancient shell banks or coral reefs.

lithify To consolidate from a loose sediment to a solid rock.

lithologically immature Term applied to clastic sediment that has been differentiated or evolved from its parent rock by processes acting over a short time and/or with a low intensity. Characterized by relatively unstable minerals (such as feldspar), abundance of mobile oxides (such as alumina), presence of weatherable material (such as clay), and poorly sorted and angular grains.

lithology The physical character of a rock.

loess A widespread, homogeneous, commonly nonstratified, porous, friable, slightly coherent, fine-grained blanket deposit, consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand; generally buff to light yellow or yellowish brown. The mineral grains are fresh and angular, and generally are held together by calcareous cement. Traversed by networks of small narrow vertical tubes (frequently lined with calcium-carbonate concretions) left by successive generations of grass roots, which allow the loess to stand in steep or nearly vertical faces. Originates as windblown dust derived from unconsolidated and unvegetated alluvium, outwash, or lake beds uncovered by recent lake drainage.

M

mafic A term applied to (a) igneous rocks composed chiefly of one or more ferromagnesian, dark-colored minerals, (b) those constituent minerals.

marble A metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite and/or dolomite, usually with a crystalline to sugary texture.

matrix The finer-grained material enclosing, or filling the interstices between, the larger grains or particles of a sediment or sedimentary rock; the natural material in which a sedimentary particle is embedded. The term refers to the relative size and disposition of the particles, and no particular particle size is implied.

meander One of a series of regular freely developing sinuous curves, bends, loops, or windings along the course of a stream. Produced by a stream swinging from side to side as it flows across its floodplain.

meltwater Water derived from the melting of snow or ice. Commonly forms streams that flow within, under, or along the margins of melting glacier ice.

metamorphic Pertaining to the process of metamorphism or to its products.

metamorphism The mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions which generally have been imposed at depth below the surface zones of weathering and cementation, and which differ from the conditions under which those rocks originated.

moraine A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, that is deposited chiefly by direct action of glacier ice. Forms a variety of topographic landforms that are independent of the surface on which the drift lies.

mottled Applied to soil, sediment, or sedimentary rock that is marked with spots of different colors, usually as a result of oxidation of iron compounds. Soils that are irregularly mottled with spots or patches of different colors usually have developed under conditions of poor aeration or seasonal wetness.

mud A slimy, sticky, or slippery mixture of water and silt or clay-sized earth material, with a consistency ranging from semifluid to soft and plastic.

muddy Pertaining to or characterized by mud (for example, water made turbid by sediment or sediment consisting of mud).

N

non-finite radiocarbon age A radiocarbon age given as "greater than" a certain number of years. Such an age can be used only as a minimum limit on the antiquity of an organic sample.

O

openwork A term applied to a gravel that contains unfilled voids.

ophiolite An assemblage of mafic and ultramafic igneous rocks, including gabbro, peridotite, basalts, rocks rich in serpentine, and deep-marine sediments. Represents former ocean crust.

outburst episode See glacier outburst flood.

outwash Stratified detritus (chiefly sand and gravel) transported from a glacier by meltwater streams and deposited in front of or beyond the glacier's end moraine or active margin. The coarser material is deposited nearer to the ice.

outwash train See valley train.

overbank deposit Fine-grained sediment (fine sand, silt, and some clay) deposited from suspension on a floodplain by floodwaters that cannot be contained within the stream channel.

overburden The upper part of a sedimentary deposit, compressing and consolidating the material below. Also applied to the loose soil or sediment overlying bedrock.

overturned fold Applied to a fold, or the limb of a fold, that has tilted beyond the perpendicular.

oxbow A closely looping stream meander having an extreme curvature such that only a narrow neck of land is left between two parts of the stream. If the stream breaks through that neck of land, it commonly abandons its former course, leaving behind an oxbow lake that marks its former channel.

oxide A mineral compound characterized by the linkage of oxygen with one or more metallic elements, such as iron or manganese.

oxidized Applied to a rock or sediment modified by exposure to atmospheric oxygen or oxygen-rich waters.

