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TECHNICAL PAPER NO. 18

PLEISTOCENE GEOLOGY OF ANAKTUVUK PASS, CENTRAL BROOKS RANGE, ALASKA

By

STEPHEN C. PORTER

PUBLISHED APRIL 1966

THE ARCTIC INSTITUTE OF NORTH AMERICA

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Stephen C. Porter[1]

Abstract

Anaktuvuk Pass, a broad low valley at the crest of the north-central Brooks Range, underwent intensive alpine glaciation during the later part of the Pleistocene Epoch. Ice of the last major glaciation, the Itkillik, flowed north from an ice divide south of the present stream-drainage divide and formed a broad piedmont lobe beyond the north front of the range. At Itkillik maximum Anaktuvuk Pass was buried under ice to a minimum depth of 2,000 feet. The Anivik Lake readvance, which occurred during the final phases of glacier recession, produced a prominent end moraine that crosses the floor of the Anaktuvuk Valley north of the pass. Extensive ice-contact topography behind the moraine points to subsequent stagnation and rapid wastage of the glacier as the climate became noticeably milder. Radiocarbon dates indicate that the Itkillik glaciation can be correlated broadly with the late (classical) Wisconsin glaciation of central North America. Two post-Wisconsin episodes of valley glaciation, the Alapah Mountain and Fan Mountain, were restricted to cirque valleys in the higher parts of the range. Modern alpine glaciers, which appear to be in a state of disequilibrium, are shrunken remnants of more extensive Fan Mountain glaciers.

Comparison of altitudes of Itkillik cirque floors, altitudes of modern glaciers, and deduced and measured altitudes of the modern snowline suggest that the meteorological pattern at Itkillik maximum was similar to that of today; the main difference was a mean summer temperature which was at least 3.8°C lower than today. Abundant evidence points to a recent warming of the climate that has promoted widespread melting of ground ice, northward extension of floral and faunal habitats, and recession and thinning of existing glaciers. Close agreement between dated climatic events at Anaktuvuk Pass and those from other parts of North America supports the concept of widespread synchrony of late-Pleistocene climatic change throughout the continent.

Introduction

The Brooks Range of arctic Alaska, long a remote and little-known part of the continent, has been receiving increasing attention from scientists in recent years. Although a tentative sequence of glaciations in the northern part of the range has been worked out, few details of the Pleistocene history are known, owing to a lack of intensive studies in critical areas. The present investigation was begun with the aim of mapping in detail the surficial geology of a rather small, selected area in the hope that greater insight into the Pleistocene history of the range would be attained. Specifically, it was hoped that the detailed glacial history of a major valley might be worked out and that a chronology of late-Pleistocene events based on radiocarbon dates, might be formulated. If this

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were possible, correlation of glacial events in the Brooks Range with events in other parts of the continent might provide significant evidence bearing on possible synchrony of major Pleistocene climatic fluctuations throughout the hemisphere.

The initial phase of the project, the results of which comprise this report, centred about Anaktuvuk Pass in the north-central Brooks Range, where features resulting from late-Pleistocene glaciation are very much in evidence. A subsequent phase of the study extended the work north beyond the range front to include prominent end moraines and associated features of the last major glaciation (Porter, 1964a).

A secondary aim of the study was to investigate the geology of certain important archaeological sites at Anaktuvuk Pass that were excavated by John M. Campbell (1962). The results of these investigations have already been reported (Porter, 1964b).

This paper summarizes the evidence on which is based a reconstructed Pleistocene history of the north-central Brooks Range. An understanding of the bedrock geology of the area was necessary for the proper interpretation of certain aspects of the glacial history, and bedrock studies were pursued in conjunction with the mapping of surficial deposits. Details of the bedrock stratigraphy and structure may be found in other reports (Porter, 1962; 1963; in press).

Field work and acknowledgments

Field work was carried out during the months of June, July, and August of 1959 and 1960. Base camps were established on Contact Creek near the Eskimo village of Anaktuvuk Pass, and numerous advance camps were occupied for varying periods of time at selected locations throughout the area. Pre-arranged airdrops by Arctic Research Laboratory aircraft greatly facilitated reprovisioning and early completion of field work. Assistance in the field was provided by Kenneth Perry, Jr. and Edwin S. Hall, Jr. during the summer of 1959, and by John L. Livingston and Garret W. Brass during the 1960 field season.

I am grateful to the Arctic Institute of North America which, under contract from the Office of Naval Research, provided financial support for this study. I am equally indebted to Max C. Brewer, director of the Arctic Research Laboratory at Barrow, and to his staff for logistic support of the field parties.

This report constitutes part of a doctoral dissertation presented to the faculty of Yale University in 1962. The encouragement and counsel offered by Professor Richard F. Flint of Yale are acknowledged with particular gratitude. Professors Eric B. Kraus, John Rodgers, Irving B. Rouse, John E. Sanders, and A. L. Washburn contributed valuable and much appreciated criticisms of the manuscript.

Considerable benefit was derived from conferences with J. T. Dutro, Jr., T. N. V. Karlstrom, George Gryc, and Henry W. Coulter of the U.S. Geological Survey on various aspects of Brooks Range geology. Many stimulating discussions on soils of the Anaktuvuk Pass region with Jerry Brown and Fiorenzo Ugolini, and on the archaeology and ethnology of Anaktuvuk Pass with John M. Campbell and Nicholas J. Gubser added appreciably to several aspects of this study.

I would also like to thank Edward S. Deevey, Jr., Minze Stuiver, and the staff of the Yale Geochronometric Laboratory for processing a series of radiocarbon samples that were instrumental in establishing the late-Pleistocene chronology presented in this paper.

Special thanks are extended to the friendly and hospitable citizens of Anaktuvuk Pass, and to Simon Paneak, Elijah Kakinya, and Homer Mekiana, for whose help and advice on many occasions I am extremely grateful.

I am especially indebted to my wife, Anne H. Porter, both for encouragement throughout the course of the project and for substantial help in the initial preparation of the manuscript.

Place names

The lack of officially recognized names in the area made it necessary to use new names for many features. Only the following names are officially recognized for this area: Anaktuvuk Pass, Anaktuvuk River, Anivik Creek, Cache Lake, Contact Creek, Eleanor Lake, Inukpasugruk Creek, John River, Kollutuk Creek, Kollutuk Mountain, Kungomovik Creek, Napaktualuit Lake, Napaktualuit Mountain, and Three River Mountain. Most new names chosen are those used by the Eskimo inhabitants of the pass or are Eskimo in origin. The name Eleanor Lake, given by Schrader and Peters (Schrader, 1904) to the lake on the drainage divide in the main valley, is not used by the inhabitants of the area, despite its presence on United States Geological Survey maps. In this report the more generally applied name, Summit Lake, has been adopted.

GEOGRAPHY

Location and general features

This report deals with an area of approximately 120 square miles centred about Anaktuvuk Pass in the north-central Brooks Range of arctic Alaska (Figs. 1 and 2). The pass lies at the Pacific-Arctic drainage divide in a wide, low valley that transects the range. High rugged mountains comprise approximately two-thirds of the area, while the remaining third consists of broad, relatively flat valleys that are floored with glacial drift of variable thickness.

The Anaktuvuk Pass area includes some of the highest peaks found between the 151st and 152nd meridians within the Brooks Range, several reaching altitudes in excess of 6,000 feet. Peaks commonly are connected by sharp-crested ridges that have formed by the intersection of cirques or glaciated tributary valleys. Although maximum relief within the area is approximately 4,400 feet, the average relief between valley floors and mountain crests probably is between 2,500 and 3,000 feet.

The floors of major valleys that cross the map area are low, having a maximum relief of about 225 feet. As a rule, they are many times wider than the flood plains that border modern streams. The main valley, in which lie the

Anaktuvuk and John rivers, ranges in width from 2 to 4 miles. It is widest just north of Anaktuvuk Pass where the west-flowing Anaktuvuk River changes course and flows north to the range front.

The valley of Inukpasugruk Creek averages a mile in width and has a pronounced U-shaped cross profile (Pl. 1). Several small hanging tributary valleys that head in cirques enter the valley of Inukpasugruk Creek at altitudes of 500 to 700 feet above the stream.

Contact Creek flows through a deep U-shaped trough bounded by steep cliffs that rise nearly 3,000 feet above its floor. It averages half a mile in width and extends west for 6 miles beyond the map area, where it terminates in a cirque. Several hanging tributary valleys are perched at altitudes up to 1,000 feet above its floor.

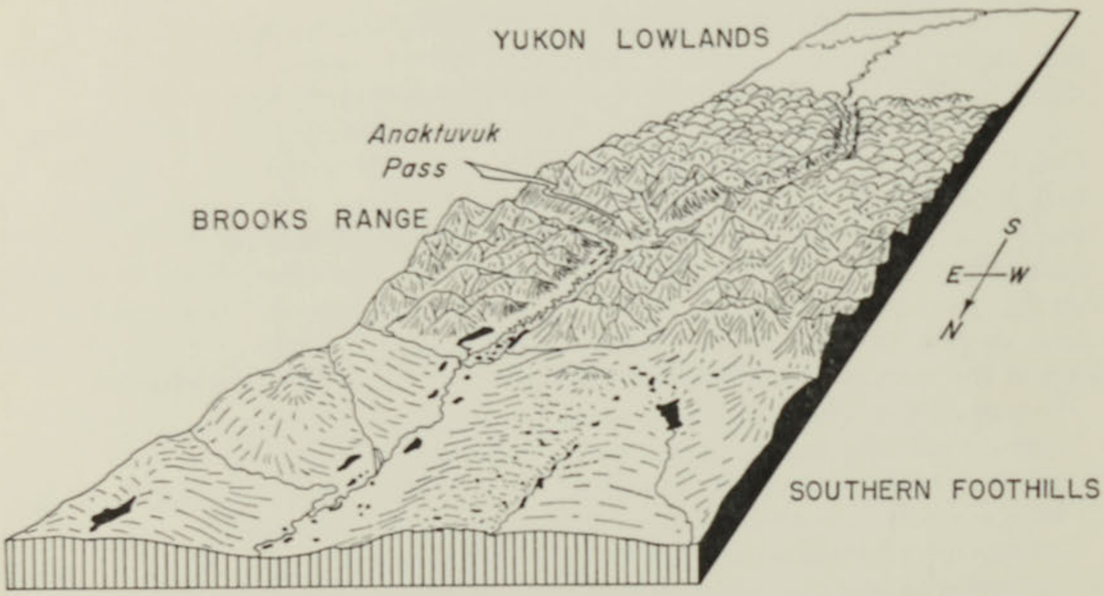


Fig. 2. Generalized diagram of the central Brooks Range in the vicinity of Anaktuvuk Pass.

Drainage

Anaktuvuk Pass occupies the low divide between the headwaters of the Anaktuvuk River and John River drainage systems. The position of the drainage divide has not remained constant, for it has shifted whenever the course of Little Contact Creek, which flows east from between Nachramkunga Mountain and Soakpuk Peak, has shifted from the John River drainage to the Anaktuvuk River drainage across a gently sloping alluvial fan (Fig. 1).

The Anaktuvuk River is one of the major north-flowing streams of arctic Alaska. From its point of origin approximately 20 miles east of the map area, it flows west toward Anaktuvuk Pass and then north out of the range into the foothills belt. Within the map area the river generally is braided and has a gradient of 60 feet per mile. To the north it begins to meander and its gradient decreases to 8 feet per mile until a prominent end moraine is reached 15 miles north of the range front, at which point it again becomes braided. Within the map area the bed load of the river is largely pebble and cobble gravel, whereas to the north it appears to be largely sand.

The John River, a tributary of the Koyukuk, originates immediately south of Anaktuvuk Pass where Contact Creek and Inukpasugruk Creek join. For a mile below this point the river is braided, and it then changes abruptly to a meandering stream with a gradient of 19 feet per mile for a distance of about 10 miles, beyond which the gradient steepens and the river enters a rocky gorge. Near the southwest edge of the map area the meander belt is deflected locally westward and straightened in two places by the encroaching alluvial fans of Alukvik and Kollutuk creeks.

Contact Creek, a swift-flowing braided stream with a gradient of 60 feet per mile, maintains a narrow channel and floodplain. Its bed load consists mainly of cobble and boulder gravel derived from glacial deposits along its course.

Inukpasugruk Creek, having a gradient of about 125 feet per mile, supplies most of the water to the upper reaches of the John River. Just east of its confluence with Contact Creek it plunges through a steep, rocky gorge in a series of rapids and small falls involving a total drop of about 130 feet in half a mile.

Most tributary streams enter trunk streams over broad, gravelly alluvial fans. Many descend valley walls in steep cascades through deep postglacial gorges.

Interstream drainage in lowland areas generally is poorly developed or nonexistent, owing to gentle slopes and a thick mat of spongy tundra vegetation. Numerous small ponds dot the surface, especially during spring and early summer when the winter snow cover melts. In places, subsurface streams flow in channels in ground-ice and emerge along the banks of larger streams as springs.

Surface drainage is limited to late spring, summer, and early fall months when the temperature is above freezing. Break-up of ice on large rivers normally occurs in late April or early May and freeze-up commonly takes place in late October. During the spring thaw, discharge is great and much erosion takes place. Run-off decreases steadily during the summer as snowfields disappear, and by August many tributary streams are dry or flow beneath the surface. Summer cloudbursts commonly cause river levels to rise abruptly by several feet within a few hours. During such periods significant changes may occur in the channel as large volumes of sediment are moved.

Numerous glacial lakes occupy basins in ground moraine or are dammed by stratified drift. Their depths range from a few feet, as in Napaktualuit Lake, to as much as 45 feet, the greatest depth found in Summit Lake. The larger lakes are drained by small outlet streams, commonly narrow, deep, and slow-flowing, that join trunk streams in the main valley. Many small ponds and lakes occupy closed basins having internal drainage. Some of these slowly disappear during summer months as the frost table is lowered by thawing, thereby permitting water to percolate through permeable gravels and drain away.

Climate

Anaktuvuk Pass is located near the boundary between two major climatic zones in Alaska, one in the central interior dominated by continental climatic conditions, the other in the north dominated by arctic conditions (U.S. Weather Bureau, 1959). The Brooks Range separates these two zones and is strongly influenced by both types of climate. Arctic weather appears to be dominant in the Anaktuvuk Pass area, although continental influences are often felt. Unlike the maritime coast of southern Alaska, arctic Alaska receives little precipitation, owing to the low moisture-holding capacity of cold arctic air masses and to the limited area of ice-free water in the Arctic Ocean that is available for evaporation. The climate of Anaktuvuk Pass is characterized by short cool summers, long cold winters, low annual precipitation, and a mean annual temperature well below freezing. At this high latitude there are long periods of continuous daylight during the summer months and similar periods of nearly total darkness during the winter.

Climatic characteristics of the Arctic Slope of Alaska have been discussed by Conover (1960), but little detailed climatologic information is available for the Brooks Range. Anaktuvuk Pass has the only permanent weather station on the Arctic Slope of the range, and measurements have been taken there only since 1953. Records of daily temperature fluctuations are reasonably complete, but measurements of precipitation and snowfall have been sporadic and frequently are based on estimates (U.S. Weather Bureau, 1953–1960). Data on wind speed and direction were accumulated during the present study, for such measurements are not regularly recorded at the station.

The weather station at the pass is located in the village at an altitude of 2,150 feet. Although weather and climate are highly variable from place to place within the range, climatic data presented here probably are representative of the Anaktuvuk Pass area as a whole if allowances are made for local differences in altitude and topography.

Temperature

The mean annual temperature at Anaktuvuk Pass is about 13.8°F (Fig. 3). Mean monthly temperatures range from 50°F in July, the warmest month, to −17°F in December, the coldest month. The large mean annual temperature range of 64°F is due mainly to the difference in summer and winter insolation. Mean temperature increases very rapidly during the spring as the length of the day increases, and decreases almost as rapidly in the autumn as the days become progressively shorter.

The recorded extreme temperatures at the station are 85°F and −47°F. Only three months of the year have mean temperatures above freezing, but frosts are not uncommon even during these months. The daily range of temperature is greatest during the summer months; it averages 22°F during July. During the winter months the range is about 13°F.

Precipitation

During most of the year the Arctic Slope of Alaska is under the influence of the arctic high-pressure system. The primary source of precipitation for the central Brooks Range consists of moist maritime air masses that originate in the Gulf of Alaska. These air masses lose moisture progressively as they travel north across the state with the result that annual precipitation is rather low throughout the Brooks Range and averages only about 11 inches a year at Anaktuvuk Pass. Farther north mean annual precipitation is even less, averaging 5.4 inches a year at Umiat and 4.2 inches at Barrow. In the warmer half of the year precipitation falls largely as rain (Fig. 3). Although rainfall usually is light, few summer days pass without at least a trace of precipitation.

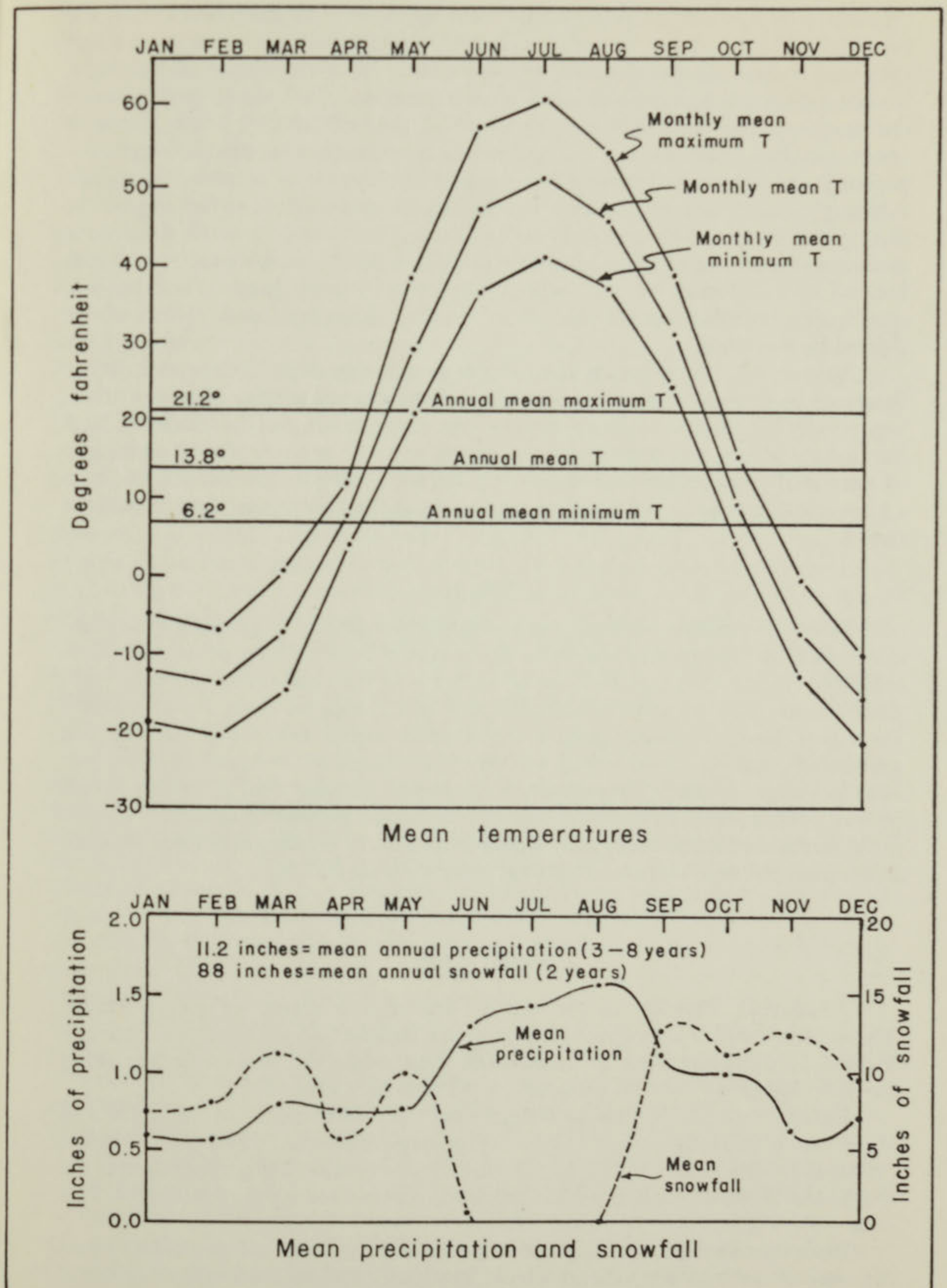


Fig. 3. Climatic data for Anaktuvuk Pass.

Much of the annual precipitation falls as snow. At Anaktuvuk Pass the recorded average annual snowfall is about 88 inches, which constitutes about three-quarters of the total annual precipitation. This value may be too high, however, for it is based on records of two years only. Average precipitation during the summer months (June–September), the bulk of which falls as rain, is about 5 inches. Because the average annual precipitation is only 11 inches, the probable average annual snowfall at the pass may be closer to 60 or 70 inches. Although snow may fall during any month of the year, snowfall is greatest during the early spring and early fall. During the winter months the air remains too cold to retain much moisture. A continuous snow cover usually has formed by mid-September and largely disappears by early June. Snow seldom accumulates to a thickness of more than 30 inches on valley floors, except where drifted by the wind.

Although precipitation is low, the region is not dry. In summer valley floors are swampy and water stands in innumerable small ponds. The main factors producing these conditions are (1) low evaporation, due to relatively high humidity and low temperatures, even during the summer months; (2) presence of perennially frozen ground underlying the land surface that inhibits seepage; (3) gentle slopes and a thick mat of vegetation in the valleys that restrict surface runoff.

Wind

Winds at Anaktuvuk Pass are strong and persistent. Commonly they are controlled by topography and blow up or down large valleys, often with considerable force. Average daily wind velocity at the pass during a two-month period in the summer of 1959 ranged from 3 to 20 miles per hour five feet above the valley floor; occasional gusts reached much higher velocities. During one particularly strong storm, wind velocity was estimated at 50 or 60 miles per hour on ridge crests. Throughout the summer months cool northeast winds prevail as cold arctic air moves inland in response to pressure gradients. Cyclonic disturbances to the south often result in southerly winds and stormy weather at the pass, but such storms seldom last more than several days.

Vegetation

Anaktuvuk Pass lies in the vast treeless tundra region of arctic Alaska The nearest stand of spruce in this part of the Brooks Range lies in the Savioyok Valley, 15 miles southeast of Anaktuvuk Pass, while the nearest timber along the John River is found 28 miles below the pass near Hunt Fork.

Detailed studies of Brooks Range flora have been made by Wiggins and MacVicar (1958), Spetzman (1959), Wiggins and Thomas (1962), and Hultén (1941–50). Spetzman (1959, p. 24) described six major plant communities for the Arctic Slope of Alaska, each of which is represented in the Anaktuvuk Pass area.

Plant communities and vegetation patterns commonly are dependent upon the type of surficial deposits on which they grow and on such other factors as slope, exposure, and drainage. Knowledge of vegetation assemblages, therefore, aids greatly in mapping areas where natural exposures are rare or absent.

Each of the following six communities mentioned by Spetzman is rather closely limited to specific types of surficial materials.

Tussock meadows are the most widespread plant community on valley floors. They consist of cottongrass (*Eriophorum vaginatum spissum*) and are found on poorly drained ground moraine. Cottongrass tussocks average 6 to 12 inches in diameter and are separated by furrows several inches to two feet wide. Bare patches of mineral soil (nonsorted circles) are present locally.

Carex sp. and *Eriophorum* sp. are the dominant plants of wet sedge meadows which are found on flat, poorly drained lowlands bordering the flood plain of the John River. This environment also supports numerous species of sedges, grasses, small willows, rushes, and heaths.

A varied plant community, which includes grasses, shrubs, sedges, and rushes exists on gravelly flood-plain deposits that border main streams. Willows (principally *Salix alaxensis*) are common in this environment and frequently grow to large size. Along parts of Inukpasugruk Creek, Kungomovik Creek, Kollutuk Creek, Contact Creek, and the Anaktuvuk River, willows with trunk diameters as large as 6 or 8 inches reach heights of 10 to 20 feet. Numerous flowering plants bloom on the flood plains during early summer.

Dry upland meadows are characterized by a mat-like plant cover in which most species seldom exceed an inch in height. At Anaktuvuk Pass this plant community is found mainly in well-drained areas that are underlain by stratified sand and gravel, and it constitutes an important criterion for distinguishing these deposits, both in the field and on aerial photographs, from tussock-covered areas underlain by till. The characteristic species in this community, which includes a variety of mosses and lichens, is *Dryas octopetala*. Where high-centred polygonal ground is developed on these gravel deposits, dwarf birch (*Betula nana*) is commonly found in the inter-polygon trenches.

In the higher mountains near Anaktuvuk Pass the plant cover is discontinuous, and vegetation grows locally where soil has formed in pockets or on small benches. Plant types vary according to altitude, rock type, exposure, and moisture content of the soil. On limestone peaks vegetation grows at all altitudes on small benches that occur along ridge crests, and on pinnacles or buttresses on dissected cliffs. Vegetation tends to be sparse and low, and consists mainly of dwarf herbs, grasses, and mat shrubs. On peaks formed of sandstone and conglomerate the soil is more acid and plants generally are larger in size than those found on limestone. Grasses, herbs, and saxifrages are the main vegetation types, with *Dryas octopetala* being locally dominant. Scrub willow and dwarf birch are common at lower altitudes and often are abundant on sliderock. The plant cover usually is extensive on shale slopes, but consists mainly of a mat-like cover of small deep-rooted herbs. In most stream courses below an altitude of 3,500 feet, regardless of rock type in the stream bed, willow is the most common form of vegetation.

Many of the numerous small lakes in the area contain marginal aquatic vegetation, principally *Carex aquatilis* and *Eriophorum angustifolium*. Emerged rooted plants grow discontinuously along the margins of all the larger lakes and are especially dense near their shallow outlets. In several of the small kettle lakes that lie on kame-terrace deposits in the valley of the John and Anaktuvuk rivers (Fig. 1) marginal aquatic plants have gradually encroached upon the lake waters. Wet sedge meadows have subsequently formed along the edges of the lake basins and, growing inward, are replacing the aquatic vegetation. Lakes displaying various stages of this process are present on the kame terrace immediately east of Summit Lake.

Permafrost

The Brooks Range lies in the zone of continuous permafrost in arctic Alaska (Hopkins, Karlstrom, and others, 1955, Fig. 5). Within this zone the thickness of perennially frozen ground varies greatly; a maximum recorded value of 1,330 feet has been reported near Point Barrow (Brewer, 1958).

At Anaktuvuk Pass permafrost commonly is encountered several inches to several feet beneath the surface. The ground thaws during spring and summer to a variable depth that depends on the character of the surface material, topography, exposure, vegetation cover, and over-all drainage conditions. At the end of the thaw period, the active layer on till extends as much as 16 inches below the surface, whereas in more permeable kame-terrace gravels the depth of thaw may reach several feet. Where a thick mat of vegetation is present the ground thaws to a depth of only a few inches. Mudflow scars up to four feet deep indicate the depth of thaw on some favourably exposed slopes with limited vegetation cover. The average thaw depth by late summer, however, probably is of the order of about 12 inches.

EARLIER STUDIES

Stoney (1900, p. 53) apparently was the first to recognize that glacier ice had formerly occupied valleys of the central Brooks Range. As a result of his explorations of the upper Kobuk River drainage in 1886, he concluded that "Lake Selby is of glacial origin, shown by the peculiar formation of the banks and islands. It lies between two mountains 2000 and 3000 feet high, is five miles long and three broad, of an oval shape, and quite deep, in places no bottom at eighteen fathoms."

Schrader (1900), who studied the region along the Chandalar and Koyukuk rivers in 1899, was the first geologist to describe glacial deposits in arctic Alaska. Two years later Mendenhall (1902) made a reconnaissance of the southwestern Brooks Range and recognized abundant evidence of glaciation in the vicinity of Walker Lake. "The present outlet of the lake probably marks approximately the southern limit of the glacier at its principal stage of advance, and the materials discharged at its front, sorted and worn by the waters flowing from it, built up the valley beyond and remained as a dam after the retreat of the ice tongue." (p. 47). In summarizing his observations, Mendenhall concluded that "The high mountain group separating the headwaters of the Noatak from those of the Kowak [Kobuk] and extending thence eastward and westward was a center from which valley glaciers radiated along the principal drainage lines. . . . The ice streams, except near their source, have probably not been deep, and their principal topographic effect has been to fill valleys, disturb drainage, and build dams behind which lakes have grown. Their direct action probably has not extended far beyond the foot of the mountain range in which they originated." (p. 48).

During the summer of 1901 Schrader (1904) took part in a reconnaissance along the John and Anaktuvuk rivers. He described in some detail the glacial features of the region about Anaktuvuk Pass and noted that in this area the "till sheet" (i.e., undifferentiated glacial drift) attained a thickness of at least 130 feet. Although Schrader identified several terminal moraines, he apparently considered them to be the products of a single great glaciation. He concluded that "The glacial phenomena that have been described tend to show that, although the Endicott Mountains do not on the whole seem to have been overridden en masse by a moving ice sheet, they were doubtless, especially in their northern part, largely occupied by an ice cap or perennial névé, constituting a breeding ground for glaciers." Ice "flowage, especially during the latter part of the Ice age, was confined mainly to the valleys and drainageways in the form of alpine glaciers, of which there is ample evidence." (p. 91).

During the following three decades, numerous U.S. Geological Survey parties made observations of glacial features within the range (Leffingwell, 1919; Maddren, 1913; Mertie, 1925, 1929, 1930; Smith, 1912, 1913; Smith and Eakin, 1911; Smith and Mertie, 1930). Their reports described the distribution and character of some of the glacial deposits and developed evidence pertaining to the type and extent of glaciation. By 1930 it was realized that possibly several ice advances had occurred within the range, but no attempt was made to differentiate or to name them.

Field work by U.S. Geological Survey parties between 1944 and 1953 led to the development of a glacial sequence for the north-central Brooks Range. Detterman (1953) described evidence of five glaciations. The oldest glaciation, the Anaktuvuk, was established on the basis of fragmentary evidence along the Anaktuvuk River, mainly erratic boulders and weathered till. The Sagavanirktok glaciation, because of recognizable morainic topography, was considered to postdate the Anaktuvuk glaciation. Moraines of a subsequent advance, the Itkillik, lay within the limits of the older drift sheets and were less modified by erosion and mass-wasting. The Echooka glaciation, believed to be the last recognizable major ice advance, was limited largely to valleys within the range. A recent advance, which left bouldery moraines in cirques, remained unnamed. This sequence was tentatively correlated with other Alaskan glacial sequences, and with the standard North American sequence (Fig. 4). The correlation proposed by Péwé and others (1953) was subsequently modified by Karlstrom (1957), who added a second post-Echooka unnamed glaciation (Fig. 4).

A more detailed account of the glacial deposits and Pleistocene history of the Arctic Slope of the Brooks Range was provided by Detterman, Bowsher, and Dutro (1958). The designation of two post-Echooka glaciations, the Alapah mountain and Fan Mountain, led to further revisions in the tentative correlation of the Brooks Range sequence (Fig. 4). A brief description of glacial deposits and a summary of the glacial history in the Shaviovik-Sagavanirktok rivers region was given by Keller, Morris, and Detterman (1961, pp. 174–5).

Holmes and Lewis (1961; 1965) established a glacial succession in the northeastern Brooks Range and proposed the names Weller, Chamberlin,

	Detterman (1953)	*Karlstrom (1957)*		*Detterman, Bowsher, and Dutro (1958)*
Recent	Unnamed	Unnamed		Fan Mountain
		Unnamed		
Late Wisconsin	Echooka	Echooka		Alapah Mountain
Early Wisconsin	Itkillik			Echooka
				Itkillik
Pre-Wisconsin	Sagavanirktok	Illinoian	Itkillik	Sagavanirktok
		Kansan	Sagavanirktok	
	Anaktuvuk	Nebraskan	Anaktuvuk	Anaktuvuk

	Porter (1964), This paper	
Post-Wisconsin	Fan Mountain	Fan Mountain II
		Fan Mountain I
	Alapah Mountain	
Classical Wisconsin	Itkillik	Anivik Lake
		Antler Valley
		Anayaknaurak
		Banded Mountain
Pre-Classical Wisconsin	Sagavanirktok	
	Anaktuvuk	

Fig. 4. Correlation of Brooks Range glacial sequence.

Schrader, and Peters for four major ice advances in that region. In addition, recent ice advances, initially called "Cirque Moraine I" and "Cirque Moraine II" but subsequently designated Katak, were recognized on the basis of moraines that lie near or in contact with present glaciers. Tentative correlations were made as follows: Weller = Anaktuvuk; Chamberlin = Sagavanirktok; Schrader = Itkillik; Peters = Echooka; and Katak = Fan Mountain (and possibly Alapah Mountain). Further evidence of multiple glaciation in this region was discussed by Keeler (1959), who studied glacial deposits along the McCall Valley, and by Kunkle (1958), who worked along the Jago River.

A detailed study of glacial stratigraphy and morphology along the Chandler and Anaktuvuk river valleys led Porter (1964a) to revise the existing late Pleistocene glacial sequence (Fig. 4). The Itkillik was recognized as a major stage of glaciation containing four substages (Banded Mountain, Anayaknaurak, Antler Valley, and Anivik Lake) represented by successively less extensive drift sheets. The youngest of these, the Anivik Lake, was regarded as equivalent to Echooka drift along the Echooka River. Three post-Itkillik ice advances were recognized and designated Alapah Mountain, and Fan Mountain I and II.

BEDROCK GEOLOGY

Peaks and valleys of the central Brooks Range are carved in a thick section of strongly deformed miogeosynclinal sedimentary rocks. The geologic section at Anaktuvuk Pass consists of more than 13,000 feet of marine and nonmarine clastics and marine carbonates that range in age from Late Devonian through Permian (Fig. 5; Porter, in press). Upper Devonian rocks include more than 6,300 feet of plant-bearing nonmarine shale, siltstone, sandstone, and conglomerate that comprise the Kanayut conglomerate, and the Hunt Fork shale, a thick sequence of dark shale and slate of probable marine origin. The Mississippian section consists of nearly 4,700 feet of fossiliferous marine sandstone, shale, dolomite, limestone, and chert that have been subdivided into three formations: the Kayak shale, the Wachsmuth limestone, and the Alapah limestone. The latter two constitute the Lisburne group. Unconformably overlying the Mississippian carbonate sequence is approximately 400 feet of Permian marine shale and siltstone that belong to the Siksikpuk formation and variable amounts of faulted shaly limestone of the Triassic Shublik formation. Type sections of these rocks, which lie in areas near Anaktuvuk Pass, have been described by Chapman, Detterman, and Mangus (1964), Bowsher and Dutro (1957), Patton (1957), and by Patton and Matzko (1959). Distribution of the different formations near Anaktuvuk Pass is shown in Fig. 6.

The sedimentary section was involved in at least one major post-Paleozoic orogeny that deformed the rocks into a complex series of overturned folds and imbricate thrust faults (Porter, 1962; 1963; in press). Intensity of deformation increases toward the south and, also, thrust faults and axial planes of folds dip south, indicating a northward release of deformational stresses. Most major structural axes trend nearly east-west, as do primary joints. Belts of relatively low limestone mountains coincide with structural lows, while high rugged peaks carved in the Kanayut conglomerate tend to coincide with structural highs.

