# Surficial Geologic Map
# of the
# Bettles Quadrangle, Alaska

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Pamphlet to accompany
Miscellaneous Field Studies Map MF-2409

2002

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

## INTRODUCTION

### PHYSICAL SETTING

The Bettles quadrangle is at the interface between the Brooks Range to the north and the less rugged uplands and valleys of interior Alaska to the south. Southern foothills of the Brooks Range—the Alatna Hills, the Jack White Range, and unnamed highlands farther east—cross the northern part of the map area. The central part of the Bettles quadrangle is dominated by the middle Koyukuk River basin (Meyer, 1995), which includes the Kanuti Flats (Wahrhaftig, 1965, p. 26). The basin is an elliptical lowland about 80 km long by 45 km wide with its long axis trending northeast-southwest. Farther to the south and southeast occur hills and ridges, isolated low mountains, and the headwaters of streams that flow directly south to the Yukon River.

The middle Koyukuk River basin (here termed the *Koyukuk basin)* is drained by the southwest-flowing Koyukuk River, which issues from the basin through a narrow bedrock gorge at the west margin of the map area. Drainages entering the basin are dominated by three south-flowing rivers—the Alatna, John, and Koyukuk—that drain large glaciated valleys of the south-central Brooks Range and follow broad troughs across its southern foothills. The basin also receives drainage from the east via the Koyukuk River's South Fork and the drainage systems of Jim River, Bonanza Creek, and Fish Creek. The Kanuti River and its tributaries, which form an extensive drainage network south of the Koyukuk basin, follow a general course westward around the basin and enter the Koyukuk River at the west margin of the map.

Climatic data for Bettles Field are summarized by Cowan (1995). That community has a mean annual temperature of –5.8$^{o}$C, and it lies close to the boundary between continuous and discontinuous permafrost. According to Ferrians (1965) and Brown and others (1997), the northern part of the Bettles quadrangle and most of the Koyukuk basin are underlain by continuous permafrost, although permafrost may be absent beneath some sections of the Koyukuk River and lower courses of its principal tributaries. Uplands south and east of the Koyukuk basin may be underlain by discontinuous permafrost (Ferrians, 1965), with some south-facing slopes permafrost-free. Depth to permafrost generally is 30-50 cm in peat-covered lowlands, and it may be as much as 100-150 cm at well-drained upland sites (Cowan, 1995; Rieger and others, 1979, p. 94-95, 98, 138).

### HISTORY OF GEOLOGIC MAPPING

Bedrock geology of the Bettles quadrangle was mapped by Patton and Miller (1973, 1970), and is discussed in more recent regional syntheses by Dover (1994) and Patton and others (1994). Some morainal form lines and glacial limits were compiled from aerial photographs in 1958 by J.R. Williams (written commun., 1985). My field studies of Quaternary geology began in the Alatna River valley and adjoining parts of the Koyukuk basin during 1962-66 (Hamilton, 1969) and were completed during 1983-87 (Hamilton, 1989). Construction of the Trans-Alaska Pipeline, which traverses the eastern part of the Bettles quadrangle from north to south, provided the impetus for surficial geologic mapping along the proposed pipeline route by Kachadoorian (1971), Hamilton (1979a, b), and Kreig and Reger (1982), and also for studies of permafrost and related engineering problems (Brown and Berg, 1980). Several geologic guidebooks to the Dalton Highway, which parallels the pipeline, have been published (Brown and Kreig, 1983; Mull and Adams, 1989), and the highway has provided access for other studies such as origin of cryoplanation terraces on Caribou Mountain (Reger and Péwé, 1976).

## THE GLACIAL SEQUENCE

The late Cenozoic geologic record of the Bettles quadrangle is dominated by thick and extensive glacial and proglacial deposits that fill the Koyukuk basin (Hamilton, 1989). The older deposits are largely obscured beneath as much as 15-20 m of eolian and lacustrine silt and organic-rich muskeg and thaw-lake sediments but are locally exposed in river bluffs that commonly stand 40-50 m high within the basin and around its periphery. During major glacial advances, large ice tongues that were generated in the Brooks Range converged in the Koyukuk basin from three major valley systems: the southeast-trending Alatna, the south-trending John, and the southwest-trending Koyukuk. Smaller glaciers flowed south through the Alatna Hills into the drainage of Henshaw Creek; farther east, they extended southwest into the South Fork of the Koyukuk River, the valley of Jim River, and the headwaters of Prospect and Bonanza Creeks. Very limited local glaciation of undetermined age was generated in unnamed highlands in the southwest corner of the map area.

