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To Skip Walker
with best regards
Tom

LATE CENOZOIC GLACIATION OF THE CENTRAL BROOKS RANGE

Thomas D. Hamilton
U.S. Geological Survey
4200 University Drive
Anchorage, Alaska 99508

Walker No. 3522 File Hamilton T.D.
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ABSTRACT

Four major glacial episodes are recognized in the central Brooks Range. From oldest to youngest these are the Gunsight Mountain episode and the Anaktuvuk River, Sagavanirktok River, and Itkillik glaciations. Minor advances of cirque glaciers took place during the late Holocene Neoglacial interval.

Drift of Gunsight Mountain age has been strongly modified by subsequent stream erosion and pedimentation. North of the Brooks Range, it consists primarily of boulders of the Kanayut Conglomerate redeposited in younger terrace gravel. Probably correlative drift forms broad moraines that are deeply buried by loess, glacial-lake sediments, and alluvium in topographic basins south of the range. Drift of the subsequent Anaktuvuk River glaciation forms the outer component of massive compound lateral moraine complexes that extend north from the Brooks Range. Correlative moraines farther south outline piedmont lobes that extended into the Koyukuk and Chandalar valleys and that filled the Kobuk valley as far west as Kotzebue Sound. The Anaktuvuk River glaciation was followed by a long interval of stream erosion and downcutting during which valley systems of the Brooks Range attained their present configurations. Drift of the succeeding Sagavanirktok River glaciation forms the oldest and outermost glacial deposits on the floors of modern valleys. Distributions of glaciers indicate that by Sagavanirktok River time the Noatak and Kobuk Rivers had captured their present upper valleys, that tectonic troughs had formed or were continuing to develop south of the Brooks Range, and that tectonism was active in the eastern Brooks Range. Drift of Itkillik age is divisible into three or four components in most valleys. The oldest glacial deposits, of Itkillik I age, were formed by a single recognizable glacial advance in some valleys but by two distinct advances in others; drift of Itkillik II age forms well preserved end moraines and related deposits. Near the close of Itkillik II time, glaciers readvanced to the north flank of the Brooks Range and, south of the Continental Divide, terminated in upper parts of mountain valleys.

Glacial deposits of Gunsight Mountain advances are considered late Tertiary in age because of their extreme modification by stream erosion and pedimentation and because they resemble deposits assigned to the Tertiary elsewhere in Alaska. The Anaktuvuk River glaciation is considered to be early Pleistocene in age because correlative deposits on the Seward Peninsula are overlapped by an 800,000-year-old lava flow. The Sagavanirktok River glaciation, represented by one drift in some valleys and two in others, is considered broadly middle Pleistocene in age. Glacier advances of Itkillik I age probably occurred about 110-60 ka based on tephrochronology and on correlations with the glacial record of northwest Canada. The subsequent Itkillik II phase began about 25 ka, and a late readvance of Itkillik II age is radiocarbon dated at 13 to 11.5 ka.

The glacial record provides important insights into the tectonic, drainage, and permafrost history of northern Alaska. Distribution of the drift sheets and of associated outwash trains indicates that the major valley systems of the central Brooks Range were in place by late Tertiary time but that significant evolution continued to take place during the Quaternary. Tectonism has been minor in the northwestern part of the study area but may have remained active throughout Quaternary time to the east, as well as in troughs that parallel the south flank of the range. The oldest record of permafrost is in deposits of the early Pleistocene Anaktuvuk River glaciation, and relict glacier ice may still be present as a form of permafrost within many drift sheets of Itkillik age.

INTRODUCTION

The Brooks Range forms an arc 180-200 km wide and slightly concave to the north that extends for about 1,000 km across northern Alaska from the Canadian border to the Chukchi Sea (fig. 1). The range is only lightly glaciated today; about 1,000 small cirque and valley glaciers (Post and Meier, 1980) are generally restricted to north-facing parts of the highest peaks. Much more extensive former glaciation is indicated by numerous cirques at low altitudes, by well integrated glacial-valley systems, and by

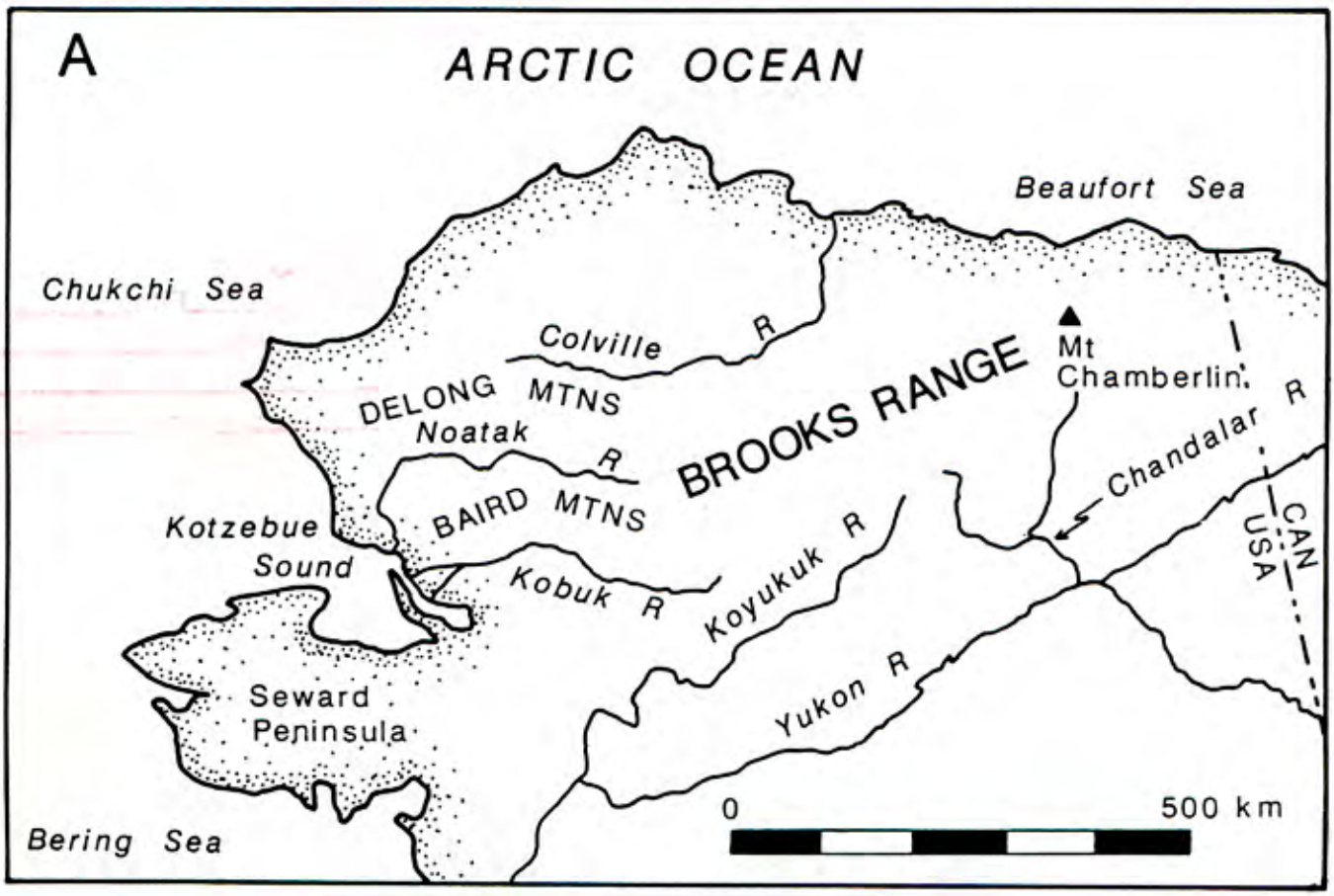
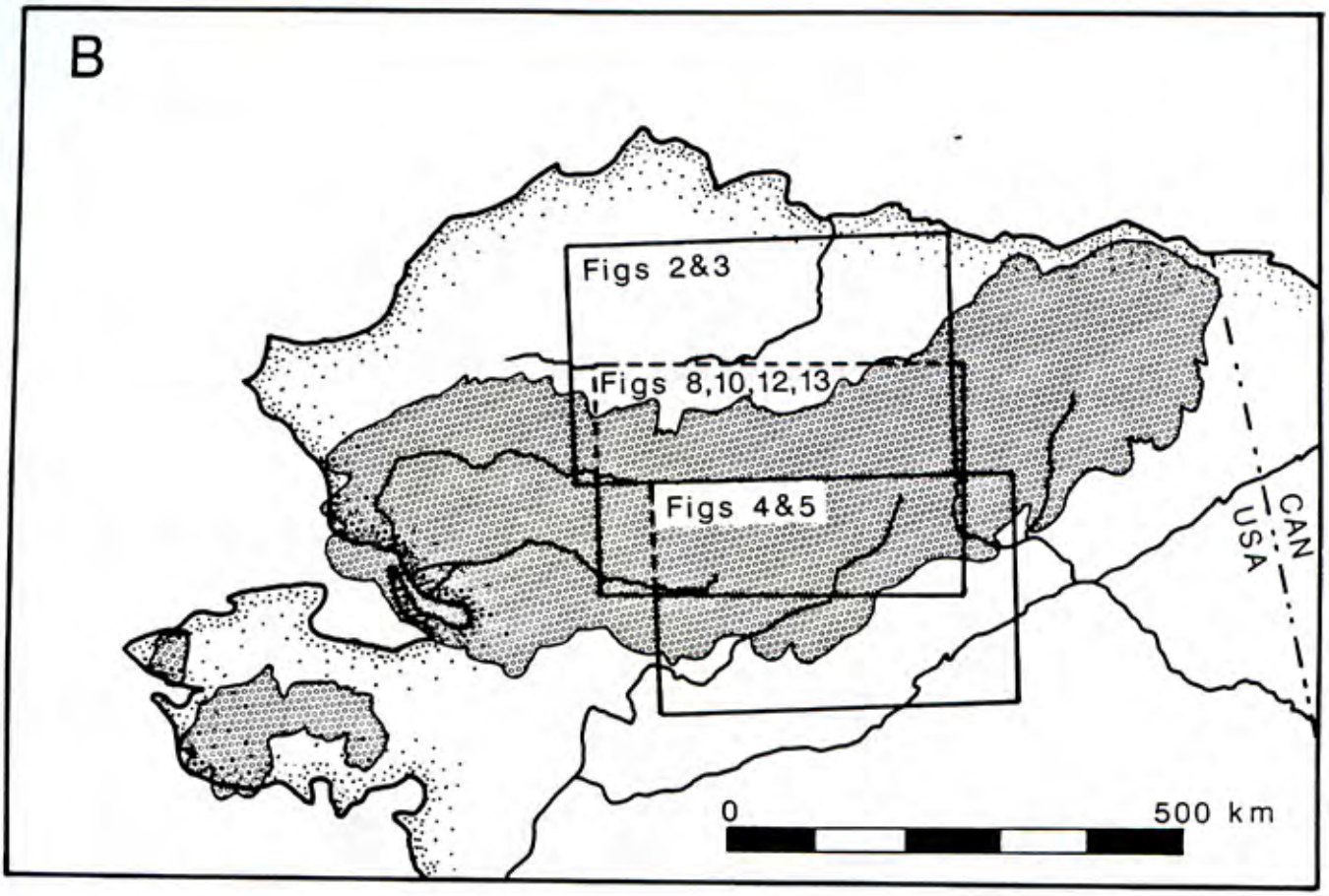


Figure 1.—Index maps to the Brooks Range. A, major geographic features discussed in text; B (on facing page), outer limits of recognizable glaciation and areas covered by detailed maps. Sources of data: central Brooks Range, this volume; eastern and western Brooks Range, Coulter and others (1965); Seward Peninsula, Kaufman and Hopkins (this volume).

abraded and streamlined landforms. Overlapping drift sheets beyond the flanks of the range demonstrate that former glaciation was not only extensive but occurred repeatedly.

The glacial record of the Brooks Range provides a sensitive paleoclimatic document because of the restricted extent of glaciation in northern Alaska, the tectonic stability of this region relative to areas farther south, and the diverse moisture sources that were available to nourish alpine glaciers. Even the glaciers that spread farthest beyond the flanks of the range did not intersect glaciers from other sources, but were free to expand until they came into equilibrium with their environment. The relative tectonic stability of the region ensures that its glacial record is less disrupted by earth movements than are glacial records of mountain ranges farther south. Former ice limits therefore reflect climatic controls, and the presence of successively older drift sheets offers a long but incomplete climatic record that extends back into Tertiary time. Modern glaciers in the Brooks Range are nourished by precipitation derived from the Bering Sea to the west, the north Pacific Ocean to the south, and the Arctic Ocean to the north. Past changes in those moisture sources should have been reflected in the relative extents of ice advances in different sectors of the range, as well as in the extent of Brooks Range glaciation relative to that farther south in Alaska (Hamilton, 1981a).

The climate of the Brooks Range ranges from arctic in the northern valleys to subarctic in the south and from continental in the eastern and central areas to maritime in the west. These climatic extremes and



the gradients between them are reflected in the modern and fossil vegetation of the region, in present and past snowlines and glaciation limits, and in distribution of permafrost. Valleys of the south-central and southeastern Brooks Range are heavily forested, but northern valleys and much of the western Brooks Range support tundra vegetation (Sigafoos, 1958). Permafrost generally is continuous throughout northern and western valleys (Ferrians, 1965), but it is absent beneath at least some of the larger lakes and rivers in south-central and southeastern parts of the range (Brown and Kreig, 1983, p. 12-13). Precipitation is derived mainly from the south and west, therefore modern and ancient snow lines and glaciation thresholds rise northward and eastward through the range (Péwé, 1975, p. 28-31; Porter and others, 1983).

The current distribution of glaciers in the Brooks Range is controlled primarily by regional patterns of altitude and precipitation (Porter and others, 1983). Glaciers are absent from the low western part of the range except on the highest peaks near the heads of the Noatak and Kobuk River valleys. Cirque glaciers and short (2-3 km) valley glaciers exist in higher parts of the central Brooks Range, where they are concentrated in a belt that extends 20-30 km northward from the Continental Divide. Farther east, the largest ice streams and most intensive glacierization occur on high peaks close to the north flank of the range, where the largest glaciers are as long as 10 km. These glaciers are nourished in part by precipitation moving inland from the nearby Beaufort Sea (Porter and others, 1983).

Individual glacial deposits in the central Brooks Range were recognized by many early investigators (for example, Mendenhall, 1902, p. 44-48; Schrader, 1904, p. 84-90; Maddren, 1913; Eakin, 1916; Mertie, 1930; Smith and Mertie, 1930, p. 242-247), but sequences of glacial deposits of differing ages were not recognized and named until much later (table 1). The general glacial

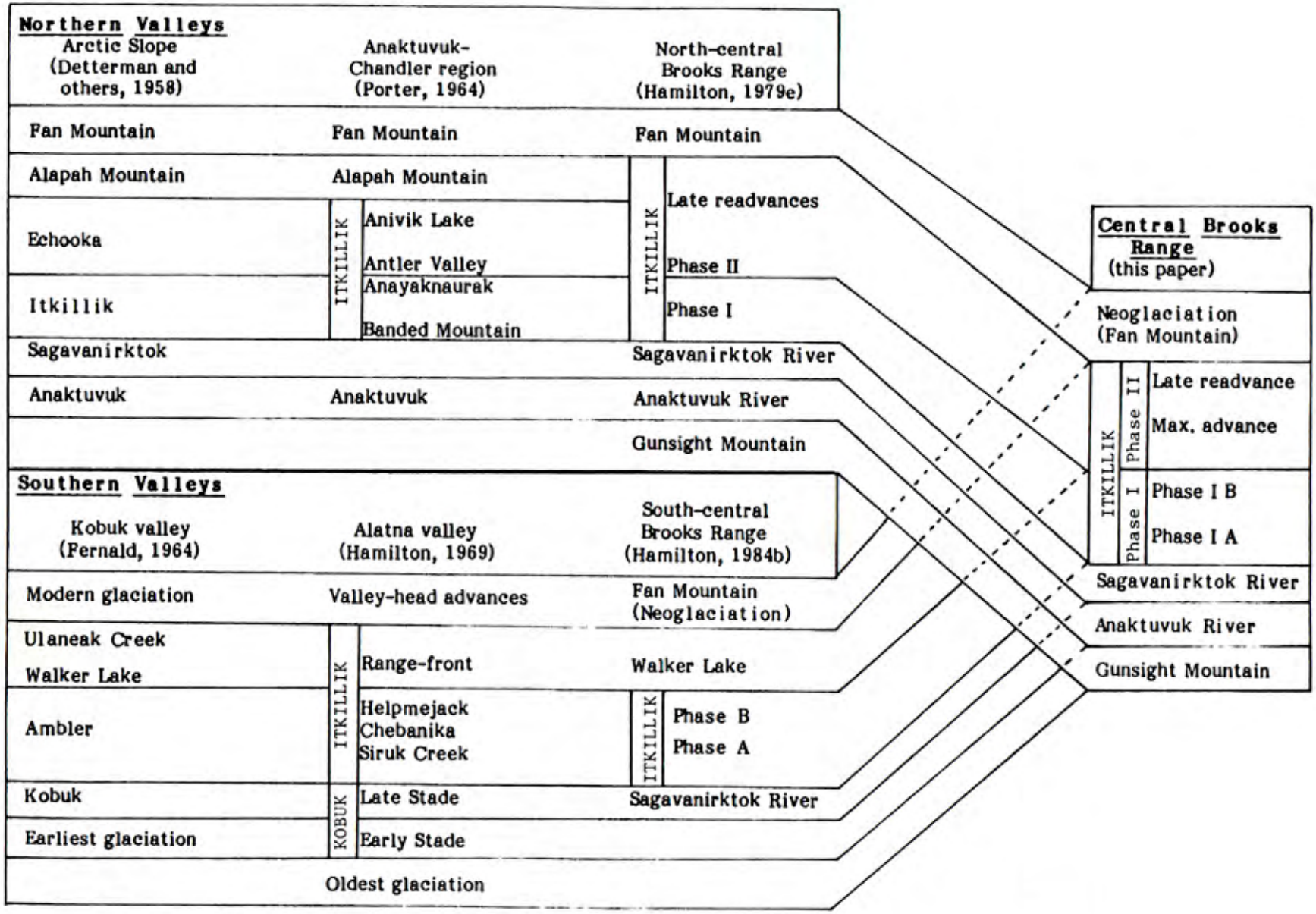


Table 1.--Glacial sequences in the central Brooks Range (modified from Hamilton and Porter, 1975)

succession for the north-central Brooks Range was established by Detterman (1953), with subsequent modifications by Detterman and others (1958). This succession has been widely applied through northern valley systems (Keller and others, 1961; Detterman and others, 1963; Chapman and others, 1964). Separate glacial sequences were developed for the Mount Chamberlin area farther to the east (Holmes and Lewis, 1965) and for the Chandalar and Kobuk River valleys of the southern Brooks Range (Williams, 1962; Fernald, 1964). More detailed studies by Porter (1964, 1966) and Hamilton (1969) used radiocarbon dates, stratigraphic relations, soil and weathering profiles, and surface morphologies to subdivide the major drift sheets of the Anaktuvuk and Alatna Valleys into component units of stadial rank (table 1). Hamilton and Porter (1975) later integrated their studies into a provisional glacial sequence for the entire central Brooks Range.