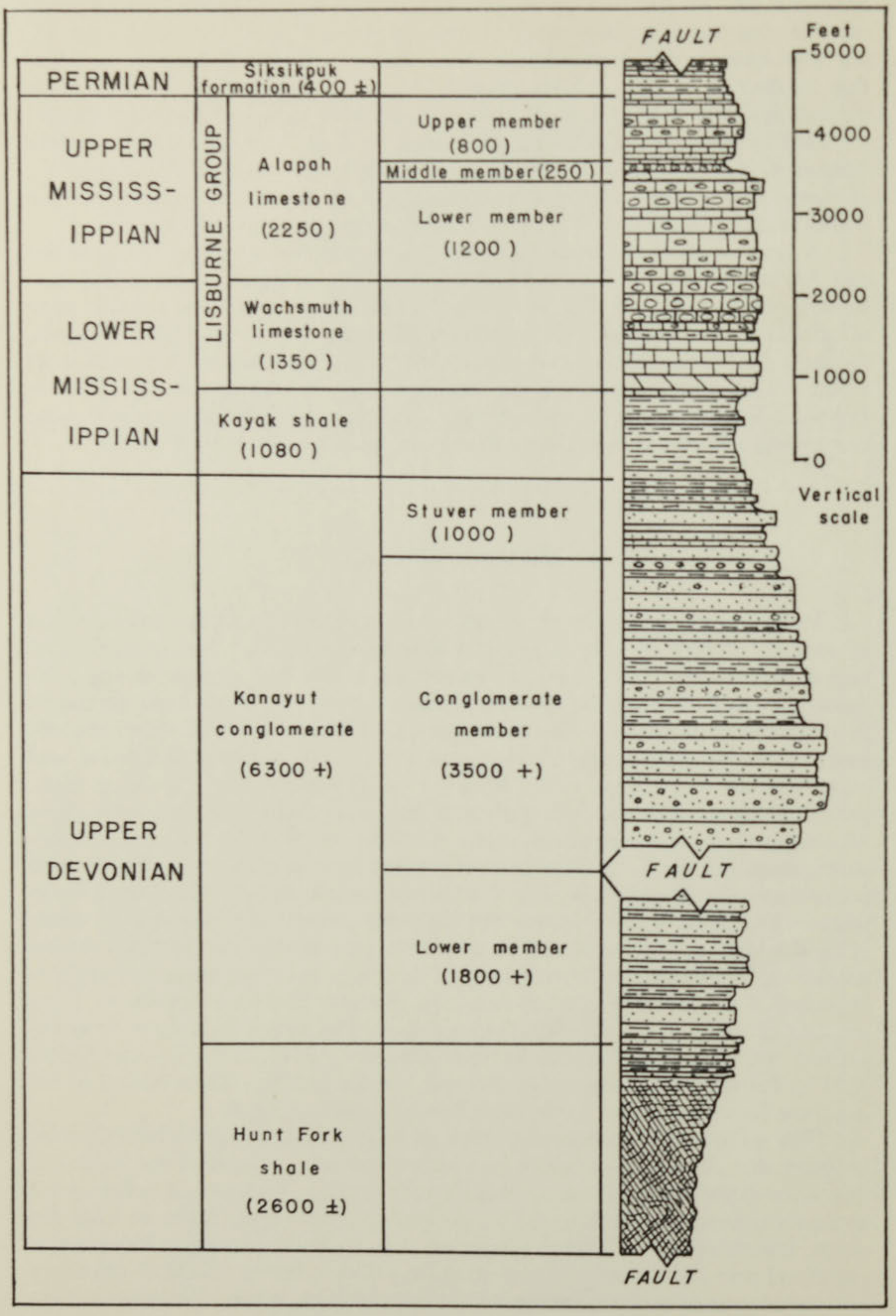


Fig. 5. Generalized stratigraphic section for Anaktuvuk Pass. Thicknesses in feet.

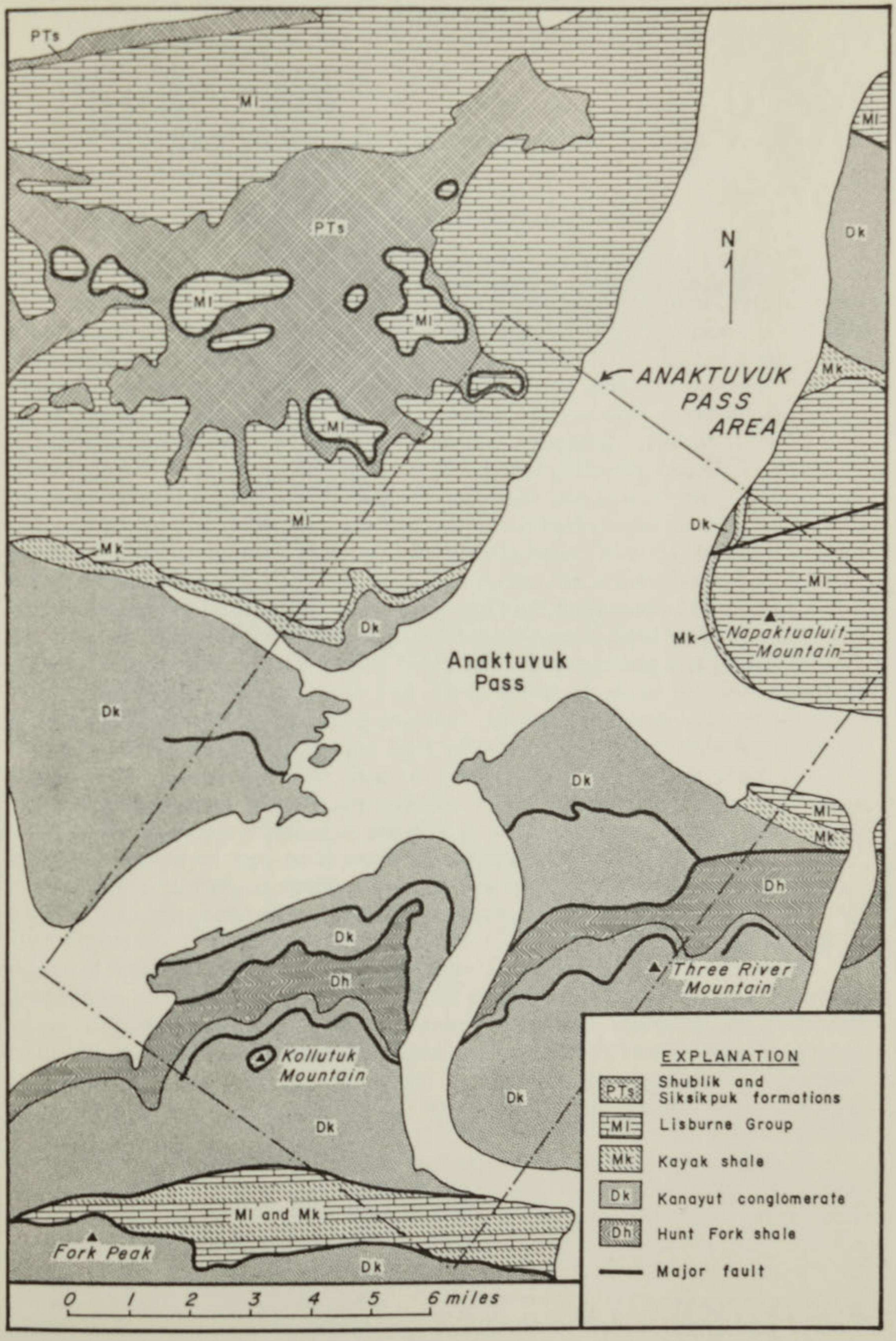


Fig. 6. Bedrock geologic map of the region about Anaktuvuk Pass.

DEVELOPMENT OF PREGLACIAL LAND SURFACE

Pre-Pleistocene erosion surface

Schrader, who viewed the north-central Brooks Range from several high peaks in the vicinity of Anaktuvuk Pass, was impressed by the apparent uniformity of summit altitudes and concluded that they represent "an ancient plateau or peneplain from which, by deep dissection, the mountains have been carved." (Schrader, 1904, p. 42). To this postulated erosion surface he gave the name Endicott Plateau. Its average height was estimated at about 5,500 feet (Fig. 2, p. 44). Schrader further suggested that the Endicott Plateau, which he believed probably extended eastward beyond the central Brooks Range, could be "correlated with the Chugach Plateau, a similarly dissected plateau surface, which is observed in the westward continuation of the St. Elias Range, at an elevation of about 6,000 feet." (p. 42). He considered the peneplain to be post-Lower Carboniferous in age, but pre-Neocene. It therefore postdated the deformation of the range, but was formed prior to regional uplift, which presumably took place near the beginning of the Pleistocene epoch.

In Schrader's photographs (Pls. IV-B and VII) a rather even skyline is apparent, but this no doubt is due to the fact that the photographs were taken from the highest peaks in the area. Distant peaks therefore appear to merge into a continuous surface, unbroken by high topography between the observer and the horizon. If the summits are assumed to be remnants of a former erosion surface, they should broadly delineate the original form of that surface. In the region surrounding Anaktuvuk Pass the summits range from about 4,000 feet to more than 7,000 feet; consequently there is no true accordance of summits as Schrader suggested. The highest peaks almost uniformly are underlain by rocks especially resistant to erosion and tend to lie along structural highs (Fig. 7).

Were the Endicott Plateau a valid concept, preserved plateau remnants might be expected on at least some of the higher summits. The mountains, however, are generally either sharp-crested ridges or matterhorn-type peaks. In the few cases where the summit of a mountain is broad and flat, structural or lithologic control appears adequate to explain the summit surface. Nowhere was a sequence of dipping strata in this structurally complex area seen to be truncated by a summit erosion surface.

If an extensive upland erosion surface existed at the summit of the Brooks Range, remnants of a residual regolith or other evidence of weathering might also be expected, but on none of the mountain peaks were such features observed. If it were assumed that climatic conditions during and since its formation were comparable to present conditions, the presence of perennially frozen ground could effectively prevent deep weathering, and greatly inhibit the formation of a thick residual soil. However, Dall (1920, p. 25), citing paleontological evidence, suggests that during the Pliocene the climate in this region was

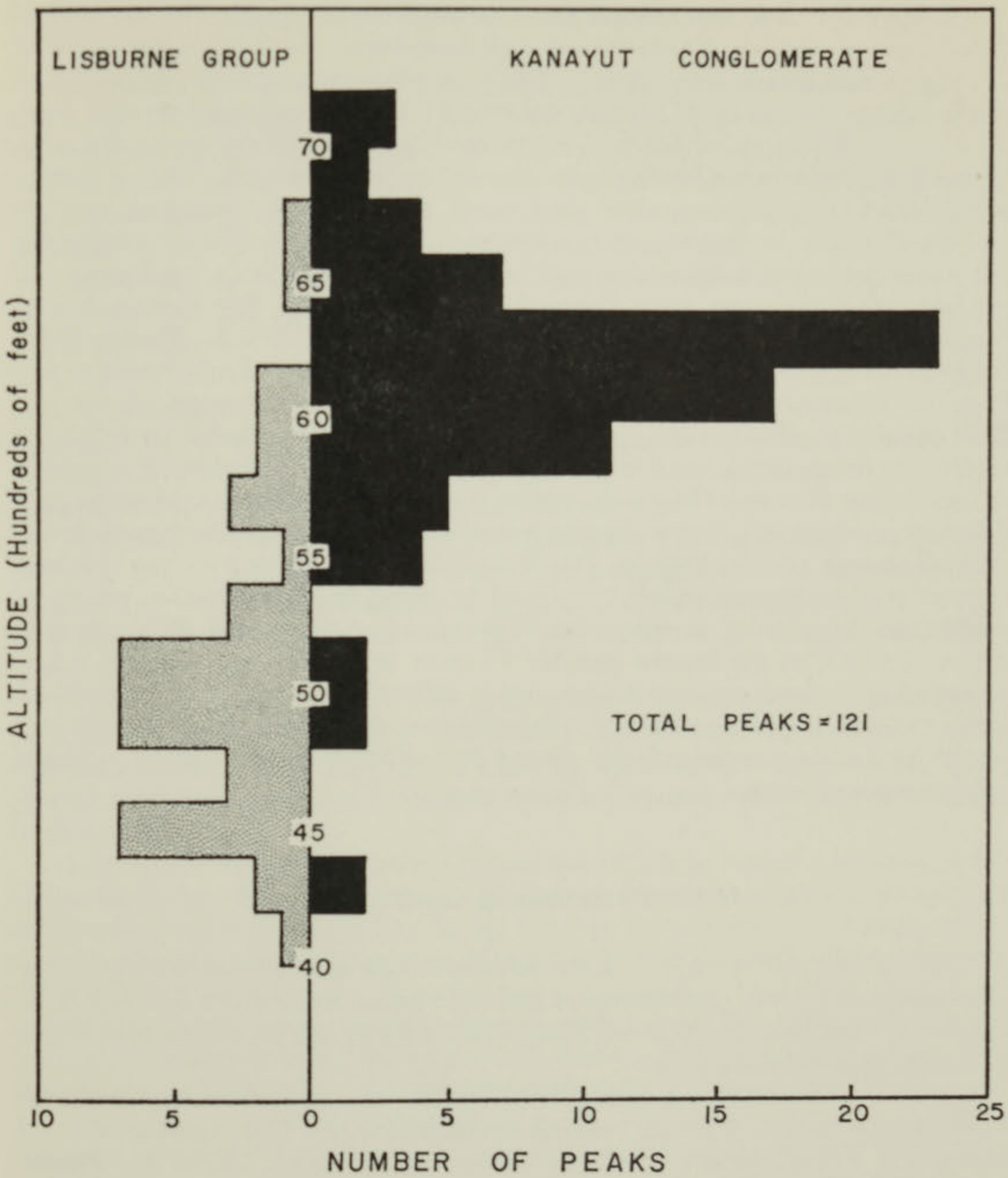


Fig. 7. Comparison of bedrock lithology with altitude of highest mountain peaks of the north-central Brooks Range in the vicinity of Anaktuvuk Pass.

milder than at present; consequently, evidence of moderately deep weathering might have been preserved locally.

Reappraisal of Schrader's concept of the Endicott Plateau, therefore, indicates that if a pre-Pleistocene erosion surface was developed in this region, no recognizable remnant of it remains today, and if such a surface ever existed, most, or all, mountain summits must lie below it. In no sense could the present range crest be considered a peneplain in the classic sense, owing to the wide range of summit altitudes, unless considerable and complicated warping of the surface is assumed.

Despite the lack of evidence for a summit erosion surface in the central Brooks Range, the late Tertiary may well have been a time when the relief of this region was rather low. Best evidence should be provided by sediments of late Tertiary age, but these are rare in arctic Alaska having been described from the Canning River region only. The nonmarine Sagavanirktok formation contains a Paleocene flora (MacNeil, Wolfe, Miller, and Hopkins, 1961, p. 1,803) and consists of poorly consolidated siltstone, sandstone, conglomerate and lignite (Keller, Morris, and Detterman, 1961). This formation may antedate the last major period of deformation within the range. Silty shale, sandstone, and mudstone that crop out along Carter Creek near Camden Bay contain marine fossils of late Miocene and/or Pliocene age (MacNeil, 1957). Rocks which Schrader (1904) included in the Colville Series and regarded as Oligocene and Pliocene subsequently were reassigned to the Upper Cretaceous and to the Pleistocene (MacNeil, 1957, p. 100). Although this is scanty evidence on which to draw conclusions regarding paleogeographic conditions in arctic Alaska before Pliocene-Pleistocene uplift, it is generally held that prior to uplift this region was undergoing widespread erosion and the Brooks Range was lower than at present (Gryc, 1958, p. 113; Payne, 1955). Whether or not the land was reduced to a position near sea level or whether it remained a region of moderately high relief is unknown. The fact that shales and siltstones constitute the bulk of the known possible Pliocene sediments may point to a low altitude for the land mass, or it may simply reflect local depositional conditions in the vicinity of known outcrops. In any event, the area of the present Brooks Range probably constituted the source for sediments deposited in adjacent marine environments.

Pleistocene uplift

According to Payne (1955), the Brooks Range was uplifted during a Pliocene orogenic episode that continued into the Pleistocene. Gryc (1958, p. 116) cited steep-walled canyons cut in glacial debris south of Hunt Fork as evidence of recent uplift in the range.

Direct evidence of late Cenozoic uplift was not recognized at Anaktuvuk Pass owing to a lack of young bedrock datum surfaces. The youngest exposed bedrock is Triassic in age, while the oldest unconsolidated unit is late Pleistocene drift. The great relief and rugged aspect of the range, however, suggest that uplift did not antedate glaciation by a very great time span.

Although steep-walled canyons eroded in late Pleistocene drift are present near Anaktuvuk Pass and elsewhere in this part of the range, they are explained adequately by variations in stream regimen brought about by climatic change. That fairly recent uplift has occurred remains a possibility, however. The recognized pre-Itkillik glaciations have not yet been dated, but conceivably they were late Pleistocene events, possibly early Wisconsin or Illinoian. Were this the case, the Brooks Range may have escaped widespread early Pleistocene glaciation if at that time the range was too low to support extensive valley glaciers. Only after comparatively recent uplift in the late Pleistocene might the mountains have become sufficiently high to promote the development and growth of large glaciers.

Inferred preglacial drainage

Major rivers that drain the central Brooks Range commonly flow north or south, normal to axial trends of primary structures. In gross aspect, therefore, the drainage can be termed cross axial. Many tributary streams, however, flow parallel to the strike of the range and are commonly adjusted to structural or lithologic features. On the other hand, the trends of some small glaciated valleys that head in cirques have no apparent bedrock control.

Cross-axial drainage was noted in the eastern Brooks Range by Leffingwell (1919, p. 167), who apparently assumed that the streams were in no way adjusted to structure. He offered three hypotheses to explain the discordant pattern. In the first hypothesis, closely-spaced north-flowing streams developed on a tilted land mass of Mesozoic and Paleozoic rocks prior to major Tertiary deformation. Throughout the main orogenic episode the streams were able to maintain their courses despite the development of large folds and faults. The streams, therefore, would be considered antecedent.

A second hypothesis rested on the assumption that following extensive deformation, the Brooks Range was reduced to a peneplain that subsequently was uplifted and tilted. Rejuvenation of streams that flowed perpendicular to the long axis of the range resulted in entrenchment and the development of consequent drainage.

The third hypothesis relied on the deposition of an unconformable cover of marine sediments on greatly deformed Paleozoic and Mesozoic rocks that had been reduced to a peneplain. Following uplift of the marine plain, rivers flowed north and south and ultimately were superposed upon discordant structures beneath.

Leffingwell favoured the third hypothesis which he believed accounted for all known facts. However, as far as is known, no remnant of an unconformable sedimentary cover in the Brooks Range has ever been described. Furthermore, the presence of a summit peneplain in the Brooks Range is seriously questioned. Consequently, although the hypothesis of superposition may have seemed attractive formerly, there appears to be no convincing evidence to substantiate it. Leffingwell assumed, in his first hypothesis, that the Brooks Range had been subjected to a single episode of mountain building, but it is now known that several periods of deformation affected the Paleozic and Mesozoic rocks (Payne, 1955). It therefore seems very unlikely that a north-south drainage pattern could have persisted through more than one episode of intense deformation. The second hypothesis, like the third, requires peneplanation, for which there is no convincing evidence. How then can the present cross-axial drainage pattern be explained? An alternative hypothesis is offered here that seems to explain the known relationships in the central part of the range.

Within the map area, the John-Anaktuvuk valley and the north-trending segment of Inukpasugruk Creek appear distinctly cross axial with respect to regional structural axes. These valleys, however, lie approximately parallel to a secondary joint set that trends between N. 10° E. and N. 45° E. (Fig. 8). Tributary valleys, as well as the east branch of the Anaktuvuk River, the east branch of Inukpasugruk Creek, and Contact Creek, all parallel the primary regional joint set that trends between N. 60° W. and N. 80° W., and also lie parallel to major regional structural trends (Figs. 6 and 8). Although some

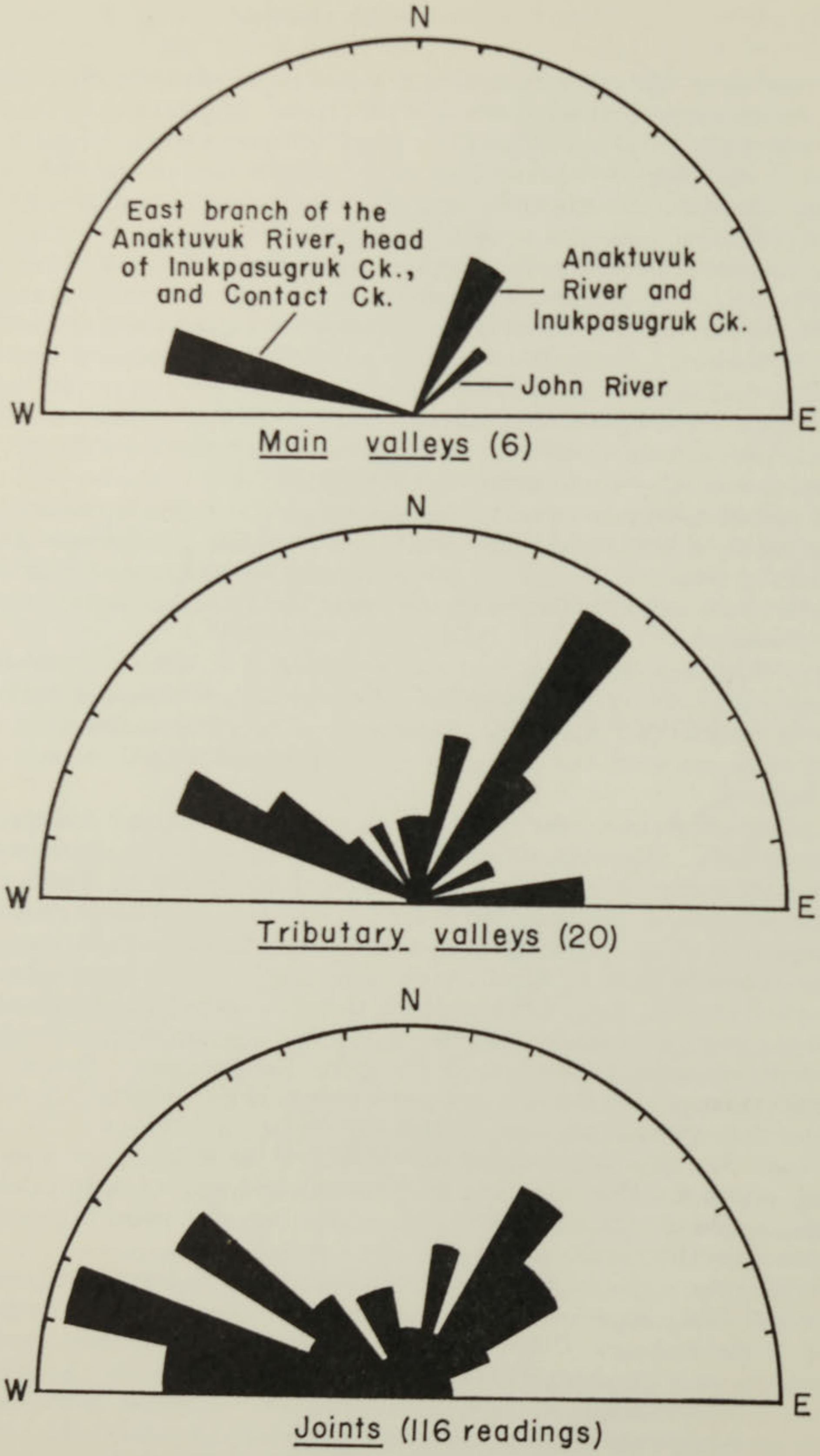


Fig. 8. Comparison of valley trends and joint trends in the Anaktuvuk Pass area.

glaciated valleys that head in cirques do not appear to be closely controlled by structure, most are aligned parallel to one of the joint sets or to a major structural feature. Therefore, despite the cross-axial pattern, major drainage lines perpendicular to as well as parallel to the long axis of the range appear to be controlled by structure.

Although some small glaciated valleys may have formed since the beginning of Pleistocene glaciation, the major glaciated valleys very likely represent preglacial drainage lines, the orientations of which have been modified but little by successive ice advances. Pre-existing stream valleys would have constituted topographic avenues that channelled glacier ice as it flowed from accumulation areas in the higher parts of the range toward the adjacent foothills. If these assumptions are valid, then preglacial drainage appears to have been well adjusted to regional structure.

Prior to Pliocene-Pleistocene uplift, the Brooks Range geanticline, although lower, probably had approximately the same areal extent as the present mountain range. If it remained a positive area throughout the late Tertiary, primary drainage lines very likely became oriented nearly perpendicular to the long axis of the land mass. Assuming sufficient time for drainage to become adjusted to structure, major streams developed parallel to the secondary joint set which is the only consistent north-trending structure in this part of the range. Tributary drainage developed parallel to the primary jointing, which in turn approximately parallels the strike of the bedrock and the axial trends of large regional structures.

During Pliocene-Pleistocene uplift, streams were rejuvenated, but the drainage pattern, which had become adjusted to structure, remained essentially unaltered. North- and south-flowing streams, oriented perpendicular to the axis of uplift, were rejuvenated more or less simultaneously. The effects of uplift were felt by east-west-trending tributaries only as the main streams, which constitute local baselevels of erosion for the tributaries, degraded their valleys. Erosion due to uplift, therefore, tended to deepen and accentuate the north- and south-flowing stream valleys. At the advent of glaciation, drainage probably was essentially as it is today. The major difference lay in the cross profiles of valleys, which very likely were deep V-shaped canyons rather than broad U-shaped troughs.

This hypothesis attempts to explain the cross-axial relationships in the north-central Brooks Range without resorting to peneplanation or superposition. It assumes that the present drainage pattern has been inherited from the pattern that existed prior to Pliocene-Pleistocene uplift of the range. Evidence from the Anaktuvuk Pass area suggests that drainage is, on the whole, well adjusted to structural features of the bedrock. Only further comparison of jointing and regional structure with drainage patterns to the west and east of Anaktuvuk Pass will indicate if this hypothesis applies to the range as a whole.

PLEISTOCENE GEOLOGY

Extent of glaciation in Alaska

Although Alaska is popularly regarded as a land of ice and snow, less than 4 per cent of its total area is presently covered by glaciers. Even at times of maximum Pleistocene glaciation much of the state remained ice-free. Alaska was never overridden by continental ice sheets, but the climate of this vast region so nearly resembled that required for continental glaciation that mountain systems were heavily glaciated. In the high mountain ranges of southern Alaska, valley glaciers coalesced to form ice caps, and ice tongues flowed out on to low country along the coast as broad piedmont lobes. The Brooks Range supported a vast though less impressive network of valley glaciers, which during times of maximum glaciation apparently covered many of the lower summits. These glaciers flowed from an ice divide both northward and southward past the margins of the range, to become large piedmont glaciers. Between the two glaciated mountain belts—the Brooks Range in the north and the coastal ranges farther south—lay a vast region within the Yukon drainage basin in which glaciation was minimal. Several of the more mountainous areas within this region supported cirque glaciers and small valley glaciers during times of maximum glaciation, but this ice was never very extensive (Capps, 1931, Pl. 1; Péwé and Burbank, 1960). Like interior Alaska, much of the Arctic Slope north of the Brooks Range was free of ice throughout the Pleistocene. Although a number of piedmont glaciers extended into this belt and, in northeastern Alaska, reached to within 10 miles of the present coast, a nonglaciated zone of varying width extends across the northern part of the state.

The present distribution of glaciers in Alaska closely reflects limitations imposed by climate and topography. Glaciers are particularly large and active in the high mountains of southern Alaska where precipitation is heaviest. Interior Alaska, despite its low mean annual temperature, has no glaciers because of light snowfall and low altitudes. In northern Alaska precipitation is even less; only as a result of very low mean summer temperature do a number of small glaciers exist in sheltered locations on the highest mountain peaks. A similar but intensified climatic regime in Alaska can be postulated for times of maximum glaciation during the Pleistocene. The almost total absence of glacier ice in the semi-arid interior of the state and the virtual restriction of ice in northern Alaska to the Brooks Range during these times is thereby explained.

Time-stratigraphic terminology

In that part of North America formerly covered by a continental ice sheet, the latest major division of geologic time frequently is referred to as the Quaternary period and is subdivided into the Pleistocene and Recent epochs. As commonly employed, the term "Recent" embraces the "presumed interglacial time following Wisconsin glaciation" (American Geological Institute, 1960, p. 55), and generally is equated with "Postglacial" time of the European pollen chronology. In keeping with this definition, the absolute age of the Pleistocene-Recent boundary obviously varies with latitude and longitude. For example, Deevey (1958, p. 30) pointed out that postglacial conditions, as determined from pollen evidence, probably began 10,000 years earlier in southern New England than in the Lake Mistassini district of central Quebec. A similar lag appears on the North Pacific coast of North America, where pollen stratigraphy indicates that postglacial time began about 10,500 years ago at latitude 49° in southern British Columbia, about 10,000 years ago at latitude 54° in northern British Columbia and southeastern Alaska, and about 9,000 years ago near latitude 60° in south-central Alaska (Heusser, 1960). According to Curray (1961, p. 1,711), the Pleistocene-Recent sedimentary contact along the continental shelves and coastal plains is "a time-transgressive unconformity, older than 11,000 on the outer shelves, and younger inside of approximately 25 to 35 fathoms." Therefore, unlike ideal geologic time-stratigraphic boundaries, the Pleistocene-Recent boundary, as defined above, is time-transgressive.

Recently there has been an effort to fix for this boundary an absolute age that would be of worldwide significance, thereby making it conform with traditional stratigraphic usage. A diversity of opinion exists, however, as to where the boundary should be placed. Frye and Willman (1960, p. 9) proposed fixing the Wisconsin-Recent boundary at 5,000 years BP, which they believe to mark the time when rising sea level reached "its present position of essential equilibrium." In terms of the radiocarbon-dated pollen sequence of Europe, Postglacial time began a little more than 10,000 years ago (Wright, 1957, p. 450). Evidence from deep-sea cores has led Broecker, Ewing and Heezen (1960) to suggest that a worldwide change in climate occurred close to 11,000 years ago, which they interpret as marking the end of the Wisconsin glacial stage. In the north-central Brooks Range, as discussed below, this appears to have been a time when active glacier ice was widespread. Unlike certain other regions of North America, the Anaktuvuk Pass area appears to contain no recognizable stratigraphic or morphologic evidence that suggests a significant environmental change at any of the times that have been proposed as marking the close of the Pleistocene and the beginning of the Recent. If the terms "Pleistocene" and "Recent" (="Postglacial") were employed for the Anaktuvuk Pass area in the above sense, many of the younger *glacial* deposits in this area necessarily would be restricted to "*Postglacial*" time, and many of the earlier deposits could not confidently be assigned to either one epoch or the other. Consequently, it is felt that a Pleistocene-Recent boundary arbitrarily placed at 11,000, 10,000, or 5,000 years BP would have little meaning in the area covered by this investigation.

For the above reasons, in this report the Pleistocene epoch is considered to extend to the present, and the terms "glacial", "late-glacial", "postglacial", and "recent" are used informally to describe Pleistocene events and surficial deposits of the Anaktuvuk Pass area. The term "glacial" refers to events occurring during a significant ice advance or to deposits formed by such an advance. "Late-glacial" refers to events occurring during a period of significant glacial recession and to deposits, formed during such an interval, whose character was influenced by the proximity of glacier ice. The term "postglacial" refers to events taking place during a time when glacier ice had disappeared to the extent

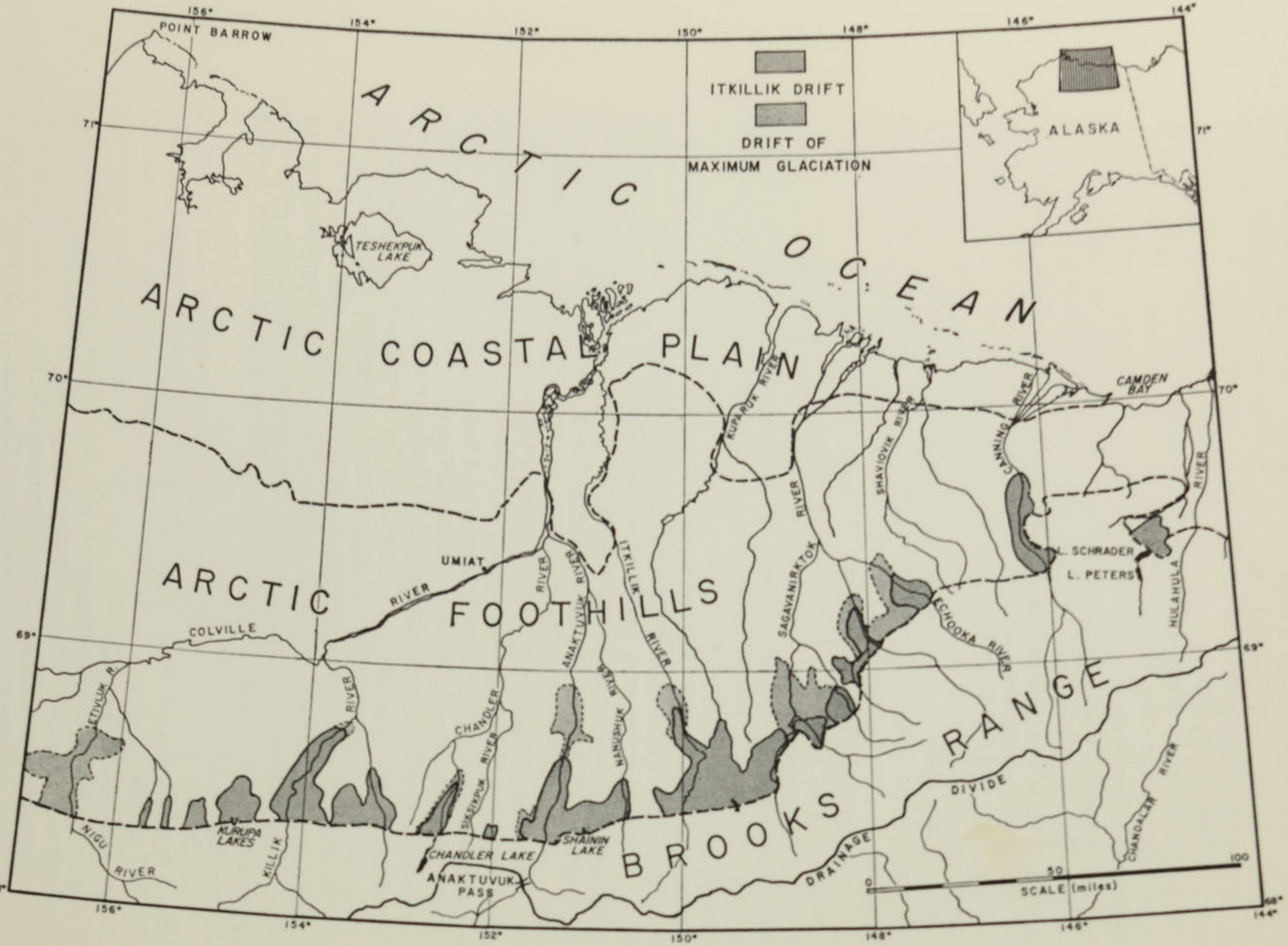


Fig. 9. Maximum extent of Itkillik and pre-Itkillik glaciers in the north-central and northeastern Brooks Range.

that it no longer constituted a recognizable influence, and to sediments deposited during such a time interval. As here defined, each of these terms describes time-transgressive events, and therefore must apply to geographically restricted areas. For example, sliderock deposited near the base of Imnak Mountain at a time when Anaktuvuk Pass was ice-free would be considered a *postglacial* deposit, yet at the same time till, a *glacial* sediment, might be deposited by a cirque glacier in the southern half of the map area. Sediments, then, have been mapped with respect to inferred local conditions at time of deposition. In this report, the term "recent" is used to describe geologic events that have occurred in an environment indistinguishable from that at the pass today. In this sense "recent" is essentially synonymous with the term "postglacial" as defined above.