P

paired terrace One of two steam terraces that face each other at the same elevation from opposite sides of the steam valley and that represent the remnants of the same flood plain or valley floor.

paleobasin A basin that formed in the past and is no longer expressed as a surface topographic feature.

paleosol A soil horizon that formed in the geologic past. Typically buried beneath younger soils and sediments.

peat An unconsolidated deposit of partly decayed plant remains in which vegetal structures are still evident. The deepest deposits accumulate in water-saturated environments such as bogs or fens.

pebble size Refers to rounded to subangular stones with diameters between 4 and 64 mm.

permafrost Any soil, subsoil, other surficial deposit, or even bedrock, in which a temperature below freezing has existed continuously for a long time (2 years or more). Characteristic of arctic, subarctic, and alpine regions.

phyllite A metamorphosed rock, intermediate in grade between slate and mica schist. Minute crystals of sericite and chlorite impart a silky sheen to its surfaces. Phyllites commonly exhibit corrugated cleavage faces.

piedmont glacier A broad mass of glacier ice at the base of a mountain range or mouth of a mountain valley. Formed by the spreading out and coalescing of valley glaciers that issue from higher elevations of the mountains.

plastic Applied to a sediment or other material in which strain produces continuous, permanent deformation without rupture.

platy Applied to (a) a sedimentary particle whose length is more than three times its thickness, (b) sediment or sedimentary rock that splits into laminae having thicknesses in the range of 2 to 10 mm.

Pleistocene An epoch of the Quaternary period, after the Pliocene of the Tertiary and before the Holocene; also, the rocks, sediments, and events assignable to that interval. The Pleistocene epoch began 2-2.5 million years ago and lasted until the start of the Holocene some 10,000 years ago.

polygon A form of patterned ground whose mesh is tetragonal, pentagonal, or hexagonal. Large polygons arctic regions are formed by thermal contraction and are associated with ice wedges.

poorly sorted Term applied to clastic sediment or a cemented detrital rock that consists of particles of many sizes mixed together in an unsystematic matter so that no one size class strongly predominates.

postglacial Pertaining to the time interval since the disappearance of glaciers from a particular area.

primary structure; primary sedimentary structure A sedimentary structure determined by the conditions of deposition such as current velocity and rate of sedimentation; and developed at the time of deposition.

proglacial lake A lake formed just beyond the front of a glacier, generally in direct contact with the ice.

pyroxenite An ultramafic plutonic rock chiefly composed of pyroxene, with accessory hornblende, biotite, or olivine.

Q

quartzite A metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert by either regional or thermal metamorphism. Also applied to very hard but unmetamorphosed sandstone, consisting chiefly of quartz grains that have been so completely and solidly cemented with secondary silica that the rock breaks across or through the grains rather than around them.

quartzose Sediments or sedimentary rocks containing quartz as a principal constituent.

Quaternary The second period of the Cenozoic era, following the Tertiary, that began 2 to 2.5 million years ago and extends to the present. Also the corresponding system of rocks, sediments, and events assignable to that period. The Quaternary period consists of two grossly unequal epochs: the Pleistocene, up to about 10,000 years ago, and the Holocene since that time.

R

radiocarbon dating also ^{14}C dating A method of determining the age of an organic material by measuring the concentration of carbon-14 remaining in it. It is based on the assumption that assimilation of carbon-14 ceased abruptly upon the death of an organism and that it thereafter remained a closed system. The method is useful in determining ages in the range of 500 to 30,000 years or to 40,000 years, although arguably it may be extended to 70,000 years by using special techniques.

recessional moraine An end or lateral moraine built during a temporary but significant pause or minor readvance during the retreat of a glacier.

rhythmites A rhythmic (repetitious) succession of beds. The term implies no limit as to thickness or complexity of bedding and it carries no time or seasonal connotation. Commonly applied to varve-like sediments for which annual deposition cannot be proven.

ripple A small ridge of sand resembling or suggesting a ripple of water and formed on the bedding surface of a sediment. Commonly appears as a small sand wave similar to a dune in shape.

ripple bedding A bedding surface characterized by ripple marks.

rounded Round or curving in shape. Applied to a sedimentary particle whose original edges and corners have been reduced to smooth curves and whose original faces are almost completely removed by abrasion.

S

sag pond A small body of water occupying an enclosed depression or sag formed where active or recent fault movement has impounded drainage.

sand size A term used in sedimentology for particles with diameters between 1/16 (0.062) mm and 2 mm.

sandstone A clastic sedimentary rock composed wholly or largely of sand-size particles set in a matrix of finer grains, and more or less firmly cemented. Intermediate in texture between conglomerate and shale. Sandstone varies in color, may be deposited by water or wind, and may contain striking sedimentary structures such as large-scale cross-bedding.

sapropel An unconsolidated, jelly-like ooze or sludge composed of plant remains, most often algae, macerating and putrefying in an anaerobic environment on the shallow bottoms of lakes and seas.

scarp A line of cliffs of any height produced by faulting or by erosion.

