# Geologic Reconnaissance of the Yukon Flats District Alaska

GEOLOGICAL SURVEY BULLETIN 1111-H

# Geologic Reconnaissance of the Yukon Flats District Alaska

By JOHN R. WILLIAMS

CONTRIBUTIONS TO GENERAL GEOLOGY

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*A reconnaissance of the bedrock and surficial geology of the Yukon Flats Cenozoic basin*

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# CONTRIBUTIONS TO GENERAL GEOLOGY

# GEOLOGIC RECONNAISSANCE OF THE YUKON FLATS DISTRICT, ALASKA

By John R. Williams


## ABSTRACT

The Yukon Flats district occupies approximately 13,700 square miles in northeastern Alaska. It is bordered by the Yukon-Tanana Plateau, the southern foothills of the Brooks Range, the Hodzana Highland, and the Porcupine Plateau. It includes the Yukon Flats, which is the alluvial lowland that lies along the Yukon River and its tributaries, and the dissected to rolling marginal upland, which separates the lowland from the bordering highlands.

The district corresponds in areal extent to the Yukon Flats Cenozoic basin and is surrounded by highlands formed largely of Paleozoic rocks. These rocks extend from the highlands to the marginal escarpment, which separates the marginal upland from the Yukon Flats. Shale, coal, and lignite of early Tertiary age crop out in a few places within the marginal upland. The early Tertiary and older rocks of the marginal upland are covered by high-level alluvium of late Tertiary or early Quaternary age. These deposits were laid down (a) by the Yukon River and its large tributaries and they are now preserved as high terraces, and (b) by the numerous small streams that drain the highlands and they now are coalescent piedmont alluvial fans. The high-level alluvium is mantled in most places by eolian sand and loess of Quaternary age.

The Yukon Flats is underlain by more than 290 feet of quiet-water (lacustrine?) silt and silty sand of late Tertiary to early Quaternary age which probably extends below present sea level. The quiet-water deposits are overlain by alluvial deposits, which form the alluvial fans, terraces, and flood plains of the Yukon Flats. These deposits range in age from early or middle Pleistocene to Recent. The alluvial fans of the Chandalar, Christian, and Sheenjek Rivers were formed, in part, of glacial outwash deposited during Pleistocene glaciation of the southern Brooks Range. The oldest glaciation, the deposits of which are preserved only in isolated patches, probably extended into the Yukon Flats through the Chandalar, Marten, and possibly the Sheenjek Valleys in early Pleistocene time. Three younger glaciations ranging in age from early or middle Pleistocene to late Pleistocene are represented by glacial drift and moraines in the valleys of the Chandalar River and the East Fork of the Chandalar River. The oldest of these moraines in the Chandalar River valley lies 6 miles from the northern edge of the Yukon Flats. The alluvium of the Yukon Flats locally is mantled by eolian sand and loess of Pleistocene and Recent age. The deposits of the flood plain and low terraces and of the small alluvial fans that border the marginal escarpment are of Recent age.

# INTRODUCTION

## GENERAL GEOGRAPHY

The Yukon Flats district (fig. 26) is located in northeastern Alaska between 65°45′ and 67°30′ north latitude and 142°30′ and 150°00′ west

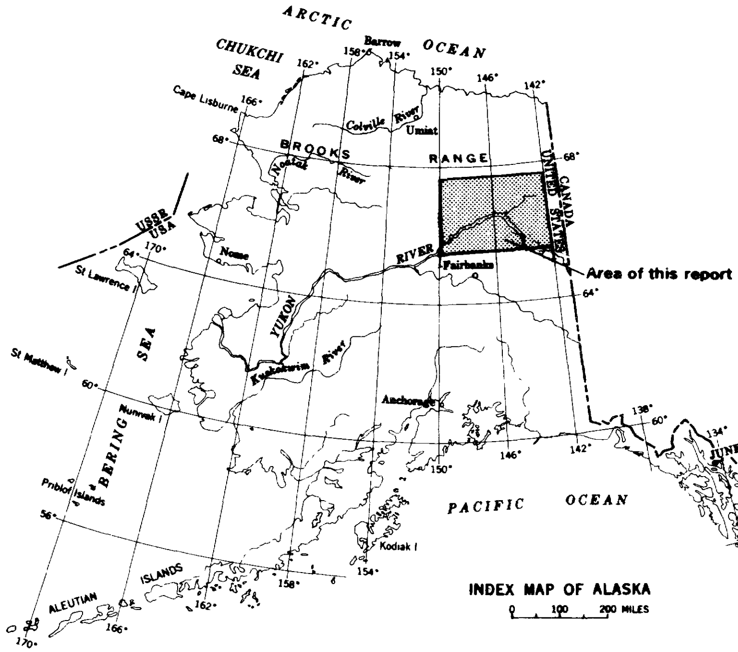


FIGURE 26.—Index map of Alaska showing area of this report.

longitude. The southern boundary is 75 miles north of Fairbanks. The principal settlements are Fort Yukon, Beaver, Stevens, Circle, Venetie, and Chalkyitsik (fig. 27). The district is accessible by air, by the Steese Highway from Fairbanks to Circle, and by the Yukon River. The boundaries of the district are approximately those defined by Smith (1939) and correspond to those of the Yukon Flats Cenozoic basin (Payne, 1955; Miller, Payne, and Gryc, 1959) (fig. 27). The district is bounded on the south by the Yukon-Tanana Plateau (Mertie, 1937, p. 23), on the east by the Porcupine Plateau (Bostock, 1948, map 922A), on the north by the southern foothills of the Brooks Range (the piedmont province of Mertie, 1929, p. 99), and on the northwest and west by the Hodzana Highland (Maddren, 1913).

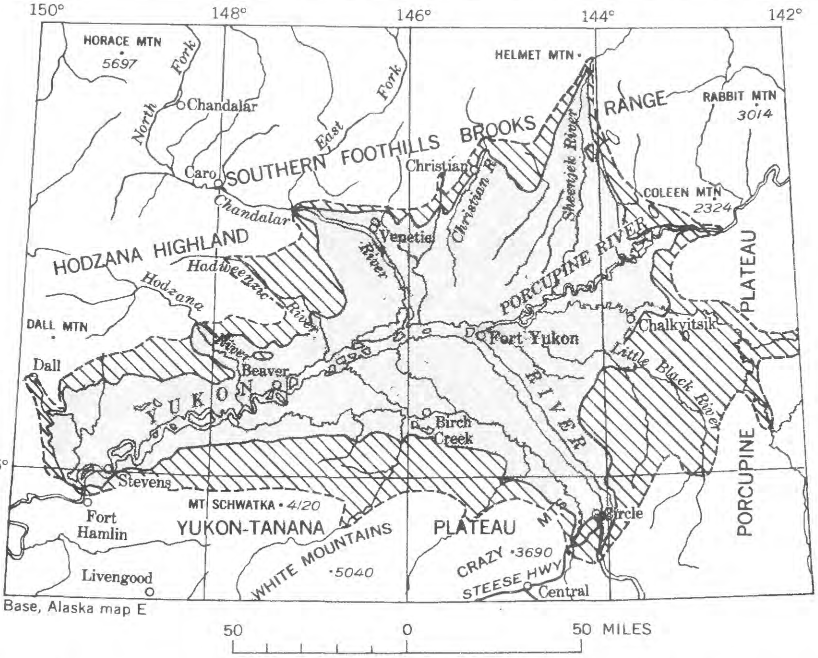


**Figure 27.—Physiographic subdivisions of Yukon Flats district—marginal upland (diagonal lines) and Yukon Flats (stippled). Boundary of district shown by dashed line.**

The district includes (a) the Yukon Flats (fig. 28), a broad lowland of approximately 9,000 square miles which lies along the Yukon River and the lower courses of its tributaries between Circle and Fort Hamlin, and (b) the marginal upland of about 4,700 square miles which separates the Flats from the surrounding highlands. The Yukon Flats has local relief of less than 150 feet; its landforms include river flood plains, terraces, alluvial fans, and sand dunes. The marginal upland consists of rolling to dissected high ground separated from the Yukon Flats by a 100- to 500-foot high marginal escarpment. The escarpment is a steep, river-eroded bluff in which bedrock is locally exposed. The marginal upland merges with the surrounding highlands and mountains along a boundary that approximately coincides with the 1,000-foot contour line. The Yukon River drains the entire district. Upstream from Fort Hamlin, where the Yukon leaves the Yukon Flats and enters the deep Fort Hamlin-Rampart Canyon (fig. 29), the river has a drainage area of about 200,000 square miles, of which 75,000 square miles are drained by the tributaries that join the Yukon in the Yukon Flats.


FIGURE 28.—Confluence of Yukon and Porcupine Rivers at Fort Yukon, central Yukon Flats district. Oblique aerial photograph west from altitude 4,000 feet taken by Army Air Corps, Ladd Field, Photo section, January 30, 1945.

FIGURE 29.—Entrance to Fort Hamlin-Rampart Canyon at lower end of Yukon Flats.

The climate of the Yukon Flats district is cold continental and is characterized by extremes of temperature between summer and winter, long cold winters, warm summers, low precipitation, and relatively little cloudiness. Records of significant duration are available only at Fort Yukon (summarized through 1952 by U.S. Weather Bureau, 1922 and 1952) within the district, but records of less duration are available for Circle Hot Springs, Central, and Rampart in the surrounding highlands. Mean total precipitation at Fort Yukon is 6½ to 7 inches and mean total snowfall is 45 inches. The highland stations have 50 percent more total precipitation but approximately the same total snowfall, suggesting that summer rainfall is greater in the surrounding highlands than in the central part of the Yukon Flats. Mean annual temperature of 20.7° F at Fort Yukon is equal to that at Central, but 2° less than that at Rampart and Circle Hot Springs. The range between the maximum temperature of 100° F and minimum of −71° F at Fort Yukon is slightly more extreme than the range in temperatures shown by the shorter period of record for the highland stations. Prevailing winds at Fort Yukon are generally north to northeast, except for a brief period in summer and during passage of winter storms when the winds are generally west to southwest. Wind velocity is generally low, except during the storms. Surface winds are locally channeled by topography in the marginal upland.

The entire district lies below regional timberline and is covered with interior spruce and birch forest (Sigafoos, 1958, p. 171). The forest is best developed along the Yukon River and its tributaries, but away from the rivers the forest is interspersed with muskeg and marsh and has been extensively modified by forest fires. The fires that have repeatedly swept the district have produced a dense scrub or brush cover consisting of willow, birch, aspen, and alder. Only a relatively small proportion of the district away from the rivers supports stands of mature white spruce. The last major fires burned more than a million acres, or about 12 percent of the area of the district, in the summer of 1950.