Summary of glacial history

Multiple glaciation in the northern Brooks Range is now well documented, but only the history of the later ice advances is at all well understood. These later glaciations (Itkillik and younger) are late Pleistocene in age and can be correlated with classical Wisconsin and post-Wisconsin events elsewhere in North America.

A change to colder climates in northern Alaska in conjunction with significant Pliocene-Pleistocene uplift of the Brooks Range produced conditions favourable for the development and growth of alpine glaciers. The earliest record of glaciation consists of weathered drift assigned to the Anaktuvuk glaciation. During this advance large valley glaciers flowed north as much as 40 miles into the foothills belt, mainly along the axes of preglacial stream valleys, and coalesced to form broad piedmont lobes. The advanced degree of dissection and mass-wasting of the deposits differs from that of the next-younger ice advance, the Sagavanirktok glaciation, evidence of which has been found only in the eastern part of the north-central Brooks Range. Glaciers were not as extensive as during the preceding glaciation, for at the Sagavanirktok maximum the largest reached a position only 30 miles from the northern front of the range. Both during this advance and the Anaktuvuk glaciation, valleys within the range probably were filled with ice to depths of several thousand feet, so that only the highest summits protruded above the glaciers. The inferred maximum northward extent of Pleistocene glaciers in the north-central part of the range is shown in Fig. 9.

In comparison with older drift sheets, glacial deposits of the Itkillik and younger advances appear fresh and little altered by postglacial erosion and mass-wasting. Piedmont lobes of the Itkillik glaciation generally were less extensive than those of the older glaciations (Fig. 9), but in some areas they may have covered older drift completely. Most glaciers extended 10 to 30 miles beyond the range front, where they overflowed low interstream divides and coalesced to form piedmont lobes, as in the earlier glaciations. Major stream valleys within the range were buried under ice to depths of 2,000 to 3,000 feet. After reaching a maximum northward extent, glaciers began a fluctuating retreat, and a series of recessional moraines were built behind the outermost terminal ridge (Fig. 10). Two major readvances, the Anayaknaurak and Antler Valley, occurred during the initial period of recession (Fig. 10), and following the younger

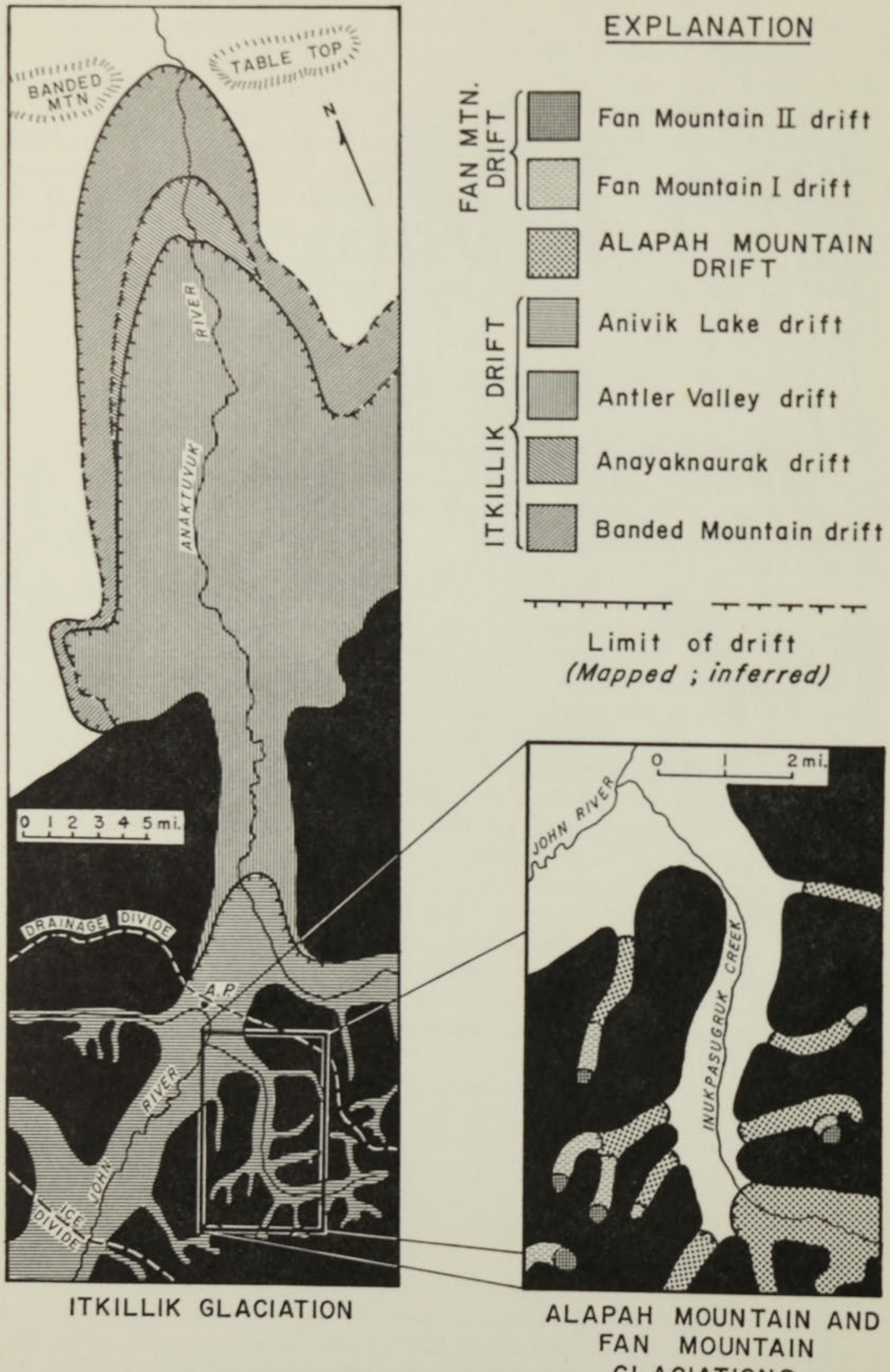


Fig. 10. Limits of late Pleistocene drift sheets in the Anaktuvuk Valley and its tributaries.

of these the terminal portions of glaciers stagnated. As ice in the major valleys wasted away, vast quantities of meltwater were released. Gravel, carried by meltwater streams, was deposited along the valley floors in contact with stagnant residual ice, giving rise to a variety of topographic features. Well back within the range, however, ice remained active, and a still later climatic oscillation resulted in a final significant readvance of the ice. This readvance, designated the Anivik Lake, probably was short-lived. Valley glaciers, then much reduced in size, built end moraines that cross the floors of most major stream valleys (Fig. 10). Appreciable melting was taking place at this time, for most terminal drift consists of water-sorted sand and gravel. As the climate again warmed, Anivik Lake ice in the main valleys became completely stagnant and wasted away. Upstream from terminal Anivik Lake drift, in the Anaktuvuk Valley, meltwater streams deposited sand and gravel in contact with residual ice. These deposits are nearly continuous with ice-contact gravel in the Anivik Lake terminal moraine which in turn appears continuous with older ice-contact gravels beyond. Glaciers in tributary valleys remained active but continued to retreat, until eventually they receded into cirques and possibly disappeared entirely during a period of much milder climate (the Hypsithermal interval).

Post-Hypsithermal ice advances in the north-central Brooks Range were limited to tributary valleys, and to cirques in the higher parts of the range (Fig. 10). The first of these, the Alapah Mountain glaciation, was characterized by valley glaciers as much as 5 miles long. Small terminal moraines were constructed across tributary valleys, and outwash fans were deposited downstream from them. Two subsequent ice advances, Fan Mountain I and II, probably occurred within the last millennium. During these advances, small glaciers built bouldery moraines in and near cirques. In some cirques deposits of the latest advance lie in contact with melting residual glacier ice. Most modern glaciers, which are restricted to protected cirques in the higher parts of the range, are small and have negative economies, reflecting a general warming trend during recent years.

Pre-Itkillik glaciations

Evidence of glacial advances older than the Itkillik glaciation has not been recognized at Anaktuvuk Pass. Although erratics are common on several mountains at altitudes up to 5,000 feet, probably they were deposited during the Itkillik glaciation. Undoubtedly many of the erosional land forms within the mountain range are products of multiple glacial advances, but the extent to which pre-Itkillik ice modified the topography cannot be determined with certainty. Because terminal deposits of known earlier advances lie beyond Itkillik terminal moraines, it is likely that the ice cover within the range was thicker and more extensive during these early glaciations. Consequently the gross form of many of the prominent erosional features in the range may be largely a result of these early ice advances.

According to Detterman (1953) and to Detterman, Bowsher, and Dutro (1958), ice of a major advance, termed the Anaktuvuk glaciation, extended at least 40 miles north of the mountain front. Deposits of this advance have been recognized along the Etivluk, Nigu, Killik, Anaktuvuk, Nanushuk, and Itkillik rivers. Erosion and mass-wasting have modified the deposits to the extent that constructional topographic features are no longer recognizable. Kettle lakes have been largely filled with sediment or have been drained, and streams are well integrated. Erratic boulders and weathered till constitute the main evidence for this glaciation.

The Sagavanirktok glaciation was named for morainal features and drift along the Sagavanirktok River (Detterman, 1953). Ice advanced about 30 miles beyond the mountain front along the Sagavanirktok River and about 18 miles along the Echooka and Ivishak rivers, and built moraines that are still recognizable. Many kettle lakes associated with terminal drift have been filled or drained, and streams are rather well integrated. Deposits referred to this glaciation have been mapped by Detterman, Bowsher, and Dutro (1958) and by Keller, Morris, and Detterman (1961) only along and east of the Sagavanirktok River. Drift of similar character has not yet been identified near any of the rivers along which deposits of the Anaktuvuk glaciation have been recognized. Although several ice lobes of the Anaktuvuk glaciation reached as much as 40 miles beyond the range front, those along the Killik and Etivluk rivers extended out only 25 to 30 miles. Possibly, therefore, the Sagavanirktok deposits are broadly equivalent to the Anaktuvuk drift but for some reason have been less modified by erosion and mass-wasting. It is also possible that they represent a late readvance of the Anaktuvuk ice that extended beyond older Anaktuvuk drift in the Sagavanirktok River region. Alternatively, Sagavanirktok drift west of the Sagavanirktok River may be largely or completely buried by drift of Itkillik age.

Itkillik glaciation

The Itkillik glaciation was named by Detterman (1953) for glacial deposits along the Itkillik River. According to Detterman, Bowsher, and Dutro (1958), ice from this advance extended north 10 to 30 miles beyond the mountain front. Earlier, drift of probable Itkillik age was recognized by Schrader (1904, p. 91) north of the range. He commented that "during the zenith of the Ice age the northern edge of the range was occupied by a more or less extensive ice sheet, which, as a small regional or piedmont glacier, thinning out toward the north, extended northward over a considerable portion of the Anaktuvuk Plateau, its occurrence at that time being, perhaps, similar to that of the Bering or Malaspina glaciers of to-day." This glaciation was the last major ice advance to extend beyond the north front of the Brooks Range. The present form of most ice-sculptured land forms near Anaktuvuk Pass probably dates from this glaciation.

Pre-Anivik Lake substages

Drift beyond the range front

A prominent drift border, the apex of which lies at the latitude of Banded Mountain, was correlated by Detterman, Bowsher, and Dutro (1958, Fig. 3) with the border of the type Itkillik drift sheet along the Itkillik River. Porter (1964a) subsequently showed that this border represents the maximum advance of ice along the Anaktuvuk Valley during the earliest recognized substage (Banded Mountain) of the Itkillik glaciation. The drift border trends southwest from Banded Mountain as far as Natvakruak Lake, from which point it appears to extend south toward the range front. East of the Anaktuvuk River the drift border extends southeast and then east to a point north of Shainin Lake. The drift sheet thus delineated forms a broad lobe that averages about 10 miles wide and extends 23 miles north of the range (Fig. 10).

During the initial phase of deglaciation two significant readvances occurred, the evidence for which lies between 4 and 10 miles upstream from the terminal moraine at Banded Mountain. The Anayaknaurak readvance left a poorly defined drift border 4 miles behind the Banded Mountain moraine; the main stratigraphic evidence is preserved in a section exposed in a cutbank along the Anaktuvuk River (Porter, 1964a). During the maximum of the still-younger Antler Valley substage, the ice margin lay 16 miles north of the range front. The Antler Valley moraine, characterized by irregular knob-and-kettle topography, contrasts sharply with smoother, more gentle slopes on older drift to the north, and with nearby nonglaciated terrain. Behind both the Banded Mountain and Antler Valley moraines lie a series of recessional moraines formed during retreat of the glacier from these ice positions (Fig. 10).

Drift within the range

Most pre-Anivik Lake drift within the Anaktuvuk Pass area dates from the Antler Valley substage of the Itkillik glaciation and lies largely north of the Anivik Lake moraine near the northern boundary of the map area. It consists of ground moraine and of stratified sand and gravel of probable ice-contact origin deposited during deglaciation.

On ground moraine west of Nulak Lake and southwest of Kungomovik Creek vegetation is thick and drainage generally is poor. Water collects in numerous small ponds that form in swales between solifluction lobes. Vegetation consists primarily of *Eriophorum* tussocks and in many places grows on a peaty organic layer a foot or more thick. Erratic boulders are uncommon on the surface. Any original surface boulders probably have been largely buried by vegetation or by mass-movement of surface sediment. Exposed erratic boulders show some evidence of weathering; however, none observed possessed a weathering rind more than a quarter-inch thick.

Pre-Anivik Lake till was nowhere found exposed within the map area but samples were obtained by digging in areas underlain by ground moraine. Because of the shallow frost table, none of the samples were collected from below a depth of one foot. Very likely this sediment has been considerably disturbed by frost action but the over-all composition may approximate that of undisturbed till beneath. This light olive-gray sediment is nonsorted and contains no stones larger than pebbles. These consist almost entirely of sandstone and conglomerate derived from the Kanayut conglomerate. Included fragments of black chert could have come either from the Kanayut or from the Lisburne group. Red and black shale fragments probably were derived from the Kanayut and the Kayak shale. More than 90 per cent of the pebbles are angular; the remainder are rounded or subrounded. The till matrix which consists of approximately 60 to 65 per cent sand, 20 per cent silt, and 15 to 20 per cent clay, is limy and effervesces moderately in dilute hydrochloric acid.

Owing to lack of exposures, the thickness of Itkillik till near Anaktuvuk Pass is unknown. In discussing the Itkillik drift in the north-central Brooks Range, Detterman (1953, p. 11) stated that "Over much of the area the till forms a thin mantle, 30 to 50 feet thick, over bedrock. A few well-developed moraines are as much as 200 feet thick."

Tundra-covered mounds and linear ridges of stratified sand and gravel, which probably had an ice-contact origin, are found on the valley floor beyond the Anivik Lake moraine. Most are topographically sharp, having experienced little modification by mass-wasting. Where exposed in cutbanks along the Anaktuvuk River, the sediments generally are poorly sorted, although lenses of well-sorted material are present locally. Particle size ranges from fine sand to boulders 1 to 2 feet in diameter, but small cobbles are most common. Cut-and-fill stratification is characteristic of sand bodies within the deposits. The under surfaces of cobbles and pebbles in the upper foot or two of the gravels are encrusted with calcium carbonate as much as half an inch thick. Lower in the deposits, the carbonate coating is generally absent or very thin. Hill and Tedrow (1961, p. 99) suggested that such carbonate crusts result from leaching of carbonate from limestone cobbles in surface horizons, with reprecipitation below. Carbonate crusts on the under sides of stones in stratified drift are characteristic of well-drained sites where Arctic Brown soil is present. Therefore leaching and precipitation of carbonates probably are part of the soil-forming process.

Pre-Anivik Lake gravel half a mile northeast of Anivik Lake (pebble-count locality 0 on Fig. 1) consists of 61 per cent limestone, 20 per cent chert (probably largely from the Lisburne group), 11.5 per cent sandstone, 3.5 per cent shale, 2.5 per cent siltstone, and 1.5 per cent conglomerate. Although the percentages may vary somewhat farther north, depending on the type of bedrock cropping out along the valley, Lisburne limestone and Kanayut conglomerate probably constitute the bulk of the stratified Itkillik sediments, even beyond the range front.

Erratics

Erratics were seen on all mountains in the northern half of the map area and on several peaks bordering Inukpasugruk Creek. None were seen on Ridge Peak however. Although ice-transported stones undoubtedly are present on Ridge Peak and on the contiguous mountains to the south, they were not recognized as erratics because they are of the same lithology as the bedrock on which they rest.

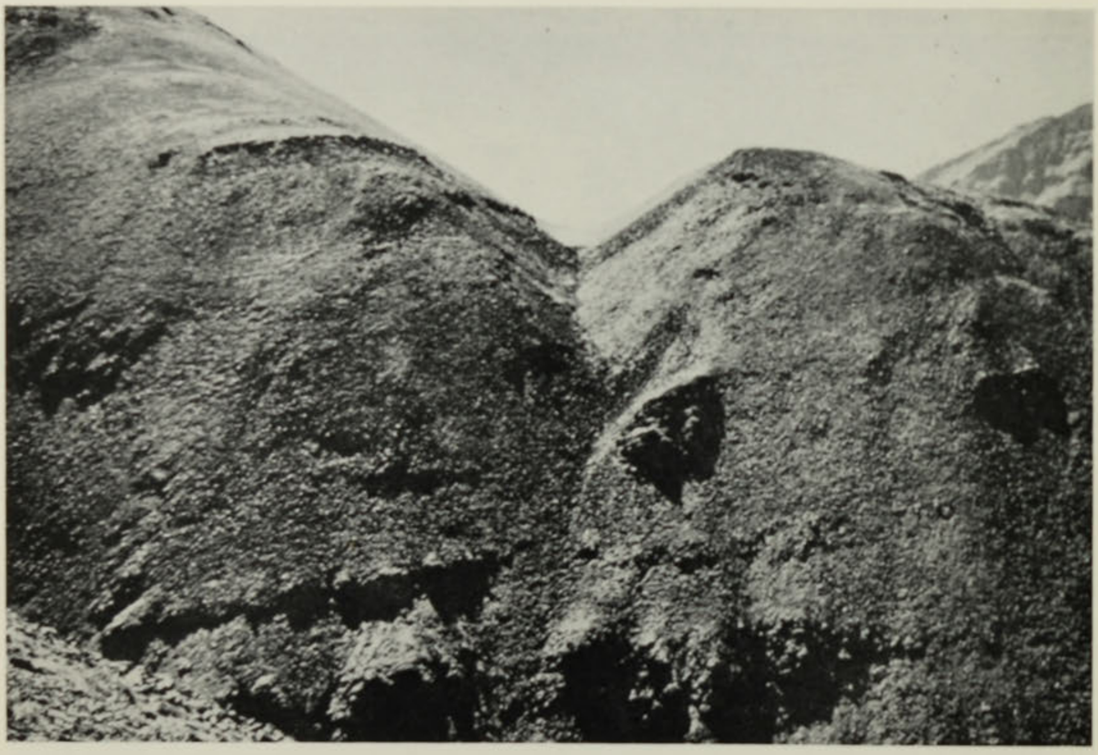
Erratics range in size from pebbles to large boulders as much as 10 feet in diameter (Pl. 2). On limestone peaks erratics consist of conglomerate or sandstone derived from the Kanayut conglomerate. Limestone erratics that originated in a belt of deformed Lisburne rocks at the head of Inukpasugruk Creek are found on mountain slopes of Kanayut conglomerate along the lower part of Inukpasugruk Creek. Conglomerate erratics occur at several places on the Hunt Fork shale.

Most erratics show little evidence of weathering. Some conglomerate erratics have a weathering rind up to a quarter-inch thick, which is typical of many postglacial bedrock exposures as well. Limestone erratics appear to have undergone some solution, but otherwise they appear fresh and unweathered.

Pl. 1. View south up glaciated valley of Inukpasugruk Creek showing U-shaped cross-profile of valley, truncated spurs, hanging tributary valleys, and cirques.

Pl. 2. Conglomerate erratic resting on Hunt Fork shale on the south side of Mount Rulland at an altitude of 4,150 feet (about 1,700 feet above Inukpasugruk Creek).

Pl. 3. View east up glaciated hanging valley between Mount Hago (left) and Mount Ahgook (right). Note truncated spurs facing Inukpasugruk Creek (bottom), lateral moraine at base of left spur, and postglacial gorge cut in bedrock at lip of hanging valley.



Pl. 4. Abandoned meltwater-stream channel on northwest ridge of Mount Ingstad seen from continuation of channel on next ridge north. Depth of channel segment is about 100 feet.

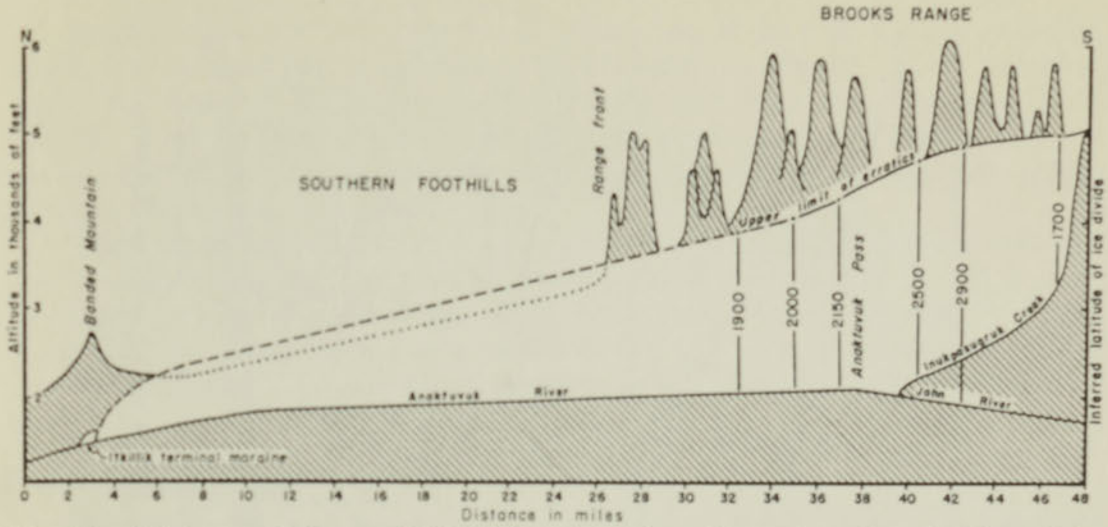


Fig. 11. Minimum thickness of Itkillik ice along the valleys of Anaktuvuk River, John River, and Inukpasugruk Creek at glacial maximum, as inferred from upper limit of erratics near Anaktuvuk Pass. Inferred ice thicknesses in feet.

In several locations, notably along the base of Imnak Mountain and in the channels of Little Contact Creek and Kungomovik Creek, erratics are extremely common. Higher up the mountain they are restricted generally to benches or to areas where slopes are gentle. On Nachramkunga Mountain, Amaguk Mountain, and Imnak Mountain, erratics were not found above a certain altitude, here designated the *upper limit of erratics* (Fig. 1). On Nachramkunga Mountain the highest erratics lie at 4,200 feet. On the north side of Imnak Mountain erratics were encountered only below 3,900 feet. Limestone erratics were found on Mount Rulland to an altitude of 4,300 feet and conglomerate boulders occur on the Hunt Fork shale on the southwest ridge of this mountain at altitudes up to 4,700 feet, a short distance below the summit. On Tigmiakpuk Mountain a conglomerate cobble was found on limestone of the Lisburne group and could only have arrived at that location by glacier transport. The stone was undoubtedly derived from the cirque to the south, the headwall of which consists of Kanayut conglomerate.

The upper limit of erratics in the Anaktuvuk Pass area slopes northward from the pass with a gradient of about 75 feet per mile (Fig. 11). If it is assumed that this limit is also the upper limit of ice action during the Itkillik glaciation, then an approximate minimum thickness of the ice at Itkillik glacial maximum (Banded Mountain substage) can be deduced. In the vicinity of Mount Rulland the ice must have been about 2,500 feet thick. It decreased in thickness northward to about 1,900 feet at the northern border of the map area, and southward up Inukpasugruk Creek to about 1,700 feet in the vicinity of Tigmiakpuk Mountain. Erratics on the Hunt Fork shale near the summit of Toyuk Mountain suggest that this peak was completely buried by ice at glacial maximum. If so, ice in the John Valley at this latitude was at least 2,900 feet thick. If a line representing the upper limit of erratics for the Anaktuvuk Pass area is freely extrapolated northward beyond the range front to the vicinity of the Banded Mountain moraine at the limit of Itkillik drift, the estimated ice thickness several miles upstream from the glacier terminus is between about 800 and 1,000 feet (Fig. 11).

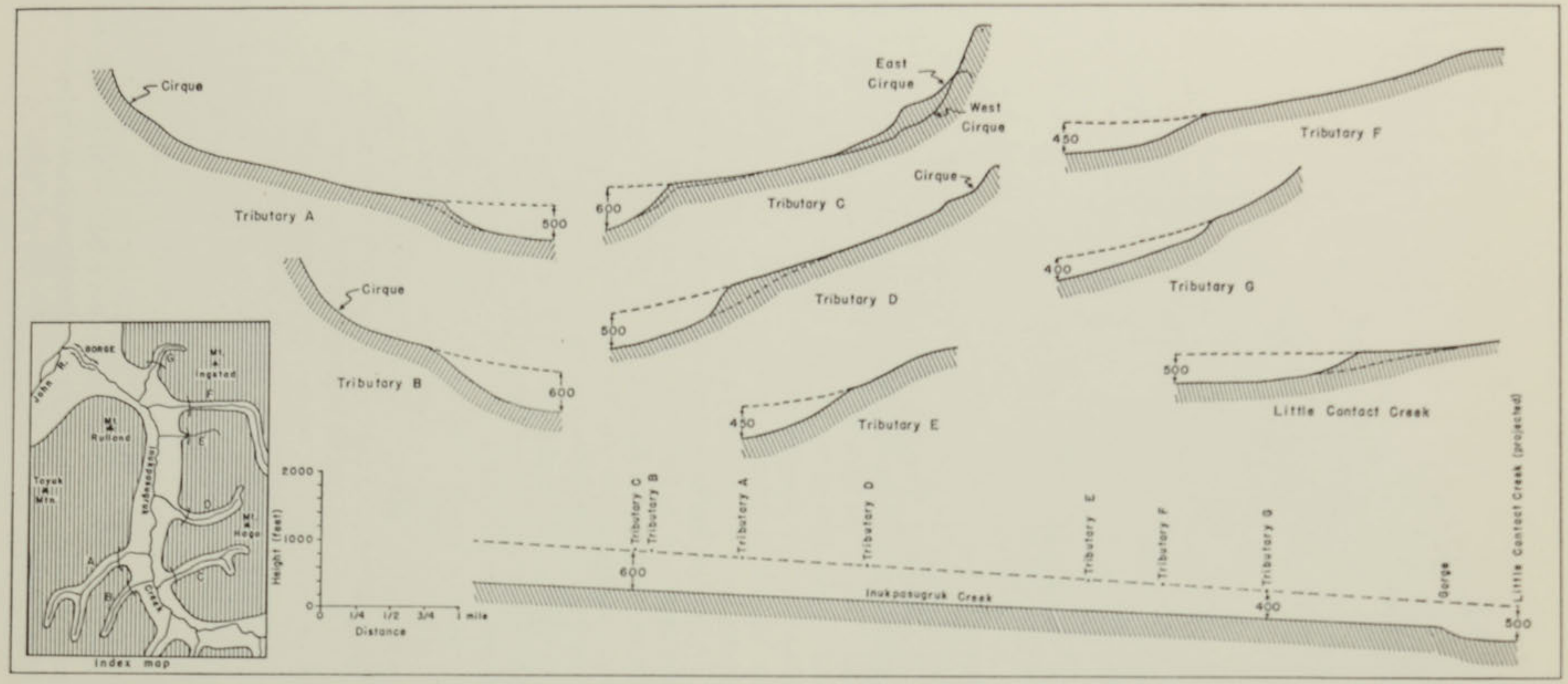


Fig. 12. Reconstructed long profile of Inukpasugruk Creek representing a time when tributary valleys were graded to the main valley.

In arriving at the above figures, the thickness of drift on the valley floors, which for the most part is unknown, has not been considered. Possible lowering of the bedrock valley floors since Itkillik maximum also has been disregarded. Each of these factors could alter the above figures, possibly by more than a hundred feet, but because they operate in opposite directions, they would tend to compensate each other.

These estimates of inferred ice thickness near Anaktuvuk Pass are comparable to values cited by Detterman, Bowsher, and Dutro (1958, p. 52) for inferred thickness of glaciers in the Killik River area. They state that " . . . the upper limit of ice-action is about 1,800 to 2,000 feet above the valley floor and erratics are found 1,200 feet above the river in the foothills north of the mountains."

Erosional land forms

Ice-sculptured land forms in the north-central Brooks Range are products of more than one major glaciation, but their present configuration is due largely to modification by Itkillik ice. Large U-shaped valleys undoubtedly existed prior to the Itkillik advance and cirques probably were as numerous as they are today, but a significant amount of erosion has taken place since the advent of the Itkillik glaciation, as evidenced by the extensive mantle of drift behind the Itkillik terminal moraine. An estimate of the minimum amount of valley deepening that has occurred since the beginning of the Itkillik advance can be obtained by studying the relationship of hanging tributary valleys to trunk valleys. Tributary valleys join the valley of Inukpasugruk Creek at altitudes several hundred feet above the present stream (Pl. 3). If the long profiles of these tributary valleys are extended to a position above Inukpasugruk Creek, the points where the extended profiles cross the creek lie between 400 and 600 feet above the valley floor (Fig. 12). If connected, these points define a sloping line that approximately parallels the present long profile of Inukpasugruk Creek. If it is assumed that this line represents the valley profile when tributary valleys were graded to the valley of Inukpasugruk Creek and that the profile dates from a post-Anaktuvuk, pre-Itkillik nonglacial interval (possibly a major interglacial), then the difference in altitude between the reconstructed long profile and the present long profile represents the *minimum* amount of valley excavation by Itkillik and post-Itkillik ice. In making the reconstruction, it is also assumed that deepening of tributary valleys since the disappearance of Itkillik ice has been negligible. If extended to the centre of the John Valley, the reconstructed long profile lies 500 feet above the John River. The extended long profile of Little Contact Creek, which enters the main valley as a hanging tributary, lies 500 feet above the valley floor at Anaktuvuk Pass. Post-Itkillik ice erosion is not a factor in the case of Little Contact Creek, for its valley does not head in cirques and has remained free of glaciers since the disappearance of Itkillik ice. The foregoing relations suggest that from the drainage divide south, the John Valley may have been deepened by at least 500 feet since the beginning of the Itkillik glaciation. North of the drainage divide, hanging tributary valleys are absent, and an estimate of valley deepening is not possible.

Greater erosion in the upper reaches of Inukpasugruk Creek Valley very likely is the result of a longer period of glacier activity. Glaciers there eroded the valley floor during the early phases of the Itkillik glaciation before they reached the main valley, and probably were active long after ice in the main valley had ceased to flow. Glaciers also actively eroded the upper 5 miles of the valley floor during the subsequent Alapah Mountain glaciation. The over-all effect of Itkillik and post-Itkillik glacial erosion, therefore, was to decrease slightly the gradient of Inukpasugruk Creek by overdeepening the headward portion.

Truncated mountain spurs along the margins of the main valleys rise precipitously above the valley floors. Along the John-Anaktuvuk valley these faces range in height from 2,000 to 2,800 feet; along the valley of Inukpasugruk Creek they stand as much as 2,200 feet above the valley floor (Pls. 1 and 3). Although the present height and steepness of the faces in themselves do not indicate that Itkillik ice extended to the crests of these spurs, the fact that erratics attributed to this glaciation lie even higher on some of the mountains suggests that the present form of the truncated spurs is due largely to modification by Itkillik ice.

Cirques located in the southern third of the map area undoubtedly have been occupied repeatedly by glacier ice during each successive alpine glaciation. The headward growth of cirques on opposite sides of some mountain crests has produced knife-edge arêtes and matterhorn peaks. Typical of such land forms are Kollutuk Mountain, Pyramid Peak, Cirque Peak, and Mount Hago. Although the present form of cirques may be largely a result of erosion during the Itkillik glaciation, end moraines of younger ice advances point to locally substantial post-Itkillik modification. Continued frost action since the disappearance of glaciers from cirques has kept cirque headwalls steep and ridge crests sharp.

Meltwater-stream channels

A number of trenches cut into bedrock spurs or perched on mountain sides in the Anaktuvuk Pass area are believed to be abandoned segments of former glacier-margin stream channels. The orientation of these channels characteristically bears no relation either to lithology or structure. Several are continuous for more than half a mile. Channels lie within a wide range of altitudes, but none were observed above the upper limit of erratics. Probably these features can be ascribed to the recessional phases of the Itkillik glaciation.

The origin of similar meltwater channels has been described in detail by Tarr (1908) and by von Engeln (1911, p. 128) who cited an example of a marginal stream of the Hidden Glacier near Yakutat Bay which, within a period of not more than three years, cut a channel in bedrock that was 6 to 9 feet deep and 4 to 6 feet wide. Channels like those at Anaktuvuk Pass might therefore have resulted from relatively short but vigorous periods of stream erosion.

Among the most prominent of these features at Anaktuvuk Pass is a channel that lies on the northwest ridge of Mount Ingstad at an average altitude of 3,550 feet (Pl. 4 and Fig. 1). It is half a mile long and as much as 100 feet deep. It cuts across the strike of the bedrock, and bears no apparent relation to structure. The floor of the channel is covered with vegetation, and locally is covered with rubble from the adjacent mountain slope. Some rounded cobbles, apparently stream worn, were seen near the south end. From its southwestern extremity, where it terminates in space at an altitude of 3,650 feet, the channel slopes northeast at about 3 degrees. This channel is also seen on the next ridge to the north which it crosses at an altitude of 3,450 feet. The northward slope of the channel floor indicates that the stream that carved this feature originated to the south in the valley of Inukpasugruk Creek and flowed north across the mountain spur. Part of its course apparently lay on glacier ice, but locally it cut a deep, sharply defined channel in bedrock.

At several places along the northeast side of the valley of Inukpasugruk Creek benches, apparently uncontrolled by either lithology or structure, lie at altitudes between 3,000 and 3,500 feet. Possibly these benches have also been eroded by ice-marginal meltwater streams that flowed north along the valley side.

Several small channel-like features cross the lower part of the northwest ridge of Red Rock Mountain in the area underlain by Hunt Fork shale. The highest lies at an altitude of 3,950 feet. Two lower channels cross the ridge at 3,750 feet and 3,600 feet. Each was probably excavated by meltwater derived from ice that occupied the tributary valley between Mount Ingstad, Three River Mountain, and Red Rock Mountain. Erratics at 4,000 feet on this ridge indicate that the area where the channels occur was buried under ice at glacial maximum, so the channels must have been excavated during glaciation.