The present report is based on helicopter-supported mapping of surficial deposits through the central Brooks Range during 1975-1985 (Hamilton, 1978a,b, 1979a,b, 1980a, 1981b, 1984a,b). More than 150 radiocarbon dates provided a chronology of glacial fluctuations and related environmental changes during the past 35,000 years (Hamilton, 1982a). Several hundred measured sections provided stratigraphic context for the radiocarbon dates as well as a relative chronology for older events (Hamilton, 1979c,d, 1980b,c, 1982b; Hamilton and Brubaker, 1983). Quantitative measurements of morphology, soil development, and boulder weathering also were obtained on more than 200 end moraines (Bauer and others, 1984). Those relative-age data allowed correlation of drift bodies between separate mountain valleys and between northern and southern parts of the range.

Recent modifications of the central Brooks Range glacial sequence (table 1) reflect information gathered during fieldwork since 1975, as well as recent changes in the North American Stratigraphic Code. Concepts such as "glaciation" and "stade", upon which most mapping of glacial deposits in the Brooks Range had been based, now are considered by the North American Commission on Stratigraphic Nomenclature (1983) to be too tenuous and too subjective to be used as a basis for establishing formal stratigraphic units. Geologic-climatic units accordingly have been eliminated from the Stratigraphic Code, and unconsolidated Quaternary deposits can be formally delineated only on the basis of distinctive lithology, properties, or physical limits.

The general glacial succession followed in this paper (table 1) preserves stratigraphic names most widely used in the Brooks Range during the past 32 years. However, the names are applied to glacial deposits (drift sheets) rather than to "glaciations" and are based on observable field evidence rather than on inferred climatic changes. The sequence of glacial deposits represented by the Gunsight Mountain, Anaktuvuk River, Sagavanirktok River, and Itkillik drift sheets are allostratigraphic units distinguished in part by their bounding discontinuities. Small end moraines and associated deposits near existing glaciers in higher parts of the range comprise the Fan Mountain drift sheets, which formed within the past 4,400 years according to radiocarbon dating and lichenometry (Ellis and Calkin, 1984).

DRIFT OF GUNSIGHT MOUNTAIN AGE

Type Area

I have used the informal term Gunsight Mountain drift (Hamilton, 1979a) for highly modified glacial deposits near Gunsight Mountain west of the Anaktuvuk River (fig. 2; fig. 3, locality 1); that terminology is retained in this report. Drift having nearly featureless topographic expression is present in some localities, but the former glacial deposits more commonly are represented only by scattered boulders of the Kanayut Conglomerate, an unusually resistant rock type derived from the Brooks Range (Moore and Nilsen, 1984; Nilsen and Moore, 1984). Drift and erratic boulders occur on a dissected erosion surface 70-130 m above the level of modern streams; they lie beyond subdued morainal topography of drift of Anaktuvuk River age as defined by Detterman (1953) and as mapped in the Anaktuvuk River region by Detterman and others (1958, 1963).

End moraines of Gunsight Mountain age generally have been obliterated by mass wastage and erosion, but one arcuate remnant between the Chandler and Siksikpuk

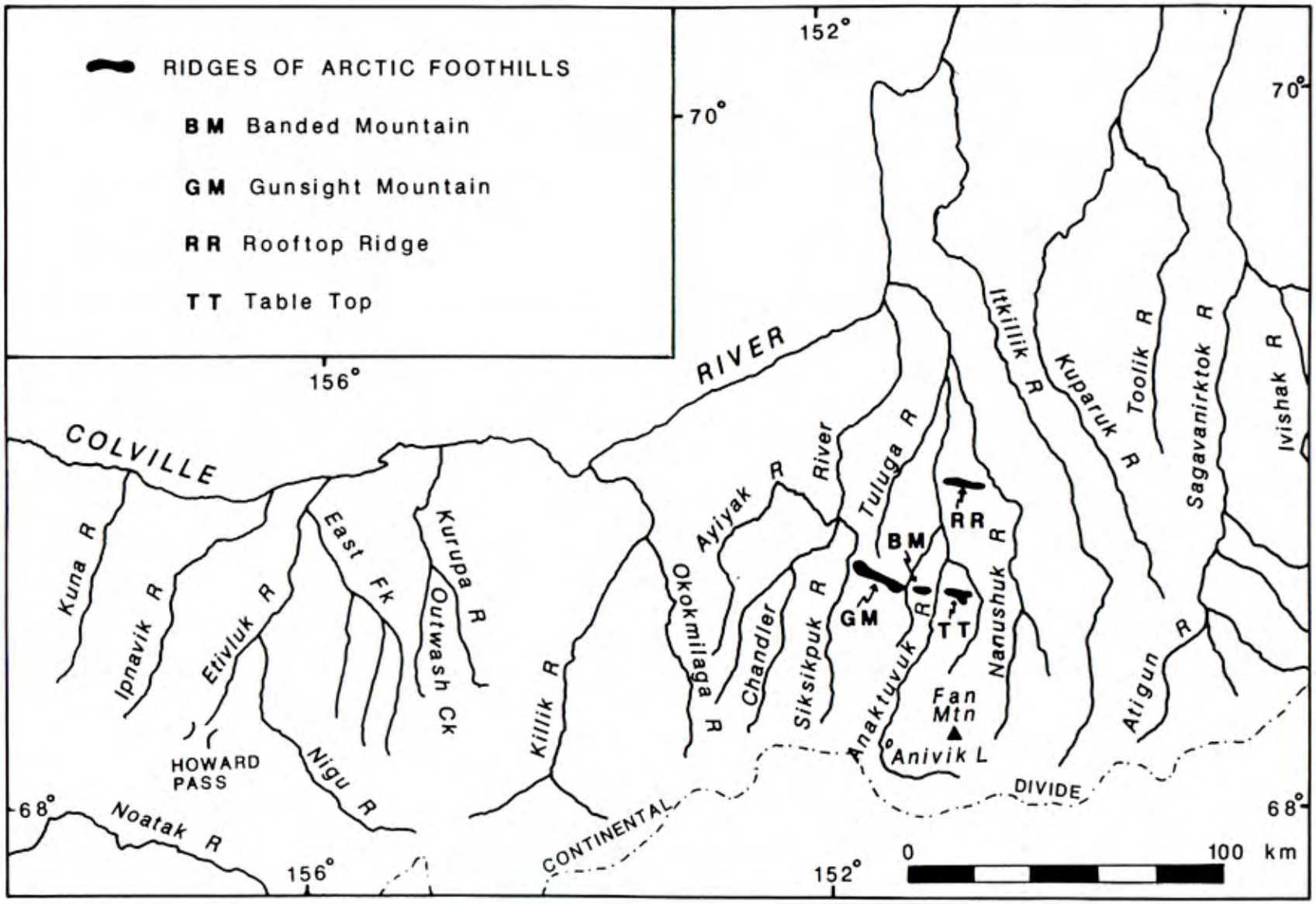


Figure 2.—The northern Brooks Range and Arctic Foothills, showing major rivers and other localities discussed in the text.

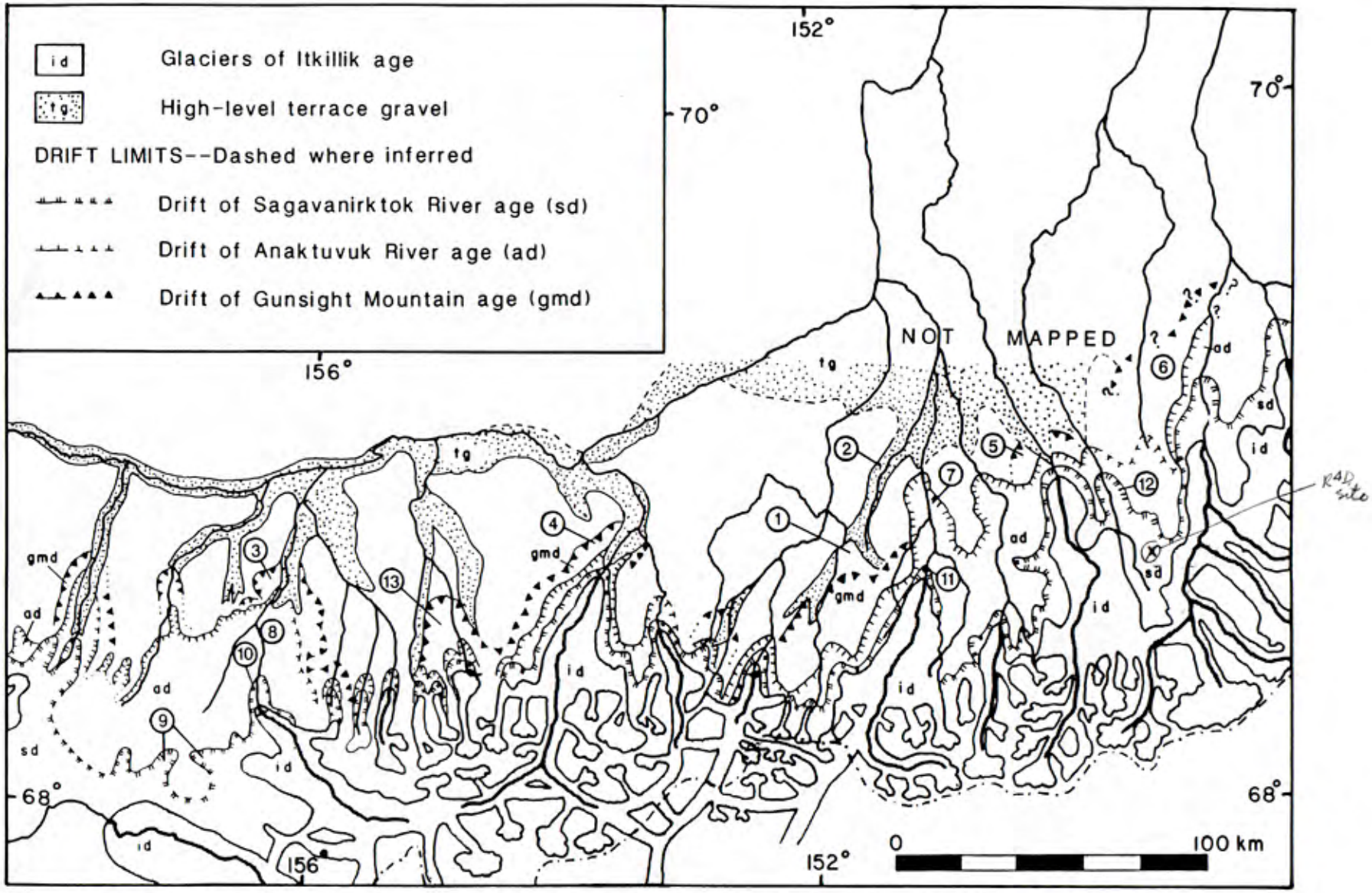


Figure 3.—Glacier limits and high-level terrace gravel, northern Brooks Range and Arctic Foothills. See figure 2 for significant place names. Numbers refer to localities discussed in the text

Rivers is about 2 km wide, with almost imperceptible surface relief and a thick and continuous cover of sod and frozen silt. A single surface exposure reveals boulders of Kanayut Conglomerate embedded in coarse gravel.

South of Gunsight Mountain, a formerly extensive drift sheet is represented only by boulders and angular boulder fragments of Kanayut Conglomerate on a broad, dissected, north-sloping, pediment-like erosion surface 50–130 m above modern stream levels. The boulders generally are rounded to well rounded and stained by iron oxides; their maximum diameter is 2.5 m. They are most common near the edges of incised stream valleys where loess cover has been thinned or removed by erosion. The boulders in some places are embedded in strongly oxidized alluvium that consists dominantly of local rock types and therefore probably is nonglacial in origin. At its southeast margin, the erosion surface grades into a nearly featureless drift sheet whose outer edge is indented several kilometers along stream courses. This deeply crenulated zone of contact indicates that the pediment-like surface was produced from the drift sheet by erosion processes that were most active along streams. The drift remnant lies beyond recognizable moraines of Anaktuvuk River age and is much more subdued topographically than those deposits. If this drift is of Gunsight Mountain age, its present outer margin is now as much as 15 km southeast of its initial position near Gunsight Mountain. Such magnitude of backwastage could only have taken place during a very long interval of time.

Other remnants of Gunsight Mountain drift, which occur locally where protected from stream erosion, are poorly drained and have a nearly featureless topographic expression. They contrast in appearance with unglaciated terrain, where east-west-trending regional bedrock structures commonly are evident, and their outer margins are indicated by the limits of large boulders of Kanayut Conglomerate that form lag deposits in the beds of streams.

Fragmentary terrace remnants 130–150 m above modern streams outline an abandoned course of the Chandler River that extended for about 90 km northeast to the Anaktuvuk River (fig. 3, loc. 2). The terrace remnants stand at and slightly above the level of Gunsight Mountain drift, and they occur only beyond its outer limits. Younger terrace remnants 80–90 m high are inset within the older terrace and also occur inside the limits of the Gunsight Mountain drift. These remnants also extend northeast, forming the floor of a broad (3–4 km) ancient valley that is occupied today by the underfit Tuluga River. Regional drainages evidently were 80 m or more above present streams during and after glacier advances of Gunsight Mountain age.

Other Northern Valleys

Probable limits of former drift bodies correlative with drift in the Gunsight Mountain type area are traceable for at least 330 km across the Arctic Foothills from the Kuna River east to the Itkillik River (fig. 3). The drift was overridden in some places by more extensive glaciers of Anaktuvuk River age, but commonly it is present beyond the end moraines of that ice advance in the form of till or erratic boulders on erosion surfaces that stand about 100 m above modern drainage levels.

The westernmost mapped drift, in the valley of Kuna River, consists of till remnants, probable outwash gravel, scattered erratic boulders, and abundant boulder fragments on an erosion surface that declines northward from a height of 100–110 m above modern stream levels at the range front to about 50 m height in the terminal zone. The glacial deposits outline an ice lobe about 18 km wide that extended 30 km north of the range.

A larger glacier lobe centered on the Etivluk River extended to within 20 km of the Colville River (fig. 3, loc. 3). Abundant boulders and smaller clasts of granitic gneiss demonstrate that the ice tongue originated in part from plutons at the head of the Noatak valley. Bouldery gravel and lag concentrates of erratic boulders and boulder fragments in the terminal zone occur on a nearly planar erosion surface 55–70 m above modern drainages. Former ice limits locally are marked by transition from unsorted bouldery deposits to coarse gravel containing clasts as large as 35 cm diameter—a size limit typical of most outwash deposits in the region.