The Koyukuk basin glacial sequence consists of five advances that are named (from oldest to youngest) the Gunsight Mountain, Anaktuvuk River, Sagavanirktok River (main and late phases), and the Itkillik glaciations (Hamilton, 1989) from type localities along the north flank of the Brooks Range. Although correlations with the well-established northern Brooks Range glacial sequence (Detterman and others, 1958; Porter, 1964; Hamilton, 1986, 1994) are tenuous, the names used on this map have value for distinguishing each major glacial advance and glacial-lake stage and for placing these events in a relative-age sequence. However, absolute age assignments should be considered tentative.

The Gunsight Mountain advance is the oldest glacial advance recorded in the Koyukuk basin, and its drift marks the outermost known limits of glacial deposition in the Bettles quadrangle. The drift has been highly eroded and in many places is obscured by as much as 30-40 m of eolian and lacustrine silt. It is best exposed on high hilltops and ridge crests, where highly weathered granitic boulders and boulder fragments are evident. These drift remnants outline a broad glacial lobe, probably formed by coalescence of the Alatna, John, and Koyukuk ice streams, that filled the Koyukuk basin and extended into uplands around its southern rim. This lobe probably blocked the Kanuti River system, forcing it into an ice-marginal course westward around the basin.

The subsequent Anaktuvuk River advance is marked by more continuous arcuate end moraines with broad crests that extend largely beneath eolian and lacustrine silt across the floor of the Koyukuk basin. Two separate glacial lobes flowed southeast down the Alatna valley and southwest down the Koyukuk-John valley system; they joined in the center of the Koyukuk basin near the present-day mouth of Henshaw Creek. Nearly level surfaces around and above the moraines indicate that lakes at two distinct levels filled the basin during and after the Anaktuvuk River ice advance. Deposits of the older glacial lake, which probably formed during Anaktuvuk River glaciation, are present at altitudes up to about 250 m (800 ft contour on map's topographic base) across the basin and extended southward at the same altitude up the Kilolitna River system to near the south margin of the map. Closer to the Brooks Range, along the upper course of the South Fork of the Koyukuk River, probably contemporaneous lake deposits occur to modern altitudes perhaps as high as 335 m (1,100 ft on topographic base). These deposits may have been elevated by glacial-isostatic uplift after retreat of the glaciers of Anaktuvuk River age.

Better preserved remnants of a younger proglacial lake with an upper limit at about 200 m (650 ft on topographic base) occur widely across the Koyukuk basin and extended farther south at about the same altitude along the Kanuti drainage system. The lake is traceable at altitudes of 214-245 m (700-800 ft on topographic base) up the Alatna and Koyukuk Rivers and the Koyukuk's South Fork, where it overlaps subdued and commonly fragmentary drift assigned to the Sagavanirktok River glacial advance. The absence of well defined end moraines at these localities provides supporting evidence that the glaciers of Sagavanirktok River age probably terminated as floating ice tongues in an extensive proglacial lake. A younger advance, assigned to a late phase of the Sagavanirktok River glaciation (map unit $\mathbf{sd_2}$), is present as moraine remnants that were nearly overridden by moraines of the outermost Itkilllik-age advance west of the John River near its mouth.

The Itkillik advance had multiple phases and subphases within the south–central Brooks Range (Hamilton and Porter, 1975; Hamilton, 1979a, 1981, 1986), but only its outermost end moraines and associated drift extended south into the Bettles quadrangle. An end moraine of Itkillik Phase I age forms prominent river bluffs that stand about 50 m high near Bettles Field, which itself is situated on an extensive outwash valley train of the same age.

## OTHER QUATERNARY EVENTS

Alluvial terraces along the Koyukuk River and its tributaries can be grouped into three general levels. The oldest and highest terraces are 40-50 m high, increasing to 75 m along Henshaw Creek. These terraces merge upvalley with outwash aprons and terraces assigned to the Anaktuvuk River glaciation. Terraces at an intermediate level are generally 20-30 m high, increasing to 35 m along Henshaw Creek. They are traceable upvalley into outwash of Sagavanirktok River age and downvalley into deltaic and lacustrine deposits of corresponding age. The lowest Pleistocene terraces are 8-14 m high in upper valleys, decreasing in height to 4-6 m down the Koyukuk River. They are probably of Itkillik age.