The most impressive set of abandoned meltwater channels in the area lies on the east face of Ridge Peak. This channel system begins at an altitude of 3,500 feet and extends to the valley floor near the base of the mountain at 2,300 feet. The channel system records successive positions of a meltwater stream that flowed along the base of Ridge Peak during deglaciation. Except for one branch, each of the perched channel segments slopes north or northeast. At an altitude of 2,950 feet the uppermost channel changes from a northeast course along the mountain side and turns abruptly south and east. The shift in direction of drainage may relate to disappearance of ice in the main valley, which allowed the stream to flow directly downslope to a lower level. There is some indication that this channel continues east for about half a mile across the valley floor before swinging north again. The lower part of the channel system may date from late in the Anivik Lake substage, in which case the east-trending segment of the channel might have been occupied by a meltwater stream that flowed beneath or beside stagnant Anivik Lake ice. There is no recognizable difference between the channels lying along the floor of the valley and those perched high on the mountain side. The channel system seems, therefore, to record nearly continuous deglaciation beginning at least 1,500 feet above the valley floor, with excavation of meltwater channels at successively lower levels on the valley side.

A series of three benches on the east face of Ridge Peak that lie between 2,500 and 2,700 feet may also be stream-cut features. Like the benches along the valley side of Inukpasugruk Creek, they bear no apparent structural relation to the bedrock.

Two meltwater channels beyond the map area and just east of Napaktualuit Mountain at altitudes of 2,970 and 3,165 feet were excavated by meltwater streams that flowed west along the valley side toward Anaktuvuk Pass.

A number of other channel-like features that are situated at local meltwater spillways lie at higher altitudes throughout the area. Several of these, such as the one west of Imnak Mountain, and the one on the east ridge of Nachramkunga Mountain, are only slightly below the upper limit of erratics. None of these higher channels are as deep as those at lower altitudes, possibly owing to smaller volume of meltwater flowing through them and to a shorter period of stream erosion.

Direction of ice movement and position of ice divide

As a result of his reconnaissance studies in the central Brooks Range, Schrader (1904, p. 91) concluded that "The zone of maximum snowfall, and consequently of maximum ice accumulation, trending in an east-west direction, was apparently in the northern part of the range at least somewhat north of its median line." Although he did not define exactly the position of the ice divide, he apparently believed that it lay north of Fork Peak. "In the region of Fork Peak, near the head of John River, at the confluence of several of its tributaries, the valley is wide and open and is floored by a till sheet at least 150 feet in thickness. The surface declines to the southwest, denoting that the deposit has largely come from the northeast, a view which is supported by bedrock striæ farther down the valley." (p. 84). He thus implied that the ice divide lay to the northeast, probably near the position of the present drainage divide.

Several lines of evidence suggest that the ice divide actually lay south of the present drainage divide at Anaktuvuk Pass. The presence of conglomerate erratics on Nachramkunga Mountain at altitudes up to 4,200 feet suggests that the ice divide must have been situated at least south of Contact Creek, for the nearest conglomerate outcrops at comparable altitudes are on Ridge Peak. If the ice divide had coincided with the present drainage divide, these erratics would be anomalous, for there are no conglomerate outcrops north of Contact Creek on the west side of the valley above 2,800 feet.

Abandoned meltwater-stream channels provide additional evidence. As pointed out above, channels on the east face of Ridge Peak slope consistently north. The perched channel on the west side of Mount Ingstad also slopes in this direction, as do similar channels that lie just south of the map area on the east side of the John Valley at an altitude of about 4,000 feet. These features indicate that during deglaciation, meltwater flowed north along the John Valley and the glacier surface must have sloped north from a divide that lay south of Kollutuk Creek.

Three miles south of the present drainage divide on the west side of the John Valley, numerous bedrock outcrops on the valley floor show well-developed stoss-and-lee topography. The southwest sides of the outcrops generally are smooth and abraded; northeast sides commonly are small, steep scarps determined by joint planes. Evidently these features are the result of glacial abrasion and glacial quarrying, respectively. The consistent asymmetry of the outcrops indicates that in this area ice moved north up the valley. Although these features may have formed largely during the Anivik Lake advance, the ice divide at that time, as pointed out below, is believed to have coincided with that of the Itkillik maximum. Stoss-and-lee topography south of the pass, therefore, supports an inferred ice divide south of Anaktuvuk Pass along the John Valley.

Although it was not possible during the present investigation to study the John Valley south of the map area, the probable position of the Itkillik ice divide lies opposite Fork Peak in the region where the John Valley widens appreciably (Fig. 13). This is the same area that Schrader observed to be floored by a "till" sheet at least 150 feet thick. This broad basin, at the margins of

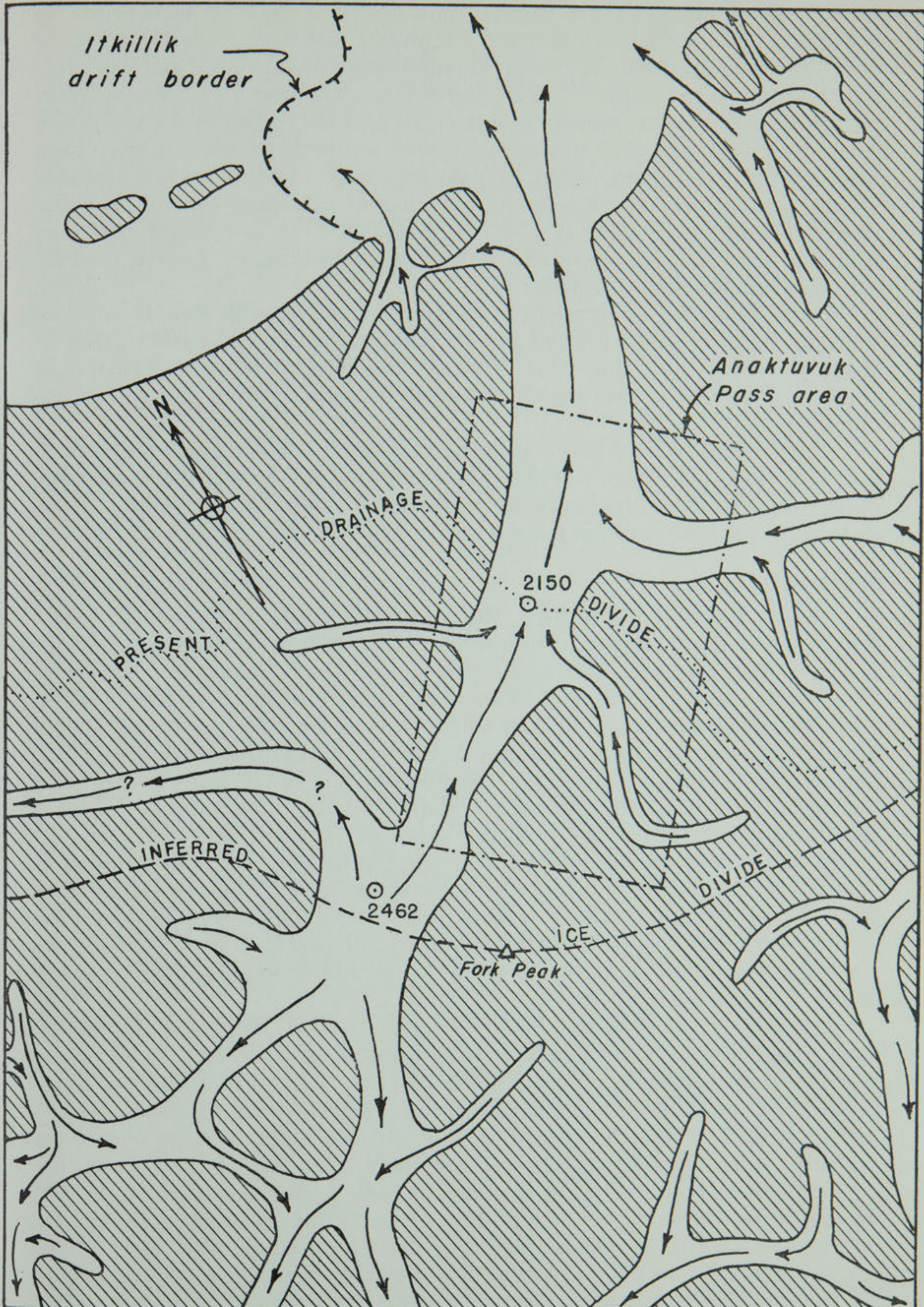


Fig. 13. Inferred directions of ice flow and position of ice divide during Itkillik glaciation. Altitudes in feet.

which four tributary streams enter to join the John River, is surrounded by high peaks up to 6,000 feet in altitude. It would have been a likely site for the development and growth of a large ice mass from which valley glaciers could flow both north and south. This region at present appears to receive far more precipitation during the summer months than does the region in the vicinity of Anaktuvuk Pass, probably owing to its more southerly position in the range. During glacial maximum, when temperatures were lower, snowfall probably was far greater here than it is today, for a higher percentage of the total precipitation would have fallen as snow. Consequently this area might have constituted a more likely catchment basin that could nourish large glaciers, than the area at the present drainage divide.

If the upper limit of erratics, as delineated at Anaktuvuk Pass, is extended south to the inferred position of the ice divide, it would lie nearly 3,000 feet above the valley floor (Fig. 11). All but the highest peaks would have been covered by ice at the time the erratics were deposited farther north at Anaktuvuk Pass.

North of the inferred ice divide, glaciers generally flowed north to the foothills belt (Fig. 13). South of the divide the flow of ice was more complex, owing to the system of transverse interconnecting valleys but, in general, it was directed toward the southern margin of the range.

Summary of history

During the Itkillik glaciation, valley glaciers in the north-central Brooks Range flowed north and south from an ice divide that lay near the 68th parallel. North of the mountains large valley glaciers overflowed interstream divides to form broad coalescing piedmont lobes. During the Banded Mountain substage, when Itkillik glaciers achieved their maximum size, ice extended 23 miles north of the range front along the Anaktuvuk River. Within the range all but the highest peaks were inundated, the John-Anaktuvuk valley being buried to a minimum depth of nearly 3,000 feet at the ice divide. Thickness of the piedmont lobe north of the range probably averaged between 1,000 and 1,500 feet at that time. As a result of glacial scouring and quarrying, the floor of the main valley probably was deepened by several hundred feet. Tributary valleys were left hanging as trunk glaciers eroded their valleys more rapidly than their smaller tributaries. A till sheet of unknown but probably variable thickness was deposited on valley floors within the range and in the foothills belt north of the mountain front.

After reaching its maximum extent near Banded Mountain, the glacier occupying the Anaktuvuk Valley began a fluctuating retreat. Small lobate moraines mark successive terminal positions of the ice front during the recessional phase. As the ice front retreated, the glacier also melted down and ice-margin streams within the range cut channels into bedrock spurs and across mountain faces. During retreat, two important readvances of the glacier occurred bringing the terminus to positions 19 and 16 miles, respectively, beyond the north margin of the range. Following the second readvance, the glacier terminus receded to a position near the front of the range. The part of the glacier lying north of the Anaktuvuk Pass area then apparently became largely stagnant. Meltwater streams deposited sand and gravel among wasting ice masses which, on melting, left isolated ice-contact land forms on the valley floor. Depressions formerly occupied by stagnant ice became the sites of small drift-dammed lakes. Postglacial drainage lines were closely controlled by the distribution of drift on valley floors. Re-establishment of tundra vegetation probably kept pace with deglaciation, so that little of the deglaciated terrain remained free of vegetation for long.

Anivik Lake substage

The youngest recognized substage of the Itkillik glacial stage, the Anivik Lake, is named for a small body of water near the northern border of the Anaktuvuk Pass area which immediately adjoins terminal drift deposited by the Itkillik glacier during a final and probably brief readvance or stillstand (Porter, 1964a). Detterman, Bowsher, and Dutro (1958) correlated glacial deposits herein designated Anivik Lake drift with type Echooka drift along the Echooka River in the eastern Brooks Range that was originally named and described by Detterman (1953, p. 12). End moraines in other parts of the range which they correlated with the type Echooka moraine generally lie between 20 and 40 miles from accumulation areas in cirques. Maximum ice movement during this period probably occurred along the Killik and Nigu rivers, where glacier termini lay as much as 50 miles from cirques.

Detterman, Bowsher, and Dutro considered the Echooka to be a rather minor glacial advance or perhaps only a readvance or period of stillstand within the Itkillik glaciation. This assumption has been borne out by the present investigation which has further shown that most of the surficial features and glacial deposits within the map area along the valleys of the John and Anaktuvuk rivers were formed during the final advances of the Itkillik ice.

Anivik Lake moraine

Broad linear ridges of till and irregular bodies of stratified gravel form an arcuate morainal complex bordering the Anaktuvuk River in the northern third of the map area. This complex, here designated the Anivik Lake moraine, marks the terminal position of the Anivik Lake advance and delineates a former ice lobe that was approximately 2.5 miles wide at the latitude of Cache Lake. The moraine is discontinuous and has been considerably eroded by the Anaktuvuk River. Postglacial mass-wasting has smoothed the topography on those parts of the moraine in which till directly underlies the surface. Sections that consist of stratified gravel, although locally dissected by streams, show little postglacial modification and are sharp morphologic features.

Three linear arcuate ridges of till that lie immediately west of Anivik Lake probably record successive positions of the glacier terminus during this readvance. The outermost stands about 50 feet above the general surface of the valley floor and merges both north and south with stratified gravel. Anivik Lake is partly dammed by this morainal ridge and by adjacent ice-contact gravel deposits. The inner two ridges are lower and may merely be thickened portions of the ground moraine. Till is nowhere exposed on these ridges, but poorly size-sorted mineral soil is seen locally in nonsorted circular patterned ground that breaks the otherwise continuous tussock cover.

Similar linear ridges of till west of the Anaktuvuk River are believed to be other segments of the terminal moraine. One lying immediately south of

Nulak Lake, is about 30 feet high and is bordered by stratified gravel along its north side.

Southwest of the alluvial fan of Kungomovik Creek another long ridge parallels the valley wall about half a mile from the base of Amaguk Mountain. Mineral soil exposed in patterned ground is similar to that seen on the moraine segment near Anivik Lake. Surface boulders are uncommon and mass-wasting has smoothed out the topography. Vegetation cover on this ridge is less dense than on adjacent ground moraine to the west and the surface is better drained.

An appreciable part of the Anivik Lake moraine east of the Anaktuvuk River consists of stratified gravels (Pl. 5) that are distributed irregularly and are topographically varied. Knolls and closed depressions are common features, but some deposits are broad and flat-topped or gently undulating. Many moundlike gravel bodies are typical kames; others are long linear ridges that appear to be ice-channel fillings.

The gravel consists mainly of pebbles and cobbles with some interstitial sand. Its composition is fairly uniform; approximately half the stones consist of limestone and chert derived from the Lisburne group, and the remainder consist of conglomerate, sandstone, and siltstone typical of the Kanayut conglomerate (Fig. 14). All rock types crop out along the valley walls upstream (southwest) from the moraine.

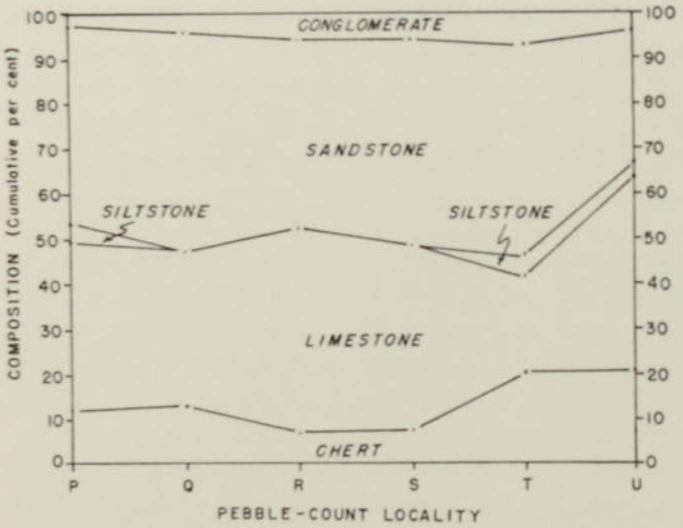


Fig. 14. Pebble composition of gravel deposits of the Anivik Lake moraine. Letters indicate pebble-count localities (see Fig. 1).

The gravels are nearly continuous from Anivik Lake, where they lie between half a mile and a mile from the valley wall, to the south side of Napaktualuit Mountain, where they are found at the base of limestone cliffs and in places are partly covered with sliderock. The kame-and-kettle topography indicates deposition adjacent to or in contact with ice that was either stagnant or very thin and slow-flowing.

Inukpasugruk Creek moraine

A mile above the mouth of Inukpasugruk Creek remnants of a small end moraine, here named the Inukpasugruk Creek moraine, lie adjacent to the creek. The position of this moraine suggests that it formed during the final recession of the Anivik Lake glacier. The moraine has been dissected by Inukpasugruk

Creek and by a tributary that originates on the west side of Mount Ingstad. The moraine segment that lies immediately east of Inukpasugruk Creek stands 45 feet above the valley floor. The upstream side has been eroded by the creek and forms a steep face; the downstream side slopes gradually north and is overlain by alluvial-fan sediments that head in a stream gorge on Mount Ingstad. Boulders and cobbles, common on the upper surface of the moraine, are particularly abundant along its north side. A channel-like feature, probably cut by glacial meltwater, follows the downstream edge of the moraine. Near the foot of Mount Rulland the moraine is hummocky and contains a large number of boulders. The boulders, as well as those on the moraine segment on the opposite side of the creek, consist of Kanayut conglomerate and support a sparse cover of lichen on exposed surfaces. On the whole, this moraine is less densely vegetated than the Anivik Lake moraine.

Lateral moraines

No lateral moraines were recognized along the John-Anaktuvuk valley within the map area. Well-defined lateral moraines are present, however, along the valley of Inukpasugruk Creek (Pl. 6). Their top surfaces lie between about 2,800 and 2,900 feet in the lower part of the valley, and between about 3,000 and 3,100 feet in the vicinity of Mount Ahgook. Upstream from Turret Peak no lateral moraines were recognized.

The moraines are discontinuous along the valley sides and are noticeably absent or poorly developed within the outcrop belt of the Hunt Fork shale. They are particularly prominent beneath steep cliffs of Kanayut conglomerate on the east side of the valley. This distribution, plus the fact that rubble in the moraines consists of Kanayut conglomerate, suggests that the bulk of the material was derived from immediately adjacent cliffs and travelled only a short distance down valley. Most of these lateral moraines are sharp features and have been little altered by mass-wasting, probably because they consist largely of angular blocks of rubble which form a highly permeable deposit.

Where tributaries enter the valley of Inukpasugruk Creek, moraines either are missing or have been greatly dissected. Locally, as at the west end of Mount Hago, talus cones cover the moraines.

Ground moraine

Exposed till was seen at only three places within the map area during the course of this study: in a cutbank bordering the south side of Contact Creek at the Eskimo village of Anaktuvuk Pass, along the north rim of the Inukpasugruk Creek gorge, and in a cutbank along the north side of Kollutuk Creek. The floors of the main valleys are believed to be largely underlain by till, however, and much of these have been mapped as ground moraine.

Ground moraine, which commonly has a nearly continuous cover of *Eriophorum* tussocks, tends to be rolling; it contrasts sharply with ice-contact topography and bedrock elsewhere on the valley floors. Perennially-frozen ground at shallow depths inhibits drainage, and the ground generally is wet. During spring, snow meltwater collects in inter-tussock areas forming innumerable small ponds. Scattered patches of nonsorted patterned ground on ground moraine expose pebbly silt that probably is grossly similar to the till. Surface boulders are more plentiful on Anivik Lake ground moraine than on pre-Anivik

Lake ground moraine and range up to 10 feet in diameter. Few are fully exposed to view. Some are faceted and striated while others are angular and have irregular surfaces; many are covered with lichens. All boulders observed were composed of Kanayut conglomerate, and most had a weathering rind about a quarter-inch thick.

Three feet of stony till is exposed a few yards west of the footbridge that crosses Contact Creek at the Eskimo village. Overlying the till is approximately 12 feet of stratified sand and gravel which decreases in thickness in the upslope direction. The light-olive-gray matrix consists mainly of sand (82 per cent) with lesser amounts of silt and clay. It is calcareous and effervesces strongly in acid. Till stones range in size from fine pebbles to large boulders. Most are angular or subangular, while some are faceted and striated. Till stones were derived largely from the Kanayut conglomerate, 12 per cent being conglomerate and 78 per cent sandstone. The remaining stones are chert (7 per cent) and limestone (3 per cent) from the Lisburne group. A fabric measurement on 71 elongate stones from this locality shows that the mean direction of ice flow at the time of till deposition was N. 80° E. The calcareous nature of the till matrix and the presence of limestone and chert from the Lisburne group suggest that the ice that deposited this till flowed out of Contact Creek, which is the nearest source of Lisburne rocks along the John River drainage. The till fabric supports this inference, for its orientation is oblique to other directional ice-flow indicators (grooves and striations) which approximately parallel the trend of the John-Anaktuvuk valley near Anaktuvuk Pass (Fig. 1).

Approximately 5 feet of till is exposed along the north rim of the Inukpasugruk Creek gorge. In general it is similar to that exposed at Contact Creek but contains no recognizable carbonate, either in the matrix or as till stones. The matrix is largely sand (79 per cent), and till stones are angular fragments of Kanayut conglomerate.

Very stony yellowish-gray till is exposed along the north side of Kollutuk Creek approximately a mile above its junction with the John River. The matrix of this till is calcareous and contains some fragments of dark-gray limestone which probably were derived from Lisburne rocks that crop out in the deformed belt at the head of Kollutuk Creek. Fragments of Hunt Fork shale are abundant in the pebble-size fraction. Most of the till stones, however, consist of Kanayut conglomerate.

As is to be expected, till composition closely reflects the type of bedrock that crops out in the valleys through which the glaciers flowed. With the exception of small areas at the head of Contact Creek and near the head of Kollutuk and Inukpasugruk creeks, Anivik Lake ice south of the Anivik Lake moraine flowed entirely over bedrock of Devonian age. Kanayut conglomerate, which is the most resistant and widespread unit, forms the bulk of the till. The marked absence of carbonate till stones, even in till derived from valleys in which limestone crops out, probably is attributable to the ease with which limestone is broken up and ground into fragments. The strong reaction to acid of till matrix from Contact and Kollutuk creeks indicates that appreciable calcium carbonate is present in the finer size grades at these localities. In general, though, Anivik Lake till along the John-Anaktuvuk valley probably contains little carbonate. Only in tributary valleys that head in cirques carved from the Lisburne group is limestone sufficiently abundant to be recognizable in the till.

Pl. 5. Ice-contact gravels of the Anivik Lake moraine west of Napaktualuit Lake.

Pl. 6. Anivik Lake lateral moraine in valley of Inukpasugruk Creek along west base of Mount Hago.

Pl. 7. Isolated kame on tundra-covered ground moraine north of Summit Lake showing contrast between vegetation on ground moraine (foreground) and on stratified drift.

Pl. 8. Small kettle pond on pitted surface of kame terrace, east side of Contact Creek a mile south of Summit Lake. View is north toward front of range.

Ice-contact stratified drift

Behind the Anivik Lake moraine, the floors of the principal valleys are discontinuously mantled with gravel of ice-contact origin. The bulk of these deposits forms kame terraces adjacent to modern streams, but isolated kames and ice-channel fillings are also common, both in the vicinity of the present streams and on ground moraine beyond the margins of the kame terraces (Pl. 7).

Kames vary widely in size and shape. A number of them occur near Cache Lake (Fig. 1) between two subparallel kame terraces. They rise from 10 to 50 feet above the valley floor and consist largely of cobble gravel. Half a mile south of the Eskimo village at Anaktuvuk Pass a remnant of a small kame, now largely dissected, stands above the flood plain of Contact Creek. Similar kames, surrounded by alluvium, occur in the vicinity of Kollutuk Creek.

The two kame terraces that parallel the John River and the lower part of Contact Creek and extend north to the Anivik Lake moraine, constitute prominent landforms on the valley floor. The eastern terrace is a nearly continuous feature, although in places it has been dissected by streams and locally is covered by alluvial-fan sediments. The western kame terrace is more discontinuous. A mile-long gap in it occurs near the pass, while south of the pass there are frequent gaps. Opposite Kollutuk and Alukvik creeks the deposits are more continuous and more nearly resemble a true kame terrace.

The upper surfaces of the kame terraces lie about 100 feet above the level of the modern streams. A quarter mile southwest of the village the western kame terrace rises 132 feet above the river flood plain. The terrace faces, now largely stabilized by vegetation, rest at angles of 20 to 35 degrees. Apparently little or no postglacial stream modification has occurred beside and north of Summit Lake; here the terrace fronts seem to be original ice-contact faces, although undoubtedly modified to some extent by mass-wasting. Along Contact Creek and the John River the present terrace faces are largely the end product of postglacial stream dissection, and it is doubtful whether any original ice-contact slopes are preserved intact.

Exposures generally are few and poor; at no place was a section sufficiently well exposed to show collapse features in the stratified sediments. The geographic distribution of the deposits and their surficial morphology, especially north of Summit Lake along the inferred ice-contact face, is sufficiently convincing, however, to establish an ice-contact origin for them.

The upper surface of the eastern kame terrace is highest at Anaktuvuk Pass, where it reaches an altitude of 2,225 feet. From this point it declines in altitude both north and south. In the vicinity of the Anivik Lake moraine the top of the terrace lies at about 2,000 feet, only 10 feet above the Anaktuvuk River. Near the southwest corner of the map area it lies at approximately 2,005 feet. Between Inukpasugruk Creek and Summit Lake the upper surface of the terrace is extremely irregular and pitted (Pl. 8). Many closed depressions contain ponds or small lakes, some of which have been partly filled by encroaching vegetation. In contrast, the upper surface north of Summit Lake and south of Inukpasugruk Creek is nearly flat and has a uniform slope; the only major surface irregularities are linear trenches that mark the boundaries between ice-wedge polygons (Pl. 19). Near the southwest corner of the map area the western kame terrace appears to merge with kettle-and-kame topography west of the mouth of Kollutuk Creek. In this region numerous small lakes lie in

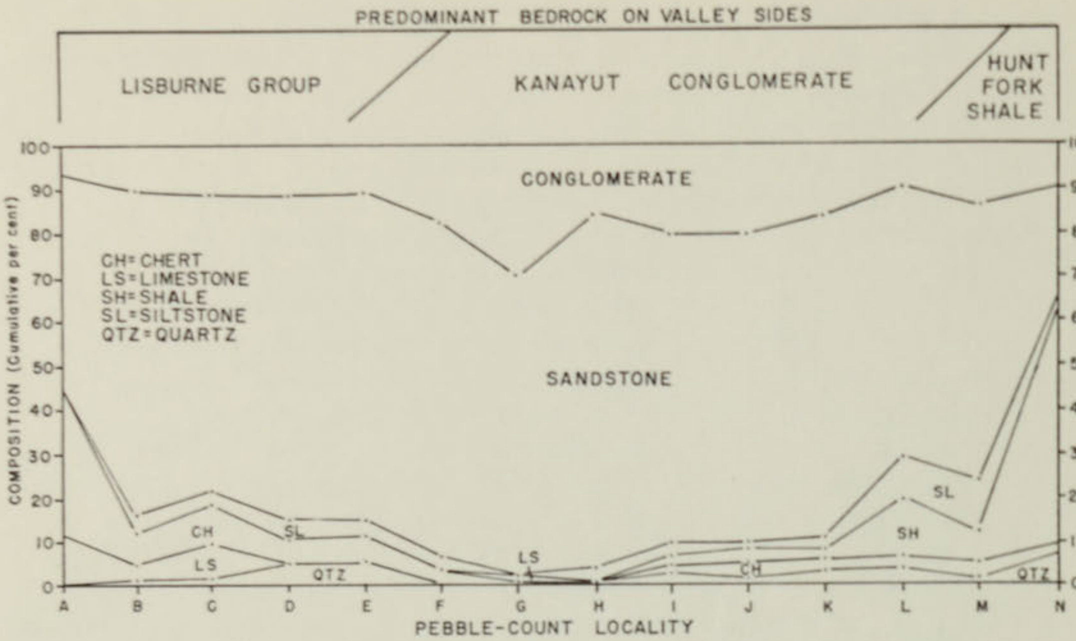


Fig. 15. Pebble composition of kame-terrace sediments along the John-Anaktuvuk valley. Letters indicate pebble-count localities (see Fig. 1).

closed depressions among hills of stratified drift, and the distribution of ice-contact gravel is very irregular. The kame terrace on the east side of the John River at this latitude is largely covered by alluvial-fan sediments deposited by Alukvik and Kollutuk creeks.

Although some erratic boulders up to 3 or 4 feet in diameter are present in the ice-contact deposits, sediments generally range in size from fine sand to small boulders 18 inches in diameter. Well-rounded cobbles 4 to 6 inches in diameter are most common. Many stones in the upper foot or two of the deposits are encrusted with calcium carbonate on their under surfaces, but usually the crust is thinner than that found on stones in Itkillik ice-contact sediments and on stones in outwash of Alapah Mountain age along Contact Creek. The gravel is well drained and perennially-frozen ground commonly is encountered only at depths of more than a foot. The tops of kames and kame terraces are covered with a thin growth of mossy and herbaceous vegetation, in which *Dryas* is the most common form. Locally, especially in trenches between ice-wedge polygons, willow and dwarf birch are abundant.

Pebble counts of the cobble-and-pebble fraction of kame-terrace gravel show that the sediments closely reflect the composition of the local bedrock (Fig. 15). In the vicinity of Kollutuk and Alukvik creeks the percentage of shale and siltstone is unusually high, owing to nearby exposures of the Hunt Fork shale. Along most of the John Valley, conglomerate and sandstone make up the bulk of the sediments. North of Summit Lake, limestone and chert appear in the gravel, as rocks of the Lisburne group begin to crop out on the valley sides. In the pitted area immediately south of Summit Lake the gravel contains a small percentage of limestone; limestone is absent, however, south of Inukpasugruk Creek. To the north limestone appears in the sediments only north of Cache Lake. In the vicinity of Summit Lake, soils within the pitted zone of the kame terrace are noticeably calcareous while those immediately to the north are acid (Jerry Brown, personal communication, 1960). The presence of limestone cobbles in the gravel and the development of calcareous soil on the deposits suggests that sediments in the pitted section of the kame terrace were at least in part derived from a source different from the bulk of the kame-terrace deposits. The most likely source is the valley of Contact Creek, along which rocks of the Lisburne group crop out extensively.

A kame terrace is present also along the north side of the Anaktuvuk River south of Napaktualuit Mountain. This terrace is less well developed than those along the John Valley, but it can be traced discontinuously for at least 3.5 miles to the east edge of the map area. The top of the kame terrace generally lies no more than 20 to 30 feet above the present river level. This terrace appears to have been modified not only through erosion by the Anaktuvuk River and by tributary streams, but by mass-wasting. The poorly exposed sediments consist of nearly equal amounts of Lisburne rocks and Kanayut conglomerate.

Discontinuous isolated bodies of ice-contact gravel on the south side of the Anaktuvuk River may be either remnants of a matching terrace or merely isolated kames that have been modified by postglacial stream erosion.

Gravel bodies of probable ice-contact origin are also found discontinuously along Inukpasugruk Creek south of the Inukpasugruk Creek moraine. That these sediments are not outwash associated with the Turret Peak moraine upstream is indicated by their irregular topography and by the fact that they consist of cobble gravel similar to that of the kame terraces along the John River, rather than of well-sorted silt and sand like that which forms the bulk of the outwash associated with the Turret Peak moraine. These gravel deposits are most numerous from half a mile to a mile and a half upstream from the Inukpasugruk Creek moraine. All have been dissected to some degree by the stream and some have been partly buried by alluvial-fan sediments.

Outwash

Outwash directly associated with the Anivik Lake moraine was not recognized within the map area but may be present farther north beneath younger sediments. Although stratified sediments of the Anivik Lake moraine are believed to be largely ice-contact in origin, some outwash may be included. Immediately north of the moraine the valley floor is mantled with recent alluvium and alluvial-fan sediments, so even if Anivik Lake outwash exists farther north, probably it would not be possible to trace it directly to the moraine.

Isolated bodies of stratified sand and gravel northwest of the Inukpasugruk Creek moraine are believed to be outwash associated with this moraine. Although they are discontinuous and cannot be traced directly to the moraine, they appear to be graded to its upper surface. Probably much more extensive formerly, they have been dissected by Inukpasugruk Creek and partly buried by alluvial-fan sediments. Outwash of Anivik Lake age was seen only downstream from the Inukpasugruk Creek moraine and above the head of the gorge. Possibly outwash was deposited only along this section of the creek, for increased stream competence caused by the abrupt change in channel gradient at the head of the gorge may have prevented deposition downstream from this point. On the other hand, if the building of the Inukpasugruk Creek moraine and of the kame terrace along the John River were simultaneous events, then outwash from the moraine may grade into ice-contact sediments of the kame

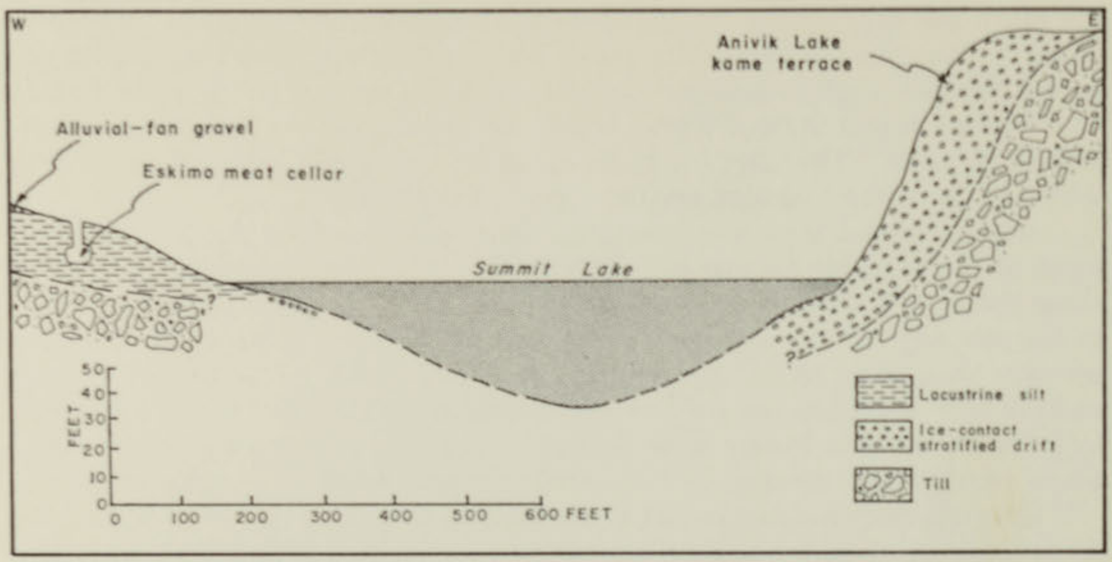


Fig. 16. East-west section across Summit Lake showing inferred distribution of surficial sediments.

terrace. Subsequently, outwash near the gorge would have been eroded away when ice in the John Valley disappeared and Inukpasugruk Creek began cutting a channel through the kame terrace and underlying till-covered bedrock.