Gunsight Mountain drift is less extensive between the Etivluk and Killik Rivers

(fig. 3), and it has been intensely eroded by streams in this area. Former glacier margins are marked by the northern limit of erratic boulders and boulder fragments; these consist almost entirely of Kanayut Conglomerate, generally occur dispersed in coarse cobble gravel, and occur on erosion surfaces that stand 20-35 m above modern streams. The largest ice lobe, which extended 30 km north from the range in the Kurupa River area, occupied a surface that rises southward into a boulder-littered pediment that has been isolated from the range front by canyon-cutting to depths as great as 320 m.

The Killik valley lobe of Gunsight Mountain drift extends 58 km from the north flank of the Brooks Range, terminating only 20 km from the Colville River (fig. 3, loc. 4). It is nearly covered by end moraines of Anaktuvuk River age; these overlap the older deposits east of the Killik River and extend to within 1-7 km of the outermost erratic limits in the valley's center and along its western flank. Rounded erratic boulders of Kanayut Conglomerate as much as 1.2 m in diameter are dispersed in coarse gravel on an alluvial terrace that stands 45-50 m high around the confluence of the Killik and Okokmilaga Rivers.

East of its type area, Gunsight Mountain drift is definitely recognized only along the Itkillik River (fig. 3, loc. 5), where boulders of Kanayut Conglomerate have been reported by Carter (1983). The boulders are associated with arcuate remnants of a high alluvial terrace, which can be matched with similar arcuate remnants east of the river. The terrace remnants may have been defended from erosion by concentrations of resistant erratic boulders, accounting for their unusual persistence at this site. If this inferred relation is valid, then similar paired arcuate remnants of the high alluvial terrace could reflect the former presence of Gunsight Mountain drift in other valleys farther to the east where detailed geologic mapping has not yet been carried out. Such features are evident on aerial photographs of the Toolik-Sagavaniriktok Rivers region in positions 7-10 km beyond the outermost moraines of Anaktuvuk River age (fig. 3, loc. 6).

Drift of Gunsight Mountain age is associated with a regional terrace system along the Colville River and its principal tributaries (fig. 3). The alluvial terrace rises progressively eastward from a height of about 45 m along the Kuna River and adjoining parts of the Colville River: it stands 55 m high near the mouth of the Etivluk River, at 60-70 m near the Killik River, at 85-100 m in the Anaktuvuk-Chandler Rivers region, and at 100-110 m near the Sagavanirktok River. Terrace gravels close to former ice limits are markedly coarser (clasts as large as 40 cm) and thicker (to 50 m) than comparable gravel a few kilometers farther to the north, indicating that the terraces were formed in part by outwash from glaciers of Gunsight Mountain age.

Southern Valleys

Drift provisionally correlated with glacial advances of Gunsight Mountain age occurs beyond the limits of younger glacial deposits in the Koyukuk River valley and probably also in the basin occupied by the Hogatza River farther to the west (figs. 4 and 5). Its outer margin, where mapped in the Kanuti Flats (fig. 5, loc. 1), is close to that of the oldest drift deposits recognized by Karlstom and others (1964). A broad (4-5 km), arcuate, probable end moraine at the south margin of Kanuti Flats was planed by wave action below 200 m altitude when a glacier-dammed lake later occupied this basin. (See the following section.) Its heavily forested surface is draped by loess and lacustrine silt. Rare exposures on the surface and flanks of the moraine are primarily alluvial gravel that evidently was formed during later reworking of the moraine by streams. The glacial origin of the ridge is confirmed by erratic boulders along the banks of the Kanuti River at both places where it crosses the moraine. Boulder lithlogies are those of the Brooks Range and foothills east of the Alatna River; gneisses from the Arrigetch Peaks are lacking. A separate glacial lobe farther west flowed up the valley of the Mentanontli River and terminated about as far south as ice in the Kanuti Flats. Boulders as much as 1.6 m long occur along the river near the terminal position shown in figure 5; these include abundant granitic gneisses from the Arrigetch Peaks. Between the areas occupied by the two former ice lobes, the Kanuti River flows through a narrow rock-walled gorge more than 100 m deep. As

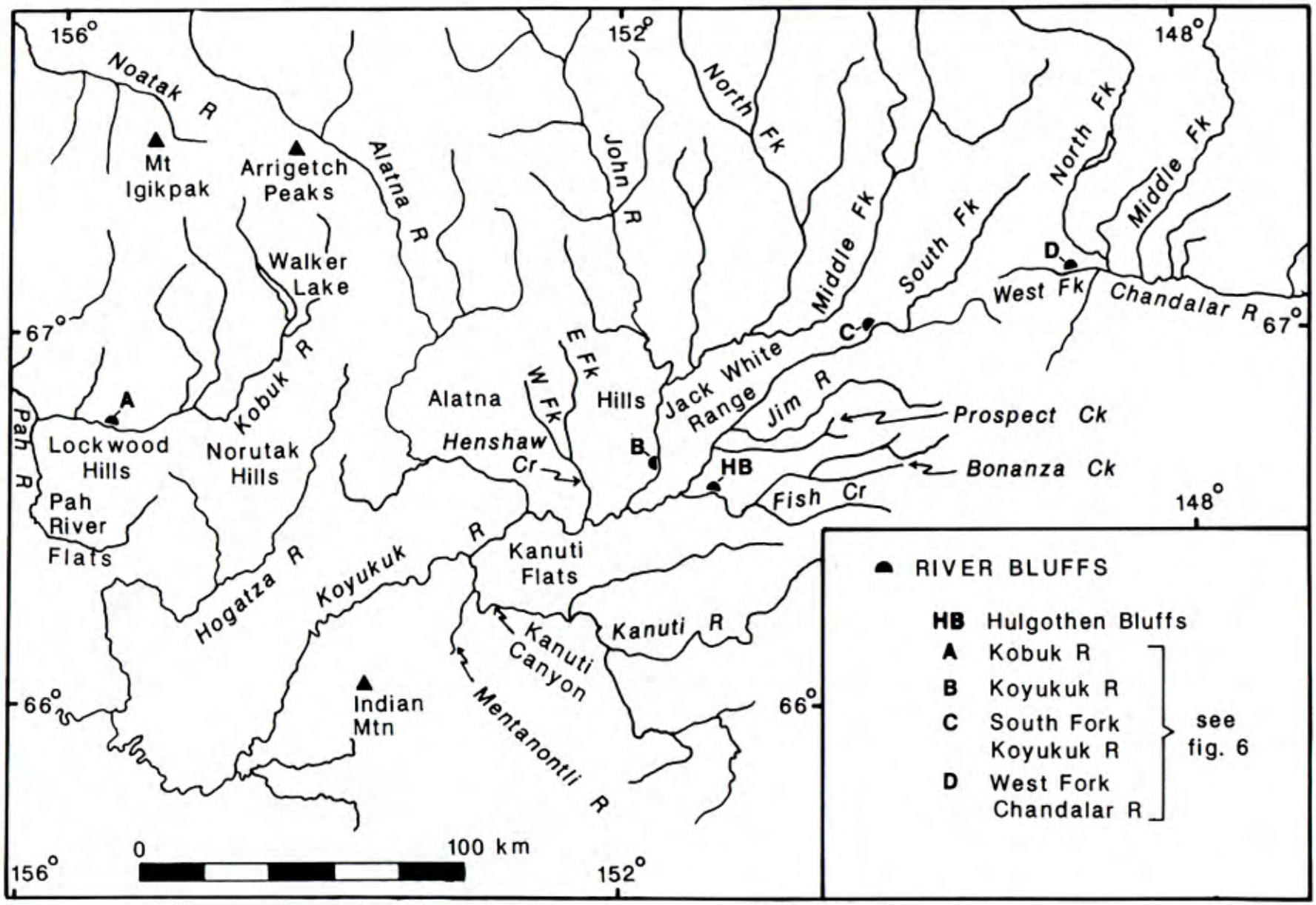


Figure 4.—The southern Brooks Range and adjoining valleys, showing major rivers and other localities discussed in the text.

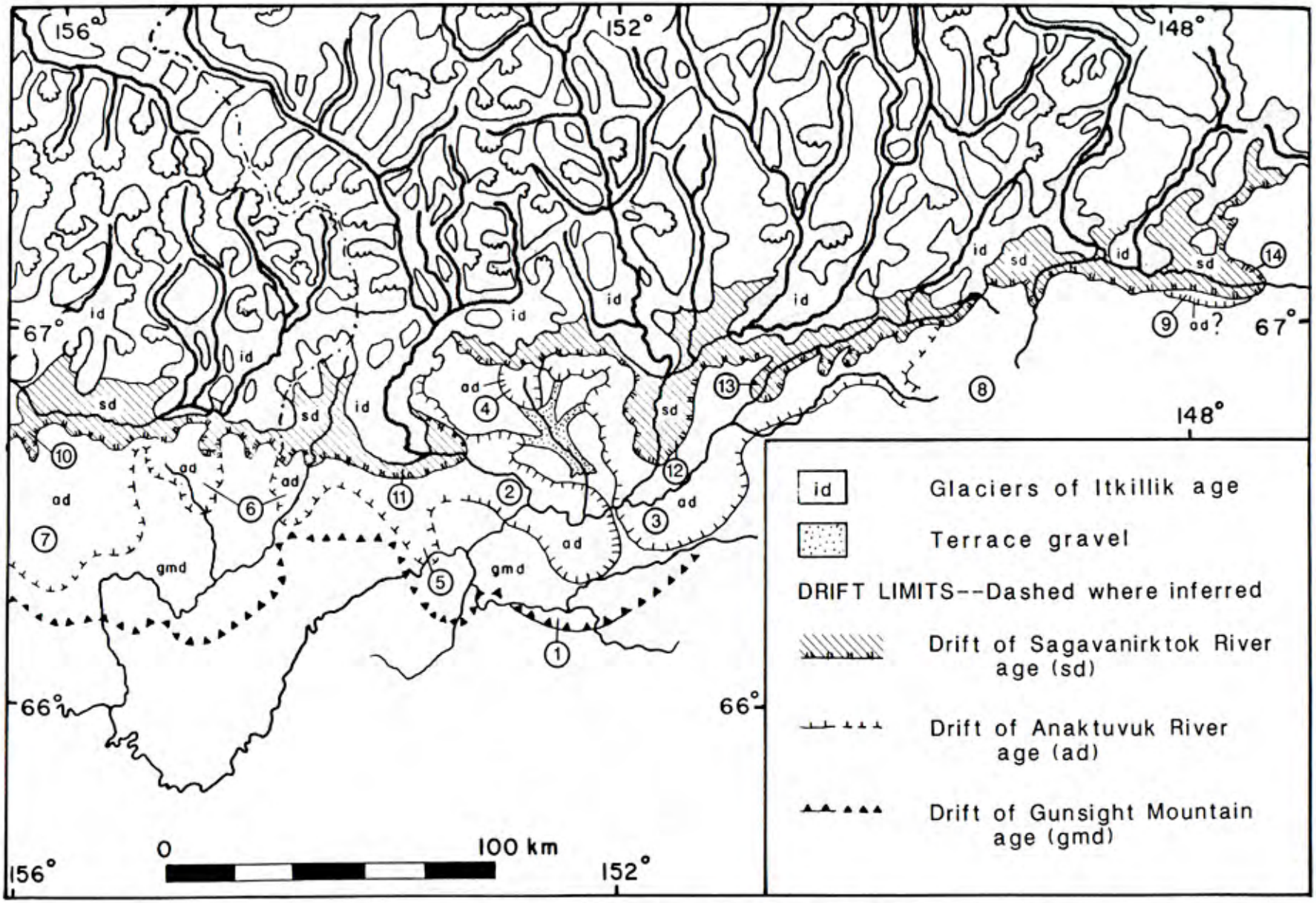


Figure 5.—Glacier limits and high terrace gravel, southern Brooks Range and adjoining valleys. See figure 4 for significant place names. Numbers refer to localities discussed in text.

glaciers extended into the Koyukuk valley, the river must have been displaced from its former northward course into Kanuti canyon (fig. 4), a new westward route superimposed across a bedrock ridge. The moraine is traceable for about 70 km east-northeast from Kanuti Canyon, but its location farther east is obscure.

I have not had the opportunity to map drift of Gunsight Mountain age west of the Mentanontli River, but examination of aerial photographs and Landsat imagery suggests that a very ancient glacier may have extended to the south margins of the Pah River Flats and the basin of the Hogatza River (fig. 5). The advance of that glacier may have occurred during Gunsight Mountain time.

DRIFT OF ANAKTUVUK RIVER AGE

Type Area

The Anaktuvuk River glactiation was named by Detterman (1953) for erratic boulders and subdued morainal topography that extend about 65 km north of the Brooks Range along the Anaktuvuk River (fig. 3, loc. 7). Drift of Anaktuvuk River age (hereafter termed Anatuvuk River drift) is relatively well preserved on the west side of the river, but it has been intensely eroded along the east side of the valley. Drift limits in the Anaktuvuk valley were mapped by Detterman and others (1958, 1963) and later modified slightly by Hamilton (1979a).

North of the limit of Gunsight Mountain erratics, where Anaktuvuk River drift abuts against unglaciated terrane, its outer margins are defined by segments of moraine cores exhumed by downcutting and by the limits of (1) widely scattered erratic boulders, (2) bouldery lag deposits in streams, and (3) broadly hummocky to ridge-like deposits above bedrock. Farther to the south, where it abuts older drift, deposits of Anaktuvuk River age can be distinguished by (1) preservation of erratics on exposed sites such as bedrock knobs and ridges, (2) abundant sandstones, as well as conglomerates, among Kanayut Conglomerate erratics, and (3) deposits with steeper flanking slopes and more regular morainal morphology than those of Gunsight Mountain age.

In its terminal zone west of the Anaktuvuk River, Anaktuvuk River drift bears a thick and continuous cover of silt. Only a few large erratic boulders are exposed, and most of these protrude no more than 10 cm above the ground surface. Drainage networks are well integrated, and streams typically cross drift limits without being deflected. Arcuate morainal ridges are rare and occur mainly where downcutting by streams that parallel the ridges has maintained morainal relief. Moraine crests are generally about 0.5 km wide, with gentle (1-2 degree) flanking slopes. Solifluction is active on all slopes and has leveled most original depressions on the drift surface. The drift surface is indented by several large (as much as 4 km^2), deep (30-40 m), nearly closed kettle-like depressions containing shallow ponds that have undergone multiple cycles of thaw-lake activity as described by Walker and others (1980). Some depressions occur at the heads of drainage systems that are incised deeply into the drift, indicating that the basins formed or continued to form long after deglaciation.

Anaktuvuk River drift has been severely eroded throughout the terminal zone east of the Anaktuvuk River. Scattered erratic cobbles and boulders of Kanayut Conglomerate overlie remnants of a gravel terrace 100-120 m above modern streams; they also litter bedrock surfaces that stand 40-50 m higher than the gravel. The eroded remnants of gravel and bedrock may represent the former valley floor down which the glacier advanced.

Farther south, deposits of Anaktuvuk River age form massive lateral moraines that rise as high as 350 m above the floor of the Anaktuvuk valley. The moraine west of the river resembles Anaktuvuk River drift farther downvalley in its broad crest, gentle flanking slopes, and widely dispersed boulders of Kanayut Conglomerate. The moraine east of the river has been overlapped by younger lateral moraines and heavily scoured by meltwater streams that have largely obliterated its original morphology.

Erratics of Kanayut Conglomerate mark the lateral limits of Anaktuvuk River drift on Banded Mountain, Table Top, and Rooftop Ridge (fig. 2). Cobbles, small boulders, and shattered fragments of larger clasts are nearly buried in fragments of the local sandstone; they rarely protrude more than 10 cm above the general rubble surface. Tors as high as 8.5 m, present below

the erratic limit on Table Top, have been intricately etched by differential weathering. They could not have been overridden by glacier ice and must have developed since Anaktuvuk River time.

The drift sheet was broadly incised by the Anaktuvuk River during a very long interval of postglacial erosion. The stream-scoured surface inset within the drift sheet is as much as 6 km wide, stands 60 m above the modern floodplain, and is traceable for more than 25 km along the valley center.

Other Northern Valleys

Drift of Anaktuvuk River age has been mapped from the Kuna River area east to the Sagavanirktok River—a distance of 380 km (fig. 3). It is unusually broad in the Etivluk valley, but elsewhere forms long, narrow lobes confined by massive lateral moraines several hundred meters thick. The drift lobes were deposited by individual ice tongues that issued from deeply incised mountain valleys. Throughout this region, Anaktuvuk River drift is differentiated from glacial deposits of the Gunsight Mountain advance on the basis of (1) recognizable morainal morphology and outwash remnants, (2) preservation of kettle-like basins, (3) more abundant and lithologically varied surface erratics, and (4) preservation of erratics on exposed sites such as bedrock outcrops. It is differentiated from all younger glacial deposits by its extensive postglacial erosion and by its association with ancient landscapes 50 m or more above the levels of modern streams.