Faults that cut Quaternary sediments along the south flank of the Alatna Hills may be reactivated strands of the Kobuk fault zone (Brogan and others, 1975; Avé Lallemant and others, 1998). Additional faults were mapped farther south. The northeast-trending fault near Sithylemenkat Lake in the south-central part of the map area was named the Kanuti fault by L.A Cluff (Brogan and others, 1975). Faulting also may have played a role in the controversial origin of Sithylemenkat Lake. On the basis of satellite imagery, Cannon (1977, 1978) claimed a meteorite impact origin for that lake, but field evidence appears to contradict that assertion (Patton and Miller, 1978). Patton and Miller favored a glacial origin for Sithylemenkat Lake, but my Quaternary geologic mapping uncovered no evidence for Brooks Range glaciation extending this far south in the Bettles quadrangle.

Pollen analysis of a sediment core from Sithylemenkat Lake indicates that the stable bedrock basin occupied by the lake has existed for more than 14,000 $^{14}C$ years (Anderson and others, 1990). Pollen data show a late glacial and Holocene succession of herbaceous tundra giving way to shrub tundra and then to boreal forest that is typical for north-central Alaska. However, the youngest pollen zone, which begins about 3,800 $^{14}C$ yr B.P., reflects the spread of extensive muskeg vegetation across the Kanuti Flats (Anderson and others, 1990).

## CONCLUDING REMARKS

This map and a companion map of the Hughes quadrangle (Hamilton, 2002) complete a series of ten surficial geologic maps of the central Brooks Range and its foothills. The Bettles quadrangle extends farther south of the Brooks Range than the areas mapped previously in this series (for example, Hamilton, 1979a, 1981), and its surficial geology is much more complex and more obscure. Diverse individual upland areas and depositional basins are present south of the Brooks Range and each has its own distinctive Quaternary geologic history. Very old unconsolidated deposits cover a large part of the map area. They have been extensively eroded in some places and commonly are obscured beneath thick cover of silt and muskeg. Most of the map area also is heavily forested, obscuring surficial geologic deposits and causing access to be poor. In addition, sediments accumulating in the Koyukuk basin tend to form “stacked” units (for example, glacial drift overlapped by glaciolacustrine deposits and capped by thick windblown silt). Stacked units have been designated where significant subsurface deposits are evident in bluff exposures or can be inferred from physiography, erratic boulders, or other indirect evidence. They are designated by slashes (for example, **si/al**), which indicate that deposits of the first unit overlie known or inferred deposits of the second unit.

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## DESCRIPTION OF MAP UNITS

[Map units shown in parentheses, such as **(s)**, indicate thin and generally discontinuous deposits over near-surface bedrock. These units are described below only where additional explanation is necessary. Map units shown with slashes, such as **si/al**, indicate deposits of the first unit over known or inferred deposits of the second unit. These units are described below only where additional explanation is necessary.]

### FAN DEPOSITS

**f** **Fan deposits (Holocene to Pleistocene)**—Range from poorly sorted, weakly stratified, subangular, silty sandy coarse gravel at mouths of mountain valleys to gravelly sand and silt within Koyukuk basin

**$f_i$** **Inactive fan deposits (Pleistocene)—**As described in unit **f**. Generally completely vegetated

**$f_{sa}$** **Sandy fan deposits (Holocene to Pleistocene)—**Predominantly sand- to granule-sized sediments. Common in Olsons Lake basin (east-central map area), where they consist mainly of weathering products (grus) derived from granitic bedrock

**fd** **Fan-delta deposits (Holocene and Pleistocene)—**Alluvial-fan deposits, as described in unit **f**, that grade downslope into deltaic and lacustrine facies (well sorted and generally well stratified silt and sand, commonly with some fine gravel). Mapped only near north margin of map area and along south side of Koyukuk River near mouth of Jim River

### ALLUVIUM

**al** **Alluvium, undivided (Holocene)—**Varies from moderately sorted, stratified, coarse gravel in northern part of map area to well sorted sandy fine gravel and gravelly sand along Koyukuk River and its lower tributaries. Commonly contains beds and lenses of sand and silt. Along smaller streams, unit includes fan, flood-plain, and low terrace deposits that are too small to be designated separately