## PREVIOUS INVESTIGATIONS

The earliest geologic investigations were exploratory surveys of the Yukon River by Dall (1870), Raymond (1900), Schwatka (1885), and Spurr (1898); of the Yukon and Porcupine Rivers by McConnell (1891), Ogilvie (1898), and Russell (1890); of the Chandalar River by Schrader (1900); and of the Dall River by Mendenhall (1902). The work of Collier (1903), Prindle (1906, 1908, 1913), Prindle and Hess (1906), and Stone (1906) in the Yukon-Tanana Plateau began the program of geologic reconnaissance mapping by the Geological

Survey. The work was extended to the north and west of the Yukon Flats by Maddren (1913) and Eakin (1913, 1916). Later, Mertie (1925, 1929, 1930a, 1930b, 1930c, 1932, 1937, 1938, and 1942) continued the reconnaissance mapping in the southern Brooks Range, in the upper Yukon Valley, and in the Yukon-Tanana Plateau. Cairnes (1914) working on the International Boundary Survey, mapped a part of the Porcupine Plateau. Studies by Emmons (1898), Maddren (1905, 1912), Brooks (1906), Brooks and Kindle (1908), Kindle (1908), Yanert (1917), Fitzgerald (1944), and White (1952) have contributed to knowledge of the district and the surrounding highlands. These works have established the geologic framework for much of the region, but large geologically unknown areas still exist in the Hodzana Highland, in the Marten Creek-Christian River area, between the Sheenjek and Coleen Rivers, and in much of the Porcupine Plateau along the lower Black and Little Black Rivers. Geologic knowledge has been summarized on maps of Alaska by Smith (1939) and by Dutro and Payne (1957).

## PRESENT INVESTIGATION

The geologic reconnaissance on which this report is based was made by the Geological Survey as part of its program of terrain and permafrost investigations in Alaska. The work was supported, in part, by funds made available to the Geological Survey by Engineer Intelligence Division, Office of the Chief of Engineers, U.S. Army. Fieldwork consisted of river and foot traverses in the area near Beaver in 1948 and along the Yukon and its tributaries in 1949. Because only 10 percent of the area was examined on the ground, the geologic map (pl. 42) for the most part, was prepared by interpreting and sketching the geology from aerial photographs. U.S. Army Air Corps 1941–47 trimetrogon aerial photographs were used for most of the compilation, except for part of the Beaver and Chandalar 1:250,000 quadrangles where gaps in the trimetrogon coverage were filled by twin-low oblique (1955) photographs and Navy vertical (1948) photographs. Alaska Reconnaissance Topographic Series (1951) Beaver, Black River, Chandalar, Charley River, Christian, Circle, Coleen, Fort Yukon, and Livengood 1:250,000-scale quadrangles were used as a base for compilation of the geology. Ground water and permafrost (Williams, 1955a), river freezing and break up (Williams, 1955b), river migration (Williams, 1952), and interaction of vegetation and soil-frost phenomena (Benninghoff, 1952) have been described in reports based on this study.

## ACKNOWLEDGMENTS

Reconnaissance flights in 1948 were provided by Tenth Rescue Squadron, U.S. Air Force, then based at Ladd Air Force Base. The hospitality and courtesy of the residents of the district did much to make the fieldwork more enjoyable, and the information they volunteered has been of great value in compiling the geologic map. Alaska District, Corps of Engineers, U.S. Army, made available the log of the deep well drilled at Fort Yukon August 7 to October 1, 1954, and many other records. Professor George S. Tulloch, Department of Biology, Brooklyn College, Brooklyn, N.Y., kindly furnished a sample from a depth of 393 feet in the Fort Yukon well. The writer appreciates the services of W. D. Carter (1948–49) and R. L. Staples (1948), geologic field assistants, J. P. Emerson (1948), cook, and N. C. Ross (1949), camphand. W. S. Benninghoff, botanist, was in charge of the investigation in 1948, and joined the writer in the field for 10 days in 1949. In 1959 Benninghoff made pollen and spore examinations of the Hodzana River coal and the sample collected by Professor Tulloch from the Fort Yukon well.

## DESCRIPTIVE GEOLOGY

Most of the highlands and marginal uplands that border the Yukon Flats are formed of Paleozoic sedimentary, volcanic, intrusive igneous, and metamorphic rocks; a few areas in the bordering highlands are formed of metamorphic rocks of possible Precambrian age, Mesozoic sedimentary and intrusive igneous rocks, and Cenozoic volcanic and sedimentary rocks (geology summarized by Dutro and Payne, 1957). The rocks of the highlands and marginal uplands are mapped in this report (pl. 42) chiefly along the northern edge of the Yukon Flats district where gaps in earlier geologic reconnaissance mapping exist. The pre-Cenozoic rocks in the mapped area are grouped into (a) lower Paleozoic (pre-Devonian?) and possibly Precambrian metamorphic rocks and associated igneous rocks and (b) Carboniferous sedimentary and volcanic rocks and associated intrusive igneous rocks. Bedrock bluffs of unknown lithology and age are shown on the map as "bedrock" along the Black (Fitzgerald, 1944) and Hodzana Rivers where mapped from aerial photographs and on Jefferson Creek where reported by local residents.

The Yukon Flats Cenozoic basin can be divided into a shallow part and a deep part along a boundary which in many places follows the marginal escarpment. The shallow part of the Cenozoic basin, occupying much of the marginal upland, has many exposures of pre-Cenozoic rocks in gullies and in the marginal escarpment. These rocks are covered in a few areas by lower Tertiary sedimentary rocks and Tertiary volcanic rocks, but in most of the marginal upland high-level alluvial deposits of late Tertiary or early Quaternary age cover the pre-Cenozoic rocks. The high-level alluvium is covered by

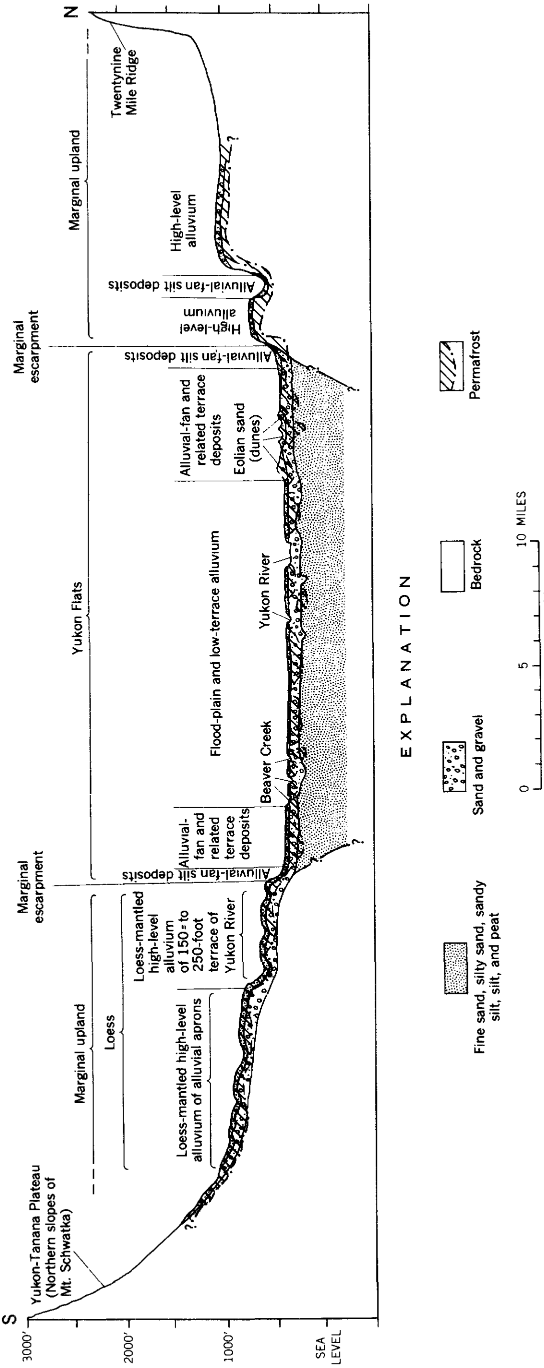


**Figure 30.—Diagrammatic section through Yukon Flats district between Twentynine Mile Ridge and Yukon-Tanana Plateau showing geologic units and permafrost.**

Pleistocene, and possibly locally Recent, loess and eolian sand. The deep part of the Cenozoic basin coincides approximately with the Yukon Flats (fig. 30). The deposits of the alluvial fans, terraces, flood plains, and dunes that form the surface of the Yukon Flats extend at Fort Yukon to a depth of 148 feet. They are underlain by more than 290 feet of quiet-water silt and silty sand of late Tertiary to early Quaternary age. The base of the silt and silty sand was not reached in a well that penetrated to 20 feet above sea level; and their base probably lies below sea level at an unknown depth.

The Yukon Flats district lies within the discontinuous zone of permafrost (Black, 1950; Williams, 1955a). Within this zone permafrost in the unconsolidated deposits and bedrock is broken by unfrozen zones, which occur chiefly beneath water bodies and well-drained sites, and by layers of unfrozen deposits within the permafrost (fig. 30). Permafrost is recorded to a depth of 320 feet at Fort Yukon, but may be much deeper. Perennially frozen fine-grained sediments in poorly drained localities contain abundant small veins and stringers and large masses of ground ice, commonly arranged in polygonal networks. Ground ice is common in alluvial-fan silt, in loess, locally in the silt deposits of the alluvial fans and related terraces, and locally in flood-plain and low-terrace silt. Ice masses are especially common where these deposits are covered with peat in muskeg.

## BEDROCK

### LOWER PALEOZOIC (PRE-DEVONIAN?) AND POSSIBLY PRECAMBRIAN METAMORPHIC ROCKS AND ASSOCIATED INTRUSIVE IGNEOUS ROCKS

A belt of metamorphic rocks lies north of the Yukon Flats from the upper Dall River eastward to the hills between East Fork Chandalar River and Marten Creek. The metamorphic rocks described by Mendenhall (1902, p. 33) along the Dall River northwest of the Yukon Flats consist largely of well-laminated fine even-grained quartz-biotite schist. Other variations recognized are coarser, less well laminated, and less quartzose than the biotite schist; calcareous and graphitic variations are also recognized. Beds of gray coarsely crystalline limestone occur within the schist. The schist is cut by granite porphyry, gneissoid porphyritic rocks of granitic and dioritic composition, and silicic dikes (Mendenhall, 1902, p. 33). The metamorphic rocks along the Chandalar River are divided by Mertie (1925, p. 224–228) into two groups: (a) quartzite and quartzite schist cut by massive white quartz veins along the Chandalar-Hadweenzic divide, and (b) younger mica schist, quartz-mica schist, and phyllite, which occurs north of the Chandalar River and along the East Fork.

Quartzite and quartzite schist are associated with the younger rocks along the East Fork near its confluence with the Chandalar. Continuity of the metamorphic belt between the upper Dall and Chandalar-Hadweenzic Divide is suggested by the composition of the gravel that forms the bed of the Hodzana and Hadweenzic Rivers. The gravel of the Hodzana River is about 60 percent vein quartz and schist, 15 percent schist, and 5 percent quartzite, all apparently derived from metamorphic rocks in the unmapped headwater region; the gravel contains 10 percent granitic rocks and 10 percent volcanic and other rocks. The gravel of the Hadweenzic River, also rich in schist and vein quartz, suggests that the belt of metamorphic rocks extends eastward into the headwaters of the Hadweenzic River and probably connects with the rocks described by Mertie (1925) on the Hadweenzic-Chandalar Divide. Metamorphic rocks probably form Twentynine Mile Ridge, for the alluvium on the southeast slope contains pebbles and cobbles of crenulated chlorite schist, quartzite, and vein quartz, to the exclusion of all other types except a small amount of chert.