A very large body of ice about 65 km wide at the range front filled the Etivluk valley and extended north to within about 25 km of the Colville River (fig. 3, loc. 8). Broad passes in the Brooks Range and abundant erratics of granitic gneiss indicate that much of the glacier was derived from the Noatak valley. The northwest margin of the drift sheet, which is traceable nearly continuously for about 35 km, is marked by the limits of erratic boulders, by linear concentrations of coarse bouldery gravel, by abrupt edges of hummocky deposits superimposed on bedrock, by remnants of former outwash trains, and by abandoned drainage channels. The linear concentrations of coarse bouldery gravel parallel the general drift limit and probably represent the downwasted cores of end moraines. The more intensely eroded east side of Etivluk valley contains widespread stream-scoured surfaces as high as 85 m above modern drainages. Drift of Anaktuvuk River age in this part of the valley is represented mainly by dispersed erratic boulders and boulder fragments.

East of the Etivluk valley, Anaktuvuk River drift generally forms the outer sectors of compound lateral moraines that flank river valleys on the west and east. The moraines typically have broad crests, and flanking slopes are smoothly graded by solifluction to angles of 1-2 degrees; they are best preserved along western valley sides. Surface boulders are widely dispersed and are almost entirely of Kanayut Conglomerate. Exposed surfaces of Kanayut Conglomerate boulders are etched into 2-4 cm relief; pebbles stand in positive relief and bedding planes in negative relief. Drift lobes have been broadly dissected and contain inset terraces 40-60 m above modern streams that continue downvalley into regional terrace systems 30-50 m high. Postglacial streams have developed extensive, well integrated networks that cross drift margins with little or no deflection. Closed to nearly closed kettle-like basins containing compound thaw lakes occur in the terminal zones of the drift sheets in the Nanushuk and Itkillik valleys and are common along the western lateral moraine of the Sagavanirktok valley lobe. The kettles commonly occur within postglacial terrace gravels, indicating that some glacier ice persisted for long periods after general deglaciation.

Anaktuvuk River drift in the Killik valley is exposed in a narrow (1-7 km) symmetrical belt that overlaps Gunsight Mountain drift and is partly covered along its inner flank by younger glacial deposits. Drift lobes farther east in the valleys of the Nanushuk, Itkillik, Kuparuk, Toolik, and Sagavanirktok Rivers are less symmetrical and have been more severely affected by postglacial drainage changes. An abandoned channel extends northeast from the Nanushuk River to the Itkillik River across drift with many kettle-like depressions, and a similar channel extends northeast through the terminal zone of the Sagavanirktok valley glacier. The Nanushuk and Sagavanirktok Rivers evidently were deflected east of their

present courses for some time after deglaciation and while residual glacier ice still was locally present. Although the Kuparuk and Toolik valleys supported large alpine glaciers during Anaktuvuk River time, their present streams are small, originate north of the Brooks Range, and have incised the moraines to only shallow depths. The Kuparuk and Toolik Rivers possibly were beheaded during or shortly after deglaciation, and therefore were unable to erode their end moraines to depths that would be normal for drift of Anaktuvuk River age.

Southern Valleys

I have examined drift of inferred Anaktuvuk River age most closely in the Koyukuk valley (figs. 4 and 5). Subdued, arcuate end moraines and sediments exposed in river bluffs define two large glacier lobes: a western lobe centered on the Alatna River valley and an eastern lobe in the valleys of the Koyukuk River and its South Fork (fig. 5, locs. 2 and 3). Each lobe extended about 70 km south of the Brooks Range and terminated in standing water. Drift at the east and west margins of the western lobe is exposed in two bluffs along the Koyukuk River, and a bluff along the Kanuti River intersects its outer limit. The exposure at the western edge of the lobe contains strongly jointed, compact till that is oxidized dark yellowish brown (10YR 3/4) along joint planes to its full exposed depth of 25 m. A second bluff 30 km farther up the Koyukuk River exposes clayey diamicton and strongly jointed glaciolacustrine silt. The exposure along Kanuti River also contains compact stony silt of probable glaciolacustrine origin. The glacier clearly dammed the Koyukuk River, and its terminus must have been partly afloat.

The eastern lobe (fig. 5, loc. 3) is represented by a separate moraine that crosses the Kanuti Flats and then trends north to the Koyukuk River, where it may have been in contact with the Alatna valley lobe. Drift is best exposed at Hulgothen Bluffs (fig. 4), where 23 m of compact, jointed, silty till is capped by organic deposits that are overlain by thick glaciolacustrine beds assigned to a younger ice advance. The west margin of the lobe trends north to the Brooks Range along the east side of the valley of Henshaw Creek; the east margin trends northeast into uplands south of Jim River.

Knolls and ridges on the drift left by the two lobes within the Kanuti Flats contain only redeposited gravel. Gravel accumulations on moraine crests generally were shaped by waves in a glacial lake; those on moraine margins were reworked by streams during downcutting. Rounded pebbles and small cobbles predominate, with some larger cobbles and very small boulders derived from the original drift. Most surface exposures are strongly weathered: upper parts of boulders have disintegrated to ground level, soils show strong oxide coloration (7.5YR 4/6 to 5/8), and pebbles in some boulders of Kanayut Conglomerate have been etched into as much as 2.5 cm relief. Kanayut rock types predominate in the eastern lobe (55–90 percent of all surface boulders), indicating that much of the ice was derived from sources along the Continental Divide east of the Killik River. Granitic gneiss from the Arrigetch Peaks is common in drift of the western lobe.

Severely eroded drift outlines the former position of a smaller glacier that extended about 11 km into the Koyukuk valley along the West Fork of Henshaw Creek (fig. 5, loc. 4). The drift lobe has been eroded to a width of 2 km by the West Fork, and the outer 3 km of its western flank has been nearly obliterated by small tributary streams. The eroded moraine remnants are fronted by a gravel terrace 30–35 m high formed by a meltwater stream that extended south, received additional discharge from glaciers to the west and east, and terminated in the glacial lake. Erratic boulders are present where modern streams cut the drift sheet and in gravel knolls and ridges along crests and flanks of partly eroded moraines. Kanayut Conglomerate rock types are common east of the West Fork; granitic rocks from the Arrigetch pluton are common farther to the west.

Thick (20–45 m) deposits of stony silt in the valley of the Mentanontli River are comparable in thickness, stratigraphic position, jointing, and deep oxidation to deposits of inferred Anaktuvuk River age elsewhere in the Koyukuk valley. Deltaic deposits of similar thickness and stratigraphic position near the west end of Kanuti Canyon formed where the Kanuti River debouched into

standing water at that time. The lacustrine deposits indicate that the Koyukuk River must have been blocked by an additional ice tongue somewhere west of the Alatna lobe, most likely at a point 12 km below the mouth of the Kanuti River (fig. 5, loc. 5).

Anaktuvuk River drift has not been traced farther to the west, but examination of aerial photographs supports the contention of Karlstrom and others (1964) and Coulter and others (1965) that glaciers terminated within the basins of the Pah and Hogatza Rivers during a very old ice advance (fig. 5, locs. 6 and 7).

Farther to the east, separate glaciers were generated in mountains around the head of Jim River (fig. 5, loc. 8). Erratic boulders of Kanayut Conglomerate are mixed with granitic boulders from local plutons, indicating that local glaciers coalesced with ice from the Brooks Range. The resulting glacier complex flowed south across the drainage divides; it inundated the valley of Jim River, covered much of the drainage basin of Prospect Creek, and extended a short distance into the North Fork of Bonanza Creek.

Along the south side of Chandalar valley, a glacier limit of possible Anaktuvuk River age is marked by faint ice-marginal drainage channels, by truncation of ridge spurs and flattening of ridge crests, by deflection of tributaries into ice-marginal courses, and by rare patches of outwash (fig. 5, loc. 9). The glacier margin lay 1-2 km beyond, and 200-250 m higher than, the south limit of more continuous glacial deposits and fresher-appearing ice-marginal drainage channels assigned to the subsequent ice advance of Sagavanirktok River age. Its terminus on the floor of the Chandalar valley evidently was overridden by the younger ice advance, but remnants of its outwash terrace clearly stand beyond and have been truncated by outwash of Sagavanirktok River age.

DRIFT OF SAGAVANIRKTOK RIVER AGE

Type Locality

The Sagavanirktok River glaciation was named by Detterman (1953) for glacial deposits with morainal topography that extend about 50 km north of the Brooks Range along the Sagavanirktok River. Detterman's type locality is on the Ivishak River, which was incorrectly labeled the "Sagavanirktok River" on older maps (R. L. Detterman, U.S. Geological Survey, oral commun., 1985). Drift at this site forms a well defined, arcuate, massive pair of lateral moraines that rise as high as 200 m above the modern river. Moraine crests are smooth, and their flanks slope 3 or 3.5 degrees except where steepened by subsequent erosion. Boulders are present locally along moraine crests, but generally the drift has an unbroken cover of silt and tundra vegetation. Terraces inset within the drift sheet are fragmentary and are no higher than a few meters above modern stream level.

Measurements taken on end moraines of Sagavanirktok River age in the Itkillik, Kuparuk, Toolik, and Sagavanirktok valleys show that these features commonly change laterally from one morphologically distinct class to another (table 2). For most of their length, the moraines generally resemble those of the type area in having broad, smooth crests with gentle flanking slopes and sparse surface boulders of Kanayut Conglomerate. However, some segments of the moraines are narrower and steeper than the norm, with more irregular stony surfaces and more diverse erratic lithologies. These younger appearing moraine segments commonly occur where meltwater channels of Itkillik age intersect normal moraines of Sagavanirktok River age or where axial streams have dissected moraines in valley centers. Many of these moraine segments have terraced flanks, gravel-covered beveled crests, and mixtures of weathered and unweathered surface stones. They evidently have been exhumed by stream erosion, which commonly was associated with drainage displacement or with cycles of alluviation and downcutting that accompanied advances of Itkillik-age glaciers. Despite their variability, moraines of Saganvanirktok River age are readily distinguished from older glacial deposits, which were eroded broadly by streams flowing 50 m or more above their present levels.

Other Northern Valleys

Drift sheets similar to those along the Sagavanirktok River occur in all glaciated valleys of the north-central Brooks Range. Large lobes extended 45-60 km north of the

Table 2.—Station data for moraines of Sagavanirktok River age Itkillik valley to Sagavanirktok valley

	Undisturbed (n = 3)	Exhumed (n = 3)
Crest width (m)	75-200	15-50
Slope angles (°)	2-3.5	8-24
Irregularities per 200 m	0	3-5
Clast lithology (%)		
Kanayut Conglomerate		
conglomerate facies	80-97	52-70
sandstone facies	3-20	20-43
ferrug. ss. facies	0-4	±5
Other rock types	0	0-5
Boulder frequency (boulders per 250 m^2)	1-10	68-230
Soil colors	Gleyed above shallow permafrost	Brown to yellowish brown (10YR 5/3 to 5/6)
Weathering of surface boulders	Weathering rinds 0.5-3 mm thick. Kanayut Conglomerate pebbles stand in 1-2 cm relief; sandstone facies bedding planes etched as deep as 1.5 cm	Variable. Some Kanayut Conglomerate shows 1 cm relief; some clasts of sandstone facies split along bedding planes. Other boulders have original abraded surfaces
Kettles	Small kettles completely filled; large ones rounded, with smooth solifluction slopes. Many are second generation	Some deep, with steep flanks, irregular perimeters, and gravel rims
Remarks	Graded solifluction slopes; depressions are filled with ice-rich silt.	Stones form lag pavements in places. One moraine has terraced flank; another has flattened gravel-covered crest

mountains along the Killik, Anaktuvuk, Itkillik, and Kuparuk Rivers; more than 20 smaller glaciers developed in intervening valleys. Despite great differences in size and despite morphologic differences due to local exhumation or other factors, most glacial deposits of Sagavanirktok River age are readily differentiated from older and younger glacial deposits.

Paired lateral moraines of Sagavanirktok River age curve unbroken into valley centers; they generally terminate at levels no more than 15-20 m above modern floodplains and lie only 3-8 km beyond terminal

moraines of Itkillik age. Surface boulders are more abundant than on drift of Anaktuvuk River age, and some stones protrude as much as 1 m above ground level. East of the Etivluk River, boulder assemblages generally are derived entirely from the Kanayut Conglomerate: sandstones of this formation are dominant (typically 50-60 percent), conglomerate is second in abundance (30-45 percent), and ferrugineous sandstone commonly is present (0-12 percent). Kettles are rounded and shallow, with gently sloping flanks. Thaw lakes commonly occur within kettle basins, which have been partly filled by loess and solifluction deposits. The drift sheets have been dissected by axial streams flowing close to their modern levels, and the width of dissection typically is 13-18 percent of total lobe width. Postglacial stream erosion commonly has progressed to a depth of only 12-15 m. Much of the lateral erosion occurred during times of high melt-water discharge from Itkillik-age glaciers, the outwash trains from which are inset within the older drift. These inset deposits commonly contain numerous kettles where they intersect end moraines of Sagavanirktok River age.

The end moraines are bordered by outwash terraces that are recognizable as far downvalley as 35 km. These terraces generally stand 20-25 m above modern streams at their points of origin and decrease in height downstream to 8-15 m. Stream cuts expose generally unweathered sediments capped by oxidized zones from 1.5 to 2 m thick throughout which clasts and matrix are discolored, partly decomposed, frost-churned, and intermixed with eolian silt. Caps of ice-rich silt, which are thick and ubiquitous on older alluvial surfaces, are thin to absent on outwash terraces of Sagavanirktok River age. These younger outwash terraces therefore lack the large compound thaw lakes that characterize older stream terraces and erosion surfaces.

Glaciers of the Kuna-Etivluk region had limited source areas during Sagavanirktok River time, and they generally did not extend beyond the north flank of the Brooks Range. No glaciers appear to have formed in the valley of Ipnavik River or in the western part of Etivluk valley. These areas lack recognizable cirques and had received ice mainly by overflow from the south during older glacial advances. Glaciers from the Noatak and Etivluk valleys advanced north and west into Howard Pass during Sagavanirktok River time (fig. 3, loc. 9), and glacier ice extended down the Nigu valley to form a lobe 6 km wide that terminated 9 km north of the range front (fig. 3, loc. 10).

The Killik and Anaktuvuk valley glaciers advanced 43 and 56 km, respectively, beyond the north flank of the Brooks Range. The Killik valley drift lobe forms part of a symmetrical nested set of end moraines that range in age from Gunsight Mountain to Itkillik. Drift of the Anaktuvuk glacier extends continuously along the west side of its valley for nearly 50 km, but it is largely covered by Itkillik-age drift east of the river. The glacier was constricted by the resistant rock ridge that forms Banded Mountain and Table Top, and only a narrow tongue of ice was able to extend about 7 km north of that ridge system (fig. 3, loc. 11). The glacier's terminus was restricted to the valley center, where most of its deposits were eroded by meltwater or covered by outwash during subsequent glacier expansions of Itkillik age.

Smaller glaciers between the Killik and Anaktuvuk Rivers formed lobes up to 7 km wide that extended as far as 21 km beyond the Brooks Range. The lobes generally had complex patterns, suggesting that significant drainage and topographic changes must have taken place along the north flank of the Brooks Range preceding or during Sagavanirktok River time. Some outwash remnants near the flank of the Brooks Range stand 45 to 50 m high, possibly due to local uplift along the range front during or following the Sagavanirktok River ice advance.

Glacial deposits farther to the east reflect large-scale drainage changes that may have been related to tectonism in the Brooks Range (fig. 3). Drift lobes of nearly equal size formed in the Itkillik and Kuparuk valleys during Sagavanirktok River time. The Itkillik valley drift lobe was largely overlapped by the succeeding Itkillik-age glacier, which was fed from sources in both Itkillik and Atigun valleys, whereas the Kuparuk valley drift lobe, which originated in Atigun valley, lies far beyond the limits of younger glacier advances (fig. 3, loc. 12). A small distributary ice tongue extended northeast from the Kuparuk valley glacier into the

valley of the Toolik River, which otherwise remained unglaciated. The Toolik River had become separated from its ancestral mountain valley by Sagavanirktok River time.

Southern Valleys

Drift assigned to ice advances of Sagavanirktok River age fills a series of east-west-trending troughs along the south flank of the Brooks Range and forms several lobes that extend farther south along major valleys (fig. 5). Throughout this region, drift of Sagavanirktok River age (hereafter termed Sagavanirktok River drift) generally can be recognized by its characteristic morphology and composition. Topographic expression of drift sheets is considerably more subdued than that of Itkillik age (discussed in the following section), but the drift is not as heavily eroded as is that of Anaktuvuk River age, and it occurs on or close to the floors of modern valleys. In most localities, drift of Sagavanirktok River age consists of sandy pebble- to small-cobble gravel containing dispersed erratic cobbles, small boulders, and rock fragments. Clasts in the gravel fraction are rounded, and quartz comprises 40-70 percent of all pebbles.

In mountain valleys, Sagavanirktok River drift forms broad, nearly featureless surfaces that rise smoothly into aprons or embankments along valley sides and terminate abruptly against steeper, more irregular slopes of bedrock and talus rubble. The smooth, sweeping slopes indicate that a long interval of intense solifluction must have followed deglaciation. End moraines, where preserved in mountain valleys and in passes through foothills south of the range, have crests as much as 30 m wide and flanking slopes of about 3-5 degrees; they commonly form drainage divides. Yellowish-brown (10YR 5/6 to 5/8) to dark-yellowish-brown (10YR 4/4) soil colors predominate. Many clasts are fragments of larger rocks that have split along bedding or foliation planes; they generally protrude no more than 10 cm above the ground surface.