**$al_s$** **Fine-grained alluvium (Holocene)**—Generally well sorted silt, sandy silt, and organic silt. Mapped along some slow-moving streams within thick silty deposits south of Koyukuk River

**$al_{sa}$** **Sandy alluvium (Holocene)—**Moderately sorted to well sorted, fine to medium sand, commonly with thin interbeds of sandy peat or organic silty fine sand. Mapped along slow-moving reaches of Kanuti River and in Olsons Lake basin

**$al_2$** **Modern alluvium (late Holocene)—**Gravel and sandy gravel, as described in unit **al**; generally unvegetated and subject to annual flooding. Differentiated only along principal streams

**$al_1$** **Low alluvial terrace deposits (Holocene)—**Gravel and sandy gravel, as described in unit **al**; mantled with 0.3-1 m of silt, sand, turf, and peat, and generally vegetated. Forms terraces generally no more than 3-4 m above modern stream levels. Differentiated only along principal streams

**gr** **Gravel deposits, other (Pleistocene)—**Designates isolated mounds of coarse gravel north of Hulgothen Bluffs (near center of map area) that were eroded along crest of end moraine by wave action in former lake. Applied elsewhere in map area to gravelly erosion remnants whose exact composition and origin are obscure

**Tgr** **Quartzose gravel (Tertiary?)—**Rounded quartz pebbles and very small cobbles up to 6-7 cm maximum length in matrix of nearly pure quartz sand. Forms extensive surfaces at heights up to 140 m above modern drainages. Quartz abundance 95%-100% on primary depositional surfaces; as low as 50% where deposits were later reworked by streams during downcutting to modern levels. Recognized only in Ray River drainage (Yukon River system) at southeast corner of map area

## TERRACE DEPOSITS

**$td_u$** **Terrace deposit (Pleistocene)**—Alluvial gravel, as described in unit **al**, that may overlie or grade into finer-grained fluvial, deltaic, or lacustrine sediments. Commonly mantled with silty or organic deposits. Designated where unassignable to any of the four regional terrace systems discussed below

**$tg_u$** **Terrace gravel (Pleistocene)**—Alluvial gravel and sandy gravel, generally capped by flood-plain deposits of silt, sand, or peat. May have thin to thick (15 m or more) mantle of eolian silt, muskeg, and thaw-lake deposits, depending on age of surface. Designated where unassignable to any of the four regional terrace systems discussed below

### A. Terrace deposits along Henshaw Creek

**$td_{A3}$** **Terrace deposit, low-level (late Pleistocene)—**Primarily alluvial gravel and sandy gravel, with finer sediments locally present. Forms terraces 8-14 m high that decrease in height to 4-5 m near mouth of Henshaw Creek

**$td_{A2}$** **Terrace deposit, intermediate-level (middle Pleistocene)—**Gravel and finer sediments, as described in unit **$td_u$**. Forms terraces up to 35 m high that decrease in height downvalley and can be traced upstream into outwash trains of Sagavanirktok River age

**$td_{A1}$** **Terrace deposit, high-level (early Pleistocene)**—Gravel and finer grained sediments, as described in unit **$td_u$**. Forms terraces up to 75 m high that decrease in height downvalley and can be traced upstream into outwash trains of Anaktuvuk River age

### B. Terrace deposits along Jim River

**$tg_{B3}$** **Terrace gravel, low-level (late Pleistocene)**—Gravel and sandy gravel, as described in unit **$tg_u$**. Forms terrace remnant 2-3 m above modern river

**$tg_{B2}$** **Terrace gravel, intermediate-level (late middle Pleistocene)—**Gravel and sandy gravel, as described in unit **$tg_u$**. Forms terraces 25-30 m high that are inset within drift and outwash of Sagavanirktok River age

**$tg_{B1}$** **Terrace gravel, high-level (early middle Pleistocene)**—Gravel and sandy gravel. Forms terraces about 50 m high. Dissected by streams and ephemeral channels. Bears moderately thick (5 m or more) silt cover. Probable distal facies of outwash trains of Sagavanirktok River age

### C. Terrace deposits along Koyukuk River (upvalley from Allakaket) and South Fork of Koyukuk River

**$td_{C3}$** **Terrace deposit, low-level (late Pleistocene)**—Terrace deposits 5-10 m high in South Fork, declining in height downvalley to 4-6 m near Allakaket. Sandy gravel generally dominant, with finer-grained deposits locally present. Locally bears thick and continuous muskeg cover (designated **$m/td_3$**). Probably grades upvalley into outwash trains associated with outermost Itkillik-age moraines