The age of the metamorphic rocks is early Paleozoic (pre-Devonian?) or possibly Precambrian. Mertie (1925, p. 224–228, pl. VI) assigned an early Paleozoic age to the younger schist and phyllite north of the Chandalar River and tentatively correlated the older quartzite schist and quartzite of the Chandalar-Hadweenzic Divide with the Birch Creek schist of Precambrian age. Mendenhall (1902) regarded the schist of the upper Dall River as of early Paleozoic age. Dutro and Payne (1957) mapped these rocks as undifferentiated Paleozoic metamorphic rocks, mostly pre-Devonian, but possibly including some rocks of Precambrian age and some of Mesozoic age.

### CARBONIFEROUS SEDIMENTARY AND VOLCANIC ROCKS AND ASSOCIATED INTRUSIVE IGNEOUS ROCKS

The known bedrock of the marginal upland and parts of the surrounding highlands is a complex group of sedimentary, volcanic, and associated intrusive igneous rocks. These rocks include the Rampart group (Spurr, 1898; Mertie, 1937) and the approximately equivalent Circle volcanics (Spurr, 1898; Emmons, 1898; Mertie, 1930b, 1937) of Mississippian age. Also grouped with these rocks in the absence of detailed mapping are the chert-slate formation of Late Devonian or Early Mississippian age (Mertie, 1929) or of Devonian age (Dutro and Payne, 1957) exposed in the Sheenjek Valley at Outlook Point and upstream, and previously unmapped rocks of similar lithology which crop out in the marginal escarpment north of the Yukon River north and west of Beaver. These rocks are grouped together because of similar lithology and, with further work, may be subdivided or reassigned into more precise map units. Not shown as a map unit, but exposed in vertical section along Rock Slough of the Porcupine River are quartzite, chert, phyllite, and breccia which may be a downstream extension of the Mississippian rocks shown at the lower end of the Lower Ramparts just upstream (Kindle, 1908; Dutro and Payne, 1957).

Shale, chert, quartzite, and minor amounts of crystalline limestone, chlorite schist or phyllite, and schistose conglomerate, are associated with basalt and tuff of greenstone habit. These rocks are intruded by dikes, sills, and small bodies of igneous rocks that range from gabbro, diorite, and diabase of greenstone habit to quartz diorite, and granite.

At the entrance to the Fort Hamlin canyon (fig. 29) rocks of the Rampart group are exposed on both sides of the Yukon River to nearly 400 feet above river level. On the west side of the river the exposures farthest upstream are of coarse-grained dioritic rocks and those downstream are of diabase, brown chert, and granitic rocks. On the east side of the river, shale is exposed in gullies at the upstream end of the bluffs; it is succeeded downstream by dioritic rocks and by medium-grained granite or quartz diorite. The chert on the west bank and the shale on the east bank strike N. 10° W., but the chert dips 30° W. and the shale dips 55° E. Bedding in the chert is truncated by the diabase. Widely scattered sulfide minerals, chiefly pyrite and chalcopyrite, occur in the diorite or gabbro and in the granitic rocks.

Fine- to coarse-textured gabbro crops out at the eastern end of the ridge 8 miles north of the mouth of the Hodzana River. The rocks are light to medium gray and on weathering are brown and dark greenish gray. The size of the interlocking mineral constituents ranges from 1 mm in the finer textured equigranular rocks to 20 mm in the plates of pyroxene of the coarse-textured rocks. In thin section the essential minerals are plagioclase of the composition of labradorite, hornblende, pyroxene, chlorite and biotite alteration products, magnetite, and ilmenite. The pyroxene is augite, and in some specimens hypersthene occurs with the augite. The rocks contain sphene, apatite, olivine, quartz, serpentine, and epidote as minor constituents and accessory minerals. In some specimens the opaque minerals are segregated. Sulfides scattered through the rock are chiefly pyrite.

Near the eastern end of the ridge, sedimentary rocks occur for a few hundred yards along the northward-facing bluffs. The rocks consist of brown to gray argillaceous quartzite, dark-gray chert with one-half inch thick layers locally cut by quartz stringers, and blue-gray to greenish-gray crystalline limestone. Only the limestone is exposed; the other rocks occur only as weathered fragments in the surficial deposits. No fossils were found in these rocks, and exposures were not good enough to determine their structure.

Several types of sedimentary and intrusive rocks are exposed in the marginal escarpment between the Hodzana and Hadweenzic Rivers. From west to east the outcrops examined in the field (marked by lithologic notes on the geologic map, pl. 42) consist of (a) quartzite, (b) complex gabbro, quartz diorite, pyroxene diorite, quartz gabbro, and chert, and (c) quartzite and chlorite schist.

The sedimentary rocks consist of gray thin-bedded and locally cross-bedded fine-grained slightly feldspathic quartzite locally containing pyrite flecks and nodules which have stained the rock brown on weathered surfaces. Near the Hadweenzic River the rocks consist of quartzite, chlorite schist, and chlorite schist containing scattered pebbles and cobbles chiefly of vein quartz. Massive, greenish-gray chert seamed with quartz stringers is associated closely with the igneous rocks.

The igneous rocks, like those exposed west of the Hodzana River, range in texture from fine-grained dense rocks to rocks containing interlocking laths and plates of feldspar and pyroxene as long as 22 mm. The rocks range in composition from quartz diorite to gabbro. In thin sections zoned plagioclase feldspar in which the rims are more sodic than the centers composes 50 percent of the specimen. In the quartz diorite the feldspar is andesine; in the gabbro it is labradorite. It is commonly altered to kaolin and sericite. The rocks contain variable amounts of pyroxene, generally augite, but also hypersthene in some specimens. The pyroxenes are altered, in part, to hornblende, chlorite, and biotite. Olivine was not recognized; serpentine was noted in one specimen. Some specimens of the igneous rocks have small amounts of amphibole, chiefly green hornblende. The opaque minerals are probably magnetite, ilmenite, and pyrite. Accessory minerals are chiefly apatite, sphene, a carbonate mineral, and, in one case, graphic quartz and orthoclase. Quartz and orthoclase feldspar constitute about 25 percent of the quartz diorite. Interstitial quartz occurs as a minor constituent of the quartz gabbro and as an accessory mineral in the pyroxene diorite. The rocks weather dark brown, green, or black, but are greenish gray in fresh exposures. They have been classed as igneous rocks of greenstone habit by Mertie (1925) who described but did not map the quartz diorite in the marginal escarpment adjacent to the Beaver-Caro trail.

Outlook Point, an isolated hill in the northern part of the Yukon Flats, is the southernmost exposure along the Sheenjek River of the chert-slate formation (Mertie, 1929, p. 119), which consists of massive light-gray chert cut by diabase and gabbro dikes. The chert-slate formation extends northward up the Sheenjek River beyond the limits of the area mapped in this report.

In the Circle area, the Circle volcanics are exposed in river bluffs separating the river valleys from the marginal upland. The basaltic lava of greenstone habit, which is intruded by diabase and gabbro, is associated with a minor proportion of chert, argillite, tuff, and flow breccia in the Yukon River bluffs for 15 miles upstream from Circle (Mertie, 1930b, p. 85). Diabase is reported from Birch Creek near the present highway bridge (Spurr, 1898; Emmons, 1898) and probably is part of the Circle volcanics, although originally correlated by Spurr with the Rampart group. About 7½ miles N. 15° E. of Circle, the 200-foot marginal escarpment on the northeast bank of the Yukon River is formed of diabase and gabbro or diorite, which is probably a downstream extension of the intrusive rocks mapped with the Circle volcanics. Bedrock outcrops extend northward from this locality but were not visited in the field.

The sedimentary and volcanic rocks of the Rampart group and Circle volcanics are of Mississippian age based on fragmentary fossil evidence from the Rampart area (Mertie, 1937, p. 126–127). The rocks at Outlook Point were thought by Mertie (1929) to be either Late Devonian or preferably Early Mississippian in age, and the possibility of a Triassic age was discussed; the Outlook Point rocks were assigned a Devonian age by Dutro and Payne (1957). The intrusive rocks associated with the sedimentary and volcanic rocks may range in age from Mississippian through Mesozoic.

### EOCENE SEDIMENTARY ROCKS

Continental sedimentary rocks occur in scattered Cenozoic basins and troughs (Payne, 1955) in the highland regions that border the Yukon Flats district, and occur locally in the marginal upland bordering the Yukon Flats. The rocks are exposed in the Dall Valley where they were visited by Mendenhall (1902) and are reported by local residents to occur near the forks of the Hodzana River. Between these two locations, an extensive area of flat-lying stratified rocks in the marginal upland has been recognized from a study of aerial photographs.

The deposits along the Dall River and its tributary, Coal Creek, consist of folded soft, gray, buff, or black shale and lignitic coal and bone (Mendenhall, 1902, p. 41, 42, and pl. VIII–A).

Coal deposits have been known for a number of years on the Hodzana River at The Mud Bank, located above the forks. The coal is reportedly associated with mud, and samples of coal washed from the bank to the river bars downstream were collected by local residents and analyzed as being of subbituminous rank, but of poor coking quality (see p. 327). Other samples of coal collected by the local residents and given to the Geological Survey failed to produce any spores or pollen upon examination by W. S. Benninghoff (written communication, 1959). The presence of coal and its association with mud suggests that the coal-bearing rocks in the Hodzana Valley are lithologically similar to the coal-bearing rocks of the Dall Valley. The thickness and areal extent of the Hodzana River coal-bearing rocks are unknown.

Flat-lying stratified rocks cover about 150 square miles of the marginal upland between the Dall River and Hodzana River. These rocks have been sketched on the geologic map (pl. 42) from aerial photographs but have not been studied in the field. Their lithologic character is unknown. However, they appear to overlie the Carboniferous and older rocks discordantly and to be less deformed than the tilted Eocene rocks in the Dall Valley (Mendenhall, 1902, pl. VIII–A) and the steeply inclined rocks of the Rampart trough (Collier, 1903; Payne, 1955). These flat-lying stratified rocks are grouped with others of Eocene age to suggest that they may be part of a single rock formation that is highly deformed in the Rampart area but progressively less deformed toward the northeast. Similar flat-lying stratified rocks have not been recognized elsewhere in the marginal upland; if they are present, they are probably buried by the high-level alluvium and eolian deposits.

The Eocene age of the rocks in the Dall Valley is based on their lithologic similarity to rocks of this age elsewhere in Alaska (Mendenhall, 1902). No fossils were collected by Mendenhall from the coal of the Dall Valley. Based on the fragmentary evidence available, the writer believes that the somewhat similar coal-bearing rocks of the Hodzana Valley and the flat-lying stratified rocks between the Dall and Hodzana Rivers are also of Eocene age.

### TERTIARY BASALT

Basaltic lava flows, dikes, and sills are exposed near the confluence of the Chandalar River and the East Fork and near the mouths of Middle Fork and West Fork (Schrader, 1900; Mertie, 1925, 1929, 1930a). The rocks near the East Fork are relatively unaltered fine-grained and porphyritic basalt, which contains 5 to 40 percent glass (Mertie 1930a). The rocks appear to be basaltic flows (Schrader, 1900) of Tertiary age (Mertie, 1930a, p. 137).