Lacustrine sediments

Parallel-bedded, well-sorted silt, exposed along the margins of several lakes in the map area, is believed to have been deposited in ice-margin lakes during deglaciation. Along the west side of Summit Lake 10 to 20 feet of dark silt are exposed (Fig. 16). From the lake margin silt can be traced 700 feet west of the lake, at which point cobble gravel from the alluvial fan of Little Contact Creek appears to overlie it. Locally, alluvial-fan sediments extend nearly to the lake shore. Eskimos living at Anaktuvuk Pass have dug two deep holes for meat cellars in the silt, which is frozen below a depth of several inches. Stratification was not seen in the walls of the cellars, the deepest of which extends 14 feet beneath the surface. Original stratification may have been largely obliterated, however, by growth of small ice lenses which are abundant in the silt. Fragments of organic matter, mainly broken willow twigs, are common throughout the body of sediment, and appear to increase in abundance toward the bottom of the cellars. Erratic pebbles in the deposit probably were ice-rafted to their present positions.

Silt is not exposed on the opposite side of the lake; there an ice-contact face of cobble gravel rises abruptly above the lake surface. The silt, therefore, appears to be limited to the west shore of the present lake. It is believed to have accumulated in a small late-glacial lake that formed beside a large block of wasting ice whose melting left the depression now filled by Summit Lake. Because both the lake sediments and the kame-terrace gravel on the opposite shore must have been deposited while ice occupied the basin of Summit Lake, the two sediments probably are approximately contemporaneous.

Similar fine-grained silt is exposed along the south shore of Hidden Lake where it forms a bluff 6 to 8 feet high. The sediment is dark gray, well sorted, and shows even, parallel stratification. The southward extent of the silt is unknown, but probably it is continuous for several hundred feet. Although this sediment is also believed to have been deposited in an ice-margin lake, the present bluff is not an ice-contact face; it is actively being eroded by waves, generated by strong north winds that blow down the valley, and is being continually modified by slumping.

Similar silt occurs along the north shore of two small lakes south of Napaktualuit Mountain. Exposures are poor and the deposits occupy only a narrow belt immediately adjacent to the lakes. Lacustrine sedimentation probably began shortly after deposition of ice-contact gravels which lie both upslope from the silt and on the opposite shores of the present lakes.

Erosional features

Striations. Striated bedrock is rarely exposed on valley floors and was seen at only a few places along the John-Anaktuvuk valley. Most exposed bedrock is covered with lichens that have obliterated any original polish or striations. Bedrock on valley floors consists almost entirely of Kanayut conglomerate which, owing to its high percentage of chert and quartz, probably has a greater tendency to fracture than to be abraded. Furthermore, it is well jointed and probably was easily plucked by the advancing ice. Striations are seen, however, on soft siltstone and sandstone. Sometimes they may be found on bedrock beneath large erratic boulders, under which lichens generally do not grow, or by carefully removing tundra and sediment from thinly till-mantled bedrock.

In general, striations parallel the main valley. Deviations from this mean, as near the mouth of Little Contact Creek, may reflect local topographic control of ice movement on the valley floor or possibly the movement of a lobe of the main trunk glacier into a tributary valley from which no ice flowed.

Stoss-and-lee topography. At two places in the main valley, east of Ridge Peak and at the west base of Mount Ingstad, stoss-and-lee topography is developed on exposed Kanayut conglomerate. At both localities south-facing bedrock slopes are smooth and abraded, while north-facing slopes are steep and step-like. As dip of jointing is nearly vertical, apparently rock was easily plucked on the lee sides of the exposures by advancing ice. The association of striations with stoss-and-lee topography at these localities indicates that during the Anivik Lake advance ice flowed north up the valley from a point south of the present drainage divide.

Meltwater-stream channels. Channels of former glacial-meltwater streams are discernible at several places on the valley floor. Although undoubtedly formed during final dissolution of the glacier following the Anivik Lake advance, several of these appear to be continuous with higher channels that probably were carved during earlier stages of the Itkillik glaciation. One swampy channel can be traced northeast from two small lakes at the foot of Ridge Peak to another small lake that lies opposite the mouth of Inukpasugruk Creek. Beyond the northern lake, the channel runs east toward the flood plain of Contact Creek which it meets half a mile above the mouth of Inukpasugruk Creek. In this stretch, where it is approximately 200 feet wide and from 30 to 40 feet deep, the channel bottom is occupied by a small stream about a foot wide and a foot deep. Similar linear depressions which probably are abandoned channels of tributary streams enter the main channel from the north and south.

Near the southwest corner of the map area, a small abandoned channel skirts the base of the western valley wall. It slopes gently north and is bordered on the east by a small bedrock ridge. Lying just upslope from the highest ice-contact gravel of Anivik Lake age, it probably constitutes a meltwater route that existed prior to deposition of ice-contact stratified drift on the valley floor.

Excavation of the rocky gorge of Inukpasugruk Creek has taken place since construction of the adjacent kame terrace ended. Very likely the position of the present channel and of the gorge is fortuitous, being largely determined by the distribution of glacial deposits near the mouth of Inukpasugruk Creek. The channel course must have been established shortly after ice in the main valley had disappeared to the extent that meltwater could flow between the two kame terraces. All meltwater issuing from Inukpasugruk Creek during final deglaciation and all subsequent stream discharge from this basin have contributed to excavation of the present gorge. Paired bedrock terraces along the rim of the gorge demonstrate some lateral cutting by the stream in unconsolidated glacial deposits before it became entrenched in the bedrock floor beneath.

Ice divide

The configuration of stoss-and-lee topography on the floor of the John Valley south of the drainage divide and the northward inclination of meltwater channels on and near the valley floor south of Anaktuvuk Pass suggest that Anivik Lake ice flowed north up the John Valley within the map area. It therefore seems likely that the ice divide during the Anivik Lake advance coincided with, or at least lay in the same vicinity as, the ice divide at Itkillik maximum. If so, ice in the John-Anaktuvuk valley reached a position approximately 17 miles north of the inferred position of the ice divide, as shown in Fig. 13, and nearly 19 miles from cirques near the head of Inukpasugruk Creek. This is slightly less than the 20 to 40 miles that Detterman, Bowsher, and Dutro (1958, p. 54) gave for the general northward extent of valley glaciers of Echooka age in the north-central Brooks Range.

Schrader (1904, p. 86 and Pl. XV-A) described and photographed a large, nearly circular mass of ice about 300 feet in diameter and 60 feet high that lay near the middle of the flood plain of the John River several miles above Hunt Fork and referred to it as "the last lingering remnant of the John Valley Glacier." Because of the presence of residual glacier ice "at this late date", he suggested that this locality lay "probably near what was the belt of maximum precipitation, and consequently of maximum ice accumulation, that traversed the mountains during Glacial time, and is therefore among the last to become free from ice."

During the present study the locality was examined from the air, but no trace of the ice mass was seen. That residual glacier ice, even though lying near the ice divide where the glacier may have been as much as 1,500 feet thick during Anivik Lake maximum, could have persisted throughout postglacial time in the John Valley seems doubtful at best. Two other explanations for the ice mass seen by Schrader appear feasible. One is that the ice mass may have been an erosion remnant of a large aufeis field that had been buried by sediment and preserved. Small aufeis bodies insulated by a thin layer of gravel and mud are common along rivers in the Anaktuvuk Pass area today. One small aufeis field near Kungomovik Creek was 20 feet thick when measured in the early summer of 1960, and it seems reasonable that considerably thicker bodies might, under suitable conditions, build up on flood plains of large streams like the John or Anaktuvuk rivers. Preservation of aufeis deposits through burial by sediment during spring floods in other areas of Alaska has been described by Leffingwell (1919, p. 201) and by Moffit (1913, p. 53). Such an ice body on a river flood plain might persist for many seasons and be appreciably affected by melting only in marginal areas or where the river is actively eroding. In such cases, a muddy gravel cap surmounting a large residual aufeis mass might easily be mistaken for till and the aufeis for glacier ice.

A possible alternative is that the ice mass photographed by Schrader was a pingo. Pingos are fairly common features on the Arctic Coastal Plain of northern Alaska and at least one sizeable pingo has been seen within the Brooks Range on the flood plain of the Noatak River in an environment similar to that of the John River near Hunt Fork (E. S. Hall, Jr., personal communication, 1962). Müller (1959) has described pingos that occur on gravelly flood plains in valleys of east Greenland. Ice in the cores of these features is comparable in thickness to the ice mass seen by Schrader, and bears a close resemblance to glacier ice. Pingos of comparable size and character also have been described from the Northwest Territories of arctic Canada (Müller, 1959; Craig, 1960, p. 7).

Regardless of the origin of the ice mass seen by Schrader, his inference that this locality lay not far from the probable belt of maximum ice accumulation appears to be supported by evidence obtained during the present study.

Displacement of the stream-drainage divide

The highest ground on the floor of the John-Anaktuvuk valley lies at the inferred latitude of the ice divide. Here the valley floor immediately west of the John River rises to an altitude of 2,462 feet (Fig. 13). This is nearly 325 feet higher than the minimum altitude of the present drainage divide at Anaktuvuk Pass. The question arises, therefore, whether the preglacial drainage divide lay farther south than it does at present, and whether it may have coincided with the inferred position of the ice divide. In addition to the topographic gradient, several other features suggest a possible shift of the divide during the late Pleistocene.

Both east and west of Anaktuvuk Pass, the drainage divide lies between 20 and 30 miles south of the northern front of the range and approximately parallel to it. In the vicinity of Anaktuvuk Pass, however, the divide makes a sudden swing to the north so that it lies within 6 miles of the range front. If the points from which the divide swings north are connected by a straight line, the line falls near the inferred position of the Itkillik ice divide.

The valley of Inukpasugruk Creek constitutes another anomalous feature. Inukpasugruk Creek is part of the south-flowing John River drainage system, yet, in joining the John River, it flows north across, rather than west along, the structural trend of the bedrock. With respect to the John Valley, the valley of Inukpasugruk Creek forms, in effect, a barbed tributary (Thornbury, 1954, p. 123). The orientation of the cross-axial segment of the stream would, however, be consistent with a former drainage system in which a preglacial stream that occupied the John-Anaktuvuk valley flowed north from a point south of the map area, that is, from a stream-drainage divide south of Anaktuvuk Pass.

If the preglacial stream-drainage divide did lie south of the map area, as postulated, the displacement of the divide must have been the result of glacial erosion, deposition, or both, along the John-Anaktuvuk valley during glaciation. As suggested above, the minimum amount of Itkillik and post-Itkillik erosion in the John-Anaktuvuk valley at Anaktuvuk Pass may be of the order of 500 feet. Glacial deepening of the John Valley immediately north of the inferred belt of maximum ice accumulation possibly was greater than that north of Anaktuvuk Pass owing to: (a) greater ice thickness and hence greater erosive capability of the glacier south of the pass, (b) the presence of erodible Hunt Fork shale on the valley floor for several miles downvalley from the south end of the map area, (c) a probable longer period of time during which active ice occupied the valley floor south of the pass than north of it, and (d) concentration of northward ice discharge from the broad basin of accumulation at the latitude of the ice divide into the more restricted valley of the upper John River, thereby favouring higher velocity of flow and deeper erosion. The result of greater downward erosion near the ice divide would have been to shift the stream-drainage divide to the north. It must be assumed, however, that valley deepening south of the ice divide was sufficiently vigorous to prevent a shift of the stream-drainage divide in that direction.

Glacial drift in the vicinity of Anaktuvuk Pass is at least 150 feet thick. It therefore is conceivable that deposition of thick drift at the pass could have helped shift the stream divide to the north. Bedrock exposures on the valley floor indicate, however, that the over-all inclination of the bedrock floor is toward the south, so that if the drainage divide has shifted, erosion south of the present drainage divide must account for most of the displacement.

Summary of history

Although deposits of Anivik Lake (Echooka) age have been ascribed by some previous workers to a separate post-Itkillik glaciation, several lines of evidence discussed above, particularly the similarity in surficial morphology of adjacent drift sheets and the apparent continuity of meltwater-drainage channels, suggest that the Anivik Lake advance was, in reality, merely an oscillation within the over-all recessional phase of the Itkillik glaciation. Ice-contact stratified drift of pre-Anivik Lake (Antler Valley) age is traceable to the Anivik Lake moraine and is virtually indistinguishable from ice-contact gravel of the moraine. It appears likely therefore that the Anivik Lake moraine was built during a stillstand or, more likely, a readvance of the ice during over-all deglaciation following the Itkillik maximum.

Low ridges of till in the Anivik Lake terminal drift suggest that the glacier was in equilibrium during deposition of at least part of the morainal complex, but widespread ice-contact topography indicates that much of the glacier terminus was stagnant or very slowly moving, and melting rapidly. The abundance of stratified drift in the moraine implies that the climate was sufficiently mild to promote thinning of the glacier, especially in the terminal zone, thereby resulting in a reduced rate of ice flow and a large supply of meltwater at the terminus. Much of the drift being transported by the ice was reworked by meltwater and deposited as ice-contact stratified drift at the margin of the glacier. Terminal drift locally dammed meltwater, giving rise to Anivik, Napaktualuit, and Nulak lakes.

Near its terminus the glacier was about 2 miles wide and covered slightly more than half the width of the valley (Fig. 17a). Distribution of the terminal deposits shows that the glacier widened upstream and apparently lay against the valley walls along the south side of Napaktualuit Mountain and east of Nachramkunga Mountain. The manner in which the terminal portion of the glacier pulled away from the valley walls is characteristic of some present-day valley glaciers having low gradients and low velocities (Speight, 1940, p. 143). The absence of lateral moraines along the valleys of the John and Anaktuvuk rivers suggests either that there was little debris supplied to the marginal part of the glacier, that the glacier was sufficiently active to carry all marginal debris to the terminal zone where it was deposited directly or reworked by meltwater streams, or that ice-margin streams transported sediment to and beyond the glacier terminus. The presence of abandoned meltwater channels along the valley sides at successively lower levels indicates that such streams were effective erosional agents.

The widespread occurrence of kames, ice-channel fillings, kame terraces, and ice-margin lacustrine deposits on the valley floors indicates that following deposition of the Anivik Lake moraine, ice in the main valley effectively ceased to flow. Rapid thinning in the terminal zone, resulting from increased ablation rates and a rise in altitude of the firn limit, may have hastened the transfer of ice from the zone of accumulation near the ice divide to the terminal region. This ice transfer might have lowered the surface of the entire glacier sufficiently to bring about stagnation shortly thereafter.

As ice rapidly thinned in the main valley, meltwater streams deposited sediment against residual ice that occupied the centre of the valley. Initially, all meltwater probably flowed north along the slope of the glacier, but as the region south of Anaktuvuk Pass was deglaciated, the underlying topography assumed control of drainage and the present drainage divide came into existence.

Despite stagnation of the main valley glacier, ice in tributary valleys apparently remained active (Fig. 17b). The fabric measurement on till from the Contact Creek exposure indicates that the last ice to move over this site flowed N. 80° E., which is at an acute angle to the trend of the main valley. The absence of ice-contact gravel west of Summit Lake and the presence of pitted ice-contact topography between Summit Lake and Inukpasugruk Creek further suggest that the valley glacier in Contact Creek extended out into the main valley and remained active after ice of the main trunk glacier had ceased to flow. This inference is also supported by the presence of limestone cobbles and calcareous soil in the area marked by pitted ice-contact stratified drift between Summit Lake and Inukpasugruk Creek; the carbonate stones probably originated in the valley of Contact Creek, which is the nearest source of limestone, and were deposited at the terminus of the Contact Creek glacier by meltwater. Meltwater from this glacier, along with meltwater from wasting Anivik Lake ice of the main valley glacier and water from Inukpasugruk Creek, flowed north and south along the John-Anaktuvuk valley and deposited gravel and sand beside residual masses of ice that lay near the middle of the valley floor (Fig. 17b). Between Summit Lake and Inukpasugruk Creek these sediments were deposited on top of terminal ice, probably stagnant, of the Contact Creek glacier. Consequently, when Anivik Lake ice disappeared from the valley floor the kame terraces north and south of Anaktuvuk Pass were flat-topped and had

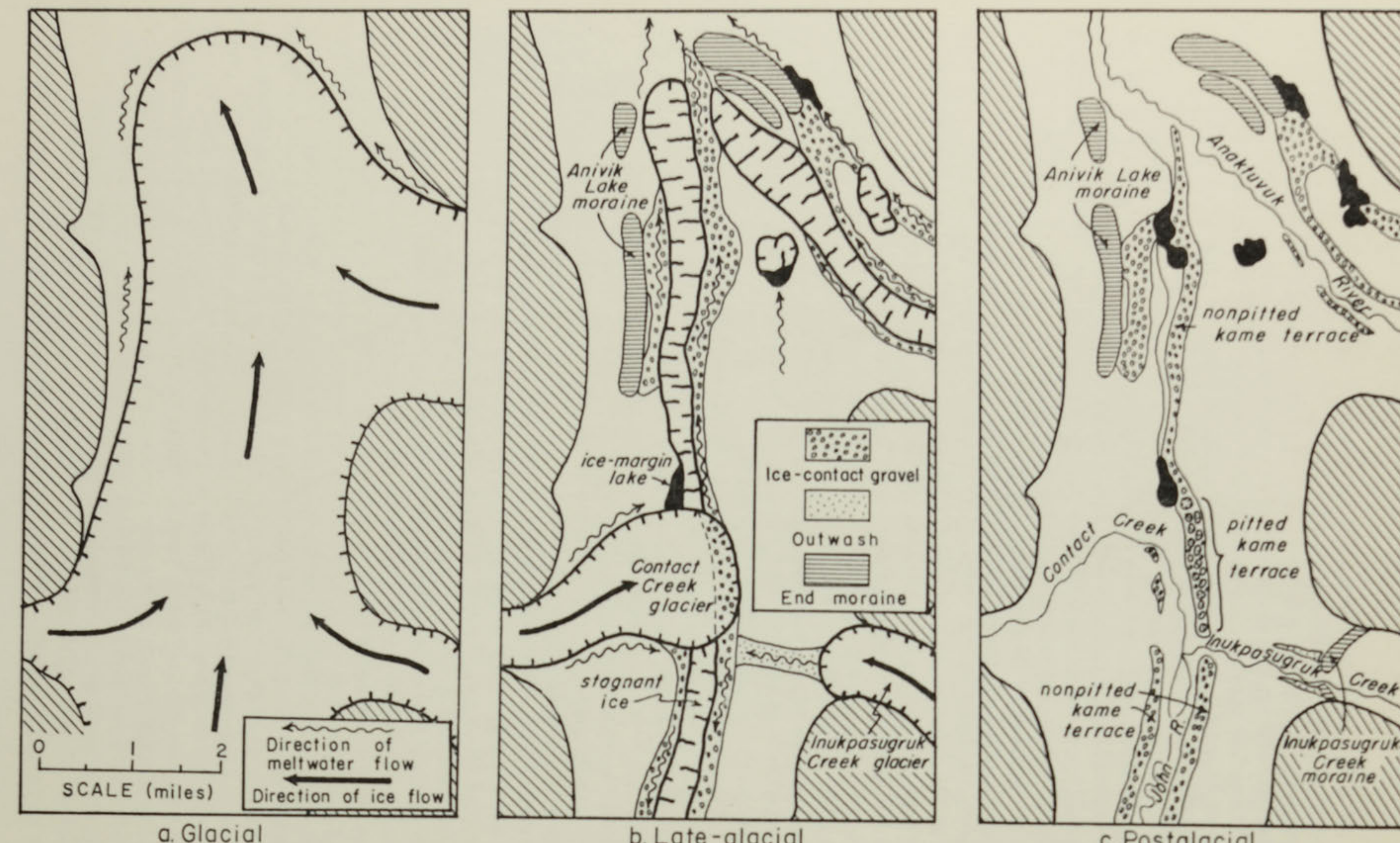


Fig. 17. Inferred pattern of deglaciation following the Anivik Lake advance.

a single ice-contact face, whereas deposits near the pass, formerly underlain by ice of the Contact Creek lobe, were irregular and pitted.

During deposition of the eastern kame terrace in the main valley, residual ice filled the basin now occupied by Summit Lake. Meltwater and normal surface runoff from the west apparently were dammed near the junction between active ice of the Contact Creek glacier and stagnant ice in the vicinity of the present Summit Lake. An ice-margin lake formed here in which organic-rich silt was deposited. As continued melting took place and Anivik Lake ice disappeared, postglacial drainage routes were established in this area, the ice-margin lake was drained, and meltwater filled the adjacent basin to produce Summit Lake.

Like the glacier in Contact Creek, the glacier in Inukpasugruk Creek also remained active during deglaciation of the main valley (Fig. 17b). At some period during deglaciation, possibly at the same time that the terminus of the Contact Creek glacier lay between the present position of Summit Lake and Inukpasugruk Creek, the Inukpasugruk Creek glacier built a moraine near the mouth of its valley. The small outwash fan built out from this moraine may have been coextensive with kame-terrace gravel along the John Valley. The moraine probably represents a late and short-lived stillstand or readvance of the ice that may have been contemporaneous with kame-terrace construction along the John-Anaktuvuk valley. Numerous small bodies of ice-contact stratified drift upstream from the moraine indicate that, following construction of the moraine, this valley glacier also stagnated.

As glacier ice disappeared from the main valley at Anaktuvuk Pass, surface drainage became adjusted to the complex topography of the glacial deposits (Fig. 17c). The John and Anaktuvuk rivers followed low avenues on the valley floor that probably were among the last places to be occupied by residual Anivik Lake ice. As the alluvial plains of these large rivers were widened by lateral shifting of the streams, kame terraces and other ice-contact features on the valley floors were eroded and in places considerably modified. Inukpasugruk Creek cut downward through the kame-terrace gravel near its mouth as the John Valley became ice-free, and was superposed on bedrock beneath, through which it has cut a steep gorge. Stream courses near the Anivik Lake moraine were controlled largely by the distribution of terminal drift and followed arcuate courses along or between subparallel ridges of end moraine.

Once ice had melted from the valleys, the ice-freed areas were soon covered by vegetation. Abundant organic matter in the lacustrine silt beside Summit Lake, indicates that even during deglaciation vegetation was growing at no great distance from the centre of the valley. Pollen evidence from the Chandler Lake area (Livingstone, 1955), further indicates that herbaceous tundra probably existed on valley floors near Anivik Lake ice and was succeeded during deglaciation by vegetation in which dwarf birch was prominent. Later, alder appeared and increased in importance as the climate became still milder.

Since deglaciation of the main valley, Anivik Lake drift has been modified to varying degrees by frost action and by mass-wasting. Solifluction has produced the most noticeable changes by smoothing the topography of ground moraine and end moraine. In addition, the upper surfaces of kame terraces have been greatly modified by the development of large ice-wedge polygons. Although some kettle lakes appear virtually unaltered, many have been drained and others are being filled by encroaching vegetation.

Alapah Mountain glaciation

The Alapah Mountain glaciation was named by Detterman, Bowsher, and Dutro (1958) for moraines left by glaciers that originated on the west and southeast slopes of Alapah Mountain, which lies approximately 23 miles east of Anaktuvuk Pass. Moraines of this advance were differentiated by them from older moraines mainly by relative position and morphology. Echooka (Anivik Lake) moraines, which commonly lie 5 or more miles farther downstream, tend to be thicker, more extensive, and more greatly modified by erosion and mass-wasting than are those of the Alapah Mountain advance. Alapah Mountain terminal moraines generally are found from 3 to 10 miles downstream from cirques in the type area.

Deposits of Alapah Mountain age within the area covered by the present study were not shown by Detterman, Bowsher, and Dutro (1958, Fig. 3) on their sketch-map of the Anaktuvuk-Kuparuk rivers region, but several moraines mapped during the present investigation are correlated with the type Alapah Mountain moraines that lie near the head of the Anaktuvuk River. At Anaktuvuk Pass, glaciers of this relatively recent advance were short and were confined to tributary valleys.

Drift along Contact Creek

One of the most prominent end moraines in the Anaktuvuk Pass area crosses the valley of Contact Creek two miles west of the village. This moraine, here designated the Contact Creek moraine, was seen by Schrader (1904, p. 85) who described it as "being about 60 feet high and one-fourth of a mile in length, measured parallel with the valley." The moraine lies approximately 6 miles from cirques near the head of Contact Creek. It has been breached by the creek and cut to a depth of from 65 to 75 feet.

The bulk of the moraine lies on the south side of the creek. Its crest, which rises from an altitude of 2,585 feet near the stream to about 2,800 feet on the northeast slope of Ridge Peak, is extremely hummocky. Judging from the few available surface exposures, the moraine contains considerable stratified sediment, much of which is well-sorted sand. Angular surface boulders up to three feet in diameter are common.

The morainal segment on the north side of the creek is smaller and reaches an altitude of only 2,540 feet. The saddle between the moraine and the south side of Nachramkunga Mountain may have been a meltwater channel, in the vicinity of which morainal material did not accumulate.

The valley floor upstream from the Contact Creek moraine appears to be underlain by ground moraine. Within the map area, no stratified drift or lateral moraines were detected along the valley of Contact Creek above the terminal moraine.

On its downstream side the moraine grades into a gravel outwash fan that has been dissected in postglacial time (Pl. 9). Remnants of the outwash body are found between the moraine and the junction of Contact and Little Contact creeks. From the moraine, the top of the outwash body has an eastward slope of approximately 200 feet per mile. The sediment is poorly sorted and consists mainly of well-rounded cobbles and of pebble gravel with some interstitial sand. Most stones are Kanayut conglomerate which underlies the floor of the valley for most of its length. Limestone and chert are present in the gravel, however, and nearly all stones in the upper several feet of the deposit are encrusted on their under surfaces with up to a quarter of an inch of secondary calcium carbonate. Large angular boulders are fairly common on the surface of the outwash fan and their presence on eroded faces of the deposit suggests that they may also occur within the outwash body.

Southeast of the Contact Creek moraine, the outwash fan is partly covered by postglacial alluvial-fan sediments derived from the northeast side of Ridge Peak. The stream that deposited these gravels appears also to have been at least in part responsible for dissection of the outwash fan.

Drift along Inukpasugruk Creek

Seven miles above the mouth of Inukpasugruk Creek and northwest of the summit of Turret Peak a moraine, here called the Turret Peak moraine, crosses the valley of Inukpasugruk Creek. The moraine lies 5 miles downstream from cirques at the head of the valley. It is a quarter of a mile wide and rises from 100 to 125 feet above the stream, which has cut a channel 250 feet wide through the moraine. Till is present in the stream cut but, owing to slumping and a cover of vegetation, no fresh exposures were seen. Several large erratic boulders occur in the side of this cut, one of which measures 20 feet in diameter and appears to be composed of solid black chert (Pl. 10). Faceted and striated stones, some consisting of limestone, are plentiful in the moraine.

On its downstream side the moraine grades into cobbly, poorly sorted and poorly stratified gravel which in turn passes northward into sandy outwash. Outwash is exposed in cutbanks along Inukpasugruk Creek for about a mile downstream from the moraine. One cut exposes 17.5 feet of coarse sand and pebble gravel with several feet of poorly sorted cobble and pebble gravel at the top (Pl. 12). Organic matter, mainly willow fragments, is interstratified with sand and pebble gravel near the base of the section.

Outwash is primarily restricted to the area upstream from a bedrock ridge that extends to the centre of the valley from the northeast ridge of Mekiana Mountain. Downstream from the bedrock exposures some outwash is present along the east side of the stream but elsewhere it must either have been eroded away or be buried by alluvial-fan sediments which mantle much of the valley floor.

As above the Contact Creek moraine, stratified drift and lateral moraines are absent upstream from the Turret Peak moraine. Ground moraine apparently forms much of the valley floor where bedrock is not exposed and where alluvium does not form the ground surface.

Basis for correlation

Correlation of post-Anivik moraines within the Anaktuvuk Pass area and correlation of these with type moraines of Detterman, Bowsher, and Dutro (1958) elsewhere in the range is based primarily on: (a) positions of end moraines relative to cirques and to older end moraines, (b) physical character of the drift, (c) degree of dissection of the moraines and associated outwash fans, and (d) relative amount of postglacial modification by mass-wasting.

Although empirically the amount and thickness of vegetation cover on drift bodies appears to bear some relationship to the relative ages of moraines as determined from the above criteria, vegetation has not been used as a means of correlating moraines because too little is known of the importance of time, relative to environmental factors, in determining the character of vegetation cover in arctic regions.

Type Alapah Mountain terminal moraines lie 3 to 10 miles from accumulation areas in cirques and 5 or more miles upstream from moraines of Anivik Lake (Echooka) age. Both the Contact Creek and Turret Peak moraines fall within these limits. The volume of drift contained in each of these moraines appears to be comparable, and outwash fans are nearly equal in extent. Unlike drift of the Anivik Lake advance, stratified ice-contact deposits are not present behind these end moraines. Morainal features are fresh and, except where breached by streams, are little modified. Mass-wasting has resulted in some smoothing out of the topography, but not to the same degree as with the older deposits. For these reasons it is felt that the Turret Peak and Contact Creek moraines can be correlated with the end moraines east of the Anaktuvuk Pass area that Detterman, Bowsher, and Dutro ascribed to the Alapah Mountain glaciation.

Drift in tributary valleys of Inukpasugruk Creek

The extent of glaciers of Alapah Mountain age in the Anaktuvuk Pass area, as shown by the position of end moraines in Contact Creek and Inukpasugruk Creek, suggests that glaciers must also have advanced in hanging tributary valleys of Inukpasugruk Creek during this glaciation. However, correlation of moraines in hanging tributary valleys with the Turret Peak moraine presents difficulties. Absence of end moraines along the valley of Inukpasugruk Creek between the Turret Peak and Inukpasugruk Creek moraines indicates that apparently at no time during this glaciation did tributary glaciers extend beyond the mouths of the hanging valleys. Consequently, there is no physical continuity between drift in these valleys and drift in the main valley below.

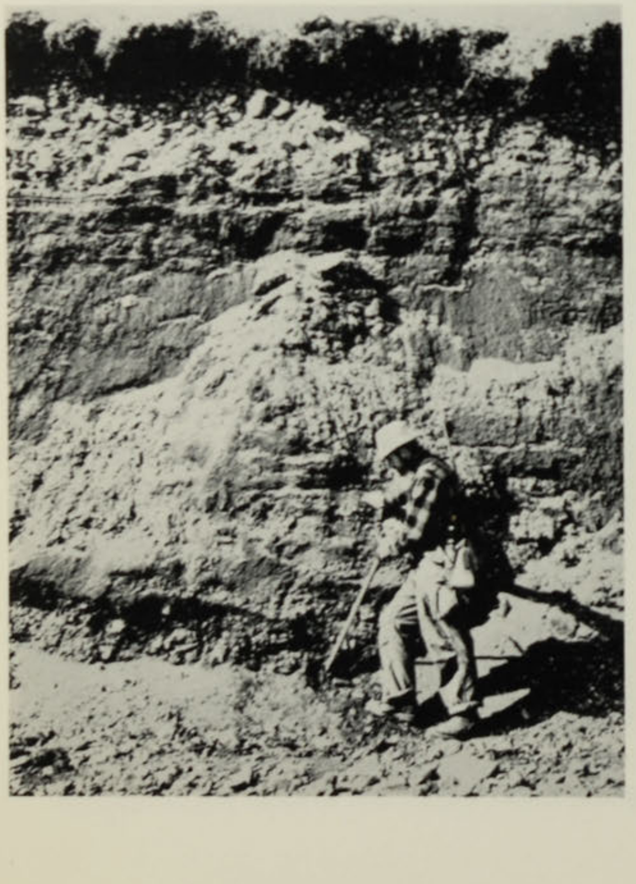
Most tributary valleys show a twofold or a threefold sequence of moraines (Fig. 18). In any one valley, the outermost moraine lies at or near the valley mouth, while the innermost moraine lies in or at the threshold of the cirque at the head of the valley. In many valleys a third prominent moraine occupies an intermediate position between the other two. The limited extent of the inner two moraines, as well as morphological differences between them and the outermost moraine, strongly suggest that the outer moraines are correlative with the Turret Peak moraine, while the inner two represent younger more restricted ice advances. The morainal sequence, as described, is best displayed in the hanging valley west of Mount Ahgook and in the Y-shaped hanging valley northwest of Mekiana Mountain (Fig. 18).

At the mouth of the hanging valley that lies east of Kollutuk Mountain stony till is exposed in the walls of a deep postglacial stream channel cut through nearly 100 feet of a thick morainal fill. Most stones in the till are angular and some are faceted and striated. Poorly sorted sand and pebble gravel is associated with the till. The upper surface of the moraine is nearly flat and supports a low growth of mossy vegetation. The moraine lies 2.5 miles below cirques at the head of the valley, with its toe resting at an altitude of about 3,000

Pl. 9. View east up Contact Creek toward Contact Creek moraine (left background) and dissected outwash fan (foreground). Note large boulders at surface of outwash fan near the moraine.

Pl. 10. Large boulder of solid black chert exposed in stream cut through Turret Peak moraine.

Pl. 11. Lake dammed between two morainal ridges near mouth of valley west of Mount Ahgook (right background). Strandline 6 feet above present lake surface marks former level controlled by spillway (right).



Pl. 12. Cutbank in outwash beside Inukpasugruk Creek a mile below Turret Peak moraine. Ice axe points to position of radiocarbon sample.

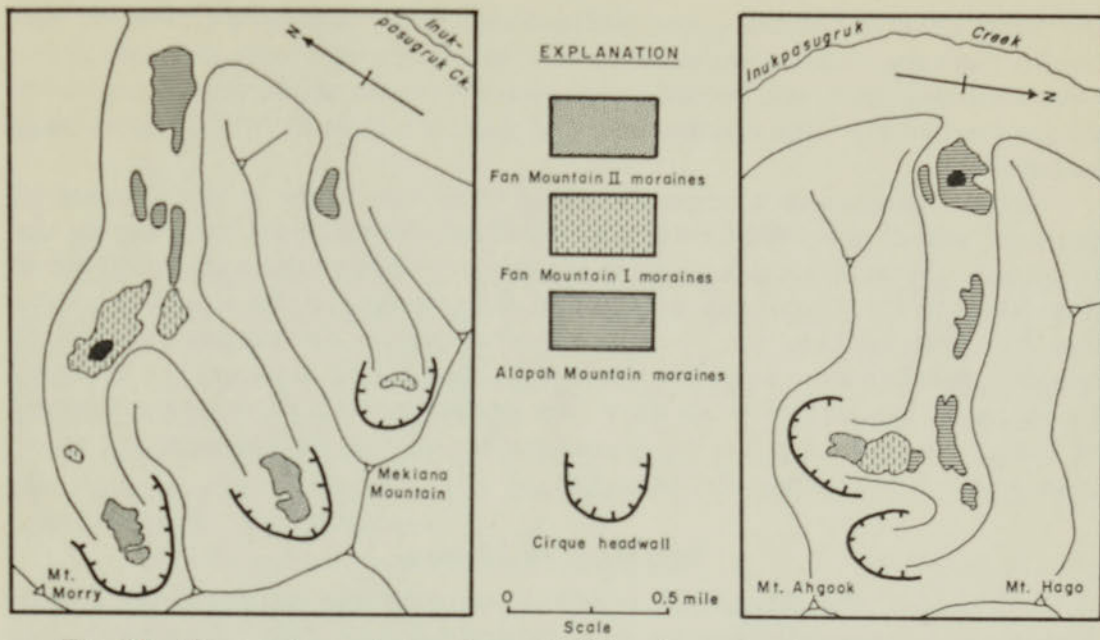


Fig. 18. Suggested correlation of post-Itkillik end moraines in tributary valleys of Inukpasugruk Creek.

feet and its crest at 3,150 feet. Lateral moraines along the south side of the valley rise 50 feet higher and extend upvalley to the vicinity of the next prominent moraines. A small end moraine lying about half-way between the mouth of the valley and the point where the valley branches probably is a recessional moraine of this glaciation. Just upstream from the terminal moraine, 5 feet of well-sorted stratified sand, silt, and pebble gravel, of either lacustrine or alluvial origin, are exposed in a stream cut. Arctic Brown Soil is developed in this deposit to a depth of 28 inches.