**$td_{C2}$** **Terrace deposit, intermediate-level (late middle Pleistocene)**—Terrace deposits about 20-25 m high that are inset within glacial-lake deposits of Sagavanirktok River age. Locally bear thick and continuous muskeg cover (designated **$m/td_2$**)

$td_{C1}$ **Terrace deposit, high-level (middle Pleistocene)—**Terrace deposits about 40 m high along South Fork that are graded to glaciolacustrine deposits of Sagavanirktok River age. Outwash gravel becomes more prominent up South fork; deltaic and lacustrine sand and silt probably dominate downvalley deposits

D. Terrace deposits along Koyukuk River below Allakaket (near west margin of map area)

$tg_{D3}$ **Terrace gravel, low-level (late Pleistocene)**—Alluvial gravel and sandy gravel, forming terraces 8-10 m above modern river level

$td_{D3}$ **Terrace deposit, low-level (late Pleistocene)**—Alluvial gravel and finer grained sediments, forming terraces of heights comparable to **$tg_{D3}$** near mouth of Kanuti River

$tg_{D1}$ **Terrace gravel, high-level (early Pleistocene)—**Alluvial gravel and sandy gravel. Forms terrace remnants 50-60 m above river level that are incised into outermost recognizable drift (unit **Tgmd**) of Koyukuk basin

$tg_{DH}$ **Terrace gravel, highest-level (early Pleistocene?)—**Gravel with oxidized sandy matrix that forms terrace remnants at heights up to 120 m above Koyukuk River. Bears eolian silt (loess) cover as thick as 30 m

## COLLUVIAL DEPOSITS

**c** **Colluvium, undivided (Holocene to Pleistocene)—**Mixed solifluction deposits and talus rubble, as described individually (see **s** and **tr**), in sheets and aprons more than about 1-2 m thick. Common on upper slopes below surface or near-surface bedrock. Subunit **(c)** is most common across uplands southeast of Kanuti River, where loess cover is thin

**s** **Solifluction deposits (Holocene to Pleistocene)**—Very poorly sorted, nonstratified to weakly stratified, stony silt and organic silt in sheets and aprons more than 1-2 m thick. Widespread except for extreme northern parts of map area that lie within limits of glacial advances of Itkillik Phase I age. Unit **s/gr** designates thick solifluction deposits that overlie gravel of uncertain age; unit **s/io** designates thick solifluction deposits that overlie outwash of Itkillik age

**fl** **Flow deposits (Holocene)—**Very poorly sorted, rock rubble in abundant silty matrix. Forms lobes subject to slow and probably discontinuous downslope movement. Mapped only along north flank of Alatna River valley and in southwest corner of map area

**ls** **Landslide deposits (Holocene to late Pleistocene)**—Unsorted, unstratified, coarse to fine, angular rubble, commonly with matrix of finer debris, forming lobes below detachment scars and slide tracks on steep rock walls. Subject to rapid downslope movement and long periods of relative stability. Mapped only along south flank of Jack White Range near north margin of map area

$rg_a$ **Rock-glacier deposits, active (late Holocene)—**Very poorly sorted, nonstratified, coarse angular rock debris with matrix of silt and fine rubble; contains abundant interstitial ice. Upper surfaces generally unvegetated, unweathered to moderately weathered, and with sparse lichen cover. Frontal slopes barren, steep, and highly unstable, meeting upper surfaces at abrupt angle. Form lobate deposits at base of talus cones along valley walls. Recognized only near northeast corner of map area

$rg_i$ **Rock-glacier deposits, inactive (Holocene to Pleistocene)—**Coarse angular rock debris, as described above, but lacking interstitial ice. Upper surfaces and frontal slopes weathered, covered by lichens, and commonly partly covered by sod and vegetation. Frontal slopes grade into upper surfaces without abrupt angles. Recognized only in northern parts of map area

$tr_i$ **Talus rubble, inactive (Pleistocene)**—Angular, unsorted, nonstratified rock debris forming cones and aprons along lower walls of mountain valleys. Also forms thinner and generally discontinuous sheets over many uplands mapped as “bedrock”. Generally weathered and lichen covered, and with partial sod cover. Recognized only in northern parts of map area