## UNCONSOLIDATED DEPOSITS

### SILT AND SILTY SAND BENEATH THE YUKON FLATS

Silt and silty sand were found in Fort Yukon water well No. 2 (see table below) from a depth of 148 feet to the bottom of the hole, 440 feet below the surface. The top of the silt and silty sand in this well lies at an approximate altitude of 310 feet, only a few feet higher than the estimated height of the bedrock threshold at the upper end of the Fort Hamlin-Rampart canyon. The base of these deposits, not reached in the Fort Yukon well which bottomed at 20 feet above present sea level, is probably below present sea level and is at least 250 feet lower than the bedrock threshold at the upper end of the canyon. The presence of at least 292 feet of these deposits suggests that they probably have a widespread distribution beneath the alluvial and eolian deposits of the Yukon Flats (fig. 30). The silt and silty sand deposits seem to be absent in the marginal upland; the only sand and silt noted in the upland forms the surface mantle which is interpreted as loess and eolian sand in this report. Permafrost is logged to a depth of 320 feet, but the well log shows that ice lenses were found between 320 and 390 feet. Professor G. S. Tulloch of Brooklyn College collected a sample of frozen silty sand from a depth of 393 feet during the drilling operations. The base of permafrost, therefore, may be deeper than that recorded in the log of the well.

*Driller's log, Fort Yukon water well No. 2*

[Drilled Aug. 7 to Oct. 1, 1954, by Alaska District, Corps of Engineers, U.S. Army, at a site about half a mile east of the village]

| Depth (feet) | Driller's log of materials | Permafrost (depth, in feet) | Writer's interpretation |
|---|---|---|---|
| 0–48 | Light-tan silty sand | 8–48 | Pleistocene and Recent dune sand. |
| 48–148 | Gray sandy gravel | 48–148 | Pleistocene alluvium of Yukon alluvial fan. |
| 148–320 | Blue silt | 148–320 | Lacustrine (?) deposits of late Tertiary or early Quaternary age. |
| 320–390 | Gray silt, poorly consolidated, few ice lenses. | | |
| 390–425 | Silty sand, 85 percent passing No. 100 sieve, 15 percent passing No. 200 sieve. | | |
| 425–440 | Silt | | |

The data obtained from Fort Yukon water well No. 2 appear to contradict the report (Mertie, 1937, p. 16) of bedrock at a depth of 237 feet at Fort Yukon. The data also show that the writer's earlier (Williams, 1955a, fig. 7 and p. 126) estimate of as much as 200 feet of sand and gravel beneath the Yukon Flats requires revision to include the fine-grained deposits in the Fort Yukon well.

The silt and silty sand, overlain by Pleistocene alluvial gravel and Pleistocene and Recent dune sand, are interpreted as lacustrine(?) deposits of late Tertiary or early Quaternary age. However, no geologic evidence is now available by which the alternate hypotheses of marine or estuarine origin can be eliminated, or by which the age can be firmly established. The sample collected by Professor Tulloch at a depth of 393 feet was examined by Harlan Bergquist of the Geological Survey and found lacking in microfossils.

William S. Benninghoff of the Department of Botany, University of Michigan, has examined the sample of silty sand from a depth of 393 feet for spores and pollen. His preliminary results (written communication, July 6, 1959) show that the material consists of about 20 percent colloidal organic material suggestive of that deposited in a deep lake. After more detailed, but still incomplete, study of the material he has furnished (written communication, Mar. 7, 1960) the following information about the tree genera:

> * * * abundant are pine, spruce, alder, birch, hemlock, and fir. Pollen of hickory has also been found in the sediment, along with pollen believed to belong to two Asiatic genera in the hickory family, *Pterocarya* and *Platycarya*. If one can discount the possibility that these pollen grains were redeposited from Tertiary sediments bordering the basin, these genera are evidence of late Tertiary age for the sample horizon.

### HIGH-LEVEL ALLUVIUM

High-level alluvium lies on bedrock in most places observed in the marginal upland. They are 100 to 500 feet above the adjacent parts of the Yukon Flats and the deeply incised major tributary valleys through the upland. The deposits are even higher at places within the marginal upland that are remote from the marginal escarpment and the tributary valleys. These deposits were formed (a) by small streams, which drained the highlands and deposited an apron of gravel as coalescent alluvial fans on the adjoining parts of the marginal upland, and (b) by the Yukon River and its tributaries, which truncated the gravel apron and deposited gravel that is now preserved as high terraces in the parts of the marginal upland closest to the marginal escarpment and tributary valleys. Quaternary eolian deposits overlie and conceal the high-level alluvium in all parts of the marginal upland except that north of the Yukon River. The alluvium has been observed by the writer at a few places and has been reported from others by local residents. Enough data are available to show that the high-level alluvium is widely distributed beneath the eolian deposits of the marginal upland, but the details of its distribution and character are still poorly known.

The alluvium consists of stratified sandy pebble-cobble and pebble-cobble-boulder gravel. Scattered lenses and beds of sand and silt occur in the gravel. Locally the particles are stained and slightly cemented by iron oxide. The gravel particles are subangular to well rounded and in almost all respects resemble the modern river deposits. Where observed, the deposits range from a few to 100 feet in thickness, but, without doubt, in many places they may be thicker than 100 feet. The known outcrops of high-level alluvium are described briefly below.

South of Birch Creek segment of the Yukon Flats the high-level alluvium of the marginal upland is reported by local residents to be dominantly gravel exposed beneath the loess mantle in the river bluffs that border the valleys of Preacher, Beaver, Jefferson, and Lost Creeks. This section of the marginal upland consists of two zones separated by an indistinct break in slope (shown on pl. 42 by hachures and arrows) which marks a difference in altitude of about 100 feet. The lower, northern zone, as much as 6 miles wide along the marginal escarpment, is 150 to 250 feet about the Yukon Flats and is interpreted as a dissected loess-covered Yukon River terrace. The higher zone to the south is much more highly dissected; it is interpreted as a loess-covered northward-sloping alluvial surface, which was probably formed as a gravel apron by the small streams draining the highland to the south. This gravel apron may have once been graded to some level of the Yukon River even higher than that represented by the 150- to 250-foot terrace.

Near Circle the high-level alluvium is exposed in river bluffs and in road cuts along the Steese Highway. The dissected loess-mantled marginal upland between the Yukon River and Birch Creek at the highest point on the highway is about 600 feet above the Yukon River. Gravel is exposed in borrow pits along the highway at mile 4.7 and mile 13.8 from Circle at heights of 230 to 360 feet above the river. Nearly 100 feet of sandy gravel (fig. 31) is exposed in the pit at mile 13.8. The gravel consists of pebbles, cobbles, and boulders of flint or chert, volcanic rocks, limestone, quartzite, gritty sandstone, and granitic rocks similar to the rocks of the upper Yukon Valley (Mertie, 1930b). The deposits are stained and lightly cemented by iron oxide, and the wood and other organic material in the silt and sand lenses is largely replaced by iron oxide. A sample of the wood from the pit 13.8 miles from Circle was burned for radiocarbon analysis by Meyer Rubin of the Geological Survey low-level radiation laboratory (oral communication); the sample yielded insufficient gas for counting and the residue formed a metallic bead, presumably of iron oxide. Loess-mantled Yukon River gravel of similar lithologic character is exposed near the top of the rocky bluffs east of the Yukon River 4 miles S. 40°

FIGURE 31.—Stratified fine gravel and sand of high-level alluvium in Steese Highway borrow pit about 1½ miles north of Birch Creek bridge. Exposures masked, in part, by slumped loess.

E. of Circle at a height of 470 feet above the river. The downstream continuation of these bluffs forms the marginal escarpment east of the Yukon River. Gravel is exposed on bedrock 200 feet above the Yukon River where the bedrock bluffs form the northeast bank of the Yukon River 7½ miles north of Circle. At higher altitudes, back from these bluffs, the marginal upland is mantled with thick eolian silt which conceals the underlying deposits.

To the north of the Circle area, in the valleys of the Black and Little Black Rivers, no information is available on the presence of gravel beneath the loess mantle of the marginal upland. Northwest of Rock Slough, Porcupine River, the marginal upland is about 150 feet above the river. It is covered by mixed silt and angular stones, a material that probably originated as residual soil weathered from bedrock or possibly as glacial till, rather than alluvium. The writer has not visited the marginal upland north of the Yukon Flats between Rock Slough and the Hadweenzic River. Within this part of the upland (Mertie, 1929, p. 119) reports that 50 feet of gravel is exposed in the 300-foot bluff west of the Sheenjek River about 10 miles upstream from Outlook Point. Two higher levels farther upstream, according to Mertie, are (a) a rock-cut terrace at 2,600 to 2,800 feet above sea level or about 1,400 feet above the valley floor, and (b) a rock-cut terrace at 3,400 feet above sea level. High rock-cut terraces 300 to 600 feet above the Chandalar River are visible on aerial photographs of the slope that separates the older part of the Chandalar alluvial fan between Venetie and the mouth of the East Fork from the hills to the northeast.

The marginal upland bordering the Hadweenzic River is mantled by eolian sand. Test pits dug through the sand to bedrock on the upland west of the river disclosed no gravel. However, gravel occurs at the surface of the marginal upland between the Hadweenzic and Hodzana Rivers about 13 miles N. 20° E. of Beaver and 450 to 500 feet above adjacent parts of the Yukon Flats (fig. 30). It occurs at the surface at a similar altitude along the Beaver-Caro trail 4 miles S. 70° E. of Twentynine Mile Ridge. The sandy gravel contains subangular to well-rounded pebbles, cobbles, and boulders as much as 6 inches long of quartzite, chert, vein quartz, and, locally, chlorite schist. Gravelly sand containing small pebbles chiefly of vein quartz occurs 9 miles west of the Hodzana River on the ridge between the Hodzana Valley and the Yukon Flats at a height of about 300 feet above the Hodzana Valley. Rock-cut terraces occur on the south slope of this ridge 3 or 4 miles west of the Hodzana River at heights of 100 to 300 feet above the Yukon Flats. No further information is available on the high-level alluvium westward from this point to the upstream entrance to the Fort Hamlin-Rampart Canyon, where small subrounded quartz pebbles observed in some of the gullies east of the Yukon River suggest the possibility that the high-level gravel occurs beneath the loess mantle and above bedrock.

The high-level alluvium of the Yukon Flats district is without doubt the remnant of deposits of a complicated system of high river terraces of the Yukon and its tributaries. These deposits are unconsolidated and undeformed, in contrast to the consolidated or semiconsolidated Eocene continental sedimentary rocks which were deformed in Miocene time (Mertie, 1937). Therefore, the high-level alluvium is probably younger than Miocene. The gravel of even the lowest terrace of the high-level alluvium in the marginal upland lies above the level of the older part of the Chandalar alluvial fan, which is tentatively dated below as early to middle Pleistocene. The high-level alluvium, therefore, is older than early to middle Pleistocene, and is of late Tertiary or early Quaternary age.