During Sagavanirktok River time, a large glacier, fed from the north, filled the upper Kobuk valley and flowed west to about long 156°15' W. where it terminated in standing water (fig. 5, loc. 10). The glacier was confined to the south by the Lockwood and Norutak Hills, against which it built morainal embankments and into which meltwater carved ice-marginal drainage channels. Small lobes of the glacier extended short distances farther south along the Pah and Hogatza Rivers and through two unnamed passes between the Lockwood and Norutak Hills. Tongues of ice also entered several higher passes in the Norutak Hills.

Near its terminus in the Kobuk valley, drift of Sagavanirktok River age forms a broad, gently undulating surface 65 m above river level. The Kobuk River has incised the drift to a width of about 1 km, and a terrace of Itkillik age at 30 m above river level is inset within the drift sheet. Surface exposures of drift are limited to knolls of rounded pebbles and small cobbles, mixed with sparse larger clasts in a matrix of dark-yellowish-brown to yellowish-brown (10YR 4/4 to 5/8) oxidized sand. Granitic gneiss from the Arrigetch Peaks, although sparse, is present in nearly all exposures. Erratic boulders as much as 2 m long occur along the Kobuk River where it intersects the drift sheet.

Several high (to 60 m) bluffs expose till above fluvial gravel that probably is nonglacial in origin (fig. 6A). The till consists of unsorted, unstratified, rounded pebbles and small cobbles with sparse striated, subrounded larger stones as much as 65 cm in diameter. Matrix generally is compact, jointed, silty sand, with some oxidation along joint planes; sandy or clayey silt predominate where the drift was water laid. Colors range from grayish brown to olive gray (5Y 4/2), with the upper several meters commonly oxidized. The underlying alluvium, as thick as 28 m, is pebble- to small-cobble gravel in which clasts are more rounded and quartz is more abundant (40-50 percent of all pebbles) than in late Pleistocene outwash or modern alluvium. Deposits above the till typically are loess, eolian sand, and alluvium; however, silt, clayey silt, and silty fine sand predominate where the retreating glacier was in contact with standing water. Some glaciolacustrine deposits along the Kobuk River contain rhythmically laminated couplets with dropstones, and one bluff along the Hogatza River exposes deltaic sediments that grade distally into couplets of gray silt and very fine sand.

In the Koyukuk region, glaciers of Sagavanirktok River age filled troughs north

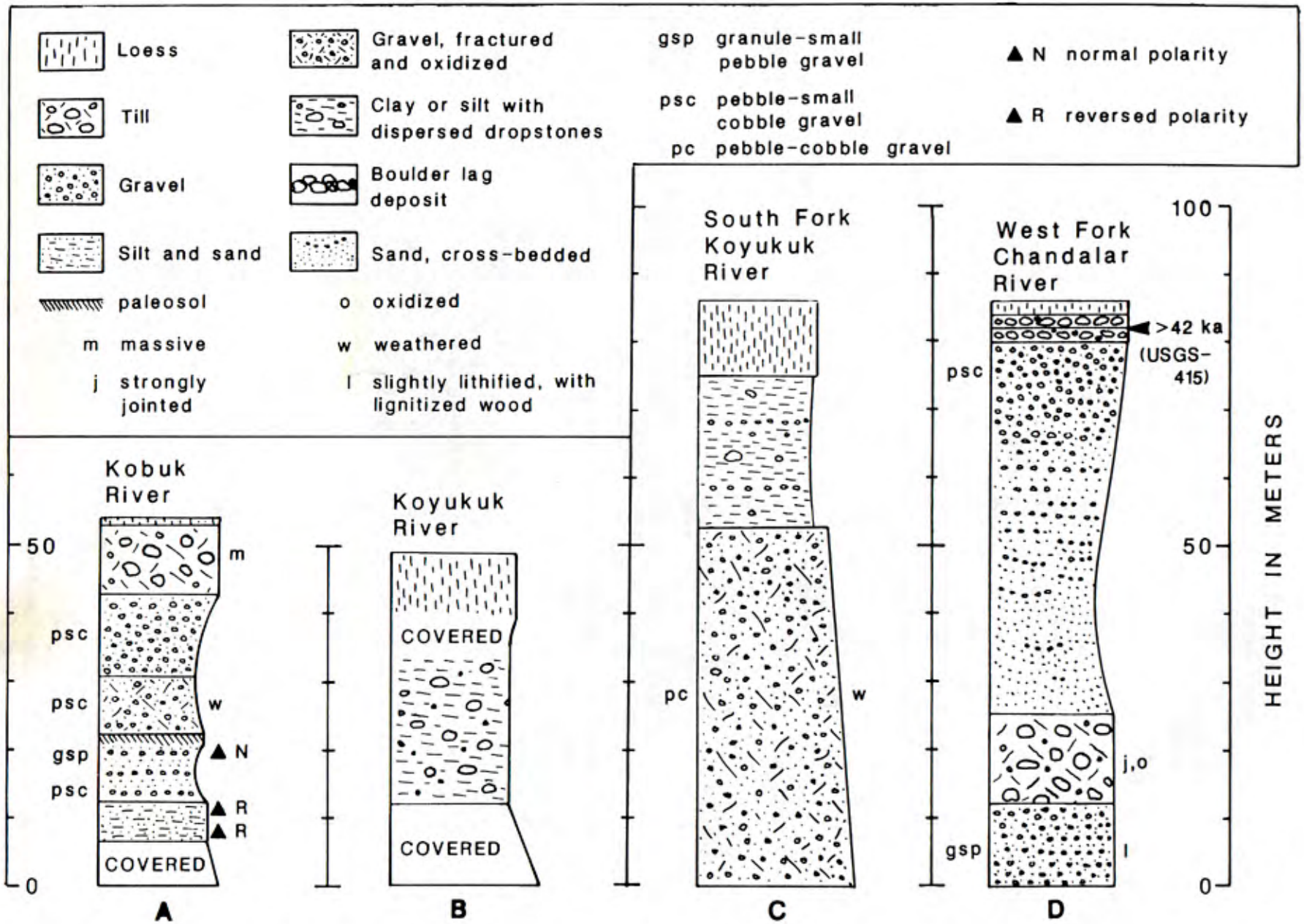


Figure 6.—Stratigraphic sections showing drift of Sagavanirktok River age and associated interglacial deposits. See figure 4 for locations.

of the Alatna Hills and the Jack White Range. Glacier lobes spilled south along the Alatna River, the Koyukuk River, and the South Fork of the Koyukuk (fig. 5, locs. 11-13); moraine morphology and sparse exposures indicate that they terminated in a lake that filled the Koyukuk basin. Drift of Sagavanirktok River age is poorly exposed along the Alatna River, but knolls along the Hogatza-Alatna divide are similar to those farther west—they consist of quartz-rich pebble-to small-cobble gravel with sparse larger clasts. Matrix material is sandy and oxidized across the divide, but it is gray and silty in the Alatna valley where the glacier probably entered the lake.

The Koyukuk drift lobe is almost imperceptible east of the Koyukuk River, being represented by a broad, low, arcuate ridge with no till exposures. The lake must have been deep here and the ice tongue afloat. Drift is exposed, however, along the north side of the river at the projected crossing point of the end moraine, where 15-30 m of till and glaciolacustrine stony silt are overlain by 15 m of loess (fig. 6B). Clasts are rounded to subrounded pebbles and small cobbles, with sparse, faintly striated, subangular to subrounded larger cobbles and rare very small boulders in a matrix of moderately compact, very dark gray gritty silt. Kanayut Conglomerate is dominant among the larger clasts.

Several exposures along the Koyukuk's South Fork show till and glaciolacustrine sediments in bluffs as much as 100 m high (fig. 6C). The till consists of faceted and striated stones in an unsorted to poorly sorted, compact, gray, sandy to silty matrix; the glaciolacustrine sediments are clayey and contain dropstones as large as medium boulders. Kanayut Conglomerate is dominant (54-72 percent). The South Fork lobe must have terminated in standing water at about 300 m altitude because only drift above this level forms broad, hummocky till plains with sparse large rounded kettles.

Near the Koyukuk-Chandalar divide, drift of Sagavanirktok River age consists generally of pebble-sized rounded gravel or angular fragments of quartz and schist, mixed in some places with the arkosic weathering products of local granitic plutons. Subrounded cobbles and small boulders intermixed with the finer clasts include Kanayut Conglomerate and other rock types from the Brooks Range. One deep exposure near the head of the West Fork of Chandalar River contains two beds of bouldery gravel, interpreted as lag deposits of Sagavanirktok River age (Hamilton, 1979c) above 54 m of cross-bedded alluvium that coarsens upward into imbricated pebble- to small-cobble gravel (fig. 6D).

Glaciers entered the Chandalar valley from its North and Middle Forks and through smaller tributary valleys farther to the east. The eastern terminus of the glacier complex was about 11 km wide (fig. 5, loc. 14), and the drift sheet has been eroded to a width of 2 km by the Chandalar River; it is fronted by an outwash terrace 48 m high. The drift shows little surface dissection and contains several well-rounded kettles. Upvalley from the terminus, glacier limits along the south side of the Chandalar valley are defined by ice-marginal channels and by sparse erratic boulders that were derived from the Brooks Range. A 30-m terrace that originates at end moraines of Itkillik age is inset within the drift. Glacial deposits in the valley center and marginal features along the south valley wall suggest two ice advances. Both advances probably took place during Sagavanirktok River time because their drift deposits (1) converge on similar lateral limits upvalley, (2) follow the modern valley system and are distributed across its floor, (3) are incised to the same width by the Chandalar River, (4) contain the same single inset terrace, and (5) match in number the two bouldery lag deposits near the head of the West Fork.

DRIFT OF ITKILLIK AGE

Introduction

The Itkillik glaciation of Detterman (1953) was named for relatively fresh and little modified glacial deposits that extend about 56 km north of the Brooks Range along the Itkillik River (Detterman and others, 1958). The Itkillik drift sequence later was subdivided into Itkillik I, Itkillik II, and late Itkillik II phases (Hamilton and Porter, 1975; Hamilton, 1978b, 1979a), and that nomenclature will be followed in the present paper.

The outer border of Itkillik-age drift is the most striking discontinuity in the late

Cenozoic glacial sequence of the central Brooks Range (fig. 7). This boundary separates older glacial deposits—with smooth slopes, broad crests, mature drainage patterns, sparse erratic boulders, and uniform tussock tundra—from a suite of younger glacial deposits with steeper and more irregular topography, stony surfaces, deranged drainage, discontinuous vegetation, and more varied erratic rock types (table 3). The younger deposits, of Itkillik age, are readily differentiated into linear moraines, irregular knob and kettle topography, and flat-surfaced outwash. Limits of Itkillik-age glaciers also are marked by (1) heads of outwash aprons and valley trains, (2) limits of recognizable ice-marginal drainage channels, (3) limits of subangular kettles, and (4) abrupt narrowing of river floodplains.

Flow patterns of Itkillik-age glaciers become progressively more complex westward across the study area (fig. 8). To the east, separate valley glaciers flowed north and south from cirques along the Continental Divide and terminated beyond both flanks of the mountains. North-flowing glaciers formed relatively simple systems 70-90 km long that were fed by numerous tributary glaciers en route to the range front. South-flowing glaciers traversed longer distances (as much as 130 km) through intricate valley systems. Some southern tributaries fed ice into main valley glaciers; other valleys either supported smaller separate glaciers, served as conduits for ice that overflowed between valley systems, or remained unglaciated and were partly backfilled by ice from the main valleys.

Transection glaciers in the central part of the study area flowed north and south from ice divides a few kilometers south of the range crest. North-flowing ice streams

Figure 7.—Outer boundary of Itkillik-age drift, Sagavanirktok valley (lat 68°51.5' N., long 149°03' W.). Note sharp contact between stony, irregular drift (left) and smooth, sod-covered surface of Sagavanirktok River drift (right).

crossed low passes at the heads of the Killik, Okokmilaga, Chandler, and Anaktuvuk valleys and terminated beyond the range front. Southbound glaciers traversed the intricate valleys of the Koyukuk drainage system, received additional nourishment from cirques near the south flank of the range, and coalesced into piedmont lobes beyond the mountains.

Glaciers in the western part of the study area flowed primarily into the west-trending Kobuk and Noatak valleys. Relatively short (30-60 km) glaciers issued from cirques in the Baird Mountains. Outlet glaciers flowed radially from an ice cap near the head of the Nigu River, and a smaller ice cap farther to the southwest discharged into the Noatak and Kobuk drainages.

Table 3.—Characteristics of drift of Itkillik age in the Itkillik valley (Data from end moraine of Sagavanirktok River age are shown for comparison)

	Sagavanirktok R. (end moraine)	Itkillik I			Itkillik II (Walker Lake)	
		Terminal moraine	Lateral moraine	Kame field	End moraine	Kame field
Morphology						
Crest width (m)	100-200	5-10	6-8	—	4-5	2
Maximum slope angle (°)	2.5-3	15	21	20	17	17.5
Irregularities per 200 m	0	7	6	17	8	8
Weathering						
Boulders per 250 m^2	1-5	197	—	58*	203	121*
Boulder protrusion (% of diameter)	5-20	25	50	50	40-60	> 50
Soil color, maximum	10YR 4/4	7.5YR 3/2	—	—	10YR 4/3	10YR 4/2
Weathering rinds (mm)	—	0.5-1.5	0.4	1.3	0.5-1.0	0.5-1.5
Clast Lithology (%)						
Kanayut Conglomerate						
conglomerate facies	78	64	56	80	40	55
sandstone facies	15	33	25	20	35	40
ferrug. sandstone facies	7	trace	0	0	0	0
Nanushuk Formation	0	2	15	0	16	5
Lisburne Group ls.	0	1	4	0	9	0
Vegetation						
Cover (%)	100	—	50	85	80	80
Composition	Cottongrass tussocks	← Dryas heath →				

* Very stony surface, but most stones are smaller than boulder size

Itkillik-age drift of the southern Brooks Range is far more diverse than drift in the northern valleys. The southern glaciers flowed farther through valley systems that contain a variety of rock types. Many glaciers terminated in lakes, forming subdued drift lobes; others terminated as rugged moraines in higher parts of mountain valleys. The southern drift sheets also support a mosaic of boreal forest, shrub tundra, and alpine heath tundra that contrasts with the widespread arctic tundra to the north. Most of the forested areas have been swept repeatedly by wildfires, further complicating patterns of vegetation and records of weathering and soil formation.

Drift of Itkillik I Age

During Itkillik I time, large glaciers extended 40 km or more north of the Brooks Range along the valleys of the Killik, Anaktuvuk, Itkillik, and Sagavanirktok Rivers; smaller glaciers occupied 25 other northern valleys (fig. 8). In the Itkillik valley (fig. 8, loc. 1), moraines of Itkillik I age typically have slightly flattened crests 5-20 m wide and flanking slopes as steep as 15-20 degrees. They generally have irregular profiles consisting of elongate stony hillocks that alternate with sod-covered swales. Higher parts of the crests support a discontinuous cover of Dryas and other heath plants typical of well-drained sites, and they are littered with boulders and shattered boulder fragments (fig. 9). Clasts derived from Kanayut Conglomerate predominate, but other rock types commonly comprise 5-20 percent of each assemblage. Many rock types have disintegrated down to ground level, but some resistant boulders protrude 25-50 cm—as much as half their diameters.