## SAND, SILT AND ORGANIC (MUSKEG) DEPOSITS

**ds** **Dune sand (Holocene and late Pleistocene)—**Moderately well sorted, fine to medium sand, commonly interbedded. May exhibit slip faces, parabolic ridges, and other surface features characteristic of eolian origin. Younger and older subunits **$ds_2$ (late Holocene)** and **$ds_1$ (Holocene and late Pleistocene)** are differentiated where part of a stabilized deposit has been reactivated by wind

**sa** **Sand deposits (Holocene to late Tertiary)—**Commonly stratified, silty fine sand to coarse sand with granules and sparse small pebbles. Most common where sandy weathering products (grus) fill basin within granitic highlands in east-central part of map area. Unit **sa+gr** (age uncertain) designates deposits of very sandy gravel along Kanuti Chalatna Creek

**si** **Ice-rich silt deposits (Holocene to Pleistocene)—**Silt deposits, commonly with ice-wedge polygons, more than 1-2 m thick in swales and other depressions. Also common along valley centers, where silt may overlie alluvium. Composite unit **si/al** designates thick deposits of ice-rich silt that overlie alluvium on floors of river valleys

**us** **Upland silt deposits (Pleistocene)**—Poorly to moderately sorted, generally unstratified, silt, organic silt, and slightly stony silt on uplands of low to moderate relief. Represents loess mixed by frost action with local organic matter and weathering products. Commonly grades downslope into solifluction deposits

**m** **Muskeg (Holocene to Pleistocene)—**Peat, organic silt, and organic detritus more than 1-2 m thick in areas of restricted drainage with water table at or close to surface

## LACUSTRINE AND GLACIOLACUSTRINE DEPOSITS

**b** **Beach deposits (middle Pleistocene)**—Moderately well sorted, coarse to medium sand, commonly mixed or interbedded with platy fine gravel. Locally forms ridges of poorly sorted, gravelly sand to sandy coarse gravel where mixed by ice shove. Mapped only near Sithylemenkat Lake (south-central map area) and at Birch Hill Lake (east of Bettles)

**l** **Lacustrine deposits (Holocene to Pleistocene)—**Well stratified clayey silt, silt, and sand, grading into sand and gravelly sand near former shorelines and sandy fine gravel near former river mouths. Shown only by stippled pattern where buried beneath younger deposits. Include beach deposits too small to be designated separately. Designated primarily within Alatna Hills. Unit **l/B** (lacustrine deposits above bedrock) is mapped only north of Bonanza Creek above mouth of Fish Creek

$\mathbf{l_2}$ **Lacustrine deposits, low-level (late to middle Pleistocene)**—Stratified silt and related deposits, as described in unit **l**, that underlie near-horizontal, poorly drained surfaces around Lake Todatonten (southwest corner of map area). Capped by muskeg with abundant lakes

$\mathbf{l_1}$ **Lacustrine deposits, high-level (early Pleistocene)—**Stratified silt and related deposits, as described in unit **l**, at altitudes up to about 210 m (680-690 ft on topographic base) around Lake Todatonten. Separated from unit $\mathbf{l_2}$ by bluffs up to about 30 m high. Lakes and marshes abundant. Segments close to valley sides commonly are obscured by thick aprons of solifluction debris. Probably distal equivalent of glaciolacustrine unit **agl** (shown near mouth of Kanuti Canyon)

**gl** **Glacial-lake deposits, undivided (Pleistocene)—**Stratified silty deposits, as described in unit **sgl** (below) of uncertain age. Generally of Sagavanirktok River or Anaktuvuk River age where mapped in Koyukuk basin

**sgl** **Glacial-lake deposits of Sagavanirktok River age (middle Pleistocene)**—Stratified silt, clayey silt, and silty fine sand, commonly with dispersed dropstones. Grades into gravelly sand to sandy fine gravel near former stream mouths. Generally muskeg covered. Widespread across Koyukuk basin up to altitudes of about 200-215 m (650-700 ft on topographic base). Overprint designates glacial-lake deposits that have been partly eroded by downcutting rivers and streams (for example, near mouth of Kanuti River). These eroded deposits may be capped by thin layers and lenses of alluvium. Unit **sgl/ad** designates glacial-lake deposits of Sagavanirktok River age that overlie drift of Anaktuvuk River phase. Upper surface of the drift commonly was beveled by wave erosion during Sagavanirktok River time, leaving lag concentrations of bouldery gravel. Unit **sgl/Tgmd** designates glacial-lake deposits of Sagavanirktok River age that overlie wave-eroded drift assigned to Gunsight Mountain glaciation