### GLACIAL DRIFT

Deposits of four glaciations are recognized in the southern Brooks Range adjacent to the Yukon Flats district. In order to show the multiplicity of glaciations and their relation to the alluvial and eolian deposits of the Yukon Flats district, the glacial deposits were mapped from aerial photographs and correlated from valley to valley by comparing the morainal sequence and topographic expression of the deposits in each valley. The glacial deposits and landforms of the southern Brooks Range have not been studied by the writer in the field; they have been described, but not mapped in detail, by Schrader (1900), Maddren (1913), and Mertie (1925, 1929, 1930a). On the geologic map (pl. 42) are shown the isolated drift deposits of the oldest glaciation (by notation southeast of the lower valley of East Fork Chandalar River) and the deposits of the three subsequent glaciations, each bounded by end- and lateral-morainal complexes. The glacial deposits of the other highland areas have received little attention, and for the most part are confined to the higher elevations away from the Yukon Flats district. Two moraines are recognized in the Hodzana Highland.

Evidence for the oldest glaciation consists of isolated patches of drift and ice-scoured slopes and summits above and beyond the limits of the oldest recognizable end and lateral moraines. Isolated patches of drift with gently undulating topographic expression are recognized along the East Fork Chandalar River at the mouth of Cornucopia Creek and to the east in the protected valleys of northward-flowing streams in the hills between the East Fork and Marten Creek. An apparently ice-scoured hillside borders the northeastern edge of the older part of the Chandalar alluvial fan between Venetie and the mouth of the East Fork. Some of the hill tops at the eastern tip of the Hodzana Highland and southwest of the confluence of the Chandalar River and East Fork Chandalar River appear ice-scoured. This evidence for an early, extensive glaciation is based on interpretation of aerial photographs and requires checking in the field. The maximum extent of ice during this glaciation is unknown, but it probably extended into the Yukon Flats via the Chandalar, Marten, and Sheenjek Valleys.

The oldest mappable glacial drift consists of till, gravel, sand, and silt of the end and lateral moraines that mark former glacial boundaries and of the ground moraine that lies within these boundaries. A system of lateral moraines associated with marginal melt-water channels along the south side of the Chandalar Valley west of Mountain Creek marks the southern limit of the ice. The end position as shown by convergence of the lateral moraines was about 6 miles upstream from the mouth of the East Fork. Ground moraine is exposed along the Chandalar River in bluffs about 100 feet high from Mountain Creek westward to the mouth of the Middle Fork. Schrader (1900) noted yellowish or buff-colored till in these bluffs and reported glacial deposits at elevations as high as 2,200 feet south of the Chandalar River opposite the mouth of Flat Creek. In the valley of the East Fork a complex of end and lateral moraines describes the former boundaries of a glacier that advanced to the mouth of Coal River. The lateral moraine that lies between the East Fork and both the Christian River and Marten Creek is especially prominent. Channels leading from the lateral moraine carried melt water via both the Christian River and Marten Creek to the Yukon Flats. The boundaries of the oldest morainal complex are approximately those mapped by Brooks (1906) as the outer boundary of the glaciated area.

Younger glacial drift forms the prominent lobate moraines in the Chandalar Valley at the mouth of the Middle Fork and near the confluence of the North Fork and West Fork, in the valley of Flat Creek, and on the East Fork at the northern edge of the mapped area. The topography of these moraines is generally rougher than that of the older drift; more undrained depressions and kettle lakes occur on the younger moraines, and the drainage is less-well integrated than on the older drift. The deposits, chiefly till and gravel, have been described by Schrader (1900), Maddren (1913), and Mertie (1925, 1929, 1930a).

The youngest glacial drift forms topographically fresh moraines downstream from Chandalar Lake on the North Fork, south of Big

Lake and south of the two lakes at the head of Phoebe Creek in the Bettles River drainage, between Rock Creek and Trilby Creek on the Middle Fork, and on the East Fork north of the mouth of Wind River (north of mapped area). These deposits are chiefly till and gravel, but also include silt and sand; they have been described by Maddren (1913) and Mertie (1925, 1929, and 1930a). Moraines similar to those of the Chandalar drainage but north of the mapped area occur on the Sheenjek River upstream from the Forks.

Outwash aprons in front of each moraine extend downstream as a valley train, which is now preserved as one flight of the discontinuous terrace remnants that border the flood plains of the trunk rivers within the Brooks Range and its southern foothills. It is difficult to trace these terraces as far as the Yukon Flats because they have been masked in many places by alluvial-fan deposits of tributary streams and have been eroded away in the narrow, constricted valleys through which the rivers flow as they enter the Yukon Flats. However, a tentative correlation is made between the oldest morainal complex and the deposits of the older part of the Chandalar River alluvial fan in the Yukon Flats.

The glacial drift is of Pleistocene age. The earliest glacial deposits of early Pleistocene age lie in remnant patches well above and beyond subsequent glacial deposits of early to middle Pleistocene age. The oldest mappable morainal deposits, by correlation with the older part of the Chandalar alluvial fan, are of early to middle Pleistocene age. The younger morainal deposits are of middle to late Pleistocene age. The isolated patches of drift and the oldest morainal complex are probably equivalent, by correlating parallel sequences, to the Anuktuvuk and Sagavanirktok glaciations of pre-Wisconsin age on the Arctic slope of the Brooks Range, and the younger moraines are equivalent to the Itkillik and Echooka glaciations, which Detterman, Bowsher, and Dutro (1958, p. 60) have correlated with the Wisconsin stage of midwestern United States.

### ALLUVIAL-FAN AND RELATED TERRACE DEPOSITS

Alluvial-fan and related terrace deposits occupy most of the central and eastern part of the Yukon Flats. The major alluvial fans are (a) the Yukon fan, which extends to the marginal escarpment on either side of the Yukon River flood plain between Circle and Fort Yukon, and (b) the coalescent alluvial fan formed by the Chandalar, Christian, and Sheenjek Rivers along the north side of the Yukon and Porcupine Rivers between the Hadweenzic River and Shuman House. The fans consist of numerous terrace levels, most of which are only a few feet above the adjoining part of the fan. However, the fans appear to be divisible into two broad units: a younger part, which borders and grades into the flood plain and low terraces along the modern rivers, and an older part preserved as a complex of river terraces slightly higher than the younger fan complex. In addition to their lower height above the river, the younger fans are covered with fresher appearing braided channel scrolls, and have a soil profile in which the oxidized zone is comparatively thin, generally less than 2 feet. The older part of the fan, on the other hand, has a less well preserved system of abandoned channel scrolls, and has a soil profile in which the oxidized zone is generally deeper than 2 feet.

Terraces of the Porcupine and Black Rivers are graded to the alluvial fans of the Yukon River and to the fan complex formed by the Chandalar, Christian, and Sheenjek Rivers. These terraces have steeper gradients than those of the modern flood plains. Many of the terrace surfaces in the western part of the Yukon Flats were formed by the Yukon River and its tributaries when they flowed at levels slightly higher than the present rivers. Some of these terraces are downstream continuations of the alluvial fans in the eastern and central part of the Yukon Flats. Others are probably terraces formed during the meandering of the Yukon River as it cut vertically into its own alluvial fill and laterally into the tributary alluvium deposited at the margins of the Yukon Flats and graded to one or another of the Yukon terrace levels.

These terrace and alluvial-fan deposits are similar in texture and lithology to the alluvium of the modern stream beds. The deposits consist of stratified layers and lenses of well-sorted sandy pebble-cobble gravel and pebble-cobble-boulder gravel and lenses and beds of sand, silt, and organic material. The gravel is generally mantled by sand, silt, and organic material as thick as 25 feet. The older alluvial-fan and related terrace deposits in places are slightly to heavily stained and slightly cemented by iron oxide. The deposits generally are perennially frozen, but thawed zones occur beneath water bodies and well-drained places. Ground-ice masses, chiefly vertical ice wedges 2 to 3 feet wide, occur locally where the surficial fine-grained sediments are more than 8 feet thick.

These alluvial-fan and related terrace deposits are of Quaternary age, chiefly Pleistocene, but probably Recent in some of the lower levels adjacent to the flood plain and low terraces. The following two areas are of special interest in dating the alluvial-fan and related terrace deposits of the Yukon Flats and correlating them with the glacial sequence of the southern Brooks Range: (a) the outwash apron and valley train leading from the oldest lateral moraine on the East Fork down Marten Creek to the older part of Chandalar fan, and (b) exposures in the older part of the Chandalar alluvial fan near Venetie.

In the first area of interest the prominent oldest lateral moraine formed by the East Fork Chandalar glacier on the divide between the East Fork and upper Marten Creek is bordered by outwash aprons which lead to upper Marten Creek and one of its western tributaries. The outwash aprons apparently merge with terrace remnants along the valley of Marten Creek and are believed, on the basis of interpretation of the aerial photographs, to be a part of the same alluvial surface as the alluvial fan of Marten Creek, now preserved as a terrace bordering that stream where it enters the Yukon Flats about 5 miles northeast of Venetie. Therefore, the melt-water drainage from the glacier as it stood at or slightly back of the lateral moraine probably formed a valley train that was graded to the older part of the Chandalar alluvial fan. This part of the fan is probably correlative in age with the oldest morainal complex.

In the second area of interest, near Venetie, the Chandalar River has exposed sediments that compose the older part of the Chandalar alluvial fan. The older fan forms a terrace northeast of the Chandalar River from the East Fork downstream to Venetie, where it is 33 feet above the river. The older part of the fan is believed to represent the valley train of the oldest morainal complex in the Chandalar Valley, the terminal position of which lies 6 miles upstream from the East Fork. Residents report that mammal remains occur in exposures in the older part of the fan at Venetie and points upstream from the village. A fragment of horse jaw found at the base of the river bank just upstream from Venetie was identified as the "symphysis and greater part of the right ramus of mandible with teeth of *Equus lambei* Hay * * * of probable early to middle Pleistocene age."[1] The age of the horse jaw is consistent with the comparatively great age suggested by the staining and selective cementation of the terrace deposits by iron oxide from the top of the bank to river level, a depth of 33 feet. Even though the jaw fragment was not collected in situ, its presence at the base of the river bank in which terrace deposits are exposed and absence of any sign of abrasion strongly suggest that it fell from the bank and that it dates the deposits of the older part of the alluvial fan of the Chandalar River. It is, of course, possible that the jaw fragment and the other bones were older material redeposited in the alluvium of the older part of the alluvial fan, but the lack of nearby older deposits and lack of abrasion of the jaw fragment suggest that this possibility is unlikely.

[1] Identified by Jean Hough, U.S. Geological Survey, who prefers that *E. lambei* be considered a subspecies of *Equus caballus*. Collected and donated by Elijah John of Venetie.

The older part of the Chandalar alluvial fan, correlated with the oldest morainal complex, is dated as early to middle Pleistocene. The older parts of the Christian, Sheenjek, and Yukon Rivers alluvial fans and the terrace deposits related to them are not necessarily of the same age as the older part of the Chandalar alluvial fan, but probably can be correlated either with the oldest morainal complex or perhaps with the next younger moraine. The younger part of the Chandalar alluvial fan, lying west of the Chandalar River, is apparently of an age that is equivalent, at least in part, to the alluvial fans south of the Yukon River, west of the Christian River, and west of the Sheenjek River, and to some of the terraces in the western Yukon Flats. The younger part of the Chandalar alluvial fan is probably of middle to late Pleistocene age, and is correlated with the two younger morainal complexes in the Chandalar Valley. The alluvial-fan deposits that merge without appreciable topographic break with the flood-plain and low terrace deposits are in part of Recent age, but insufficient data are available by which the Pleistocene deposits can be subdivided from those of Recent age.