A similar, but smaller, wedge-shaped morainal fill lies near the mouth of the next valley to the south. Its foot lies at an altitude of 3,300 feet and its crest rises to 3,600 feet. Most of the visible material on the sides of a deep (150–200 feet) stream cut in the moraine is loose angular rubble. Although the moraine is but a mile below the head of the valley, the glacier which built it originated in a single small cirque; consequently, it cannot be expected to have advanced as far as the glacier in the valley to the north which was nourished by ice from two larger cirques.

Similar moraines are present in the valley between the west ridges of Mount Ahgook and Mount Hago. A prominent terminal moraine, attributed to the Alapah Mountain glaciation, lies at the mouth of this valley. It is at least 125 feet thick and its crest, which lies near the lip of the valley, rises to an altitude of 3,375 feet. The top of the moraine is very hummocky and is covered with angular boulders. Herbaceous vegetation grows on the surface and exposed boulders are covered with lichens. Behind the terminal ridge, another lower moraine crosses the valley floor. A small lake is dammed in a shallow depression between the two ridges of drift (Pl. 11). Upvalley from it a deposit of well-sorted sand and silt, probably deposited in a small postglacial lake, is being dissected by the modern stream.

Lateral moraines lie along both sides of the valley but are best developed on the north side. They rise steeply as much as 100 feet above the valley floor and are partly covered on their upper surfaces with mossy vegetation; most exposed boulders are encrusted with lichens. In places, sliderock from the cliffs above covers the moraines, and beneath some couloirs on the south side of the valley where particularly large accumulations of sliderock have formed, it completely buries them.

Several short arcuate ridges that trend transverse to the lateral moraine on the west side of the valley are probably recessional moraines built during deglaciation. A small arcuate moraine at the outer edge of the western cirque in this valley is also tentatively referred to this glaciation. Its slopes are more heavily vegetated than the younger moraines within the cirque, and surface boulders sustain a more extensive cover of lichens. This moraine, like the small recessional ridges farther down the valley, probably was built during a stillstand of the glacier or by a minor readvance during over-all retreat from the maximum stand of the Alapah Mountain ice.

Summary of history

Glaciers of the Alapah Mountain advance in the north-central Brooks Range were restricted primarily to tributary valleys. Near Anaktuvuk Pass terminal moraines built by coalescing valley glaciers lie as much as 5 miles from accumulation areas in cirques, but in hanging tributary valleys most glaciers were less than 3 miles in length. The total volume of terminal deposits is relatively small, suggesting that little erosion occurred during this ice advance. Much of the material in Alapah Mountain deposits probably is reworked Anivik Lake drift and post-Anivik Lake, pre-Alapah Mountain alluvium and colluvium. The absence of recessional moraines and bodies of ice-contact stratified drift behind the Contact Creek and Turret Peak moraines suggests that ice retreat was fairly uniform at lower altitudes in the larger valleys. Recessional moraines in the hanging tributary valleys of Inukpasugruk Creek, however, appear to reflect fluctuations of glacier termini during general recession. Their somewhat higher altitude and smaller size may have made these glaciers more sensitive to minor climatic fluctuations than were larger glaciers at lower altitudes.

The extent of glaciers following the Anivik Lake advance is not known, but possibly they retreated into cirques, disappeared, and were then regenerated during the Alapah Mountain glaciation. Although unsupported by physical evidence, the possibility exists that ice did not entirely disappear from the Anaktuvuk Pass area between the Itkillik and Alapah Mountain glaciations. In any event, the Alapah Mountain advance may justifiably be regarded as a separate, though relatively restricted, glacial event in the recent history of the central Brooks Range.

Fan Mountain glaciation

The Fan Mountain glaciation was named by Detterman, Bowsher, and Dutro (1958) for glacial deposits found near the thresholds of cirques in the vicinity of Fan Mountain, 18 miles east of Anaktuvuk Pass. Drift of this glaciation in the Anaktuvuk Pass area consists mainly of rubbly end moraines that lie in or slightly beyond cirques now devoid of active glacier ice. The fresh appearance of this drift and its geographic location in cirques and cirque valleys that generally lie above an altitude of 4,000 feet, suggest that this was a relatively recent and short-lived glaciation that involved numerous small glaciers at high altitudes. Residual glacier ice in some cirques probably dates from this glaciation.

Character and distribution of drift

End moraines that lie in and beyond cirques upvalley from Alapah Mountain moraines occur in most cirque valleys within the Anaktuvuk Pass area, and are attributed to the Fan Mountain glaciation. The drift sequence is best displayed in the valleys northwest of Mekiana Mountain, west of Mount Ahgook, and north of Cirque Peak (Figs. 1 and 18). In each of these valleys at least two sets of moraines are present upstream from Alapah Mountain drift. The innermost moraines lie within or at the thresholds of cirques, while the outer moraines lie up to 1.5 miles beyond the cirques.

In the Y-shaped valley northwest of Mekiana Mountain the outermost set of moraines lies near the junction of the two cirque valleys (Fig. 18 and Pl. 14). The western moraine rises sharply from an altitude of 3,600 feet at its foot to 3,900 feet at its crest. A small outwash fan extends several hundred feet downstream from its base. The moraine has been entrenched by a stream to a depth of 50 to 100 feet, and stony till containing faceted and striated cobbles is exposed on the walls of the stream cut. A small lake, now slowly filling with silt, is dammed by the moraine. At its west edge another small moraine crosses the valley. The stream has breached this moraine also, producing a cut 10 feet deep and 20 feet wide. Upstream from it is a flat area underlain by silt of probable lacustrine origin. Both moraines are covered by a thin growth of vegetation and most boulders are partly encrusted with lichens.

A moraine of smaller dimensions but of comparable geographic position crosses the mouth of the eastern branch of the valley. This moraine formerly dammed a small lake, but the water has been drained and lacustrine silt is exposed in the stream banks.

At the head of both valleys bouldery moraines occupy the floors of cirques. The moraine in the western cirque rises from an altitude of 4,400 feet at the base to 4,775 feet at the crest. Vegetation is absent on the surface of this moraine except along the margins of small streams. Between the crest of the moraine and the cirque headwall is a large depression 70 feet deep which probably marks the location of the last glacier ice to occupy the cirque.

The lip of the eastern cirque, above which rises a steep bedrock cliff, has an altitude of 4,325 feet. Above the cliff a bouldery moraine reaches an altitude of 4,600 feet. As in the western cirque, a sizeable depression, here 50 feet deep, lies behind the crest of the moraine.

In the cirque valley west of Mount Ahgook a similar morainal sequence is present, but it is confined to the westernmost of the two cirques at the head of the valley (Fig. 18). Moraines are lacking in the eastern cirque which lies at an altitude of 4,600 feet, suggesting absence of glacier ice in post-Alapah Mountain time. On the floor of the western cirque, however, which lies at 4,200 feet, three end moraines are present (Pl. 13). The lowest and outermost is hummocky and supports vegetation over approximately 80 per cent of its surface. Owing to similarity in surficial morphology between this moraine and moraines farther down the valley, it is interpreted as a recessional moraine of the Alapah Mountain advance.

Standing steeply above this moraine is a massive end moraine that consists of blocky rubble. The rocks are partly encrusted with lichens, and mossy vegetation, growing in pockets where soil is present, covers approximately 25 per cent of the surface. Behind the moraine and extending well up toward the head of the cirque is a younger moraine that consists of blocky unweathered debris derived from the surrounding cliffs. Lack of vegetation on this deposit and the absence of lichens on exposed rocks indicate that this moraine was built recently.

A massive blocky moraine lies just below a small tarn in the valley north of Cirque Peak. Above rises a second massive moraine that rests immediately in front of residual glacier ice. Meltwater streams issue from the front of the moraine and follow its lateral margins. On its east side a series of small superposed morainal ridges lies north of the residual ice body, indicating that a number of minor advances and retreats marked the latest phase of the glacier's history.

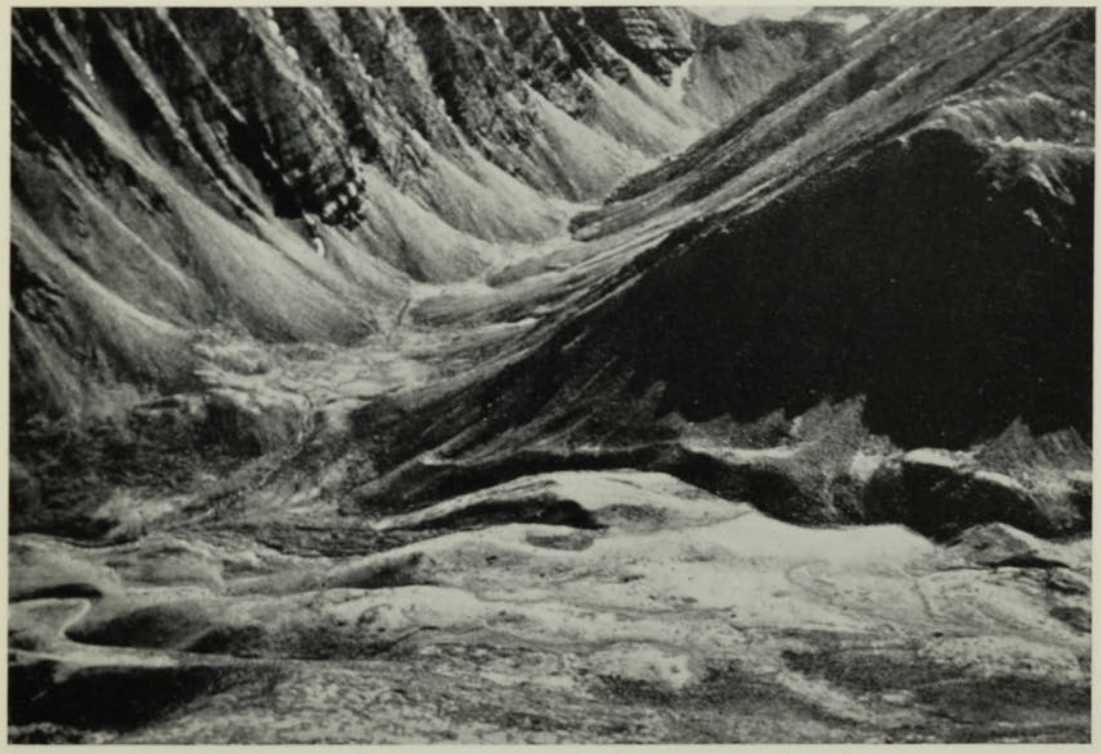
The massive character and unstable nature of the youngest blocky moraines suggests that they may be cored with ice. Similar moraines having exposed ice cores were seen in cirques south of the Kurupa Lakes, approximately 80 miles west of Anaktuvuk Pass, in 1965.

Morainal sequences similar to those described above are present in other cirque valleys and differ only in details. All occupy comparable positions relative to Alapah Mountain moraines and to cirques. Their differences in size and distance from cirques appear to be a function mainly of cirque size, cirque orientation, and possibly the altitude of adjacent peaks.

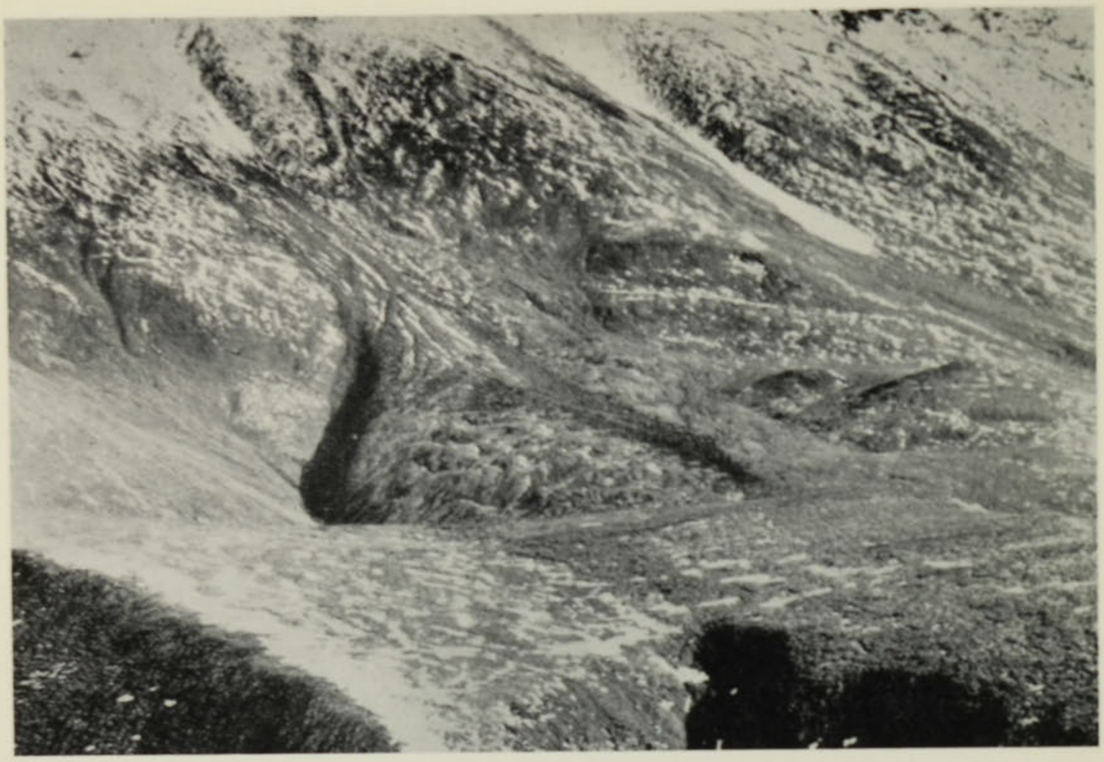
Evidence of multiple stages

The presence of two distinct end moraines behind moraines of the Alapah Mountain glaciation in the Anaktuvuk Pass area is evidence of two separate ice advances or stillstands some time after the maximum extent of Alapah Mountain glaciers. Possibly one or both of these moraines were built during recession from the maximum start of Alapah Mountain glaciers. However, because they differ from Alapah Mountain terminal moraines with respect to both position and physical characteristics, and because they appear similar to moraines referred to the Fan Mountain glaciation by previous workers, the designation Fan Mountain has been used here. In this report the outermost moraines are designated Fan Mountain I moraines and the innermost Fan Mountain II moraines. In the Anaktuvuk Pass area several distinctive features help to differentiate these moraines and permit correlation between different valleys. Fan Mountain II moraines, where present, always lie in cirques, whereas most Fan Mountain I moraines lie at varying distances downstream from the thresholds of cirques. Fan Mountain II moraines consist of unweathered blocky debris that is extremely unstable and lies at a high angle of repose. Boulders are free of lichens and vegetation is absent from the surface. Drainage is mainly subsurface. Fan Mountain I moraines are stabilized; surface boulders are encrusted with lichens to varying degrees; and mossy vegetation grows discontinuously over the surface. Except for steep narrow stream cuts, these moraines show little or no postglacial modification.

Pl. 13. Superposed moraines in west cirque of Mount Ahgook. Prominent ridge in right centre of picture is Fan Mountain I moraine which overlies low recessional moraine of Alapah Mountain age. Fan Mountain II moraine is visible higher up in cirque.



Pl. 14. Fan Mountain I moraines in valley east of Kollutuk Mountain. Moraine in centre of picture has dammed a small lake. Moraine to left has been breached by stream and former lake behind moraine has been drained.



Pl. 15. Inactive lobate rock glacier on north slope of Red Rock Mountain. Front of lobe is at centre of picture in line with talus cone and couloir upslope.

Pl. 16. Active tongue-shaped rock glacier in cirque a mile west of Turret Peak. Note steep front and microrelief features on surface of rock glacier.

Although these two sets of moraines are not present in all cirque valleys, the fact that they are recognizable in at least six cirque valleys of the Anaktuvuk Pass area suggests that these advances were separate and significant events and that evidence of them should appear elsewhere in the range.

Moraines representing two recent but distinct glacial advances in the Mount Chamberlin area of the eastern Brooks Range have been described by Holmes and Lewis (1961, p. 861). A fresh moraine in contact with the Chamberlin Glacier ("Cirque Moraine II") appears to be physically similar to Fan Mountain II moraines of the Anaktuvuk Pass area. Slightly weathered moraines downstream ("Cirque Moraine I") that support a sparse growth of alpine plants and in which the debris is more stable may be comparable with Fan Mountain I moraines at Anaktuvuk Pass.

Existing glaciers

Modern glaciers in the Brooks Range are restricted almost entirely to the higher portions of the range and generally lie in well-protected north-facing cirques. They are largest and most numerous in the eastern Brooks Range where some peaks reach altitudes in excess of 10,000 feet. In the central part of the range glaciers are less common and occur mainly near the headwaters of the Itkillik and Nanushuk rivers where summits reach altitudes of 7,000 feet or more. Farther west glaciers generally are absent owing to lower altitudes.

Active glaciers are not present in the Anaktuvuk Pass area. The nearest occur on the north side of the high (6,508 feet) mountain at the head of Contact Creek. There three small glaciers, each less than a square mile in area, are found between altitudes of 4,200 and 6,200 feet. Larger glaciers, some nearly 2 miles in length, are present in the vicinity of Alapah Mountain, 23 miles east of the pass.

Although active glacier ice does not occur in the immediate vicinity of Anaktuvuk Pass, residual glacier ice is present in the cirque north of Cirque Peak at an altitude of 4,500 to 4,800 feet. In mid-July 1959 a thin layer of snow covered the upper part of the ice mass. The lower part was mantled with angular rubble and lay close to Fan Mountain II moraines. Several subparallel cracks running horizontally across the ice mass may have been incipient crevasses, but no other features suggesting movement of the ice were seen. Numerous meltwater streams, spaced 5 or 6 feet apart flowed down the surface of the glacier. The large volume of meltwater issuing from this ice mass and its very limited extent within the cirque, strongly suggest that the ice is rapidly disappearing. Very likely the ice in this cirque is the same glacier, now much reduced in size, that built the Fan Mountain II moraines near the threshold of the cirque.

To date, detailed observations have been reported for only three glaciers within the range, and each of these lies in the eastern Brooks Range (Sater, 1959; Anderson, 1959; Larsson, 1960; Sable, 1961). Preliminary reports of I.G.Y. studies on the McCall Glacier in the Romanzof Mountains indicate that in the recent past the snowline in this region has risen appreciably, thereby creating conditions in which ablation far exceeds accumulation (Austin S. Post, personal communication, 1960). Present climatic conditions seem to be unfavourable for the growth of existing glaciers, for temperature is sufficiently high for rain to fall at high altitudes during summer, which is the period of maximum precipitation.

Comparison of photographs of the Okpilak Glacier in the Romanzof Mountains has led Sable (1961) to conclude that the terminus of this glacier receded 1,000 ±100 feet during the 51-year period between 1907 and 1958. Furthermore, the terminus of this glacier receded 300 feet between 1950 and 1956, which indicates that during the very recent past the rate of recession has increased greatly. In addition to retreat of the terminus, the lower third of the glacier thinned by an average of 150 feet during the 51-year period. According to Sable, at least 25 times as much ice has been lost through thinning of the glacier as by recession of its terminus. Other glaciers in the Romanzof Mountains that are of comparable size also show evidence of recent retreat and thinning indicating that this phenomenon may be widespread.

Similar conditions apparently exist in the nearby Franklin Mountains where hydrologic studies of the Chamberlin Glacier were made in 1958. Preliminary results of this study indicate that total streamflow from the drainage basin of the Chamberlin Glacier is considerably in excess of the presumed mean annual precipitation, a condition which could result only from a large amount of glacial melting (Anderson, 1959). According to Larsson (1960, p. 76), this glacier is nowhere thicker than 200 feet and at present is characterized by overall wastage. It seems apparent, therefore, that in at least three areas within the northern Brooks Range, namely the Romanzof Mountains, the Franklin Mountains, and Anaktuvuk Pass, modern glaciers are characterized by negative economies and are diminishing in size.

Rock glaciers

Rock glaciers, abundant elsewhere in Alaska (Wahrhaftig and Cox, 1959), are present in the higher parts of the north-central Brooks Range. In the course of the present study two were examined in the vicinity of Anaktuvuk Pass. The smaller of the two lies within the map area on the north side of Red Rock Mountain (Fig. 1); the other, which is considerably larger, lies immediately south of the map area at the head of a tributary valley of Inukpasugruk Creek.

The rock glacier on the north side of Red Rock Mountain is lobate (Wahrhaftig and Cox, 1959, p. 389) and lies at the foot of a long talus cone that heads in steep bedrock near the summit of the mountain (Pl. 15). It is nearly circular in plan and measures approximately 1,400 feet in length and 1,300 feet in width. Its toe lies at an altitude of 3,650 feet and its head at approximately 3,900 feet. Although surface microrelief features, which include small transverse ridges and furrows that are convex downslope, strongly convey the impression of downslope movement, most of the surface is stabilized and is covered by fairly dense vegetation. In places the upper surface has been modified by avalanche channels that are lined with recent sliderock, but microrelief features on the lower part of the rock glacier have undergone no noticeable alteration. The turf-covered front merges with a more gentle, vegetated solifluction slope below. The lack of a steep front slope together with the turf cover, suggest that the rock glacier is now stable and may be classified "inactive" (Wahrhaftig and Cox, 1959, p. 392). Current production of sliderock by frost wedging near the summit of the mountain, appears insufficient to reactivate the rock glacier. The fact that surface microrelief features, though covered with vegetation, are still sharp and recognizable, suggests that this rock glacier may have been active within the last several centuries.

A second, much larger rock glacier, which occupies a cirque valley a mile west of Turret Peak (Pl. 16), is nearly a mile long and descends from an altitude of about 5,200 feet at its head to 3,950 feet at the base of its front slope. The cirque faces slightly north of east and the rock glacier extends for half a mile in this direction before turning abruptly north. In its upper half it is about 600 feet wide but in its lower half it spreads laterally and attains a width of nearly 1,500 feet. The ratio of length to width is such that this rock glacier should be classified as "tongue-shaped" (Wahrhaftig and Cox, 1959, p. 389).

The front slope of the rock glacier rises at an angle of 39 degrees to a height of 265 feet and meets the upper surface at an abrupt angle. The extremely unstable nature of the rubble on the front suggests that the slope probably represents the maximum angle of repose for the debris. Boulders on the upper surface are encrusted with lichen, and thin patches of vegetation are found on pockets of soil between blocks of rubble, but the front is barren of vegetation.

The barren frontal slope at a high angle of repose and the sharp angle at the top of this slope indicate that the rock glacier is advancing with the upper surface moving forward more rapidly than the base, "for in a climate in which mass-wasting predominates, the sharp angle at the top and the steepness of the slope can be maintained only by constant renewal." (Wahrhaftig and Cox, 1959, p. 397).

When viewed from a distance, an irregular dark band is seen slightly more than a third of the way down the front slope (Pl. 16). This band contains fine-grained material beneath a layer of coarser surface rubble. According to Wahrhaftig and Cox (1959, p. 397), the exposure of a fine-grained lower layer on the front of a rock glacier suggests that most or all of the rock glacier is involved in forward movement, not merely the upper layer of rubble on the surface.

Small lobate ridges, convex downslope, are present near the middle of the upper surface. These are part of a larger lobe that heads in talus cones near the bend of the main rock glacier. In effect, this lobe forms a small rock glacier lying on top of and overriding the main one. It owes its origin to the presence of an independent source of sliderock near the northeast corner of the cirque.

Microrelief features on the main rock glacier include both longitudinal and transverse ridges and furrows. Longitudinal ridges, well developed on the lower half of the rock glacier, rise between 15 and 25 feet above the sharp, V-shaped intervening furrows and are up to several hundred feet long. The distance between ridge crests normally ranges from 25 to 100 feet. Transverse ridges trend normal to the long axis of the rock glacier and are convex downstream. They are less numerous than the longitudinal ridges and occur mainly near the northeast side.

The rock glacier is bordered on both lateral margins by prominent ridges that are traceable from the terminus well up into the cirque. These ridges, which resemble lateral moraines of true glaciers, stand slightly higher than the general level of the upper surface and are bordered on their inner side by a shallow furrow. Where the small secondary rock glacier overrides the main one, the eastern lateral ridge is disrupted, but it again appears below the outer margin of the secondary lobe.

At its head, the rock glacier merges imperceptibly with sliderock derived from steep cliffs of the cirque headwall. Debris from this cliff consists of angular blocks of Kanayut conglomerate. The trace of a major thrust fault crosses the headwall, and in its vicinity the rock has been strongly shattered and oxidized to various shades of red and yellow. Very likely the shattered nature of the rock is a factor in determining the presence of the rock glacier, for rockfall continually supplies debris to the cirque floor. In adjacent cirques that have the same orientation, lie at comparable altitudes, and are carved in the same rock type, but in which the trace of the thrust fault is not present, rock glaciers are absent. The inactive rock glacier on the north side of Red Rock Mountain also lies below the trace of a particularly large fault along which the bedrock is both shattered and oxidized. If lithology and structure are critical factors in determining the occurrence of rock glaciers in this region, the general absence of rock glaciers in cirques of the Anaktuvuk Pass area may be due to the lack of similar fault traces across cirque headwalls rather than to geographic factors, which appear to be similar throughout the region. Although thrust faults do cross several cirques in the map area, the rock is not strongly brecciated and the fault traces generally lie close to cirque floors.

Summary of history

Evidence from the Anaktuvuk Pass area indicates that the Fan Mountain glaciation was a fairly recent event, consisting of at least two distinct ice advances, and that it was limited mainly to high north-facing cirques. During the earlier advance some glaciers extended as much as a mile beyond their cirques and built massive steep-sided blocky moraines across valley floors. Others were confined entirely to cirques and built moraines near cirque thresholds. A period of retreat followed during which most glaciers receded into cirques and in some instances may have disappeared entirely. Physical differences between moraines suggest that at least several centuries elapsed between the initial Fan Mountain I advance and the relatively minor Fan Mountain II advance, which probably occurred within the last two centuries. Although Fan Mountain II glaciers in the Anaktuvuk Pass area were restricted to cirques, several of the smaller and lower cirques apparently remained ice free. In at least one cirque Fan Mountain II moraines lie slightly beyond residual glacier ice. Modern glaciers, both active and inactive, appear to be remnants of Fan Mountain II glaciers that built nearby moraines, many of which have ice cores. Active rock glaciers and small inactive rock glaciers probably originated either during this latest advance or during the earlier and more extensive Fan Mountain I advance.

Radiocarbon chronology

A discussion of the radiocarbon chronology of Itkillik and younger drifts in the vicinity of Anaktuvuk Pass and its correlation with glacial chronologies from other regions has been presented elsewhere (Porter, 1964a). A brief summary of the important points is included here.

Organic matter collected from the outwash fan of the Turret Peak moraine was dated at 2,830 ± 120 years. This date should approximate the time of the maximum stand of Alapah Mountain ice in the valley of Inukpasugruk Creek. No organic matter was found associated with Fan Mountain drift, but moraines of this youngest glaciation appear to be significantly younger than Alapah Mountain moraines. Probably the Fan Mountain II moraines were built within the last several centuries. Fan Mountain I moraines may be of intermediate age.

Radiocarbon samples collected from late-glacial sediments associated with the Anivik Lake advance provide a minimum age of 7,241 ± 95 years for the advance at Anaktuvuk Pass. This is in close agreement with ages from a radiocarbon-dated pollen profile from Umiat that has been correlated with pollen profiles from the Chandler Lake area collected from deposits related to the Anivik Lake (Echooka) advance (Livingstone, 1955; 1957). The combined dates strongly suggest that the advance took place between 8,000 and 9,000 years ago. This would make it a very late Wisconsin event and suggests possible correlation with the Cochrane readvance of the central North American glacial sequence.

A close limiting age for the Anayaknaurak readvance is provided by a radiocarbon date of 13,270 ± 160 years on organic matter beneath till. The date suggests that this event can be correlated with the Port Huron readvance of the Laurentide ice sheet in the Great Lakes region of central North America.

The radiocarbon dates indicate that the Itkillik sequence in the Anaktuvuk Valley probably is broadly equivalent with the classical (late) Wisconsin sequence of the Great Lakes region and with the Naptowne glaciation of the Cook Inlet region in southern Alaska, both of which have been rather closely dated by radiocarbon. The Alapah Mountain and Fan Mountain glaciations are post-Wisconsin events that fall within post-Hypsithermal time (Porter, 1964a, pp. 458–9).

Deposits and features of non-glacial origin

Alluvium

Alluvium, which is the most widespread non-glacial surficial sediment on valley floors, is exposed principally in alluvial fans and along floodplains of major streams. Most sediments in alluvial fans consist of weathered debris eroded from postglacial stream gorges. Alluvium along Inukpasugruk Creek appears to be derived largely from nearby bedrock, for pebble counts along the course of this stream show that lithology of stream gravel closely matches lithology of bedrock outcrop belts along the valley (Fig. 19). Alluvium along the John and Anaktuvuk rivers, however, is more closely controlled by the character and composition of glacial deposits on the valley floor. Upstream from the Anivik Lake moraine alluvium on the flood plain of the Anaktuvuk River generally consists of coarse gravel that resembles, both in rounding and over-all lithology, the character of nearby ice-contact gravel that apparently was its source. Downstream from the end moraine the stream gradient lessens and coarse gravel passes into finer gravel and sand.

Along the lower part of Contact Creek in the vicinity of the village, alluvium consists both of glacially derived sediments from the valley of Contact

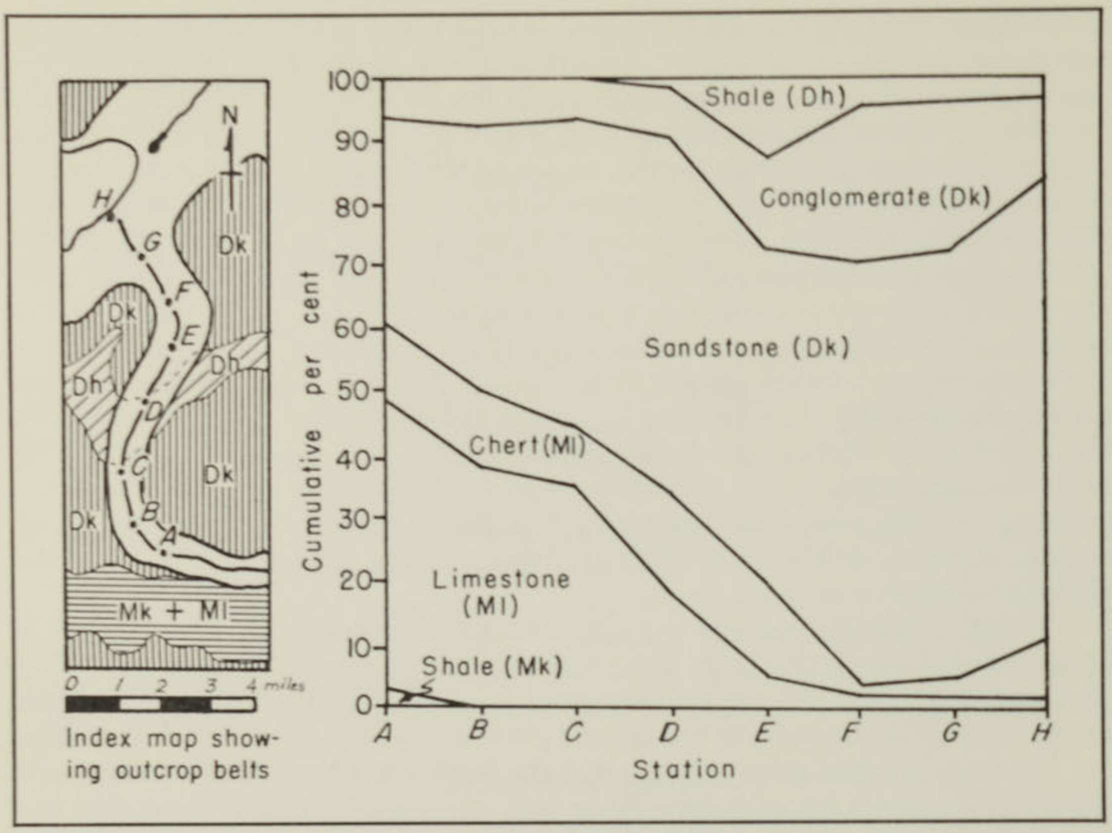


Fig. 19. Lithology of alluvium along Inukpasugruk Creek. Letters indicate pebble-count localities (see Fig. 1).

Creek and of bedrock from the valley of Little Contact Creek. Downstream from the head of the John River the stream gradient decreases abruptly, and the river meanders on a nearly flat flood plain between kame terraces. Here the bulk of the alluvium is fine gravel and sand; probably it consists of material that bypassed coarse gravel upstream and was deposited where stream competence decreased with decreasing channel gradient.

In several areas, as on the valley floor between Summit Lake and Cache Lake, the surface is underlain by organic-rich silt. Although not well exposed for study, probably both alluvial and lacustrine sediments are included in these deposits.

Appreciable areas of the valley floors are covered by alluvial-fan deposits. Most fans slope gently from the mouths of sharp, deep, V-shaped mountain gorges toward a river near the axis of a valley. In many instances fans are built over glacial deposits, and only the highest parts of kames or kame terraces protrude above the surface of a fan. Some fans coalesce to form broad continuous alluvial aprons at the base of mountain slopes, as along the John River. Coalescing fans built westward by Alukvik and Kollutuk creeks have deflected the John River against steep bluffs of ice-contact sediment, thereby destroying the meander pattern that is so pronounced upstream.

The presence of fresh, non-paired terraces along several streams, notably along upper Inukpasugruk Creek and several of its tributaries as well as along parts of Contact Creek, suggests that these streams are presently degrading their channels. Furthermore, nearly all streams on alluvial fans are deeply entrenched to depths as great as 25 feet.

Remnants of older, larger alluvial fans that have been greatly dissected occur at several places in the map area. Included are the fan along the west wall of the John-Anaktuvuk valley just south of Kungomovik Creek, and a fan on the south side of Napaktualuit Mountain. In both instances the existence of older, more-extensive fans is inferred from prominent fan remnants that have escaped destruction by stream erosion. On both these fans streams have eroded downward at least 20 feet below the original fan surface. In the case of the Kungomovik fan, the highest and oldest surface has a steeper gradient than the lower erosional surface owing to the fact that at the apex of the fan the stream has cut a 20-foot-deep channel in limestone bedrock. As a result of this downward erosion, which was accompanied by lateral shifting of the degrading stream, the lower recently developed surface of the fan appears to be nestled within a higher, more-extensive fan, remnants of which are preserved along the valley walls. The modern stream is currently entrenched below the lower erosional surface to an average depth of about 10 feet.

As is apparent from the erosional features described, appreciable dissection has occurred since the last major period of aggradation. From the entrenched nature of most modern streams, it seems that present conditions favour continued degradation of most alluvial deposits.