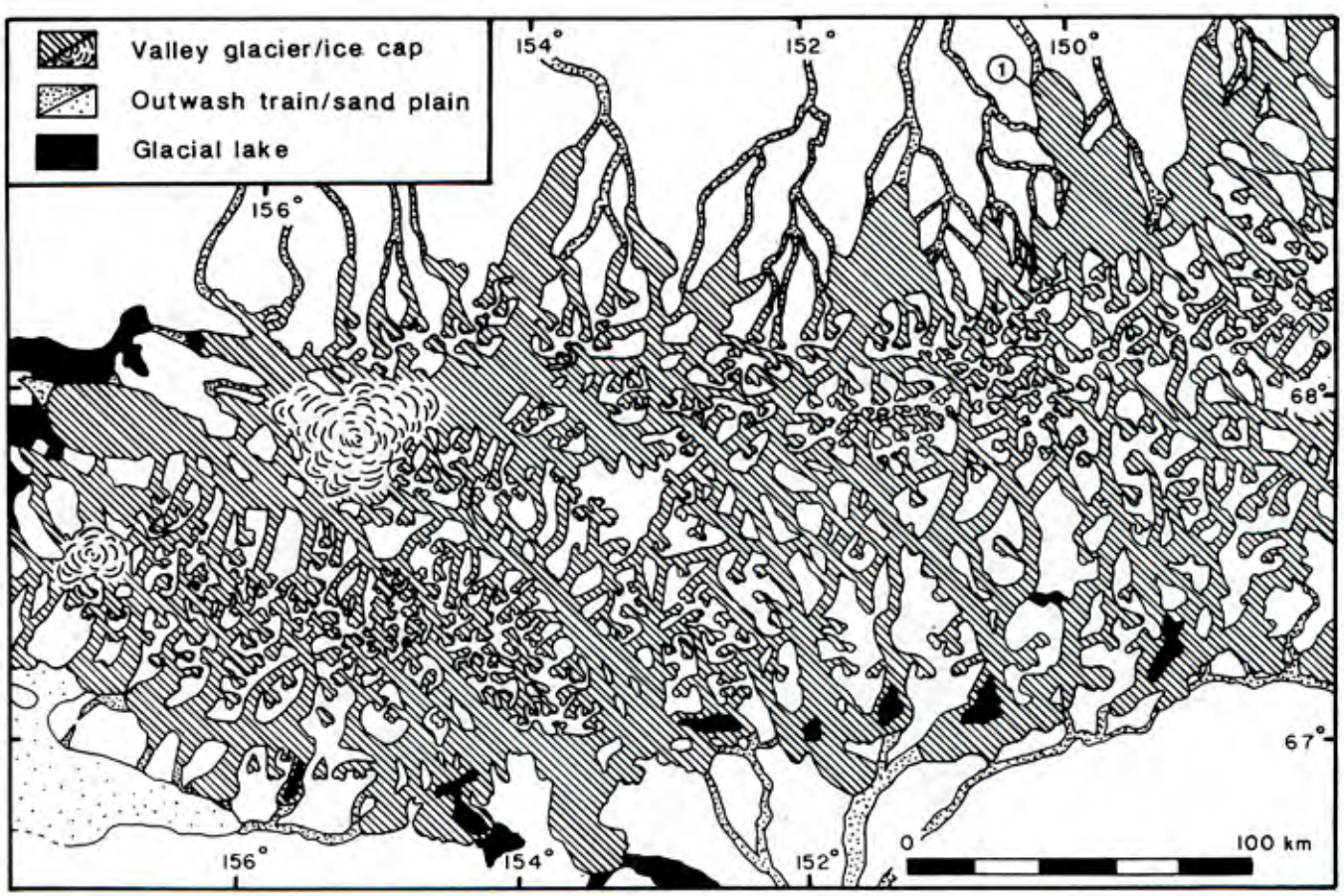


Figure 8.—Distribution of valley glaciers and ice caps of Itkillik I age, central Brooks Range. Number refers to locality discussed in text.

Lower slopes and swales are covered with silty solifluction deposits and commonly support a continuous cover of immature, cottongrass (Eriophorum) tussocks. Moraine surfaces commonly bear frost hummocks, frost boils, and secondary and tertiary polygons as described by Black (1976, p. 6-7). Kames are steeper and more irregular; they commonly contain coarse gravel with few boulders. Kettles are subrounded to subangular in outline, with grassy flanks and marshy shores; most are connected by streams. One kettle has a collapsing margin and may still be enlarging. Drainage nets are well integrated, but they are largely controlled by drift morphology. Arcuate stream courses follow depressions between recessional moraines; other streams flow from the drift margin along routes carved by meltwater drainage.

Drift of Itkillik I age in the other northern valleys is nearly identical to that in the type locality (table 4). Crestal widths generally are 10-20 m; flanking slopes are 10-20 degrees. Lateral moraines, with smooth flattened crests and polygon and hummock microrelief, are nearly continuous on gentle slopes but largely obscured by solifluction on steep slopes such as the flanks of mountain valleys. Boulder counts vary, being lowest in eastern tributaries of the Sagavanirktok River where glaciers eroded mainly limestone. Soil colors commonly are yellowish brown, varying to brown and dark brown. Boulder riffles occur where streams cross the moraines. The largest rivers have incised the end moraines to widths generally between 0.9 and 1.6 km and to depths of 30-60 m. Valley floors are markedly narrower within drift of Itkillik age than they are

Figure 9.—Drift of Itkillik I age, west flank of Itkillik valley (lat 68°40.5' N., long 150°10' W.). Note slightly flattened crests and vegetated solifluction aprons on lower flanks.

farther downvalley. Outwash terraces, which generally stand 20-25 m high near moraine fronts, decrease in height downstream and form a regional terrace system 5-10 m high. Terrace surfaces are undissected, but they generally are covered with thin (40-100 cm) eolian and solifluction deposits and commonly bear frost hummocks. Stones are visibly weathered to 1.0 or 1.2 m below the ground surface—they are cracked, exfoliated, etched, or pitted, and discolored by iron and manganese oxides.

Nested sets of recessional moraines and ice-marginal drainage channels indicate that glaciers of Itkillik I age retreated dynamically from northern valleys rather than stagnating passively within them. Five paired moraines occur in the Anaktuvuk valley, and as many as 14 recessional positions may be recorded along the heavily water-scoured east wall of Atigun valley.

Drift-mantled glacier ice persisted for long intervals in many northern valleys, and stagnant ice of Itkillik I age may still be widely present today. Angular kettles with steep and unstable sides commonly indent outwash aprons and valley trains that formed during Itkillik II time. Kettles in some valleys interrupt low alluvial terraces of Holocene age inset within the drift. Formation or enlargement of several kettles in the Killik valley appears to be continuing today. Active kettles are marked by turbid water, steep unstable flanks, and highly angular outlines. Bare gravel rather than ice-rich silt is exposed around their rims, indicating that they are not normal thermokarst features.

Moraines of Itkillik I age in the southern Brooks Range generally are continuous, with smooth, some-what flattened, hummocky crests. Drift surfaces have irregular morphology. Well-drained crests and knobs generally support open vegetation, whereas moist depressions are covered by dense Sphagnum-spruce muskeg. Crest widths and slope angles are comparable to those of northern valleys (table 4). Solifluction is widespread on the flanks of alpine moraines, but it overlaps moraine crests only where they abut valley walls or older till slopes. Subangular to subrounded

Table 4.—Selected characteristics of moraine sequences of Itkillik age in northern and southern valleys of the central Brooks Range

	Itkillik I		Itkillik II Max.		Late Itkillik II	
	Northern valleys	Southern valleys	Northern valleys	Southern valleys*	Northern valleys**	Southern valleys
Morphology						
Crest width (m)	5-20	5-15	3-5	2-3 (30-40)	5-8 (75-150)	2-5
Maximum slope angle (°)	15-20	14-20	18-23	16-22 (12-16)	13-21 (3-11)	16-17
Irregularities per 200 m	1-6	0-3	3-6	2-4 (1-2)	4 (1-2)	2-4
Weathering						
Boulders per 250 m^2	9-213	0-135	12-215	0-191 (7-857)	4-144 (2-30)	60-80
Boulder protrusion (cm)	20-50	up to 20	40-80	20-30 (5-10)	10-20 (40-50)	up to 1 m
Soil color, maximum	7.5YR 5/6	7.5YR 5/8	10YR 4/4	10YR 5/6 (7.5YR 5/6)	10YR 5/3 (10YR 4/6)	10YR 5/6

* Values for Kobuk River valley given in parentheses
** Values for Atigun and Anaktuvuk River valleys given in parentheses

kettles with vegetated and stable rims are abundant. Fewer surface boulders are exposed than in northern valleys because the rock types are less resistant and vegetation cover is more continuous. Abundance of exposed surface boulders probably is controlled more by fire history than by any other single factor. Axial stream incisions through end moraines typically are about 30 m deep, and outwash terraces about 25 m high abut the moraine fronts.

Varied rock types in the drift reflect the complex bedrock geology and glacier flow patterns in the southern valleys. Some moraines consist almost entirely of schist or granite detritus; others contain diverse assemblages of sedimentary, metamorphic, and igneous rocks. Lithologic compostion consequently has little value as a correlation tool or a relative-age measure, but it is useful in unraveling complex patterns of glacier flow. Many granite boulders are intact, and these protrude about 20 cm. Granite surfaces commonly have spalled following fires; elsewhere, they exhibit 2-3 cm depth of pitting or protrusion of quartz grains. Most schist boulders have broken down into small fragments that lie flush with the ground surface. Soil colors are varied, depending on such factors as climate, fire history, and lithology. Intense fire-reddening occurs in upper horizons of some soils, and oxide coloration is especially strong where parent material is highly ferrugineous. Soil colors in the Chandalar valley range from brown to dark yellowish brown (10YR 5/6 to 4/6); more intense brown and yellowish-brown colors (7.5YR 5/8 and 10YR 5/8) occur on some moraines in the Koyukuk and Kobuk valleys.

Cirques that have remained inactive since Itkillik I time are strongly modified by postglacial processes. Headwalls and flanking slopes are almost entirely covered by talus aprons, which have reduced the slope angles to 20-30 degrees. The taluses generally are stable; blocks are lichen-covered, and sod blankets nearly half of their surfaces.

Drift of Itkillik II Age

During Itkillik II time, large glacier tongues extended about 25 km north of the Brooks Range along the Killik, Anaktuvuk, and Itkillik Rivers (fig. 10). Smaller glaciers in the Atigun, Sagavanirktok, and other valleys terminated within 5 km of the range front. Glacier limits in northern valleys generally are marked by sharp lateral moraines, by heads of conspicuously channeled outwash aprons, and by abrupt narrowing of stream incisions within the Itkillik drift complex. End moraines in southern valleys commonly are located at the range front and enclose elongate lakes or lacustrine plains.

Drift of Itkillik II age in the Itkillik valley (fig. 10, loc. 1) forms massive ice-stagnation deposits that lack clear recessional features. The deposits are slightly more irregular, steeper sided, stonier, less vegetated, and lithologically more varied than drift of Itkillik I age (fig. 11 and table 3). Lateral moraines are less segmented by erosion; they commonly are preserved on steep as well as gentle slopes. Abandoned meltwater drainage channels along moraine margins are occupied by discontinuous ponds and short stream segments. Both lateral and terminal moraines retain minor depositional features such as cross-cutting meltwater channels, multiple crests, and small ridges or benches along their flanks. Their surfaces bear first-generation ice-wedge polygons with sharp, simple margins. Vegetation is Dryas heath, and dwarf willows and dwarf birches are present in the deepest swales. Surface boulders commonly protrude to half or more of their diameters and to heights of 60-80 cm. Boulders of Kanayut Conglomerate exhibit weathering rinds but little surface etching; boulders of other lithologies are disintegrating into smaller blocks, spalls, and slabs. Kettles have subangular outlines, and many retain extreme irregularities such as peninsulas and islands. Their shores are partly vegetated, bare gravel being widely exposed. Flanking slopes are close to angles of repose, and some are still actively slumping. Surface drainage is poorly integrated, and many kettles are isolated from streams. Several underfit streams occupy amphitheater-headed valleys that were cut by meltwater during glacier downwastage. Solifluction occurs locally on lower slopes of kettles, and narrow solifluction sheets are beginning to encroach on the edges of outwash aprons and trains. Upper slopes and

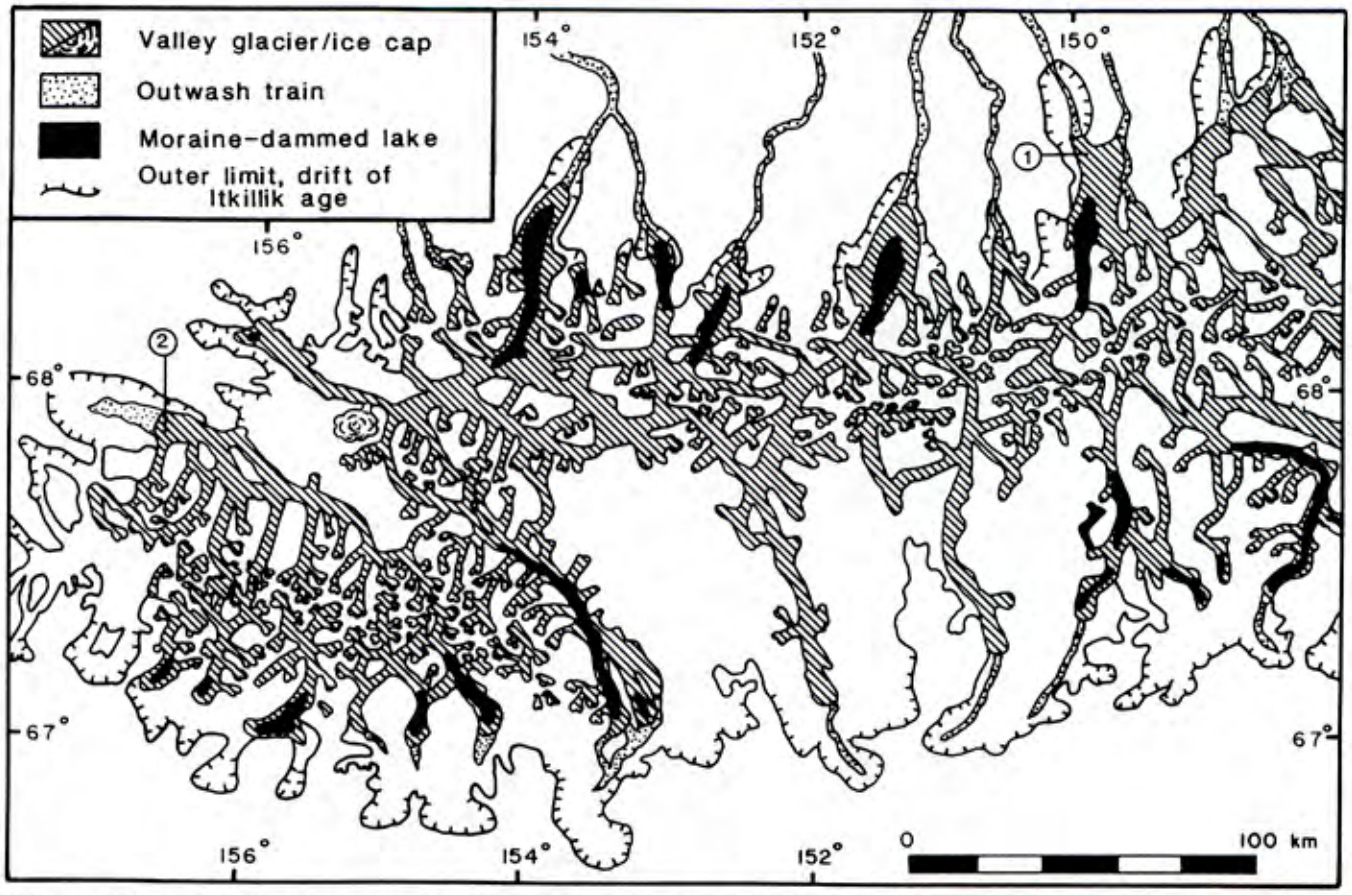


Figure 10.—Distribution of glaciers and moraine-dammed lakes of Itkillik II age, central Brooks Range. Outermost drift limits of Itkillik I age are shown for comparison. Numbers refer to localities discussed in text.

most outwash surfaces lack colluvial cover, however, and many drainage swales still retain their original gravel floors.

End moraine crests in other northern valleys typically are narrow (3-5 m), with maximum flanking slopes ranging from 18 to 23 degrees (table 4). The larger rivers have incised end moraines to widths of 600-900 m and to depths of 40-60 m; they cross the moraines through steep bouldery rapids. Outwash aprons stand 20-40 m high at moraine fronts and are as much as 5 km wide; valley trains maintain heights of 10-20 m for tens of kilometers downvalley. The channeled outwash surfaces generally have only a thin (about 0.3 m) cover of frost-mixed gravel and silt. Kettles are deep, steep-sided, and angular to sub-angular, with bare gravel exposed around much of their perimeters. Every major valley contains some kettles that still are active, as demonstrated by bare, unstable flanks, open tension cracks, turbid water, or active flows or slumps along their banks. Their very steep (up to 35.5 degrees) lower slopes lack basal debris aprons and could only be preserved by continued removal of mass below water level. Several kettles intersect low alluvial terraces and clearly remained active into at least late Holocene time.

Bulky end moraines and associated ice-stagnation deposits nearly block the centers of most northern valleys. Recessional ridges generally are absent, indicating that glaciers of Itkillik II age must have wasted in place rather than retreating upvalley.

Drift of Itkillik II age in the southern valleys of the central Brooks Range consists largely of ice-stagnation deposits. Moraines in the Chandalar and Koyukuk valleys

generally have crestal widths of 2-3 m, although widths to 5 m are common. Maximum slope angles generally are 16-22 degrees, and boulders protrude 20-30 cm on most moraines. Moraines in much of the Kobuk valley are dominantly sandy and much more subdued than those farther east; they commonly have hummocky depositional surfaces with relief of 2-4 m. Crest widths are 30-40 m, flanking slopes are 12-16 degrees, boulders generally protrude 5-10 cm. The Kobuk valley moraines either formed in proglacial lakes or consist dominantly of recycled basin-filling sand.