The tentative correlation set forth above between the alluvial-fan and related terrace deposits of the Yukon Flats and the glacial moraines of the southern Brooks Range requires substantiation by much fieldwork. The places where this work will be most fruitful are (a) the Chandalar Valley between the moraines west of the East Fork and Venetie, (b) the Sheenjek Valley between Outlook Point and the moraines near the mouth of the East Fork Sheenjek River (Mertie, 1930a, p. 130), and (c) Marten Valley from Venetie upstream to the oldest lateral moraines on the Marten Creek-East Fork Chandalar Divide.

## EOLIAN SAND

Eolian sand underlies approximately 200 square miles of the Yukon Flats and at least 250 square miles of the marginal upland. In the Yukon Flats, ridges and knolls of eolian sand are closely associated with braided channel scrolls at Fort Yukon (fig. 28) and on the terrace north of the Yukon River between the Hadweenzic River and a point 22 miles west of Purgatory, where these deposits were first mapped as dunes by Yanert (1917). Similar ridges and knolls, which have not been visited in the field, occur on the Yukon fan 40 to 46 miles southeast of Fort Yukon and 14 miles S. 80° W. of Fort Yukon, in the alluvial plain of the little Black River 20 to 25 miles east of Fort Yukon, and 7 miles south of Purgatory. In the marginal upland the sand occurs in an area of broad, undulating ridges and gentle swales bordering the lower Hadweenzic River and as dunes 10 to 15 miles northwest of Twentynine Mile Ridge and 3 to 8 miles west of the Little Dall River. The eolian sand of the upland was mapped in the field only along the west side of the Hadweenzic River and south of Twentynine Mile Ridge. Many areas of windblown sand lacking obvious dune topography and form may have escaped notice in compiling the map from trimetrogon aerial photographs.

The unit is massive well-sorted homogeneous unconsolidated gray to tan sand and silty sand, which ranges in thickness from 6 to about 60 feet. The sand is composed chiefly of quartz, feldspar, chert, mica, and a few dark minerals.

The age of the eolian sand is Pleistocene and Recent. Most of the sand deposits mapped are stabilized and covered by trees and brush. Other deposits, too small to be mapped, are still being formed in the lee of long gravel bars in the river flood plains. In the Yukon Flats many of the stabilized dunes occur on alluvial-fan and related terrace deposits of Pleistocene and Recent age. On these surfaces the dunes are surrounded by abandoned braided channel scrolls of the river that last flowed across the alluvial-fan or terrace surface. Migrating sand could not have been blown across these scrolls without filling them with more than the veneer of silt and sand mixed with organic material that now covers the alluvium. This lack of eolian fill in the channels and the unmodified braided form of the channels suggests that the eolian sand was deposited before or during the time these channels were occupied by the river, and, therefore, that the sand is also of Pleistocene and Recent age. In the marginal upland, the present location of still other eolian sand deposits is difficult to explain without postulating their formation under an environment different from that of the present. Stronger wind systems of glacial times may have been able to transport more sediment from the broader bars and channels of the aggrading, braided, outwash streams and deposit the material in its present position. In the opinion of the writer, almost all of the eolian sand of the marginal upland and much of that in the Yukon Flats is of Pleistocene age; only a small proportion is regarded as of Recent age.

### LOESS

An extensive mantle of eolian silt covers the marginal upland bordering the Yukon Flats (Black, 1951). The silt is mapped where it is more than 3 feet thick. It is too thin to be mapped where it covers high-level gravel and eolian sand of the marginal upland between the Dall and Porcupine Rivers and in most parts of the Yukon Flats where it forms a veneer over the alluvium.

The loess is massive well-sorted homogeneous unconsolidated tan to gray silt and sandy silt. Comparison of the mechanical composition of one sample of the silt collected from the marginal upland 8 miles north of Circle, three samples collected in the marginal upland between Big and Jefferson Creeks at distances of 3, 8, and 10 miles south of the marginal escarpment, and one sample from the marginal upland on each side of the entrance to the Fort Hamlin-Rampart canyon shows that the deposit is fairly uniform over a large area. The deposits sampled, according to the Wentworth classification, range in size distribution from 3 to 9 percent clay, 80 to 90 percent silt, and 3 to 14 percent very fine sand and fine sand. The mechanical composition of the silt is generally similar to that of the Fairbanks loess (Péwé, 1955). The silt contains little organic material; the only known organic remains are willow leaf impressions and the air-breathing snail *Succinea strigata* Pfeiffer,[2] which are scattered through the silt at a depth of 2½ to 8 feet on a flat interfluve 490 feet above the Yukon River east of the upper entrance of the Fort Hamlin Canyon. The massive homogeneous well-sorted character of the silt, its relatively uniform texture and size distribution over a large area, its lack of stratification, its local association with sand dunes, and its lack of well-defined upper limits suggest that the silt is of eolian origin, and that it is loess. Some alternate hypotheses to the eolian theory of origin of the upland silt of interior Alaska are discussed by Péwé (1955); these postulate origin as marine, estuarine, lacustrine, and residual deposits.

The loess is preserved in undisturbed condition only on hilltops and flat interfluves in the rolling to gullied marginal upland and in parts of the Yukon Flats. On slopes and in creek valleys in the upland the sediment consists of silt and sandy silt, which have been washed down the slope and reworked by running water. The deposits of the creek valleys are similar to the alluvial-fan silt deposits, which are largely derived from loess and deposited over the alluvium of the Yukon Flats at the base of the marginal escarpment. The creek-valley deposits consist of stratified layers and lenses of gray to brown well-sorted unconsolidated silt and sandy silt that is locally intercalated with beds and lenses of organic matter. Where the creek valleys of the marginal upland are cut deeply enough to intercept the high-level alluvium, their deposits generally consist of sand and gravel along the creek bed flanked by fine-grained deposits washed from the valley sides. The creek-valley sediments are not differentiated from loess on the geologic map because of the small scale, and because of lack of information. The maximum thickness of the reworked silt is estimated at 100 feet.

The loess and the reworked silt of the creek valleys are perennially frozen. Permafrost occurs within 3 feet of the surface on

[2] Identified by J. P. E. Morrison, U.S. National Museum. This species is also found in marshy areas bordering modern ponds in the Yukon Flats.

poorly drained interfluves and in creek valleys underlain by silt. It is 3 to 6 feet deep on the comparatively well drained slopes, in gravelly creek bottoms, and in the loess of well-drained hilltops. Depth to permafrost is greater than 6 feet in the well-drained brush-covered areas that have been burned over. Ground ice in the permafrost of the creek valleys consists of small veins and stringers, small polygonal wedges, and large irregular, tabular, and polygonal masses. In the undisturbed but poorly drained loess of the interfluves, the ice consists of small veins, stringers, and polygonal wedges. Thawing of ground ice in the creek valleys and in the interfluves may be the origin of some of the cave-in lakes (Wallace, 1948) that are prominent features of the marginal upland south of the Yukon Flats and between the Black and Yukon Rivers.

The loess is of Pleistocene and Recent age. In the marginal upland it overlies the high-level alluvium of late Tertiary or early Quaternary age, and in the Yukon Flats it is still being deposited in a few places in the lee of river bars exposed to the wind. Neither the present-day rate of sedimentation, nor the distance the materials are being transported could account for the great thickness of loess over so vast an area as the marginal upland. These loess deposits can be accounted for only by postulating (a) more extensive source area, and (b) more intense winds than the present. These conditions were probably most favorable for loess transportation and deposition during periods of glacial advance when the winds were stronger than at present and swept southward across the broad expanses of bare sand and gravel bars of the actively aggrading braided rivers of the Chandalar, Christian, Sheenjek, and Yukon alluvial fans. Sediment swept by the wind from these bars was deposited as loess on the marginal upland. Similar conditions, but with opposite wind directions, are postulated to account for the Fairbanks loess north of the Tanana Valley (Péwé, 1955). The major loess deposits of the Fairbanks area are correlated by Péwé (1955) with the Delta and Donnelly glaciations. These glaciations, formerly correlated respectively with the early and late Wisconsin glacial stages of the midwestern United States chronology (Péwé, 1953), are now regarded (Péwé, written communication, 1959) as respectively Illinoian and Wisconsin. The loess of the Yukon Flats district is probably the undifferentiated product of eolian deposition during the period from early Pleistocene to the present, but its deposition was probably most active during glaciation of the surrounding highlands. The surficial loess, for the most part, is probably of middle to late Pleistocene age and correlative with moraines of the last two glaciations in the southern Brooks Range, but locally includes a minor amount of Recent loess.

### ALLUVIAL-FAN SILT DEPOSITS

Small alluvial fans occur in the Yukon Flats at the foot of the marginal escarpment. They were formed by small permanent or intermittent streams which drain the marginal upland. The deposits consist dominantly of stratified layers and lenses of gray to brown well-sorted silt, sandy silt, and fine sand, but near the apex of the larger fans there is some sand and gravel. These deposits include layers and lenses of woody and peaty material and finely disseminated flecks of organic material. The silt is derived largely from the loess of the marginal upland, and the sand and gravel from the high-level alluvium. The deposits of the fans vary considerably, depending upon the size of the fan-forming stream. The smaller streams which are not incised into the high-level alluvium, form fans composed dominantly of silt, but the larger streams form alluvial fans that are gravelly at their apex, but become silty toward the toe. Many of the streams flowing through the marginal upland are so deeply incised that no appreciable break in slope occurs at the point of entry into the Yukon Flats, and the gravelly alluvium of the creek within the marginal upland merges with the alluvial deposits of the Yukon Flats. The alluvial-fan silt deposits probably are not more than 100 feet thick.

The alluvial-fan silt deposits generally are frozen at shallow depth. Like comparable deposits in creek valleys of the marginal upland, these alluvial-fan deposits are rich in ground ice, which ranges from thin veins and stringers to large polygonal ice wedges and irregular or tabular masses.

The surface sediments of the alluvial fans are of Recent age, and are still being deposited by the streams that formed the alluvial fans.

### FLOOD-PLAIN AND LOW-TERRACE ALLUVIUM

The term "flood plain," as used in this report, includes the river channels, unvegetated river bars, and the low islands and banks which are less than 15 feet above low water and covered with willow and balsam poplar. The flood plain is inundated every year or every 2 years, and therefore has a flood recurrence interval (Wolman and Leopold, 1957) of 1 to 2. The low terraces are slightly higher than the flood plain but are generally less than 30 feet above low water. The low terraces are covered with white spruce, aspen, willow, birch, alder, and balsam poplar in pure or mixed stands which in many places reflect the pattern of former river channels. The low terraces occupy innumerable levels, each of which has a different flood recurrence interval, ranging, for example, from 2 to 11 on spruce-covered terraces 10 to 20 feet above low water, to greater than 50 on the higher levels 20 to 25 feet above the river, such as the terrace on which the village of Beaver is situated. Beaver has not been flooded since its establishment in 1910. The flood plain and low terraces are in some places separated from the adjoining alluvial fans and related terraces by an escarpment 5 to 150 feet high, but elsewhere the boundary is gradational.