schist A strongly foliated metamorphic rock that can be split readily into thin flakes or slabs due to the well developed parallelism of most of the minerals present, particularly platy or elongate minerals (for example, mica and hornblende). Mineral composition is not an essential factor in its definition, but commonly is included in the rock name (for example, quartz-muscovite schist, amphibole schist).

scour The powerful and concentrated downward erosive action of flowing air, water, or ice (for example, on the outside curve of a river bend, or during time of flood).

shale A fine-grained detrital sedimentary rock, formed by the consolidation of clay, silt, or mud. It is characterized by finely laminated structure, which imparts a fissility approximately parallel to the bedding, and along which the rock breaks readily into thin layers. Shale is generally soft and easily scratched, but sufficiently indurated so that it will not fall apart on wetting. Its color may be red, brown, black, or gray.

shear plane A surface along which differential movement has taken place parallel to that surface.

sigmoidal cross-bedding Bedding that curves in opposing directions like the letter S. Characteristic of point-bar deposits (deposits formed on the convex sides of river meanders).

silt size A term applied to sedimentary particles larger than 1/256 (0.004) mm in diameter and smaller than 1/16 (0.062) mm.

siltstone An indurated silt having the texture and composition of shale but lacking its fine lamination or fissility. It contains hard, durable, generally thin layers, and often shows various primary current structures.

slackwater A quiet part of, or a still body of water, in a stream (for example, on the inside of a bend, where the current is slight).

slate A compact, fine-grained metamorphic rock that possesses closely spaced parallel cleavage and hence can be split into slabs and thin plates. Generally formed from shale.

slide A mass movement of earth, rock, or snow resulting from failure under shear stress along one or several surfaces that are either visible or may reasonably be inferred. The moving mass may or may not be greatly deformed, and movement may be rotational or planar. Named for the material in motion (for example, landslide, snowslide, rockslide).

slip-off slope The long, relatively gentle slope on the inside of a stream meander, produced by downcutting of the stream concurrent with the gradual outward migration of the meander.

slump A landslide characterized by shearing and rotary mass movement of a body of rock or earth along a curved slip surface that is concave upward. The slumped mass tilts backward with respect to the slope so that its upper surface commonly exhibits a reversed slope facing uphill.

sod A compact mass of living and dead grassy vegetation with interlaced rootlets that extends downward several centimeters or more from the ground surface.

solifluction The slow viscous downslope flow of waterlogged soil and other unsorted and saturated surficial material, normally at rates of 0.5-5.0 cm/yr. Especially widespread in regions underlain by permafrost that acts as a downward barrier to percolation of meltwater generated by seasonal thawing of the active layer and its snow cover.

solum The upper part of a soil profile (its A and B horizons) in which soil-forming processes occur.

squeezeup structure A diapir-like upward extrusion of plastic sediment, generally due to differential overburden pressure.

stratified Formed, arranged, or laid down in layers or strata. Most commonly applied to sediments or sedimentary rocks.

striation One of a set of scratches or minute lines, generally parallel, inscribed on a rock surface by a geologic agent (that is, glaciers or faulting).

subangular Somewhat angular; free from sharp angles but not smoothly rounded. Applied to a sedimentary particle showing definite effects of slight abrasion, retaining its original general form, and having faces that are virtually untouched and edges and corners that are rounded off to some extent. Also applied to the roundness class containing subangular particles.

subglacial (a) Formed or accumulated in or by the bottom parts of a glacier (for example, meltwater streams, till, moraine). (b) Pertaining to the area immediately beneath a glacier (for example, subglacial erosion, subglacial drainage).

subrounded Term applied to a sedimentary particle showing considerable but incomplete abrasion and an original general form that is still discernible, and having many of its edge and corners rounded off to smooth curves. Also applied to the roundness class containing subrounded particles.

syngenetic Term applied to a primary sedimentary structure, such as a ripple mark, formed contemporaneously with the deposition of the sediment Also applied to ice wedges that grow upward as the ground surface accretes (for example, by loess or peat accumulation).

T

tangential cross-bedding Cross-bedding in which the foreset beds appear in section as a smooth arc meeting the underlying surface at low angles.

tectonism Displacement of rock or sediment by directed forces, resulting in folds, faults, and other deformation structures. Glacial tectonism occurs where glaciers flow over deformable beds.

tephra A general term for all pyroclastics of a volcano. Restricted in this report to fine-grained volcanic ash derived from a distant source.

terrace Generally applied here to an aggradational deposit of unconsolidated sediment that occurs along the margin and above the level of a stream or lake, marking a former level of that water body.