**agl** **Glacial-lake deposits of Anaktuvuk River age (early Pleistocene)—**Stratified deposits of stony silt, as described in unit **sgl**. Forms stream-incised (to 20 m or more depth) erosion remnants to altitudes of 230-250 m (750-800 ft on topographic base) in Koyukuk basin. Generally bears thick cover of ice-rich silt that contains numerous thaw ponds. Unit **agl/ad** designates lacustrine deposits that overlap end moraines of Anaktuvuk River age in Koyukuk basin

## OTHER GLACIAL DEPOSITS

**d** **Drift, undivided—**Glacial deposits, as described in unit $\mathbf{id_1}$ of uncertain age. Includes small, highly subdued, drift remnants that may have formed by very old cirque glaciation in uplands near southwest corner of map area

Itkillik glaciation (late Pleistocene)

**$id_1$** **Drift of Itkillik Phase I**—Unsorted to poorly sorted, generally nonstratified, compact till ranging in composition from muddy sandy gravel to gravelly muddy sand, with local stratified ice-contact deposits consisting of moderately sorted sand and sandy gravel. Contains faceted and striated stones up to large boulder size. Mapped only in Alatna Hills and near mouth of John River

**$id_{1A}$** **Drift of Itkillik Phase IA**—Outermost outermost moraine of Itkillik complex near mouth of John River

**ik** **Kame and kame-terrace deposits**—Unusually thick and extensive water-washed sand and gravel deposits within drift sheet of Itkillik Phase I age. Mapped only at one locality near northwest corner of map area

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

**$io_1$** **Outwash of Itkillik Phase I**—Sandy gravel, as described in unit **io**, associated with end moraines or drift of Itkillik Phase I age. Occurs only in northern part of map area

**$io_{1A}$** **Outwash of Itkillik Phase IA**—Outwash train that originates at moraine of Itkillik IA age near mouth of John River

Sagavanirktok River glaciation (middle Pleistocene)

**sd** **Drift of Sagavanirktok River age**—Poorly sorted nonstratified till, probably ranging in composition from silty, sandy, bouldery gravel to clayey, stony silt, with local deposits of moderately well sorted and well stratified gravel. Generally covered by thick (more than 5 m) blanket of silt, stony silt, and organic silt (loess, solifluction, and muskeg deposits, but crests of some ridges and knolls expose weathered gravel and erratic boulders of resistant lithologies

**$sd_2$** **Drift of Sagavanirktok River late phase**—Till and stratified ice-contact deposits, as described in unit **sd**. Mapped only west of John River near its mouth, where it occurs just beyond outermost end moraines of Itkillik age

**so** **Outwash of Sagavanirktok River age**—Sandy gravel, as described in unit **io**. Associated with end moraines of Sagavanirktok River age in northern 1/3 of map area

Anaktuvuk River glaciation (early Pleistocene)

**ad** **Drift of Anaktuvuk River age**—Poorly sorted nonstratified till, probably ranging in composition from silty, sandy, bouldery gravel to clayey stony silt. Contains local deposits of moderately well sorted coarse gravel. Where thin and commonly discontinuous above bedrock, shown as **(ad)**, drift commonly contains silt, rock rubble, and organic detritus admixed by frost action

**ak** **Kame terrace(?)**—Linear gravel-rich deposit with relatively level surface within drift of Anaktuvuk River age. Mapped only at $66^{o}45'$N, $151^{o}10'$W

**ao** **Outwash of Anaktuvuk River age**—Gravel and sandy gravel, forming aprons and valley trains in front of moraines of Anaktuvuk River age. Most abundant in Henshaw Creek drainage basin; locally present along Prospect Creek and near Bonanza-Fish Creek confluence

Gunsight Mountain glaciation (Tertiary?)

**Tgmd** **Drift of Gunsight Mountain age**—Till and stratified ice-contact deposits, as described in unit **ad**. Forms isolated erosion remnants that mark apparent southern limit of late Cenozoic glaciation in Koyukuk basin. Generally mapable only where recent forest fires have exposed gravelly soils with erratic cobbles and boulders on hilltops and ridge crests