Soil hues in the southern valleys are typically 10YR. Yellowish-brown colors (10YR 5/4 to 5/6) predominate in the Chandalar and Koyukuk valleys. Soil colors are more varied in the Kobuk valley, and they commonly are more intensely developed (to 7.5YR hues). Loess thickness on the moraines varies, but 25 cm is typical. Most moraines lack solifluction cover or patterned ground. Axial streams cut through moraines in narrow boulder-choked gorges, and outwash forms conspicuous channeled aprons close to moraine fronts. The appearance of kettles varies with their location. Most kettles in forested regions are stable and have vegetated rims; those in mountain valleys are more irregular, with steeper shores in which some gravel is exposed. Kettles are typically dry where enclosing drift has good internal drainage.

Many boulders in southern valleys have fresh surfaces exposed by spalling following fires. Clasts of Kanayut Conglomerate, which occur primarily in the Chandalar and

Figure 11.—End moraine of Itkillik II age, Kuparuk-Sagavanirktok divide (lat 68°36' N., long 149°09' W.). Relative to drift of Itkillik I age, this deposit has steeper flanks and sharper, more irregular multiple crests. Second-order depositional relief is well preserved, and solifluction aprons are absent from lower flanks. (Compare with figure 9.)

Koyukuk valleys, are little altered unless thin bedded or ferrugineous. Most granite boulders retain their original surfaces and have unweathered interiors. Schist boulders are strongly etched—quartz veinlets protrude about 1 cm and foliation planes are inscribed 1-2 cm—and many are splitting into thin plates. Mafic rocks on moraine surfaces commonly are disintegrated; marbles are etched and very soft.

Moraines at higher altitudes near valley heads are similar in many respects to those of the main valleys, but rock breakdown typically is less advanced. Some schists are still intact, forming blocks up to 3 m long and 1 m high. The moraines are incised to depths of 25-50 m by axial streams that plunge through narrow gorges. The headwalls of cirques that supported glaciers of Itkillik II age are steep (60-70 degrees) and only partly covered by active talus streams and aprons.

Drift of Late Itkillik II Age

A major readvance of glaciers that originated along the Continental Divide formed distinctive end moraines 15-20 km north of the range front in the Itkillik, Killik, and Anaktuvuk valleys; less extensive moraines formed in at least eight other northern valleys (fig. 12). The moraines are morphologically similar to other deposits of Itkillik II age, but are locally more subdued owing to their high sand content. Much shorter (5-25 km) glaciers extended into southern valleys from cirques along the Continental Divide and in the Arrigetch Peaks-Mt. Igikpak area. The alpine moraines formed by those glaciers contain more boulders than do older moraines of Itkillik II age, but otherwise they are comparable in morphology and in degree of weathering and soil formation (table 4).

Drift of late Itkillik II age in the Itkillik valley (fig. 12, loc. 1) is almost indistinguishable from other deposits of Itkillik II age, but it is slightly stonier and steeper sided and readily weathered rock types are slightly more abundant (table 4). The inner flank of the Itkillik valley end moraine has been overlapped by lacustrine sediment and therefore has a more subdued appearance than other parts of the moraine. The moraine dammed a lake about 33 km long and as much as 7 km wide that subsequently filled with broad fan deltas produced by tributaries along both valley walls (Hamilton, 1978b). The lake's surface was at about 670 m altitude near its north end, and remnants of its floor rise progressively southward to 740 m altitude. Glacial deposits are absent from the area covered by the lake, but they appear abruptly at its upvalley end. Gravel clasts are silt coated, and till-like deposits have anomalously low bulk density—a feature characteristic of water-laid deposits (Easterbrook, 1964). Associated lateral moraines cannot be distinguished from other drift of late Itkillik age on the basis of quantitative morphologic or weathering criteria (table 4).

Moraines of late Itkillik age in most other northern valleys evidently were formed by glaciers that readvanced into sand-filled basins confined by older drift. Weathering of the glacial deposits appears somewhat less advanced than on older moraines of Itkillik II age: readily weathered rock types are more abundant, and some are just beginning to break apart along joint or bedding planes. Rivers cross the moraines through steep, boulder-choked rapids in gorges generally 300-500 m wide and 35-40 m deep. Outwash terraces are about 20 m high at moraine fronts and decrease in height downvalley to merge with terraces of Itkillik II age. Glacier retreat caused elongate (20-60 km) lakes to form in most valleys. Few shorelines are preserved owing to active mass wastage along steep valley walls, but fan-delta deposits and broad, marshy valley floors indicate the general extent of each former lake. The upper limit of lake deposits appears to rise southward by about 100 m in most of the larger valleys, as it does in the Itkillik valley, probably due to isostatic recovery following deglaciation.

Drift around the present Anivik Lake (fig. 12, loc. 12) is that of an ice-stagnation complex at the south end of the moraine-dammed lake that formerly filled the Anaktuvuk valley. The drift appears morphologically "younger" than the subdued sandy moraine at the north end of the ancient lake, but it is almost indistinguishable in appearance from outermost drift of the Itkillik II complex farther downvalley. Similar deposits fill the Killik valley above the limits of its lacustrine plain (fig. 12, loc. 3). The distribution of drift in these two upper valleys and in the Itkillik valley

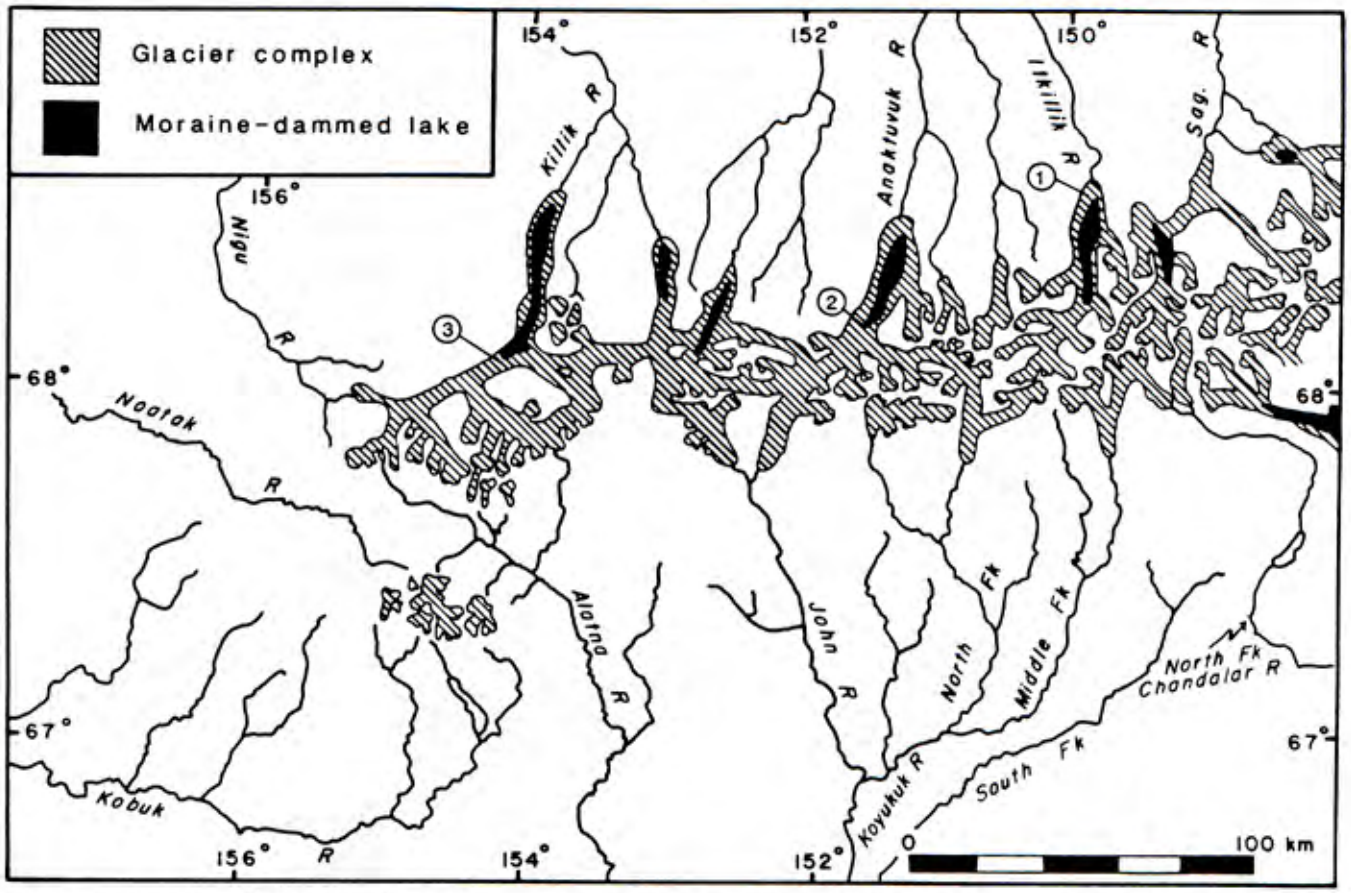


Figure 12.—Distribution of glaciers and moraine-dammed lakes of late Itkillik II age, central Brooks Range. Numbers refer to localities discussed in text.

probably reflects the positions of wasting glaciers during regional deglaciation. Their abrupt downvalley limits may represent a grounding line beyond which the glaciers floated and to which they probably retreated rapidly by calving. End moraines and outwash aprons are absent, and there is no evidence that "Anivik Lake" type deposits represent a distinct glacial advance or readvance as mapped by Detterman and others (1958) and as advocated by Porter (1964, 1966).

DRIFT OF HOLOCENE AGE

Holocene glaciation of the central Brooks Range has recently been reviewed by Ellis and others (1981), Calkin and others (1983), and Ellis and Calkin (1984); their data will not be repeated here. The late Holocene Neoglaciation (Porter and Denton, 1967) was concentrated mainly in cirques along the Continental Divide and the crest of the Baird Mountains, with smaller centers in the Arrigetch Peaks-Mt. Igikpak area and locally along the north flank of the range (fig. 13). Most moraines were formed within about 1 km of modern glacier termini.

Parts of 12 major valley systems originate in the glaciated areas; the most heavily impacted of these were the Sagavanirktok, Anaktuvuk, and Itkillik valleys (Hamilton, 1981c). Radiocarbon-dated episodes of alluviation in headward parts of these valleys show general correspondence to the lichen chronology developed by Ellis and Calkin (1984) (fig. 14), and indicate that alluviation contemporaneous with glacier expansions extended as far as 40 km down some valleys. The radiocarbon dates provide an indirect check on the lichen growth curve and lichen chronology; they strongly suggest that major

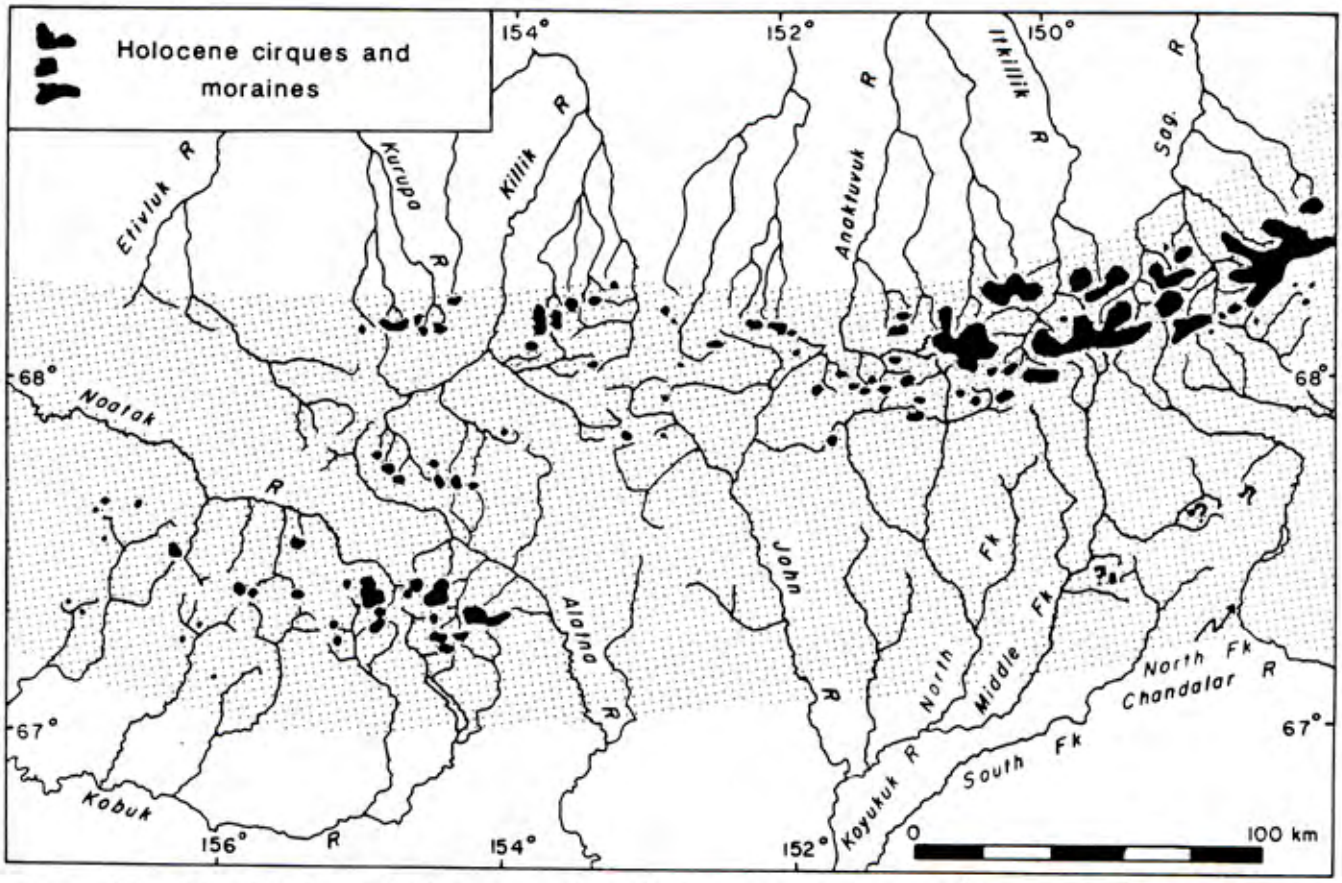


Figure 13.—Distribution of cirques active during late Holocene (Neoglacial) time, central Brooks Range. Solid pattern shows areas in which cirques occur rather than size or extent of glaciers.

expansions of Neoglacial cirque glaciers about 3,500-2,000 yr B.P. were followed by smaller or less widespread advances during the last 1,200-1,500 years.

DISCUSSION

Drift of Gunsight Mountain age consists of till remnants that lack topographic expression and of dispersed erratic cobbles, boulders, and rock fragments that represent former bodies of till and outwash. From the Kuna River east to the Gunsight Mountain area, the drift remnants occur on high erosion surfaces that extend downvalley into a high-level terrace system of the Colville River. (See Tedrow, 1977, p. 315, and references therein.) Possibly equivalent drift south of the Brooks Range extended across the Kanuti Flats and across the basins occupied by the present-day Pah and Hogatza Rivers. Drift remnants outline former large glacier tongues in the Kuna and Pah valleys that must have been fed by major valley glaciers flowing north and south across areas now occupied by headward parts of the Kobuk and Noatak Rivers. No dates are available for the Gunsight Mountain glacial interval, but deposits with similar characteristics farther south in Alaska have been assigned a late Tertiary age on the basis of degree of postglacial erosion or tectonic deformation (Carter, 1980; Kline and Bundtzen, this volume; Thorson, this volume).