Tertiary The first period of the Cenozoic era, thought to have covered the span of time between 65 and 2 to 2.5 million years ago. It followed the Cretaceous period and preceded the Quaternary.

thaw amphitheater A depression with an arcuate headwall on its upslope side and an earthflow or debris flow issuing from its downslope side. Formed by thaw of ice-rich permafrost.

thaw lake A shallow body of water whose basin is produced by collapse of the ground following thawing of ground ice in regions underlain by ice-rich permafrost.

thixotropic A clay that weakens when disturbed and behaves as a fluid.

till A primarily unsorted and unstratified glacial deposit, generally unconsolidated but commonly very compact, that consists of a heterogeneous mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape. Deposited directly by and underneath a glacier without subsequent reworking by meltwater.

tillstone A stone of pebble to boulder size in a deposit of glacial till. Commonly faceted and striated by glacial abrasion.

topset bed One of the nearly horizontal layers of sediments deposited on the top surface of an advancing delta. It truncates or covers the edges of the underlying foreset beds.

trace fossil A sedimentary structure consisting of a fossilized track, trail, burrow, tube, boring, or tunnel resulting from the activities of an animal (for example, a mark made by an invertebrate moving, feeding, hiding, or resting on or in soft sediment).

truncated Term applied to a soil profile in which upper horizons are missing.

tundra A treeless landscape characteristic of arctic and subarctic regions. It commonly has a marshy surface, which supports a growth of mosses, lichens, sedges, and low shrubs, and is underlain by dark, mucky soil and permafrost.

turbidite Sediment deposited from, or inferred to have been deposited from, a turbidity current. Characterized by graded bedding, moderate sorting, and well-developed primary structures in a characteristic upward succession (termed a Bouma cycle).

turbidity current A density current in water or other fluid, caused by matter in suspension that gives the water a density greater than that of the surrounding or overlying clear water. Used in this report to designate a bottom-flowing current, laden with suspended sediment, moving swiftly down a subaqueous slope under the influence of gravity; and then spreading laterally across the floor of a lake or other water body.

U

ultramafic An igneous rock composed chiefly of mafic minerals (for example, minerals rich in iron and manganese such as hornblende, augite, or olivine).

unconformity (a) A substantial break or gap in the depositional record where a sediment is overlain by another that formed at a much later time. It results from a change that caused deposition to be interrupted for a considerable span of time. (b) The structural relation between rock strata or sediment beds in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or erosion prior to deposition of the younger beds. Commonly marked by absence of parallelism between the strata.

underfit stream A stream that appears to be too small to have eroded the valley in which it flows. It is a common result of drainage changes effected by capture, by glacier fluctuations, or by climatic variations.

unsorted A term applied to clastic sediment that contains particles of many sizes mixed together so that no one size predominates.

unstratified Lacking sedimentary layering (stratification).

V

valley train A long, narrow body of outwash, deposited by meltwater streams far beyond the terminal moraine or the margin of an active glacier and confined within the walls of a valley below the glacier.

varve A sedimentary bed or lamina or sequence of laminae deposited in a body of still water within the span of one year. Usually applied to a thin pair of graded glaciolacustrine layers seasonally deposited, usually by meltwater streams, in a glacial lake or other water body in front of a glacier. A glacial varve normally includes a "summer" layer consisting of relatively coarse-grained, light-colored sediment (usually sand or silt) produced by rapid melting of ice in the warmer months, which grades upward into a thinner "winter" layer, consisting of very fine-grained (clayey), often organic, dark sediment slowly deposited from suspension in quiet water while the streams that fed the water body were ice-bound.

vein quartz A rock composed chiefly of quartz crystals of variable size that grew in a fracture within another rock.

vivianite A mineral: $Fe_3(PO_4)_2$. Characteristically blue or green when unaltered, but grows darker on exposure. It occurs as crystals, fibrous masses, or earthy forms in moist settings associated with clays, peat, and bog iron deposits.

W

weathering The destructive process or group of processes at or near the Earth's surface by which rocks and sediments are changed in color, texture, composition, firmness, or form through exposure to atmospheric agents with little or no transport of the loosened or altered material. Physical disintegration and chemical decomposition of rock produce an in-situ mantle of waste. Most weathering occurs at the surface, but it may take place at considerable depths in well-jointed rocks that permit easy penetration of atmospheric oxygen and circulating surface waters.

wedge The shape of a body of rock or sediment that thins out downward or laterally.

well sorted A term applied to sediment that consists of particles all having approximately the same size.

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