Eolian sediments

Although winds are strong and persistent through the pass, little evidence of their geologic work was recognized. Probably this is due largely to the nearly complete cover of vegetation on valley floors which effectively inhibits deflation. On flood plains deflation occurs locally in areas underlain by fine sediment, but the bulk of modern alluvium, being coarse pebble and cobble gravel, is not affected by wind.

Evidence of former eolian activity was seen in a cutbank of Anivik Creek half a mile northeast of Anivik Lake, where approximately two feet of non-stratified silt overlies a thin layer of dark organic matter that rests on top of bedded coarse sand and gravel of alluvial origin. The upper foot of silt contains organic matter but displays no recognizable features indicative of stream deposition. The silt is well sorted and is powdery when dry; its grain-size distribution is close to that of a typical loess (strongly unimodal). Because the deposit is covered by thick vegetation, its lateral extent could not be accurately determined, but the silt appears to extend over an area of at least several thousand square yards. It is interpreted as having been deposited during a former period of strong wind activity that may have coincided with a glacial advance. Very likely the sediment was derived by deflation either from Anivik Lake drift that is exposed to the south, from alluvium along the Anaktuvuk River, from an extensive body of water-laid sand and silt that lies north of the map area, or from a combination of these three possible sources. The deposit of water-laid sand and silt, which can be traced northward from about a mile north of the map border to at least a dozen miles beyond the range front, appears to have been reworked by the wind in the vicinity of Tulugak Lake, where dune-like features are present near the river. Most of these are now mantled with vegetation and seem to be inactive, but linear unvegetated blowouts, oriented in the direction of prevailing winds that blow parallel with the valley, are found on some dunes and indicate that winds recently have been actively eroding these deposits. Twelve-year old Eskimo graves dug on the top of one of the dune-like ridges near Tulugak Lake only now are showing signs of vegetation. This strongly suggests that the numerous blowouts along the river have been active at least within the last decade.

Sliderock

Owing to a combination of great relief, steep cliffs of well-jointed bedrock, and a frost climate, many mountain slopes near Anaktuvuk Pass are characterized by appreciable accumulations of sliderock. Although usually present on all but the steepest slopes, sliderock has been mapped only where sufficiently thick and extensive to form a conspicuous talus.

In an arctic climate like that of the north-central Brooks Range, the production of sliderock depends primarily on temperature fluctuations through the freezing point. During winter months temperatures are continuously well below freezing, whereas only rarely during midsummer does the temperature fall to the freezing point. At Anaktuvuk Pass diurnal freeze and thaw takes place on only about 10 per cent of the days each year; approximately half these days are in late spring, the other half in early fall. Very likely it is during these periods that frost wedging is most active in producing sliderock. Throughout the summer appreciable rockfall occurs in north-facing cirques, but in such high areas diurnal freeze and thaw probably extends well into the summer months. In the western cirque of Mount Ahgook significant rockfalls were noted on the average about once a minute in early August. Similar, but less frequent, rockfalls were seen in other north-facing cirques during June and July.

Sliderock is particularly plentiful beneath prominent cliffs of Lisburne rocks; on such slopes Kayak shale frequently is buried by an extensive talus. Sliderock of Lisburne origin tends to be coarse and angular, and normally rests at an angle of from 34 to 36 degrees. Beneath shale outcrops on some mountain slopes sliderock consists of fine shaly rubble that forms a more gently sloping talus. Extensive slopes of sliderock are not present in outcrop belts of the Kanayut conglomerate. In these areas sliderock usually accumulates in talus cones that lie at the foot of steep couloirs. In most cirque valleys carved in Kanayut conglomerate closely spaced talus cones coalesce to form aprons of sliderock beneath steep valley walls.

Most accumulations of recent sliderock rest at steep angles and are very unstable. They consist of fresh rubble that shows little or no evidence of weathering and generally is free of lichens or patches of vegetation. However, at the base of some mountains, stable sliderock lies downslope from unstable rubble (Fig. 1) and generally forms slopes of less than 26 degrees. The rock appears more weathered than fresh sliderock upslope and a semi-continuous, though generally thin, mat of vegetation covers the surface. These deposits, an example of which lies along the north side of Little Contact Creek, may have accumulated at a time when the climate favoured production of more sliderock than it does today. Such conditions might result from slightly lower summer temperatures which would increase the number of freeze-thaw cycles per year.

Sub-linear channels that extend from couloirs downslope across talus cones nearly to their base are common features in cirque valleys. Such channels, which probably are formed by wet-snow avalanches in spring, are up to 4 feet deep and 6 feet wide. Most have natural levées that rise from 1 to 3 feet above the general surface of the talus cone. Arcuate piles of rubble at the foot of the channels superficially resemble small arcuate morainal ridges and are convex downslope.

Protalus ramparts (Daly, 1912, p. 593; Bryan, 1934), found at the base of some mountain slopes, in many instances resemble lateral moraines and can be distinguished from them only with difficulty. Sliderock in protalus ramparts consists almost entirely of locally derived rubble from cliffs above, whereas lateral moraines often contain a heterogeneous mixture of rock types derived from various bedrock units upvalley. At times, however, glacially transported erratics that have been left on a mountain side fall downslope and become incorporated in the rubble of a protalus rampart. In protalus ramparts below Soakpuk Peak, a few conglomerate stones that are associated with sliderock of Lisburne origin are believed to have been derived in this manner. Most protalus ramparts are convex toward the axis of a valley and lie along the curved, outer margin of a talus cone. In this respect they differ from most lateral moraines, the crests of which generally parallel the valley walls.

A few protalus ramparts may be actively growing, for although usually their front slopes are vegetated and seem relatively stable, the crests of some are littered with fresh sliderock. However, a majority of those examined are completely vegetated and lie beyond modern sliderock accumulations, suggesting that they formed during an earlier period when the climate was sufficiently cool to allow snowdrifts to persist longer than they do today.

Several protalus ramparts lie beyond the Anivik Lake moraine and others are found at altitudes near, or possibly even above, the upper limit of Itkillik glaciation. These presumably could have formed at any time since Itkillik deglaciation. However, several protalus ramparts that were noted in tributary valleys lie upstream from moraines of Alapah Mountain age. Consequently, it is believed that most protalus ramparts in tributary valleys postdate the Hypsithermal interval. Direct means of correlation are lacking, but it appears likely that they formed during one or both of the Fan Mountain ice advances when the climate was cooler and snowdrifts at the foot of mountain slopes may have persisted well into the summer months. In general, there is little evidence to indicate that these features are forming today.

Landslides

Within the map area two landslides were noted, both in the outcrop belt of the Hunt Fork shale. The smaller of the two slides lies at the foot of the northeast ridge of Kollutuk Mountain. The slide scar, approximately 25 feet high and nearly 200 yards long, lies at the base of a large solifluction slope. Downslope movement of any given point in the landslide has not been more than about 100 feet. The slide debris has retained a vegetation cover and is poorly exposed, but it appears to consist largely of till and colluvium.

A second and considerably larger slide has blocked a tributary of Inukpasugruk Creek north of Red Rock Mountain. The mountain slope above the creek bed is underlain by at least 10 feet of very stony till that mantles the Hunt

Fork shale. A large fresh scar marks the site of the slide. The adjacent mountain slope is covered with a mat of vegetation, as is the surface of the slide debris at the base of the slope. Lack of vegetation on the slide scar suggests that the movement may have occurred within the last decade or two. Although a tortuous stream channel has been cut through the slide debris, the present stream flows beneath the surface during the summer months and emerges near the bottom of the wedge-shaped debris fill as a spring. Therefore, the channel through the slide debris is likely the result of vigorous erosion during times of high stream discharge, a condition that probably exists only during spring thaws.

The bulk of the landslide debris consists of boulders of Kanayut conglomerate. Parallel striations seen on a number of these boulders probably have resulted from glacial transport. Shallow, nonsystematic scratches that are present on some of the softer rocks may have formed during the slide.

The upper surface of the slide debris that fills the creek valley is hummocky and resembles morainal topography. This surface morphology, as well as the absence of backward rotation, indicates that the slide should be designated a "debris-slide" in the terminology of Sharpe (1938, p. 74). The slide probably resulted from instability due to oversteepening of the slope by downward erosion of the stream. Very likely the southern exposure of the slope was a contributory factor, for depth to permafrost probably is greater here than on adjacent north-facing slopes.

Mudflows

Bare semicircular depressions on vegetated slopes that merge downslope into hummocky fanlike deposits of soil, rubble, and turf are present on some valley sides within the Anaktuvuk Pass area. Such features, which result from sudden viscous flow of fine-grained unconsolidated sediments saturated with water, range in character from those that resemble true mudflows to those that resemble mudflows in their upper reaches and earthflows in their terminal zones. Although some combine characteristics of both mudflows and earthflows, all seem to have originated by sudden flow of saturated soil, and in this respect are most closely allied to true mudflows. Physical continuity of the terminal portions of these features generally is a result of the tough, compact mat of tundra vegetation that is carried downslope on the mobile mud layer beneath and is crumpled near the base of the flow. To such features Sigafoos and Hopkins (1952, p. 189) have given the name "tundra mudflows."

Although they vary in size and shape, the five mudflows noted within the map area have several characteristics in common. Each lies within the outcrop belt of a fine-grained clastic sedimentary rock unit (either the Hunt Fork shale or the Kayak shale), and all occur on moderately steep, vegetated slopes (10–20 degrees) that are mantled with silt- or clay-rich till. The high proportion of silt and clay in the till probably reflects the very fine-grained nature of the underlying bedrock.

Depressions at the heads of mudflows are from 3 to 6 feet deep and mudflow channels generally are from 10 to 50 feet wide. Bare mineral soil is commonly exposed for a distance of at least 25 feet below the scarp at the head, but in two cases, namely on a long mudflow west of Red Rock Mountain and on one at the south base of Soakpuk Peak, bare soil is exposed to the terminus of the flow, a distance of several hundred yards. Detached patches of vegetation lie at irregular intervals in the long shallow mudflow channel.

In a mudflow that lies northeast of Red Rock Mountain surface turf has been crumpled into superposed overturned folds that are piled up to a height of about five feet at the leading edge of the flow (Pl. 17). In places the turf is broken, and slices have been thrust forward for short distances. In this case, mud is not exposed at the front of the feature, and the terminal zone more closely resembles an earthflow than a true mudflow.

All flows seen appeared fresh and none showed evidence of being revegetated since movement. Probably none are more than several years old.

The origin and development of mudflows in tundra regions has been described by Sigafoos and Hopkins (1952, p. 188) and by Taber (1943, p. 1,458). The presence of silt-rich sediment mantling highly impervious shale-and-slate bedrock is believed to be a primary factor in determining the distribution of mudflows within the Anaktuvuk Pass area.

Solifluction features

On many mountain slopes in the Anaktuvuk Pass area, especially those that face north or east, the typical slope profile passes downward from steep bedrock cliffs to steep taluses, which in turn give way to more gentle slopes below that have been modified by solifluction. On these lower slopes, downslope transportation of weathered materials by solifluction is far more important than transport by running water, and very likely accounts for the predominance of smooth gentle profiles where mountain slopes merge with valley floors.

Solifluction sheets commonly measure several thousand square feet in area and show evidence of slow downslope movement. The vegetated sheets of sediment characteristically have an abrupt lower margin from 1 to 4 feet high that generally parallels the slope contours. On some slopes several sheets appear to be superposed, the lower end of one sheet overriding the upper part of the next lower sheet (Pl. 18).

Solifluction lobes, which are common throughout the area, are characterized by steep fronts normally 6 inches to 3 feet high, but in places reaching a height of 5 or 6 feet (Pl. 18). The lobes range in width from a foot to as much as 100 feet and are spaced at irregular intervals depending on the steepness of the slope (and possibly the character of the debris mantle). The surface sod generally is unbroken, but it may be stretched somewhat at the front of a lobe. Peat underlying the living vegetation at the base of a solifluction lobe may extend upslope beneath the lobe, indicating that the mineral soil has overridden organic material downslope. The origin and development of these lobate features has been discussed by Taber (1943, pp. 1,460–1) and by Sigafoos and Hopkins (1952, pp. 186–7).

Locally on some slopes solifluction sheets or lobes are laterally confined by outcrops of bedrock or by bodies of glacial drift and pass downslope into solifluction streams. These in turn may grade into solifluction stripes which consist of strips of bare ground that alternate with depressed strips of vegetated ground.

Although solifluction was observed on slopes underlain by all bedrock types of the map area, it is best developed on slopes that are underlain by shaly rocks. Solifluction features are particularly widespread on slopes underlain by the Hunt Fork shale, by Kayak shale, by the fine-grained Stuver member of the Kanayut conglomerate, and by the shaly middle member of the Alapah limestone. This distribution suggests that solifluction is particularly active in areas where soils contain a high percentage of silt and clay, and that soils in such areas closely reflect the nature of the parent rock.

Soils

Until recently, arctic soils were among the least studied and least well understood of the major soil groups, but extensive research within the last decade, primarily by J. C. F. Tedrow and his co-workers, has led to a better understanding of soil types and soil genesis in northern Alaska (Tedrow and Hill, 1955; Drew and Tedrow, 1957; Tedrow, Drew, Hill, and Douglas, 1958; Tedrow and Cantlon, 1958; Douglas and Tedrow, 1960; Hill and Tedrow, 1961). Tedrow and Cantlon (1958) have devised a classification of arctic soils based on moisture content of the soil and on depth of the soil profile. Arctic Brown soil (Tedrow and Hill, 1955) is regarded as characteristic of well-drained, acid environments and is the arctic counterpart of the more temperate podzol. With increasing wetness of the ground, Arctic Brown soil is replaced successively by Upland Tundra, Meadow Tundra, Half Bog, and Bog soils. These soils, collectively referred to as the tundra soils, represent the arctic equivalents of humic gley soils and bog soils of northern forested regions.

Each of the soil types mentioned above can be identified in the Anaktuvuk Pass area. Arctic Brown soil is widespread on well-drained sites which are numerous on valley floors. It is particularly well developed on kame terraces that border the John River and on kames that lie north of Summit Lake. On the kame terraces Arctic Brown soil is up to 20 inches deep and is associated with large high-centre polygons or tetragons (Pl. 19). According to F. C. Ugolini (personal communication, 1960) Arctic Brown soil is developed on the Stuver member of the Kanayut conglomerate at an altitude of about 4,000 feet at the east end of Nachramkunga Mountain.

Jerry Brown (personal communication, 1960) has identified Arctic Brown soil with podzol-like features at several places within the map area. These are localized occurrences and may reflect minor variations in micro-environmental conditions. The characteristic bleached A_2 horizon of typical podzols is poorly developed in these profiles and generally is very thin. These incipient podzols frequently are found in association with or lie near stands of dwarf birch. Hill and Tedrow (1961) noted the occurrence of a similar trend toward podzolization in Arctic Brown soil on a well-drained kame terrace along the Killik River. They state that such soils "are rarely found on the Arctic Slope and are thought to develop only under special conditions: coarse-textured, highly quartzose, acid parent materials." (p. 98).

Soils that form on flat summits, ridge crests, benches, cols, and buttresses of limestone peaks in the Anaktuvuk Pass area have been studied by F. C. Ugolini, who has described these well-drained dark-coloured soils as rendzinas (F. C. Ugolini, personal communication, 1960). They are characterized by a thick organic mineral horizon that rests either directly on bedrock or is transitional into bedrock. At such sites the frost table generally is deep (usually more than

Pl. 17. Terminal portion of tundra mudflow on northeast side of Red Rock Mountain. Tundra cover has been ruptured near head of flow but has been folded into a series of superposed folds near front.

Pl. 18. Superposed solifluction sheets on west flank of Kollutuk Mountain. Small solifluction lobes are present on the mountain side above the large sheets in the middle distance.

Pl. 19. Trench separating large polygons on kame terrace immediately east of Cache Lake. Note contrast between vegetation growing on surface of polygon and that growing in trench.

Pl. 20. Subcircular frost scar (nonsorted circle) developed on poorly drained tundra slope underlain by stony till. Dessication cracks appear on convex surface.

Pl. 21. Sorted nets on floor of drained lake basin half a mile south of Summit Lake on pitted section of kame terrace. Pocket knife indicates scale.

2 feet) and the vegetation cover normally consists of *Dryas octopetala*. Ugolini feels that these soils are controlled primarily by the microclimate induced by several physiographic variables rather than solely by altitude, for soils that occur under similar geomorphic conditions but at different altitudes appear to be comparable.

In poorly drained areas, such as those underlain by till on valley floors, tundra soils predominate. Generally the frost table lies at shallow depths, even during the warmest part of the summer, and the active layer is continuously saturated when thawed. Upland Tundra soils are present on steep slopes that are better drained than gentle till slopes of valley floors. These soils are associated with a wet tundra plant community, dominated by *Eriophorum vaginatum* and various heath shrubs. Under somewhat drier conditions *Dryas* and numerous herbs appear. On gentle, very poorly drained slopes Meadow Tundra soils and Bog soils are present. The associated vegetation consists largely of sedges, *Eriophorum angustifolium* and *Carex aquatilis*, and *Sphagnum* mosses. Where polygonal ground is developed, the elevated portions of polygons tend to be better drained than the interpolygon trenches, which generally are filled with water. Under such conditions several different soils and vegetation communities exist in close proximity in complex patterns.

There appears to be little difference in degree of soil development on glacial deposits of different ages. Well-developed Arctic Brown soils have formed in well-drained sites on drift of Alapah Mountain age, of Anivik Lake age, and of pre-Anivik Lake age. However, on a terrace at the pass on which are located several archaeological sites, the Arctic Brown profile is shallower than that developed on a nearby kame terrace east of Contact Creek which, on geologic evidence, appears to antedate the terrace at the village. If other soil-forming factors are equal, as they appear to be in this case, then the difference in depth of profile development at these two sites may be a function of time.

Patterned ground

A great variety of microrelief features exists on flat valley floors, on gentle to moderate slopes, and on some summit crests within the Anaktuvuk Pass area. Among the many types of patterned ground noted are sorted and nonsorted circles, sorted nets, nonsorted polygons, and nonsorted stripes (Washburn, 1956). While some of the larger of these frequently are difficult to recognize on the ground, they are readily apparent from the air and are seen to cover a large portion of the ground surface, being especially common in areas underlain by gravel or sand.

Cottongrass tussocks are extremely common on poorly drained ground moraine. They range in diameter from 1 to 2 feet and grow up to 2 feet high. If drainage is very poor, the inter-tussock channels may be filled with water to a depth of several inches. In many places groups of tussocks grow in nearly circular tussock rings; on moderate slopes these become elongated downslope.

Nonsorted subcircular patches of bare ground within tussock-covered areas, referred to as frost scars by Hopkins and Sigafoos (1951), are widespread (Pl. 20). Generally they range in size from several inches to several feet. During summer they tend to be convex mounds of bare, light-brown mineral soil that are crossed by small shrinkage cracks. In some areas nonsorted circles occur in great numbers and are closely spaced. A large concentration lies southwest of Napaktualuit Lake near the extensive stone pavement shown on Fig. 1.

Sorted circles were noted in cobble gravel near the margins of several aufeis fields and sorted nets ranging from a few inches to as much as 4 feet in diameter, are present on the floors of some drained kettle-lake basins on the pitted section of the kame terrace that lies east of Summit Lake and Contact Creek (Pl. 21). In several places small sorted nets formed in silty sand and pebble gravel lie within larger nets bordered by cobbles and small boulders. Similar features occur on the ridge crest between Three River Mountain and Cirque Peak, where nets ranging from 6 to 18 feet in diameter occur at an altitude of 5,850 feet.

Polygonal patterned ground is even more widespread than circles and nets. Low-centre polygons of large dimension are developed in swampy areas near Summit Lake and along the alluvial flood plain of the John River. Such features commonly range in diameter from 4 or 5 feet to as much as 100 feet. Small ridges of peaty organic matter 1 to 2 feet high form the boundaries between adjacent polygons. The low central areas of the polygons normally are covered with several inches of stagnant water.

High-centre polygons are widespread on nearly flat-topped deposits of coarse stratified drift. They are particularly well developed on the kame terrace immediately east of Cache Lake, where polygons reach diameters of more than 100 feet (Pl. 19). Inter-polygon trenches commonly are 3 to 4 feet deep. In early July 1960 the frost table at the bottom of one of these trenches was very shallow (2 to 3 inches), whereas on the high central well-drained part of the polygons frozen ground lay at depths of 18 to 24 inches. The flat surface of the polygons supports a thin cover of mossy and herbaceous vegetation. *Dryas octopetala* is the dominant species of this environment. Inter-polygon trenches, on the other hand, generally contain growths of willow and dwarf birch. Similar polygons, found on large, level expanses of stratified drift between Anivik Lake and Napaktualuit Lake, are as much as 200 feet in diameter.

Although subsurface ice wedges were not exposed along polygon boundaries in either high-centre or low-centre polygons, they probably exist at depth. In the area of polygonal ground immediately south of Summit Lake, deep, narrow, water-filled trenches are present locally at the polygon boundaries. One trench that measured 18 inches wide and was more than 5 feet deep probably originated through melting of an inter-polygon ice wedge. The high-centre polygonal ground on the nearby kame terraces is similar in character to ice-wedge polygons found in other areas of northern Alaska that have been described by Leffingwell (1919), Hopkins, Karlstrom, and others (1955), and Carlson and others (1959).

Aufeis

Sheetlike accumulations of stratified ice that form on river flood plains during fall and winter months were referred to as aufeis by Leffingwell (1919, p. 158) who adopted the term proposed earlier by Middendorff. Aufeis forms when streams either freeze to their beds or are dammed so that water overflows the banks and inundates the flood plain, where it quickly freezes. Repeated overflow and freezing often results in thick accumulations of stratified ice.

Several sizeable aufeis fields are present at Anaktuvuk Pass (Pl. 22 and Fig. 1). While a few of these diminish greatly in size during the summer months and may disappear entirely before the fall freeze-up, some large aufeis fields persist throughout the year. A number of small aufeis bodies located both in the main valley and along Inukpasugruk Creek generally disappear by mid-summer.

The aufeis field near Kungomovik Creek is nourished by springs and surface streams that originate near the mouth of a small stream valley south of Kungomovik Creek. In mid-June 1960 this field measured approximately 2,000 by 3,000 feet. A narrow meltwater channel about 600 feet long crossed the northeast quadrant of the aufeis field. The thickness of the ice along this channel increased almost uniformly from the edges toward the middle of the transect where it reached a maximum thickness of 18 feet. By the end of the first week in August the ice mass was much reduced in size. The thickest ice measured along the meltwater channel was but 7.5 feet thick, and the west edge of the ice had melted back a distance of 325 feet during this interval.

Two types of ice were exposed in the walls of the stream channel. Wide lenticular layers of candle ice, ranging in thickness from half an inch to 2 feet and in which individual crystals commonly were from a quarter of an inch to an inch in thickness, were interstratified with sheets of granular ice that resembled firn (Pl. 23). The granular ice typically was finely layered, with from 3 to 5 layers per inch. The layered candle ice probably formed by freezing of stream overflow, whereas the coarse granular ice may have resulted from the transformation of snow into small granules of solid ice. Winter snow falling on aufeis fields that are actively building may be converted to granular ice prior to or during the next overflow of water from the source spring or stream. As some springs apparently flow throughout the winter, aufeis deposition may persist during most or all of this season. In aufeis fields that lie on flood plains of large rivers, the bulk of the ice appears to be candle ice. This suggests that overflow may be a rather rapid and continuous process on large rivers, thereby providing little opportunity for accumulation of snow and its conversion to granular ice before aufeis deposition ceases.

Interstratified between layers of candle ice and granular ice, and almost invariably found above layers of candle ice, are accumulations of very pure pale-yellow calcium carbonate crystals. Similar carbonate crystals were noted on the surface of the aufeis field and lay either along the bottom of small meltwater channels or had accumulated on the dry ice surface in windrows. The carbonate is believed to have been precipitated when the carbonate-rich streams that drain adjacent limestone peaks flowed over the aufeis field and froze. This might explain the concentration of carbonate above layers of candle ice and its general absence above layers of granular ice. Where aufeis melts away during the early summer, accumulations of crystalline calcium carbonate commonly cover the ground surface, and can be used as indicators of the original areal extent of the fields.

The Kungomovik aufeis field covers a vast stone pavement of glacially derived boulders and cobbles. The pavement is exposed only near the margins of the field and along the floor of meltwater channels that transect it. Nearly all exposed stones are oriented with a flat face parallel to the ground surface. Shallow excavations indicate, however, that fine sediment is present immediately beneath the surface stones (Pl. 24). Possibly frost heaving has brought about size sorting of the stones so that coarse material lies at the surface and fines have accumulated below. Orientation of the uppermost stones into a relatively smooth pavement may result from further adjustment under the weight of the overlying aufeis which, in some years, may reach a thickness exceeding 20 feet.

Extensive stone pavements like that described were found in association with all aufeis fields that were underlain by coarse gravel and were not located along channels of major streams. The braided reaches of the John and Anaktuvuk rivers, which are the sections where aufeis commonly forms, apparently are unfavourable sites for the formation and preservation of stone pavements owing to erosion and redistribution of gravel by laterally shifting channels. The common association of stone pavements with many modern aufeis fields at Anaktuvuk Pass strongly suggests that they are genetically related to aufeis and possibly might be used as a means of distinguishing areas formerly covered by aufeis.

Immediately southwest of Napaktualuit Lake, within an area that measures about half a mile wide and a mile long, the ground surface consists of a nearly featureless stone pavement of the type described above. Although stones are lichen-covered and mossy vegetation grows between many of the surface cobbles, the stone pavement otherwise appears very similar to those found under modern aufeis fields. Consequently, this stone pavement has been interpreted as marking the site of a former aufeis field that was far more extensive than the restricted aufeis bodies that are found adjacent to this vegetated stone pavement at present.

Ground ice

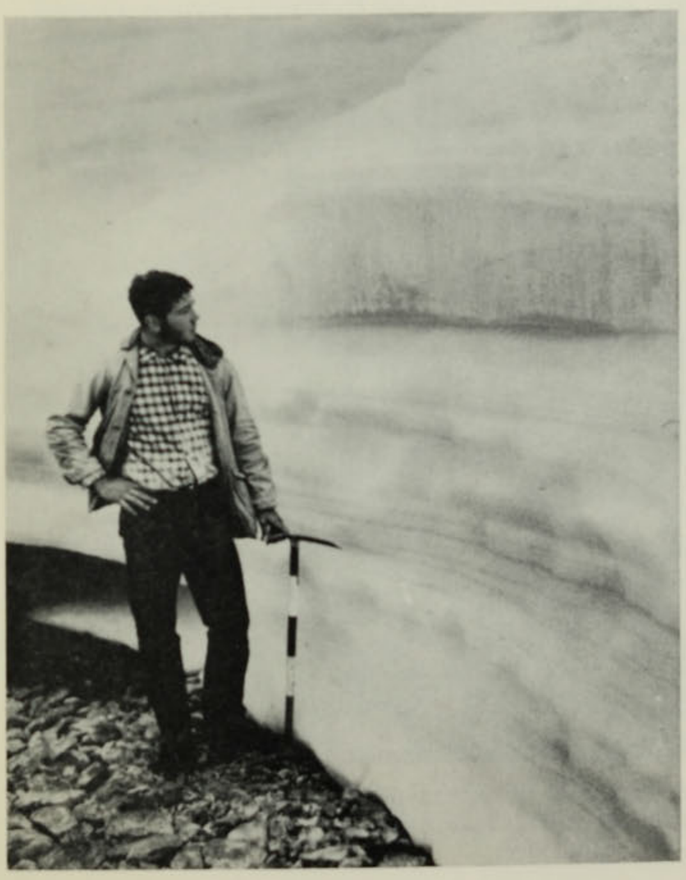
Ground ice has been defined by Leffingwell (1919, p. 180) as "bodies of more or less clear ice in permanently frozen ground." Comprehensive studies of ground ice in Alaska have been made by Leffingwell (1919, pp. 179–242) and by Taber (1943, pp. 1,510–29); observations of ground ice occurrence in northwestern Alaska have been described briefly by Chapman and Sable (1960, p. 65).

Natural and artificial exposures of ground ice, as well as the presence of certain geomorphic features, suggest that three main forms of ground ice occur in the Anaktuvuk Pass area: ground-ice lenses, ground-ice sheets, and ground-ice wedges.

In natural exposures of perennially frozen silt in river cutbanks and in artificially excavated Eskimo cellars beside Summit Lake, small lens-shaped bodies of ice are enclosed within a matrix of fine, dark-gray silt. Distribution of the ground-ice lenses gives the silts a "gneissic" look when exposed in section. Ice lenses commonly range from 0.05 to 0.25 inch in thickness and from 0.25 to 0.5 inch in width. Normally they are oriented parallel to the ground surface and are randomly spaced throughout the enclosing silt. Although ice lenses appear to constitute less than half the total volume of the frozen sediments, water formed between 60 and 80 per cent of the total volume of several thawed specimens from one of the cellars, indicating that the bulk of the frozen sediment consists of small ice lenses.

Thick sheets of ground ice, commonly from 1 to 6 feet thick and overlain by a foot or more of densely matted vegetation, occur near modern flood plains

Pl. 22. Aufeis fields on and near the flood plain of the Anaktuvuk River in mid-June. Napaktualuit Mountain in background.



Pl. 23. Channel cut through aufeis field near Kungomovik Creek showing layered structure of ice. Note layers of candle ice interstratified with layers of coarse granular ice.

Pl. 24. Excavation in stone pavement beneath Kungomovik aufeis field showing sorting of stones. Large stones oriented with flat faces parallel to ground surface are underlain by smaller randomly oriented pebbles and cobbles.

Pl. 25. Ground ice underlying thick mat of tundra vegetation near flood plain of Anaktuvuk River immediately north of Anivik Lake moraine. Exposed ice is mainly candle ice.

on valley floors (Pl. 25). Such ice is exposed infrequently in stream cuts or in places where melting has caused collapse and rupture of the vegetation cover. Several exposures of this nature were seen along Inukpasugruk Creek immediately above the gorge and opposite the west ridge of Red Rock Mountain; similar exposures were visible along the Anaktuvuk River in the vicinity of the Anivik Lake moraine. In each of these areas collapse of covering tundra vegetation, exposure of ground ice in section, and the presence of abundant meltwater in which floated many blocks and sheets of sod point to recent and apparently widespread melting of the ice.

Near Inukpasugruk Creek willows and moss overlie a ground-ice sheet, which is layered into bands of relatively clear ice separated by bands of coarsely crystalline candle ice similar to layering in aufeis.

Ground-ice wedges are not exposed to view within the map area, but their presence is inferred from the distribution of patterned ground, described previously, on kame terraces and flood plains of the John-Anaktuvuk valley.

Taber (1943, p. 1,522) discussed the origin of ground ice in Alaska and advocated a theory that "explains the formation of ice layers and ice veins as the result of a continuous process" which involves "downward freezing accompanied by the segregation of water to build up the various forms of ground ice." While this theory might adequately explain small segregated ice lenses in frozen silts and also certain ice veins associated with them, it seems inadequate to explain the thick and often extensive sheets of ground ice that lie marginal to river flood plains at Anaktuvuk Pass. The similarity in physical character between this type of ground ice and typical aufeis seen elsewhere in the map area, plus the fact that overlying material commonly is coarse gravel or, in some instances, merely layers of peat and vegetation, strongly suggests that these bodies of ground ice originated through burial of aufeis fields by stream gravels or by encroaching vegetation. This idea was proposed earlier by Leffingwell (1919, p. 242) to explain one form of ground ice in the Canning River region of northeastern Alaska. Taber (1943) acknowledged that this may be one possible source of ground ice but stated that he found no evidence of it in the nonglaciated parts of Alaska. Very likely this mode of origin would be feasible only in those arctic regions where aufeis forms today or where it has existed in the recent geologic past. The fact that ground ice at Anaktuvuk Pass of the type here attributed to aufeis burial is currently melting, implies that it is not in equilibrium with the present climate and, therefore, probably does not antedate the post-Wisconsin Hypsithermal interval, during which time the climate probably was even milder than today.

LATE PLEISTOCENE CLIMATES

Snowline and Pleistocene meteorology

Modern snowline

The term *snowline* has been defined in various ways, but a widely accepted definition is that proposed by Matthes (1942) who regarded it as the lower limit of the region of perpetual snow. Commonly the word is restricted by the use of modifying adjectives. Thus, the ***orographic snowline*** constitutes the lowest limit of retained snow at the end of the summer ablation season, and therefore is represented by the line joining the lowest edges of perennial snowbanks. The *firn limit* is considered to be the equivalent of the orographic snowline on glaciers and is the highest level to which the fresh snow cover on a glacier retreats during the summer melting season. The ***regional snowline*** generally is defined as the average regional level of the orographic snowline. Many equate this with the ***climatic snowline***, but the latter has a slightly different meaning, for Matthes (1942, p. 157) defined it as "the level above which snow accumulates indefinitely on flat surfaces fully exposed to sun and wind." By this definition, the climatic snowline is little more than a theoretical concept in rugged mountainous regions. On the other hand, the regional snowline is an observable and measurable parameter, regardless of the terrain, although it can be more closely defined in some areas than in others. Charlesworth (1957, p. 11) pointed out that the orographic snowline is controlled to a large degree by local relief and that the simpler the relief, the more closely do the climatic and orographic snowlines approach each other. In this paper the term "snowline" will be used in the same sense as the regional snowline as defined above.

The altitude of the snowline has been determined with varying degrees of accuracy for many regions of the earth. In general, it declines from the tropics toward the poles, but it is most elevated in the horse latitudes where precipitation is low and pressure high. Although as a rule the height of the snowline decreases with increasing latitude, snowfall and mean summer temperature are the main factors that control its altitude. The snowline is depressed locally in areas where winters are characterized by heavy precipitation and where summers are cloudy and humid; it is locally raised where summers are dry and sunny and where snowfall is minimal.

Few observations on the position of the snowline have been recorded for the Brooks Range. At Anaktuvuk Pass, where peaks rise to altitudes slightly in excess of 6,000 feet, the snowline commonly lies above the highest summits; however, during some years the orographic snowline descends below 6,000 feet on some sheltered north-facing slopes. Similar conditions apparently exist in the eastern Brooks Range where, according to Austin S. Post (personal communication, 1960), in the recent past the snowline has risen and now probably lies above most of the highest summits; in the majority of seasons, it may average 7,000 feet or more in altitude.

Although the altitude of the snowline at Anaktuvuk Pass is not known, its position might be estimated if the present relationship between snowline and temperature were known. According to Charlesworth (1957, p. 9), in average climates between 35° and 70° north latitude the snowline coincides with the isotherm, for the warmest month, of 4°C ± 3°C. Probably it tends to be lower where precepitation is high and higher where precipitation is low. Because of the low mean annual precipitation at Anaktuvuk Pass (11 inches) the snowline at this latitude is estimated to lie close to the isotherm of 2°C of the warmest month.

The mean summer lapse rate for the Anaktuvuk Pass area has not yet been measured. However, radiosonde data are available for Barrow and Fairbanks for the period 1949–59 (U.S. Weather Bureau, 1949–1959). Mean summer lapse rates were computed for these stations between the 850 mb and 700 mb surfaces. For Barrow, the 850-mb surface averages 1,475 metres (4,675 feet) in altitude and the 700-mb surface averages 2,986 metres (9,795 feet). The computed lapse rate is 4.9°C/1,000 metres (1.5°C/1,000 feet). For Fairbanks the average altitudes of the 850-mb and 700-mb surfaces are 1,454 metres (4,770 feet) and 3,019 metres (9,900 feet) respectively. The mean summer lapse rate is 6.8°C/1,000 metres (2.1°C/1,000 feet). A summer lapse rate of 1.6°C/1,000 feet (0.29°F/100 feet) has been computed for the Mount Chamberlin area in the northeastern Brooks Range, which lies about one degree of latitude north of the latitude of Anaktuvuk Pass (Larsson, 1960, p. 32). Although based on measurements during a single season, this value is close to that computed for Barrow. A value of 1.8°C/1,000 feet, which is intermediate between measured lapse rates for Barrow and Fairbanks, probably is close to the true lapse rate at Anaktuvuk Pass, and will be used here. At best, however, it is only an approximation.