Major regional downcutting did not occur between ice advances of Gunsight Mountain and Anaktuvuk River age west of the Anaktuvuk River, but large-scale pediment development and lateral erosion by streams took place during that time. Drift of Gunsight Mountain age is more intensely

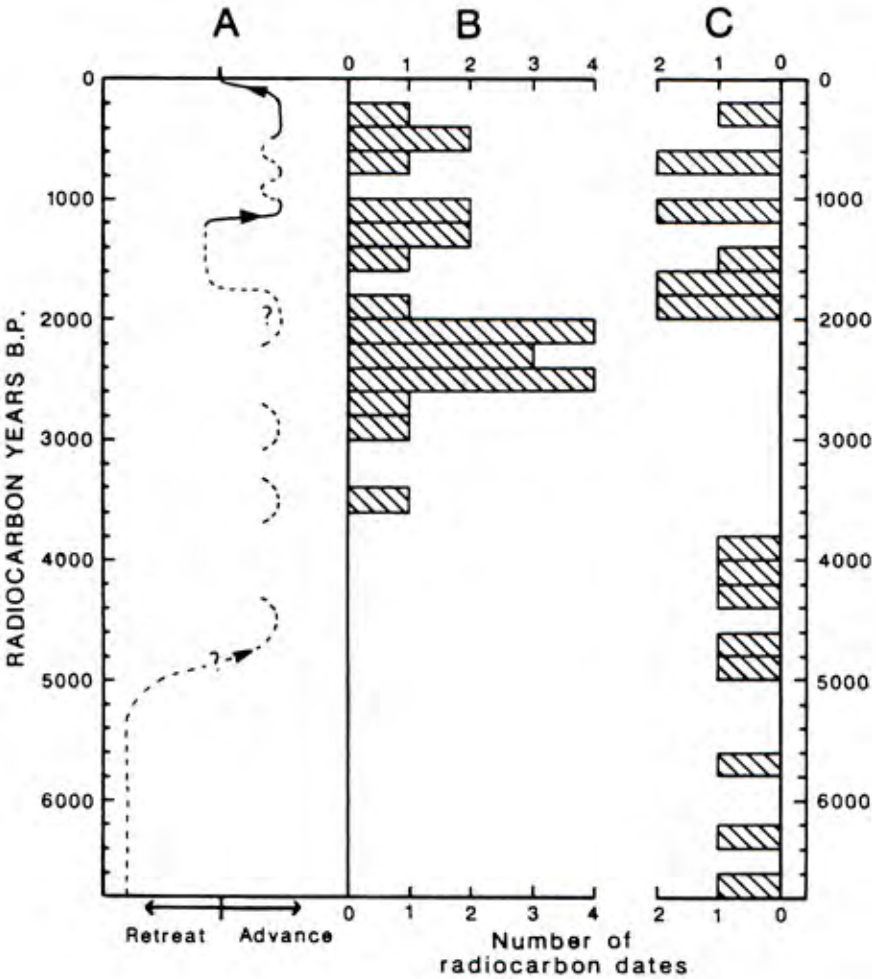


Figure 14.—Column A, Holocene glacial chronology of the central Brooks Range (Calkin and others, 1983). Radiocarbon dates on alluviation (column B) and soil formation (column C) in cirque-headed valleys (modified from Hamilton, 1981c) are shown for comparison.

eroded and topographically subdued than that of the Anaktuvuk River ice advance, and backwasting of the drift margin by as much as 15 km possibly occurred on some pediment surfaces. Abandonment of the Kurupa River-Outwash Creek area (fig. 3, loc. 13) as a major glacial valley system in the interval between the Gunsight Mountain and Anaktuvuk River advances indicates that major drainage displacements took place in this sector of the Brooks Range.

Drift of Anaktuvuk River age is distinguished from older glacial deposits on the basis of preserved moraine cores and outwash heads, hummocky drift morphology, massive lateral moraines, greater lithologic variety of surface stones, and preservation of drift and erratic cobbles and boulders in a greater variety of settings. River bluffs in the Koyukuk and Kobuk valleys expose till, glaciolacustrine sediments, and alluvium that have been deeply and intensely oxidized during a long period following deglaciation. Distribution of lacustrine deposits indicates that lobes of the Alatna valley glacier dammed the Koyukuk River at two places, forming separate lakes in the present Kanuti Flats and along the Mentanontli River. An arm of the latter lake covered deposits of the oldest known ice advance that issued from cirques on Indian Mountain (Reger, 1979). Headward expansion of the Alatna drainage system at the expense of the Kurupa River-Outwash Creek system may account for the great extent of the Alatna valley glacier at this time. Piracy by the south-flowing Alatna system could have caused concurrent reduction in the north-flowing glaciers in the area now occupied by the Kurupa River and Outwash Creek. This

relation strengthens correlations between events defined as Anaktuvuk River in age north of the Brooks Range and those inferred to be of that age in southern valleys. Extensive glacial deposits in the Etivluk River region and the Pah River Flats suggest that glaciers from the Brooks Range continued to drain north and south into these areas during Anaktuvuk River time, and that the Noatak and Kobuk Rivers had not yet extended head-ward to their present positions.

West of the study area, glaciers of Anaktuvuk River age probably filled the Kobuk and Noatak valleys and extended west to Kotzebue Sound, as described initially by Hershey (1909). These ice masses must have been nourished by moisture derived from part of the Bering Platform that may have remained submerged during times of lowered glacial-eustatic sea levels. Glacial deposits of Anaktuvuk River age are correlated with those of the Nome River glaciation of Hopkins (1953) on the Seward Peninsula because of their nearly identical physical characteristics and their comparable widespread distributions around the eastern shore of the Bering Sea (Kaufman and Hopkins, this volume). The Nome River glaciation is dated as older than 800,000 yr B.P. on Seward Peninsula (Kaufman and Hopkins, this volume), and reversely magnetized sediments in post-Anaktuvuk alluvium along the Kobuk River (fig. 6A; V. L. Pease, U.S. Geological Survey, written commun., 1985) tend to support an early Pleistocene age assignment for glacier advances of Anaktuvuk River age.

During a long interval of reduced glacial activity in the Brooks Range, drift of Anaktuvuk River age north of the Brooks Range was broadly eroded by streams flowing 45-60 m above their present levels. The regional drainage system later downcut close to present floodplain levels, forming a prominent high terrace system. Tors, pediments, and altiplanation terraces occur along the north flank of the Brooks Range within the mapped limits of Anaktuvuk River drift, but they are not present within the limits of younger glacier advances. Bluffs along the Kobuk, Koyukuk, and Chandalar valleys expose rounded, pebble- small-cobble gravel that filled a series of east-west-trending structural troughs to measured thicknesses as great as 56 m during the same long interval or reduced glaciation (fig. 6). The troughs may have continued to develop tectonically throughout this time span, thus permitting the gravel accumulation. Taken together, these features indicate that a long interval of subaerial erosion must have separated ice advances of Anaktuvuk River and Sagavanirktok River age.

Drift of Sagavanirktok River age occurs on the present-day floors of valleys and structural troughs. Distribution and extent of glaciers in northern valleys were similar to those of preceding ice advances except in the extreme western and eastern parts of the study area. Very small glaciers of Sagavanirktok River age in the Kuna and Etivluk valleys indicate that former glacier sources deep within the Brooks Range had been cut off by headward growth of the Noatak valley. East of the Anaktuvuk River, major size discrepancies between drift sheets of Anaktuvuk River and Sagavanirktok River age resulted from continued drainage integration into master valleys and possibly from continuing tectonism east of the Sagavanirktok valley. Glaciers in southern valleys tended to fill structural troughs that either had evolved or continued to develop during the preceding long interglacial. Most of the larger ice lobes in the Kobuk and Koyukuk valleys terminated in standing water. Physical blockage of the Kobuk and Koyukuk Rivers was unlikely at this time, so lake formation may have resulted from glacial-isostatic tilting similar to that reported from the Noatak basin (Hamilton and Ashley, 1983; Hamilton and Van Etten, 1984).

The Sagavanirktok River glaciation is much younger than the early Pleistocene Anaktuvuk River glaciation and is separated by a major interglacial period from succeeding glacial advances of Itkillik age. It is made up of one or more glacial advances: one drift is recognized in some valleys, but two drifts of perhaps entirely distinct glacial stages occur in several other valleys. In the absence of finite age data, the Sagavanirktok River glaciation probably should be considered a generic term for multiple ice advances of middle Pleistocene age.

In some valleys north of the Brooks Range, drift of Sagavanirktok River age was still partly ice cored when Itkillik-age

glaciers advanced. This suggests that the interglacial interval that separated advances of Sagavanirktok River and Itkillik times may have been much shorter than the older interglacials in the Brooks Range record and that permafrost persisted at least locally throughout that interval. Conversely, strongly oxidized, wood-bearing gravel beneath till of Itkillik age in the Koyukuk and Kobuk valleys indicates that, south of the Brooks Range, deep thaw and reforestation occurred between the two ice advances.

During Itkillik time, large glaciers, which occupied master valley systems 55-105 km apart, extended as far as 40 km north and 50 km south of the range. Smaller glaciers filled most intervening valleys. Glaciers in the Noatak and Alatna valleys terminated in lake-filled basins, and many glaciers in other valleys readvanced into smaller lakes dammed by their own end moraines. The Itkillik glaciation consisted of 2 or 3 major advances (Itkillik I or Itkillik IA and IB, followed by Itkillik II) and of a minor readvance during late Itkillik II time. Deposits that formed between successive major advances exhibit only immature soils and lack evidence for deep weathering or forest vegetation as extensive as that of the present. Kettle distributions indicate that stagnant glacier ice persisted between advances and that stagnant ice of Itkillik I, as well as of Itkillik II age is present today within some drift sheets. For these reasons, all Itkillik ice advances are believed to postdate the last interglacial.

The initial ice advance of Itkillik age, termed Itkillik I , was especially extensive in the western part of the region where large glacier tongues were fed from ice caps and snowfields near the heads of the Noatak and Kobuk valleys. These valleys clearly served as effective conduits for moisture derived from the west.

All ice advances of Itkillik I age are older than 55 ka, and therefore are beyond the effective range of radiocarbon dating. Two separate advances, termed Itkillik IA and IB, have been mapped in the John, Alatna, and Noatak valleys (Hamilton, 1979b, 1984a, 1984b). The inner drift sheet, with markedly sharper morphology, could be significantly younger than the outer Itkillik drift sheet. Glacier lobes in at least two of those valleys terminated in lakes, however, and the more irregular-appearing inner drift mapped as "Itkillik IB" could merely represent the grounded portion of the glacier's terminus.

If two separate advances of the Itkillik I glaciers did take place, they probably would correlate with the main phase and Sabine phase of the Buckland glaciation as mapped along the Yukon coastal plain by Rampton (1982). There, glaciomarine deposits that may correlate with the Flaxman Member of the Gubik Formation (Leffingwell, 1919, p. 142-149) are inset within the end moraine that formed during the main phase, but glaciomarine deposits are absent from ice-thrust blocks deformed by the Sabine advance (L. D. Carter, U.S. Geological Survey, oral commun., 1985). The Flaxman Member, which is dated by Carter and others (1985) at 70-80 ka, clearly was deposited after the main advance and may be roughly the same age as the Sabine phase. A similar age assessment for the older Itkillik advance in the Koyukuk valley is provided by the Old Crow tephra, which probably was deposited sometime between about 87 and 105 ka (Schweger and Matthews, 1983). Deposition of the Old Crow tephra probably occurred late in Itkillik IA time but before the Itkillik IB advance (Westgate and others, 1983). I conclude that the Itkillik IA advance occurred late in oxygen-isotope stage 5 of the marine record (Shackleton and Opdyke, 1973) and that, where a younger major advance is present, it took place somewhere between about 55 and 75 ka. This chronology also would account for the much greater extent of Itkillik I glaciers in the western part of the study area relative to that farther east. If ice advances took place while world-wide sea level remained high, then the Bering platform would have been partly submerged and could have served as an effective moisture source for glaciers and ice caps at the heads of the Noatak and Kobuk valleys.

Drift of Itkillik II age formed between about 24 and 11.5 ka (Hamilton, 1982a; Porter and others, 1983; Ashley and others, 1984); it clearly correlates with the late Wisconsin advance of the Laurentide ice sheet and with other radiocarbon-dated glacial advances elsewhere in Alaska and northwestern Canada (Hamilton, 1982a, fig. 14; Ten Brink and Waythomas, 1985). Concordant dates on river alluviation and on

periglacial activity have provided indirect evidence for the time of the Itkillik II advance in the central Brooks Range (Hamilton, 1982a). Recently obtained dates from the Noatak valley end moraine (fig. 12, loc. 9) provide direct age brackets of about 30 and 15 ka on the deposition of that feature (table 5). Significant radiocarbon dates are summarized in table 5.

Glaciers of Itkillik II age were much smaller than those of the older Itkillik advance(s), especially in the western part of the study area. World-wide sea level was about 100 m below present during maximum ice advances of the late Wisconsin. Therefore, much of the Bering Platform would have been exposed subaerially and unavailable as a moisture source. Southern parts of the Bering Sea also would have furnished little moisture to glaciers at this time owing to prolonged seasonal sea-ice cover (Sancetta and others, 1985; Sancetta and Robinson, 1983).

The Walker Lake glaciation of Fernald (1964) is a name that has been applied to ice advances of Itkillik II age in the south-central Brooks Range because a distinctive set of moraines nearly identical to those described by Fernald occurs in similar settings close to the range front (Hamilton, 1982a). In northern valleys of the Brooks Range, however, moraines of Itkillik II age form an integral part of a two- or three-fold drift complex whose outermost border is sharp but whose internal divisions are more gradational. Moreover, glaciers may not have retreated from most mountain valleys between major ice advances of Itkillik age; therefore, drift of the several advances cannot be separated in those localities and must be mapped as undifferentiated deposits of the Itkillik glaciation. For these reasons, and because of evidence cited above that the entire Itkillik complex postdates the last interglacial maximum (oxygen-isotope stage 5e), I prefer now to regard all Itkillik drift deposits as representing a single major episode of glacier advances and fluctuations in the central Brooks Range. The name Walker Lake has utility for designating a distinctive set of moraines along the south flank of the mountains, but events of Walker Lake age should not be considered a separate "glaciation".

Drift of the late Itkillik II readvance is most prominent at the north flank of the Brooks Range, where a series of moraine-dammed lakes formed during glacial recession. Radiocarbon dates demonstrate that the readvance took place about 13–11.5 ka (Hamilton, 1982a; Porter and others, 1983; table 5, this volume).

The glacial record of the central Brooks Range is incomplete owing to obliterative overlap of older drifts by more extensive younger deposits (Gibbons and others, 1984). However, the major glacial episodes—Gunsight Mountain, Anaktuvuk River, Sagavanirktok River, and Itkillik—can be considered generic terms for glacier advances of late Tertiary and of early, middle, and late Pleistocene ages, respectively. In this general sense, the deposits form a geologic record spanning approximately the last three million years—a record from which we can determine not only climatic changes but also rates and processes of valley evolution, glacial isostasy, faulting, and other aspects of crustal deformation. Relations between the successive drift sheets also provide an indirect record of permafrost history, drainage changes, and changing physical conditions in the seas that border northern Alaska.

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Table 5.—Selected radiocarbon dates on Itkillik glaciation and related events, central Brooks Range (Lab designations: AU, University of Alaska; I, Isotopes, Inc.; QL, Quaternary Research Center at University of Washington; SI, Smithsonian Institution; USGS, U.S. Geological Survey at Menlo Park, Calif.)

Radiocarbon date and lab no.	Material dated	Stratigraphic position and location	Reference(s)
		Late Itkillik II readvance	
10,580 ±150 (I-11,010)	Wood and plant fragments	Postglacial alluvium; Anaktuvuk valley	Hamilton, 1980b; Porter and others, 1983
11,750 ±150 (QL-1383)	Organic-rich lake sediments	Base of kettle filling; Alatna-Nigu divide	Brubaker and others, 1983; Hamilton and Brubaker, 1983
11,890 ±200 (AU-70)	Wood (willow)	Postglacial alluvium; Sagavanirktok valley	Hamilton, 1979d; Porter and others, 1983
12,770 ±180 (I-10,468)	Roots (willow)	Alluvium deposited during glacial readvance; Sagavanirktok valley	
12,840 ±160 (USGS-47)	Roots and wood fragments		
13,000 ±140 (USGS-695)	Wood	Interstadial alluvium within outwash; Anaktuvuk valley	Hamilton, 1980b; Porter and others, 1983
13,170 ±70 (USGS-694)	Peat and plant fragments		
		Itkillik II maximum advance	
15,030 ±200 (I-12,514)	Wood fragments	Lake beds upvalley from end moraine; Noatak valley	T. D. Hamilton, unpub. data
15,455 ±130 (SI-1876)	Wood (willow)	Alluvial episode; Koyukuk valley	Hamilton, 1982a
23,500 ±380 (SI-1875)	Sedge and grass		
22,650 ±220 (USGS-1044)	Peat	Alluvial episode; upper Kobuk valley	Hamilton, 1982a
24,300 ±250 (USGS-250)	Twigs		

Table 5.—Continued

Radiocarbon date and lab no.	Material dated	Stratigraphic position and location		Reference(s)
20,600 ±400 (I-10,573)	Peaty silt	Alluviation; South Fork, Koyukuk River		Hamilton, 1982a
14,980 ±200 (I-12,437)	Wood (willow)	II, 10 m*	Alluvial episodes, central, Kobuk River valley (Epiguruk bluff)	Ashley and others, 1984; T. D. Hamilton, unpub. field data
18,250 ±350 (I-13,093)	Wood	II, 6 m		
18,500 ±320 (I-13,209)	Wood (willow)	I, 14.5 m		
18,520 ±320 (USGS-1451)	Wood (willow)	I, 13 m		
20,870 ±190 (USGS-1655)	Wood (willow)	I, 9 m		
24,050 ±620 (I-12,471)	Wood (willow)	I, 8 m		
22,740 ±560 (I-11,238)	Wood (willow)	Periglacial fan deposit; Wild River		Hamilton, 1982a
		Preceding interstadial		
28,450 ±950 (I-10,816)	Wood	Beneath periglacial fan deposit, Middle Fork Koyukuk River		Hamilton, 1982a
30,070 ±470 (USGS-1835)	In situ rootlets	Alluvium below Itkillik II end moraine;** Noatak valley		T. D. Hamilton, unpub. data
34,840 ±950 (USGS-1836)				
33,690 ±960 (USGS-1659)	Wood and peat	Interstadial peat bed, central Kobuk valley (Epiguruk bluff)		Ashley and others, 1984; T. D. Hamilton, unpub. field data
34,900 ±320 (USGS-1444)	Wood (willow)			

* Height above present-day river
** Younger sample at 2 m depth in alluvium; older sample at 4 m depth

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