The alluvium of the flood plain and low terraces consists of well-stratified layers and lenses of gray to brown coarse to fine well-sorted rounded to subangular gravel and minor amounts of sand and silt, mantled by as much as 25 feet of well-stratified layers and lenses of silt, sand, and locally, organic matter, chiefly peat, sticks, and logs. It is perennially frozen. Thawed zones are more extensive in the permafrost of the flood plain and low terraces than in any other part of the Yukon Flats district. Thawed zones occur beneath the modern river channels, lakes, river bars, and abandoned channel scrolls (fig. 30). On the basis of the few wells in the Yukon Valley and data elsewhere in central Alaska the thickness of permafrost is estimated at 1 to 50 feet beneath the flood plain and to 1 to 150 feet beneath the low terraces. Locally in the low terrace deposits where the silt mantle is thicker than 8 feet vertical ice wedges 2 to 3 feet wide occur in the permafrost.

The flood-plain and low-terrace alluvium is of Recent age and is still being deposited as the rivers erode their banks and redeposit the materials downstream.

## MUSKEG

Major areas of muskeg are shown as an overprint on the geologic map. They are important because of their unfavorable conditions for cross-country travel in the summer and for construction. Many other muskegs occur throughout the district, but are too small to be mapped.

Muskeg is a loosely defined term that has been applied to a drainage condition, to one or more vegetation types, and to surficial deposits. In this report, it is applied to areas characterized by poor surface drainage, permafrost 1½ to 4 feet below the surface, and plant communities which generally consist of varying proportions of black spruce, heath shrubs, sedges (commonly in tussocks), willows, and mats of *Sphagnum* (peat moss). In some places the mossy turf overlying the silt and organic silt is only a few inches thick, but elsewhere it may be locally as thick as 10 feet. Muskeg areas are the principal locus of large ground-ice masses in the silt of the alluvial-fan and related terrace deposits and in the alluvial-fan silt deposits that border the marginal escarpment. The ice masses, upon melting, commonly cause subsidence of the ground surface or of structures built on or in the ground over the ice mass. In many of the muskegs of the Yukon Flats district the ground-ice masses are reflected at the surface by raised- or depressed-center polygons (Black, 1950, 1952) or by cave-in lakes (Wallace, 1948). However, many ice masses have no surface indicators by which their presence may be detected. As mapped in this report, the muskegs do not include the seasonally flooded or permanent marshes, which are characterized by a lack of permafrost at shallow depth; the marshes occur throughout the district, chiefly in abandoned channels and at pond margins. A large marshy area lies along the Little Black River east of Fort Yukon.

Large muskeg areas that have obliterated or swamped the channel scroll patterns of the alluvial deposits (Tulina, 1936) are concentrated in narrow extremities of the Yukon Flats, along the base of the marginal escarpment and in the constricted valleys of rivers flowing through the surrounding marginal uplands and highlands. Distribution of muskegs in this pattern is probably caused by the relatively poor drainage of terrace, alluvial-fan, and flood-plain deposits at the base of the marginal escarpment and perhaps by higher incidence of summer rainfall in thundershowers in these areas than in the central part of the district. Summer thundershowers seem to follow the marginal escarpment and move up and down the river valleys of the marginal upland and highlands, but seldom occur in the central part of the Yukon Flats. The muskeg formed in Recent time, and the process is still continuing.

## GEOLOGIC HISTORY

### PRE-CENOZOIC HISTORY

Rocks older than Cenozoic are not exposed in the Yukon Flats; therefore, the pre-Cenozoic history must be reconstructed on the basis of the scattered exposures of bedrock in the marginal escarpment and elsewhere in the marginal upland. The few exposures examined in the field suggest that the pre-Cenozoic history is similar to that of the surrounding highlands already described in the reports of Mertie (1930c, 1937), Miller, Payne, and Gryc (1959), Payne (1955), and Smith (1939).

Within the mapped area the oldest rocks are early Paleozoic (pre-Devonian?) and possibly Precambrian metamorphic rocks north of the Yukon Flats. These rocks, probably once marine sediments, have been subjected to many periods of deformation, at least one of which occurred prior to deposition of the Carboniferous sedimentary and volcanic rocks. The Carboniferous rocks underlie the marginal upland and form the marginal escarpment at many places north, southeast, south, and west of the Yukon Flats, and, therefore, may form the pre-Cenozoic basement beneath the Cenozoic deposits of the Yukon Flats basin. The metamorphic rocks have been intruded by large and small bodies of granitic rocks presumably of Mesozoic age (Dutro and Payne, 1957; Mertie, 1925) and by small bodies of basic igneous rocks. The Carboniferous rocks have been intruded by basic igneous rocks, chiefly in closely spaced dikes, sills, and small stocks or plugs, and locally intruded by small bodies of granitic rocks. The age of the basic igneous rocks is unknown, but probably ranges from Carboniferous to Mesozoic. As far as is known, the Yukon Flats district lacks Mesozoic sedimentary rocks, unless they are concealed beneath younger deposits.

## CENOZOIC HISTORY

The Cenozoic troughs and basins of interior Alaska originated as areas of accumulation of sediments during the early part of Tertiary time (Miller, Payne, and Gryc, 1959), for the oldest recorded sediments are of Eocene age. The Eagle trough (Payne, 1955) is probably the northwestward extension of the Tintina Valley (Bostock, 1948), which is alined with but separated from the Rocky Mountain trench by the Liard Plain, a Cenozoic basin analogous to the Yukon Flats. Whether the Rampart trough is a further extension of this trench is not known. These two troughs, one on each side of the Yukon Flats, each have several thousand feet of Eocene continental deposits, 5,000 feet in the Rampart trough (Collier, 1903), and 3,000 to as much as 10,000 feet in the Eagle trough (Mertie, 1942, p. 244). Whether a similar thickness of sediments of Eocene age occurs within the Yukon Flats Cenozoic basin is not known; the only exposed sediments of Eocene age are the shale, lignite, and coal of the Dall and Hodzana Valleys, and possibly the flat-lying sediments between these localities. Drilling has failed to reach pre-Cenozoic basement rocks beneath the Yukon Flats at a depth of 440 feet, only 20 feet above present sea level, and the presence or absence of Eocene deposits like those of the Eagle and Rampart troughs remains a matter for speculation. The continental deposits of the Yukon Flats district either represent (a) remnants of a former extensive cover of sediments that has been preserved by post-Eocene downfaulting or downwarping, or (b) deposits accumulated as the troughs and basins which originated during a phase of the Laramide disturbance (later Paleocene or post-Paleocene) continued to subside (Miller, Payne, and Gryc, 1959). Mertie (1942, p. 244) suggested that the Eagle trough was a broad subsiding valley in which a considerable thickness of sediments accumulated.

Folding and tilting of the Eocene sedimentary rocks took place during Miocene time (Mertie, 1937) and, in some parts of interior Alaska, the deformation was accompanied by intrusion of granitic and monzonitic rocks and by volcanic activity (Mertie, 1937). The basalt of the Chandalar Valley may be related to the volcanic activity. If the flat-lying stratified rocks between Dall Mountain and the Hodzana River upon examination in the field proved to be of Eocene age or older, the Miocene deformation in the Yukon Flats may have been less intense than that in the Fort Hamlin-Rampart Canyon where the Eocene rocks are strongly tilted and locally are vertical. If the flat-lying rocks are younger than Eocene, they were probably deposited after the Miocene deformation but before the high-level alluvium of late Tertiary or early Quaternary age.

The late Tertiary and early Quaternary history is based on widely scattered observations of the high-level alluvium and on the log of the single boring in which the silt and sandy silt beneath the Yukon Flats were discovered. These two groups of deposits are not in contact, and their relative stratigraphic position is not known. The high-level alluvium was deposited after initiation of the Miocene disturbance, but before early to middle Pleistocene time. The silt and silty sand are older than middle to late Pleistocene, but no meaningful lower age boundary can be fixed. Thus the silt and silty sand could as well be of Mesozoic age or be a quiet-water facies of the Eocene continental deposits as be of late Tertiary or early Quaternary age as postulated in this report. On the basis of the data, the historical reconstructions, presented below with the two alternate assumptions on which they are based, both seem to be reasonable explanations of the late Tertiary and early Quaternary history as recorded by the high-level alluvium and the silt and silty sand.

1. Assuming the silt and silty sand are slightly older than or in part contemporaneous with the high-level gravel, two alternatives can be offered:
   a. During the Miocene disturbance, the Yukon Flats basin subsided with respect to the surrounding highlands sufficiently to impound the drainage and form a lake. At the same time, stream erosion of the uplifted highlands was accelerated and huge loads of gravelly sediments were deposited in the Yukon Flats basin. The deposits gradually encroached on the lake, partially or completely filling it. The lake outlet, probably a large river, sought a course across the lowest point in the highlands that rimmed the Yukon Flats basin. The course selected between Fort Hamlin and Rampart may have been a former route for waters draining the Yukon Flats basin

or may have crossed one or more low divides separating the westward-flowing streams from the Yukon Flats drainage basin (Mertie, 1937). As time passed, the river cut down through the rocks of the highlands and formed a narrow valley in which it flowed in broad meanders. In the Yukon Flats the lake level was lowered with the fall in the level of the outlet, and the lake probably was largely filled with alluvium. By late Pliocene time, the highlands had been reduced to areas of mature dissection and moderate relief, and the lowlands had become flat plains with little relief (Mertie, 1937; Miller, Payne, and Gryc, 1959).

At the end of Tertiary time, regional uplift, possibly accompanied by local warping or faulting, lowered the base level of erosion (Mertie, 1937). The broad, meandering channel of the Fort Hamlin-Rampart segment of the Yukon River began to be incised to form the present canyon, and a broad valley was excavated in the gravel fill and the lacustrine silt and silty sand of the Yukon Flats basin. The erosion started at the end of Pliocene time and has continued intermittently to the present time. One interruption, perhaps caused by early Pleistocene glaciofluvial aggradation, may have formed the prominent 150- to 250-foot terrace in the marginal upland south of the Yukon River and Beaver Creek. On the other hand, this terrace, like many of the lower terraces along the marginal escarpment, may have been formed during lateral migration of the Yukon River and its tributaries at successively lower levels.

b. A somewhat similar sequence of events could be postulated if the subsidence of the Yukon Flats with respect to the surrounding highlands occurred at the end of Tertiary time, instead of during the Miocene disturbance. Under this hypothesis the lacustrine(?) sediments and the high-level alluvium would be of early Quaternary age. These deposits may be equivalent in age to the oldest Pleistocene glaciation, and the sediments may therefore be glaciolacustrine and glaciofluvial, respectively.

2. Assuming that the silt and silty sand beneath the Yukon Flats is younger than the high-level gravel, the following historical reconstruction can be made. Following the initiation of the Miocene disturbance, the Yukon Flats was slightly depressed and a thick alluvial fill was formed in the basin. By the end of Tertiary time the stream draining the basin had found a course across the Fort Hamlin-Rampart area. The highlands had been eroded to maturely dissected hills of moderate relief, and the Yukon Flats basin was a flat, alluvial plain. Differential subsidence by warp-

ing or faulting of the Yukon Flats with respect to the marginal upland and surrounding highlands at the end of Tertiary time temporarily ponded the drainage and formed a lake in the Yukon Flats. The outlet to the lake may have followed the old course of the river, or may have developed a new course, but the waters rapidly cut down into bedrock, forming the incised meanders of the Fort Hamlin-Rampart canyon. Sediment from the surrounding highlands was brought into the lake by rivers which trenched the high-level gravel of the marginal upland and rapidly filled the lake. Some of the sediment probably was outwash from the early Pleistocene glaciation in the surrounding highlands.