The mean temperature of the warmest month (July) at Anaktuvuk Pass is 50.5°F (10.3°C). If the altitude of the July 2°C isotherm is used to represent the mean altitude of the snowline, and if the above estimated lapse rate of 1.8°C/1,000 feet is applied, then the 2°C isotherm should lie about 4,600 feet higher than the weather station on the valley floor at 2,150 feet, or at 6,750 feet. The fact that in some years the orographic snowline locally extends below the highest summits, which lie from 5 to 10 miles south of the pass and reach altitudes of 6,000 to 6,300 feet, suggests that this figure is of the correct magnitude. This value is reasonably close to the altitude of the July isotherm of 2°C for northern Alaska which can be interpolated from a figure given by Conover (1960, Fig. 5). He, however, used a somewhat higher value for the mean July temperature at the latitude and altitude of Anaktuvuk Pass.

The altitude of the firn limit has been determined on three glaciers in the northeastern Brooks Range. These figures make possible an estimate of the probable position of the snowline for that region. On the Chamberlin Glacier near Lake Peters in the Romanzof Mountains the altitude of the firn limit was estimated at about 7,200 feet during the summer of 1958 (Larsson, 1960, p. 73), approximately half-way between the head of the glacier, which lies near the summit of Mount Chamberlin (9,131 feet), and its terminus at about 5,000 feet. The firn limit on the McCall Glacier, which is located at approximately the same latitude and which ranges in altitude from about 4,000 feet to about 7,700 feet, was found at about 7,500 feet (Mason, 1960, p. 86). Sable (1961, p. 177) placed the firn limit on the Okpilak Glacier at 6,400 ± 100 feet. This glacier, which heads at 7,400 feet and descends to an altitude of 4,500 feet, lies about 10 minutes of latitude south of the McCall Glacier. Both the McCall and Okpilak glaciers face north; it appears, therefore, that the firn limit in that region rises northward with a gradient of about 90 feet per mile.

Were latitude the only controlling factor determining the altitude of the snowline, the snowline should descend progressively northward across Alaska. But, as Charlesworth (1957, p. 9) points out, "latitude is often not permitted to exert its full effect for snowfall offsets its influence." This appears to be the case in the Brooks Range, for the snowline rises northward despite progressively lower mean summer temperatures in that direction. The primary control appears to be mean annual precipitation, which diminishes toward the north.

A similar situation prevails in southern Alaska where the snowline rises progressively northward from the humid coast toward the more arid interior. In the Chugach Mountains annual snowfall is close to 300 inches and the snowline lies at an altitude of 5,000 feet. Farther north, in the Wrangell Range, it lies at 7,000 feet, and in the Alaska Range, where annual snowfall has decreased to about 70 inches, the snowline is at an altitude of about 7,500 feet (Matthes, 1942, pp. 159–60; U.S. Army Air Forces, 1943, p. 169).

Altitudes of existing glaciers

Although the altitude of the modern snowline near Anaktuvuk Pass cannot be precisely determined, the altitudinal distribution of nearby existing glaciers should reflect the same climatic controls that determine the position of the modern snowline. Nearly all glaciers within the area under consideration (Fig. 20a) face north and most are in contact with Fan Mountain moraines. Because they generally lie in deep, sheltered cirques, and therefore owe their existence largely to orographic factors, they probably lie well below the modern regional snowline. However, all seem to be rather closely related to regional climatic controls, for their mean altitudes increase progressively northward.

Isolines connecting mean altitudes of glaciers that lie east and west of Anaktuvuk Pass range in altitude from about 4,800 feet near the southern part of the map area to about 5,500 feet near the northern border (Fig. 20a). The imaginary surface delineated by the isolines rises northward across the range with a gradient of about 40 to 60 feet per mile, becoming somewhat steeper toward the north. This is reasonably close to the gradient of the present firn limit in the eastern Brooks Range, as noted above, and suggests that a north-rising snowline may have characterized most, if not all, of the central and eastern Brooks Range during the last several centuries.

Altitudes of cirque floors

The altitude of the snowline during the last major glaciation has been determined with varying degrees of accuracy in various countries. The basis for its determination is the characteristic relationship of cirque floors to the snowline. Optimum conditions for cirque development occur in a zone where freeze-thaw activity is at a maximum. If the temperature is too high or too low, the process of cirque formation is greatly retarded. The most favourable zone seems to be that in which the mean annual temperature is near the freezing point (Charlesworth, 1957, p. 296); furthermore, cirques must form at or above the snowline in regions where snowfall is great enough to maintain glacier ice. On small glaciers the firn limit tends to lie at or slightly above the cirque floor; consequently, the floor altitudes of cirques now devoid of ice should approximate the altitude of the orographic snowline at the time the cirques formed The average altitude of the floors of a group of related cirques should therefore provide an approximate regional snowline for the period of cirque formation.

Reconstructed snowlines based on this principle show that during the last major glaciation the snowline was everywhere depressed below its present position, but not uniformly (Charlesworth, 1957, p. 652). In areas that currently receive light precipitation it was depressed by a smaller amount than in areas of heavy precipitation. Furthermore, the snowline was depressed less in arctic regions than in equatorial regions.

Mean altitudes of the floors of the lowest north-facing cirques in the region about Anaktuvuk Pass are plotted in Fig. 20b. Cirque-floor altitudes, which were taken from latest United States Geological Survey topographic maps having a contour interval of 200 feet, are considered accurate to within about 100 feet. Charlesworth (1957, p. 297) summarized some of the objections to using cirque-floor altitudes to reconstruct past snowlines, but concluded "that small cirques, particularly if at the glaciated periphery, are well adapted for the purpose". The limitations inherent in this method have been minimized in the present study by using only the floors of the lowest small north-facing cirques. Nevertheless, several parameters remain in doubt, namely, the amount of lowering of cirque floors by post-Itkillik erosion, and the effect of differences in cirque size and the height of surrounding peaks on the altitude of cirque floors.

Isolines on cirque floors cannot be equated with a snowline for the maximum of the Itkillik glaciation, however, because at that time cirques supplied ice to larger valley glaciers that extended north beyond the mountain front. The firn limit on these glaciers must have been lower than the floors of cirques at their heads, but how much lower is not known. Cirque-floor altitudes in the north-central Brooks Range therefore provide only an upper limit for the altitude of the snowline at Itkillik maximum. The altitudinal distribution of cirques may, on the other hand, closely reflect the position of the snowline during the early part of the glaciation when glaciers were initially developing, and also during the waning phases when valley glaciers had largely retreated to positions close to cirques.

Cirques, which are plotted on Fig. 1, lie only in the south half of the Anaktuvuk Pass area. The reason for this distribution is apparent if Fig. 20b is compared with altitudes of mountain peaks shown on Fig. 1. In the south half, where peaks rise to altitudes of more than 6,000 feet, appreciable portions of the mountain masses must have lain above the snowline, making conditions suitable for cirque development on mountain flanks. In the north half of the map area peaks are lower, and in most instances only the very crests of mountain peaks probably rose above the snowline, therefore cirques did not develop.

Comparison of Figs. 20a and 20b shows that the pattern of isolines on existing glaciers is broadly similar to that on lowest cirque-floors. The two surfaces delineated by the isolines are essentially parallel, but differ in altitude by about 600 feet. The relationship of these surfaces to topography and present-day climatic parameters is shown in Fig. 21.

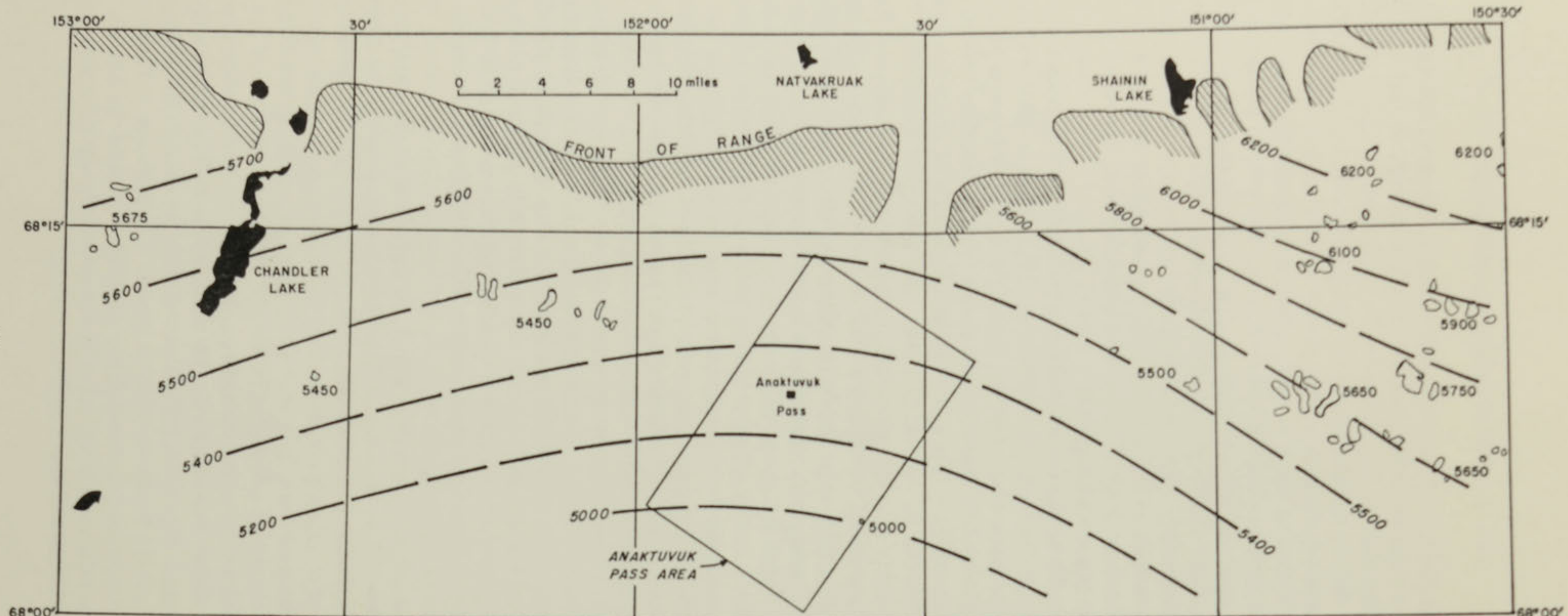


Fig. 20a. Isolines on mean altitudes of north-facing glaciers of the north-central Brooks Range. Altitudes in feet.

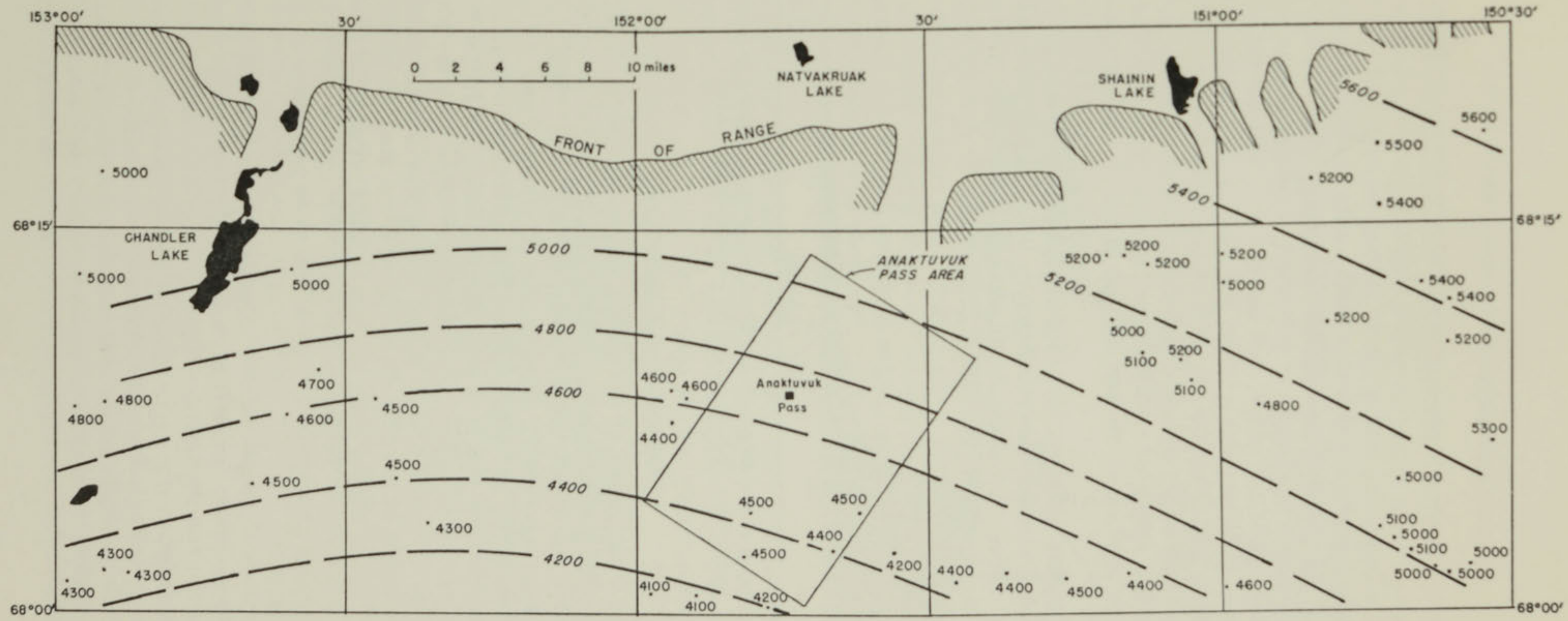


Fig. 20b. Isolines on mean altitudes of floors of lowest north-facing cirques in the north-central Brooks Range. Altitudes in feet.

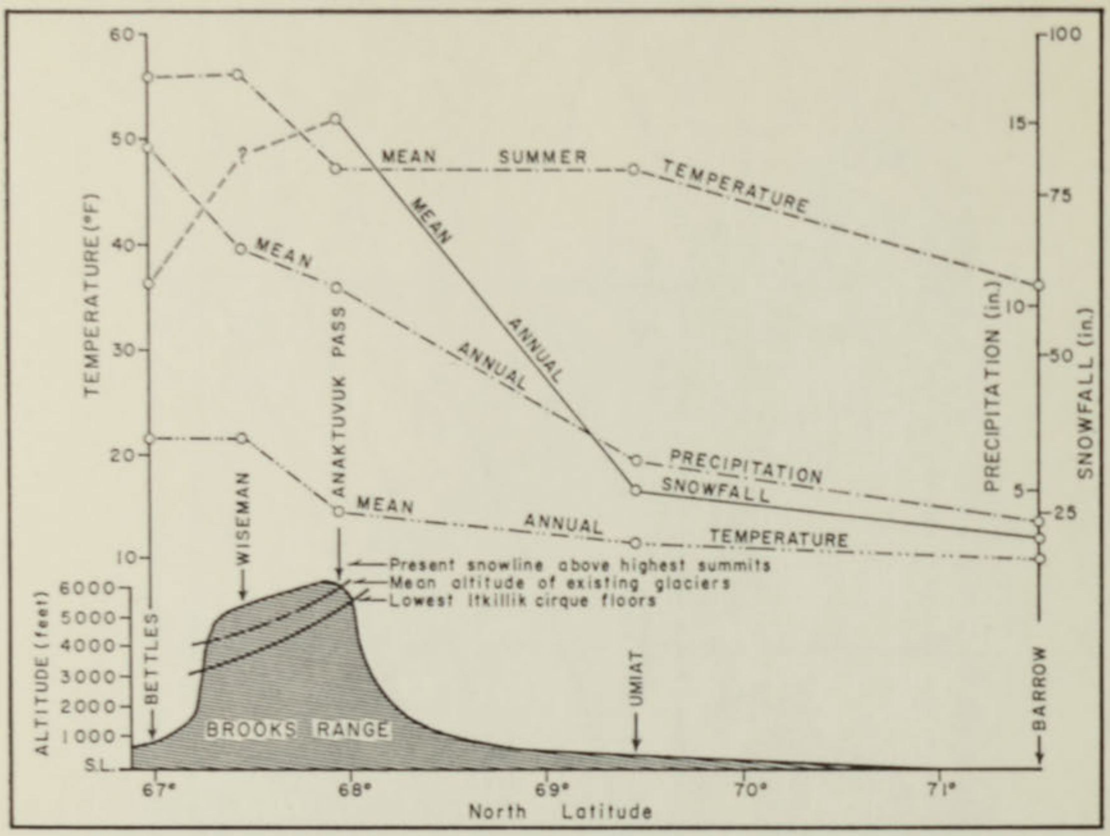


Fig. 21. Relationship of Pleistocene cirque floors and modern glaciers to topography and present-day climatic parameters in north-central Alaska.

Meteorological inferences

The general parallelism of the surface connecting cirque floors with that connecting existing glaciers suggests that the meteorological pattern during the Itkillik glaciation was broadly similar to that of the present. Had the source of precipitation been significantly different, the difference should be reflected in the slopes of these two surfaces. Their close agreement indicates, therefore, that wind directions and source of precipitation during the Itkillik were essentially the same as they are today. The change in climate since the Itkillik maximum seems to have resulted mainly in increased ablation, which implies a rise in mean summer temperature rather than a pronounced decrease in precipitation. Unless an extremely regular shift of climatic belts occurred, it is difficult to imagine that precipitation decreased uniformly throughout this large area, an otherwise necessary assumption to explain the close parallelism of the two reconstructed surfaces.

In most mountain ranges the zone of maximum snowfall is higher than the zone of maximum precipitation (Charlesworth, 1957, p. 654). Consequently, a lowering of the freezing isotherm brought about by a decline in mean temperature within a given area might cause the belt of maximum snowfall to shift into a zone of greater precipitation. In the central Brooks Range the present belt of maximum snowfall appears to lie near the north part of the range, where temperatures are lower and altitudes higher than they are farther south. Existing glaciers are located there, although many lie below the modern snowline and are in disequilibrium with the present climate. Near the south front of the range total annual snowfall is less, despite somewhat greater annual precipitation (Fig. 21), for a greater portion of the yearly precipitation falls as rain during the warm summer months. Here mountains are low and glaciers absent.

During the last major glaciation the snowline probably lay at least 2,000 feet below its present position. Lowering of the snowline may have had the effect of shifting the belt of maximum snowfall to the south into a zone of greater precipitation. Very likely this effect caused maximum snow accumulation to shift from the region near Anaktuvuk Pass southward to the region of the postulated Itkillik ice divide, which lay southwest of the map area. Such a shift might satisfactorily explain the location of the ice divide well south of the present drainage divide. It was in this area that the network of valley glaciers received the bulk of their nourishment.

Toward the end of the Itkillik glaciation the snowline rose and glaciers in the main valleys were deprived of much of their nourishment. A general rise in mean summer temperature brought about rapid ice wastage in the main valleys. Probably only in high cirque valleys near the northern part of the range were small ice tongues able to remain active during the waning phases of the Itkillik glaciation. During the post-Hypsithermal ice advances the snowline was depressed only enough to nourish small glaciers in cirques and tributary valleys near the north front of the range. The recent rise of the snowline has brought about widespread disequilibrium in these glaciers and has promoted extensive wastage.

Close parallelism of the recent snowline and Pleistocene cirque floors suggests that glaciation may have been caused primarily by decrease in mean summer temperature rather than by an appreciable change in precipitation. The amplitude of temperature fluctuations during the last glaciation has been computed for many regions of the world. Values range from 3°C to 12°C (Charlesworth, 1957, p. 645). The wide range is explained primarily by variations in latitude, altitude, and precipitation in different areas. The average amplitude of temperature lowering for the earth as a whole probably was on the order of 5°C to 7°C.

A minimum decline in mean summer temperature for the Itkillik glaciation at Anaktuvuk Pass can be computed if the amount of snowline depression is known and the average lapse rate at glacial maximum is assumed to have been similar to the present lapse rate. If the probable altitude of the modern snowline at Anaktuvuk Pass (6,750 feet), which is believed to lie above but close to the highest summits, is compared with the average altitude of nearby Itkillik cirque floors (4,650 feet), the difference in altitude is 2,100 feet. Assuming a lapse rate of 1.8°C/1,000 feet at Itkillik maximum, the minimum temperature difference between that time and the present day would be 3.8°C.

The precision of this computation is limited by several factors: (1) the present altitude of the snowline is not known with any degree of certainty and is itself dependent on an estimated lapse rate; (2) the firn limit on valley glaciers at Itkillik maximum probably lay below the level of cirque floors, but the amount is unknown; (3) the snowline is depressed less in areas of low snowfall than of high snowfall; (4) it is depressed less in arctic regions than in equatorial regions. Because the last two factors are difficult to evaluate quantitatively, the above value for amplitude of temperature fluctuation at Anaktuvuk Pass may be somewhat lower than values derived for lower latitudes or for areas at the same latitude but having considerably greater precipitation. Despite these shortcomings, the figure arrived at may be of the correct magnitude, but it should be considered a minimum value only.

Summary

1. The modern snowline lies above the highest summits at Anaktuvuk Pass but probably not far above them. During some years the orographic snowline near the pass locally descends below the highest peaks.

2. An imaginary surface connecting mean altitudes of existing glaciers rises from south to north and probably approximates the configuration of the snowline at a time when these glaciers were in equilibrium. A surface that connects the mean altitudes of lowest Pleistocene cirque floors is parallel to but lower than the surface connecting existing glaciers. The slope of the modern snowline in the eastern Brooks Range, based on the altitude of the firn limit of the Okpilak and McCall glaciers, is in reasonable agreement with the slopes of these two imaginary surfaces near Anaktuvuk Pass, but lies at a higher altitude.

3. The nearly parallel northward rise of the modern snowline, of existing glaciers, and of Pleistocene cirque floors strongly suggests that the meteorological pattern during the Itkillik glaciation was broadly similar to that of the present throughout this region. The primary source of precipitation lay to the south, and wind patterns very likely were comparable with those of today. The major difference in climate was a lower mean summer temperature, which inhibited ablation and permitted the growth and expansion of large valley glaciers.

4. Depression of the snowline during the Itkillik glaciation probably caused the zone of maximum snowfall to shift south where precipitation was greater. This would help account for the more southerly position of the ice divide at that time.

5. Mean temperatures were at least 3.8°C lower in this area at the height of the Itkillik glaciation than they are today.

Evidence of recent climatic change

Several lines of evidence, enumerated in previous pages, indicate that the climate is presently warming. Glacier ice, both at Anaktuvuk Pass and elsewhere in the range, appears to be melting, as is ground ice in the main valleys. The snowline has risen since the last small glacial advance, estimated to have taken place between 100 and 200 years ago, and existing glaciers are decreasing in size. Protalus ramparts appear stable and show little or no evidence of recent building. Streams are entrenched in alluvial fans, and rivers are actively eroding alluvium and glacial deposits on valley floors. Drained lakes on some kame terraces suggest that the frost table has been lowered locally, thereby allowing ponded water to drain away.

Geologic evidence of recent warming north of the range has also been reported. Temperature measurements in a well near Barrow that was drilled through permafrost indicate that a recent increase in surface temperature has affected earth temperature to a depth of about 300 feet (Lachenbruch and Brewer, 1962). Apparently the mean annual ground surface temperature has increased by about 4°C since about 1850, with about half of the increase occurring since 1930.

In addition to these geologic lines of evidence, other observations also point to recent warming in the Brooks Range. According to Nicholas J. Gubser (personal communication, 1961), a beaver dam was discovered at Hunt Fork in 1959. This was the first time in the memory of the Eskimos that one had been found this far north. In the summer of 1959 beaver chewings were found at Anaktuvuk Pass, and several years earlier a beaver was seen by Suzie Paneak at Tulugak Lake near the north front of the range. In addition, moose, which formerly were extremely rare in this region, have been seen in greater numbers in recent years. The migrations of these animals suggest that a warming climate has permitted them to extend their range northward.

Several of the older Nunamiut, who acted as informants for Mr. Gubser during ethnographic studies at the pass in 1960 and 1961, stated subjectively that the climate now seems warmer than in the "old days" (80 to 90 years ago).

According to Griggs (1937), timberline in many parts of western and northern Alaska is advancing. He cited a report by Robert Marshall who observed that the limit of trees was advancing northward in the vicinity of Wiseman in the south-central Brooks Range. Griggs concluded (p. 253) that "apparently the climate of Alaska has become mild so recently that the trees have not been able to keep up with the change and occupy all the territory suitable for them."

Viewed as a whole, these various lines of evidence indicate that the Anaktuvuk Pass area has been experiencing a warming trend that probably began at least 100 years ago and possibly even earlier. Prior to this the climate was sufficiently cold to cause small cirque glaciers to advance.

SUMMARY OF CLIMATIC HISTORY

Since the maximum advance of the Itkillik glaciation, the north-central Brooks Range has experienced a series of climate changes that are demonstrated both by geologic and palynologic evidence. Glaciers in the vicinity of Anaktuvuk Pass, where precipitation is low, apparently have responded to many minor fluctuations of climate during the last several millennia, and their deposits provide an excellent record of these oscillations. Pollen evidence from the Chandler Valley which has been assembled by Livingstone (1955) affords additional evidence of general climatic trends during and following the last ice advance of the Itkillik glaciation.

Figure 22 presents in tabular form the major late-Pleistocene events recorded by geologic evidence at Anaktuvuk Pass. Available radiocarbon dates are included to show absolute ages for some of these events. Pollen zones defined by Livingstone from sediment cores taken from the Chandler Lake area have been keyed to the Anaktuvuk chronology by using dates (starred) from the radiocarbon-dated pollen sequence at Umiat, which has been correlated with the profiles from Chandler Lake. General climatic trends, deduced from physical evidence, are also indicated.

Climatic Event		General Trend	Climatic Trends	Activity	Evidence	Chandler-Umiat Pollen Zone	Radiocarbon Age (Years B.P.)
Present		General warming	Warming	Dissection and terracing of drift. Melting of glaciers and ground ice	Terraces, dissected alluvial fans, melting glacier ice and ground ice, drained kettle lakes		
Fan Mountain Glaciation	Fan Mountain II Stade		Cool	Glacier advance	Fan Mountain II moraines in cirques	(Alder decline)	
	Fan Mountain I Stade		Warming	Retreat of glaciers	Recessional Fan Mountain I drift		
			Cool	Glacier advance	Fan Mountain I moraines in cirque valleys	Zone III	
Alapah Mountain Glaciation		Cooling	Warming	Fluctuating retreat of glaciers	Recessional moraines in tributary valleys		
			Cool	Glacier advance	Turret Peak and Contact Creek moraines. Moraines in tributary valleys		• 2830 ± 120
Hypsithermal Interval			Cooling Maximum warmth	Disappearance of ice in main valleys. Dissection of glacial deposits	Ice-contact stratified drift in main and tributary valleys. Dissected and terraced glacial deposits	(Alder maximum)	
Itkillik Glaciation	Anivik Lake Stade	General warming	Warming	Deglaciation	Ice-contact stratified drift	Zone II (Dwarf birch)	• 5890 ± 170* • 6260 ± 160 • 7241 ± 95 • 7530 ± 150*
			Cool	Readvance or stillstand	Anivik Lake moraine	Zone I (Herbaceous tundra)	• 8300 ± 270*
	Antler Valley Stade		Warming	Retreat of glacier	Recessional moraines		
			Cold	Readvance or stillstand	Antler Valley moraine		
	Anayaknaurak Stade		Warming	Retreat of glacier	Recessional drift		
			Cold	Readvance of glacier	Anayaknaurak drift		• 13,270 ± 160
	Banded Mountain Stade		Warming	Retreat of glacier	Recessional moraines		
			Cold	Maximum ice advance	Banded Mountain moraine		

Fig. 22. Late Pleistocene climatic sequence for Anaktuvuk Pass. Starred dates are from the pollen section at Umiat (Broecker, Kulp, and Tucek, 1956).

The climatic sequence presented here is in close agreement with radiocarbon-dated climatic trends and glacier fluctuations of southern Alaska delineated by Karlstom (1957) and by Heusser (1952; 1959; 1960). It is also in remarkable agreement with late-Pleistocene events of central North America (Porter, 1964a). The close correlation of these several sequences constitutes additional evidence in support of the concept of synchrony of late-Pleistocene climatic events throughout North America.

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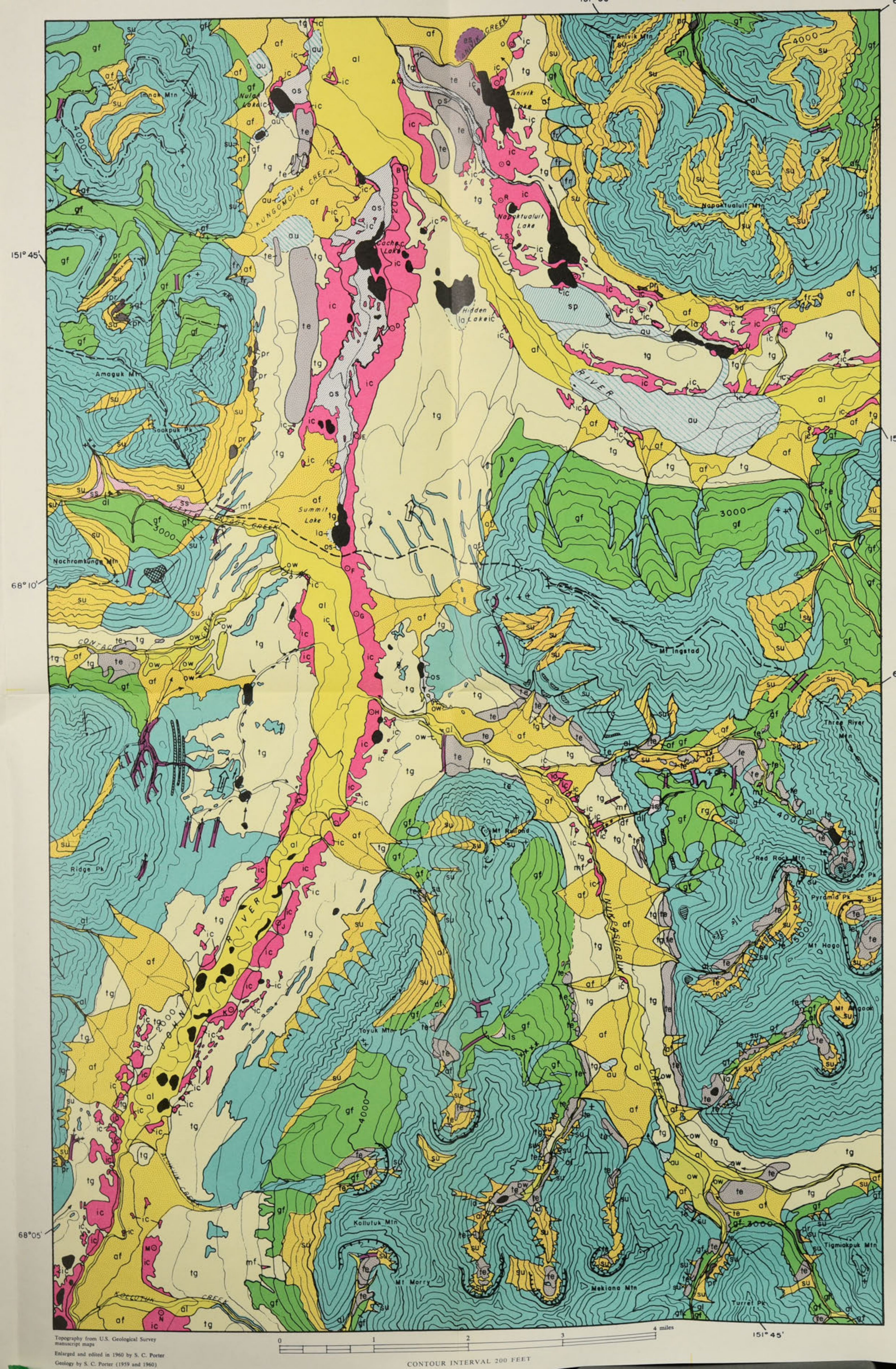
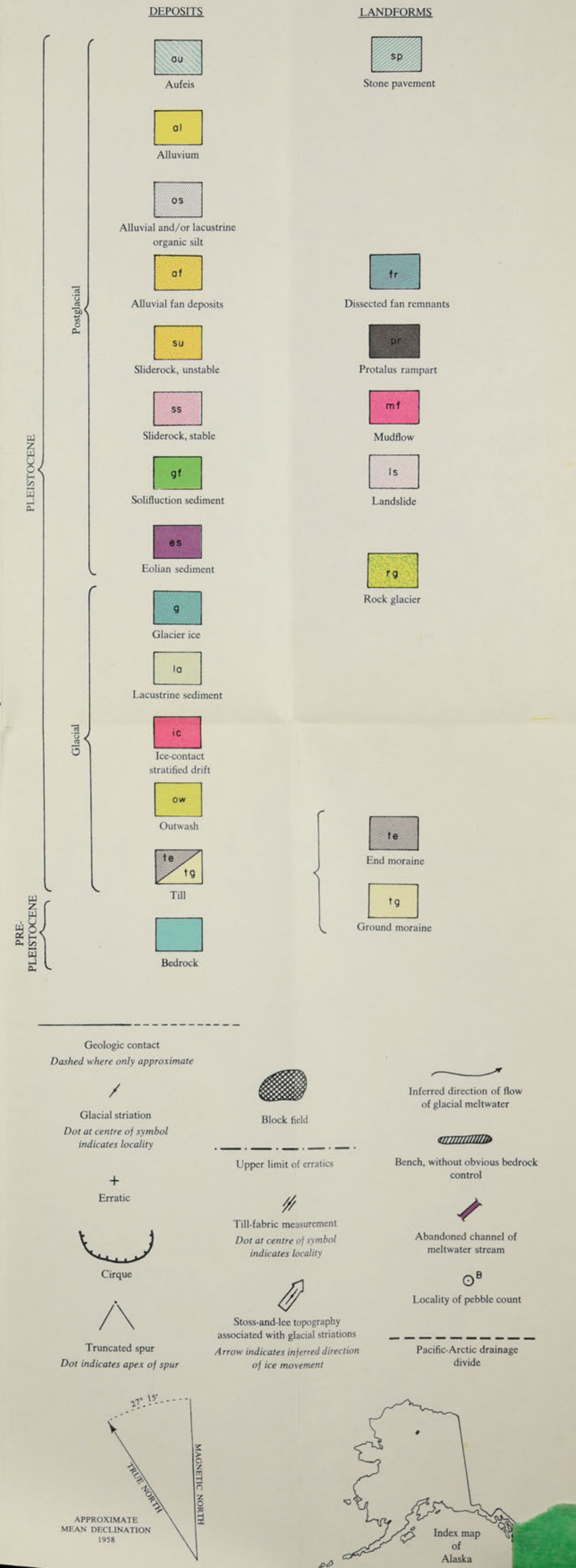


FIG. 1. SURFICIAL GEOLOGY OF THE ANAKTUVUK PASS AREA BROOKS RANGE, ALASKA



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