A Pleistocene lake in the Yukon Flats has been suggested by Spurr (1898) and others, and strongly advocated by Eakin (1916). Eakin's evidence (1916, p. 73) for such a lake is (*a*) surficial lacustrine silts, (*b*) rock-cut and gravel terraces, and (*c*) youthful development of valleys that serve as outlets to alluvial basins. He postulated that inundation occurred to at least 1,000 to 1,200 feet above sea level, and that the lake in the Yukon Flats was synchronous with the advance of the continental glacier to the Arctic Ocean. In this report the nonstratified surficial deposits of silt observed in the marginal upland from about 600 to 1,000 feet above sea level are interpreted as loess. The stratified silt exposed in the river banks and in cuts through alluvial fans along the marginal escarpment and in creek valleys of the marginal upland is of alluvial origin. The rock-cut and gravel terraces of the Yukon Flats are interpreted as of fluvial origin, and the youthful development of the Yukon Valley downstream from the Yukon Flats is explained above. In the writer's opinion, therefore, the surficial silt of lacustrine origin, according to Eakin (1916), is generally of alluvial or eolian origin, and the only deposits that seem correlative with a possible Pleistocene lake dammed by glaciers are the silt and silty sand beneath the Yukon Flats. The possibility that the glaciers which dammed such a lake originated in the Ray Mountains, which are 4,000 to 5,600 feet high and only 15 miles north of the Yukon River near Rampart, seems much more logical as a means of damming the Yukon and impounding water in the Yukon Flats than postulating that the dam was effected by the continental glacier in Canada to the northeast. Eakin (1916) reports that valleys north of the Ray Mountains were glaciated for a distance of about 20 miles from the cirques in the high part of the range, and the Tozitna Flats, separating the highest part of the range from the Yukon Valley, are largely floored by glacial outwash. Presumably the glaciation to which these features belong is correlative with one of the younger Pleistocene glaciations of the Brooks Range. It is possible, therefore, that during early Pleistocene time the glaciers may have advanced to the Yukon River. Whether they were ever large enough to form a dam across the Yukon Valley is not known. A full evaluation of this possibility must await the results of more detailed fieldwork in the Ray Mountains and in the Yukon Valley. However, any theory seeking to account for the silt and silty sand beneath the Yukon Flats by postulating a glacial dam must also account for the fact that the base of these sediments at Fort Yukon lies at least 275 feet lower than the bedrock threshold at the upper end of the Fort Hamlin-Rampart Canyon where Carboniferous rocks are exposed at the river's edge and presumably form the bed beneath the river. It would thus appear that a satisfactory hypothesis would require some form of tectonic movement to explain the difference in elevation of pre-Cenozoic basement rocks between the Fort Hamlin-Rampart Canyon and the center of the Yukon Flats. A Pleistocene glacial damming of the drainage, alone, is not an adequate explanation for this relation.

In Pleistocene time, as a result of colder temperature, increased precipitation as snow, and perhaps increased elevation, the Brooks Range and other highlands surrounding the Yukon Flats district became glaciated; the higher peaks supported extensive icecaps, which fed the valley glaciers that filled the upper reaches of the Koyukuk, Chandalar, Sheenjek, and Coleen Rivers. Because the higher peaks with their centers of ice accumulation extended farther south in the drainage of the South Fork Koyukuk River and Middle and North Forks Chandalar River than they did in the watersheds of the East Fork Chandalar, Sheenjek, and Coleen Rivers, the valley glaciers advanced to a more southerly position in the Koyukuk Valley and in the Chandalar Valley than in the East Fork, Sheenjek, or Coleen Valleys during each of the successively less extensive glaciations. During these glaciations the glaciers in the southern Brooks Range terminated 70 to slightly more than 150 miles from the present Yukon-Arctic divide where only a few small valley glaciers still exist.

Early Pleistocene glaciers in the southern Brooks Range probably entered the Yukon Flats through the valleys of Marten Creek and the Chandalar and Sheenjek Rivers. The maximum extent of the glaciers within the Yukon Flats district is not known. Glacial and glaciofluvial debris were transported by the rivers from the mountains to the Yukon Flats. Little is known of the extent of glaciation in other highland areas, but some of the higher parts of the highlands were probably covered with icecaps which fed valley glaciers at lower elevations. Whether any of these valley glaciers reached the Yukon Flats district is not known.

Erosion continued after the early Pleistocene glaciation, and by early to middle Pleistocene time the Yukon River had probably cut well below its former level in the Yukon canyon between Fort Hamlin and Rampart and in the Yukon Flats. Deep valleys were cut in the surrounding highlands and much of the early drift was removed. In early to middle Pleistocene time, as snowline gradually became lower, the higher part of the Brooks Range became an icecap which fed valley glaciers. The glaciers advanced down the main forks of the Chandalar, Koyukuk, Sheenjek, and Coleen Rivers. In the Chandalar and South Fork Koyukuk Valleys the ice coalesced into a single large glacier that had its eastern terminus at a point in the Chandalar Valley only 6 miles from the Yukon Flats. Another valley glacier in the East Fork Chandalar Valley reached the vicinity of Coal Creek. Melt water flowing from East Fork glacier fed both the Christian River and Marten Creek, and it carried glacial debris downstream to form a fan on Marten Creek, which was graded to the older fan of the Chandalar, and to form the older fan of the Christian River. Elsewhere within the Yukon Flats, most of the deposits related to this glaciation were eroded or were buried by younger alluvium. No eolian deposits related to this glaciation have been recognized. The other highland areas were probably glaciated in part, but the ice was restricted to the valleys within the highlands, as shown, for example, by the moraines of unknown age that are mapped on the upper Hodzana River. Thus, glaciers probably did not reach any part of the Yukon Flats during the early to middle Pleistocene or subsequent glaciations.

In middle to late Pleistocene time two glaciations terminated well within the valleys of the southern Brooks Range. Separate glacial lobes were formed in each glaciation in the valleys of the Sheenjek River, the East, Middle, and North Forks of the Chandalar River, and in the headwaters of the Koyukuk River to the west. Glacial outwash from these glaciers augmented the normal stream debris load to form the complex alluvial fans of the Chandalar, Christian, and Sheenjek Rivers and the related terraces bordering the flood plains and low terraces of other rivers. The alluvial fan of the Yukon, though equivalent in age, is so far removed from the terminal position of the middle to late Pleistocene glaciers in which the river had its source that it can hardly be called a glacial outwash fan. However, the Yukon River was probably subject to the same cycles of aggradation during glacial advance as the rivers heading in the Pleistocene glaciers of the Brooks Range. Correlation of the older parts of the Yukon and Sheenjek alluvial fans is still uncertain; they may be of the same age as the early to middle Pleistocene moraines or as the older of the middle to late Pleistocene moraines. The younger part of each fan is probably equivalent to the youngest moraine and, in part, to Recent time. Small valley or cirque glaciers were formed locally in the highlands bordering the Yukon Flats in middle to late Pleistocene time.

During the formation of the major alluvial fans in middle to late Pleistocene time, the periods of glaciation were presumably times of greater aggradation, hence larger areas of bare gravel bars and channels were exposed to wind action than in periods of nonglaciation when aggradation was less pronounced or when the fans were being trenched. Winds were presumably stronger when the glaciers were in advanced positions. The wind, sweeping across the exposed gravel and sand of the channels and bars, was able to transport a greater amount of silt and sand to greater distances during the glacial times than during the periods of nonglaciation. Thus, the loess and eolian sand deposits of the marginal upland are regarded as largely related to glaciation and represent the undifferentiated deposits of loess formed during middle to late Pleistocene time.

In Recent time, the modern flood plains and low terraces have been formed as the rivers migrated in their valleys and have slightly trenched the older deposits. Some of the terrace deposits and parts of the alluvial fans bordering the flood-plain and low-terrace alluvium are probably also of Recent age. Alluvial fans along the marginal escarpment are largely of Recent age and are still being deposited. Locally, loess and eolian sand are still being deposited, and probably have been since Pleistocene time.

## ECONOMIC GEOLOGY

### SAND AND GRAVEL

The principal mineral resources of the Yukon Flats district are potentially valuable deposits of sand and gravel. These deposits are available in large quantities in an unfrozen condition in or near the Yukon River and its tributaries and in large quantities from the alluvial fans and related terraces of the larger rivers in the district. In most places away from the modern river channels and bars, the gravel is buried beneath an overburden of sand and silt, which ranges from 1 to 25 feet in thickness and which is commonly perennially frozen. Sand in relatively pure condition is abundant in eolian sand deposits in both the Yukon Flats and the marginal upland, but it is commonly perennially frozen 5 to 10 feet beneath the surface.

### ROCK

Bedrock is generally too deep to be worked as a source of construction materials in the marginal uplands and it is not available in the Yukon Flats. However, bedrock may be obtained locally from outcrops in gullies in the marginal upland and in the marginal escarpment north of the Yukon River and near Circle and Fort Hamlin (as shown on pl. 42). Trap rock (basalt and diabase) and granitic rock suitable for use as riprap, crushed stone, and fill on construction projects are available locally as shown on the map by lithologic notes. A small area of crystalline limestone occurs on the north edge of the ridge west of Hodzana River, and locally on upper Dall River, but is not known elsewhere.

### COAL

Lignitic coal occurs on Dall River and its tributary, Coal Creek (Mendenhall, 1902, p. 41, 49), and subbituminous coal occurs on the Hodzana River near the forks. Coal or lignite may be included in the flat-lying sedimentary rocks between Dall and Hodzana Rivers if these rocks are equivalent in age to the coal-bearing rocks of the Dall and Hodzana River. The only available analysis is of coal collected from bars of the Hodzana River downstream from the outcrop and submitted to Alaska Railroad through the Territorial Assay Office by N. C. Ross of Beaver (Alaska Railroad analysis No. 9,299 dated Nov. 14, 1942). The coal is subbituminous "C" Cp (poor coking), as shown below.

*Analysis of Hodzana River coal*

[Air-dry loss 8.8 percent]

| Coal sample | Proximate analysis, in percent | | | | | Btu | Sulfur, in percent |
|---|---|---|---|---|---|---|---|
| | Moisture | Volatile matter | Fixed carbon | Ash | Total | | |
| Air dried | 9.4 | 49.6 | 37.8 | 3.2 | 100.0 | 10,350 | 0.5 |
| As received | 17.4 | 45.2 | 34.5 | 2.9 | 100.0 | 9,440 | .5 |
| Moisture free | ---------- | 54.7 | 41.8 | 3.5 | 100.0 | 11,435 | .6 |
| Moisture and ash free | ---------- | 56.7 | 43.3 | -------- | 100.0 | 11,850 | .6 |

### GOLD

Placer gold has been mined for many years in the creeks draining into Birch Creek to the southeast of the Yukon Flats district, at Livengood in the Yukon-Tanana Plateau, and in the Chandalar district to the north. Numerous reports have been made of traces of placer gold in the alluvium of the Yukon Flat district, but to date no significant placer deposits have been found in the district.

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