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MULTIPLE GLACIATION IN ALASKA

A PROGRESS REPORT

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By Troy L. Péwé and others

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GENERAL INTRODUCTION

By Troy L. Péwé

Alaska, with its glacier-clad mountains and glaciated lowlands, is one of the most promising regions in the world for the study of glaciers and glacial deposits. For over 50 years members of the Geological Survey have studied glacial features in the course of reconnaissance geological mapping. There was little economic incentive for the study of glacial deposits, however, and little attention was given to evidences of multiple glaciation.

The pioneer work of Mendenhall, Brooks, Capps, Moffit, Mertie, Smith, and others was summarized by Capps (1932). His report signals the closing of the early reconnaissance phase of the study of glaciation in Alaska. A somewhat different approach was adopted by Gilbert, Tarr, Martin, Cooper, Field, Wentworth, Ray, Lawrence, and others who made detailed studies of recent glacial fluctuations in the course of glaciological studies in south-central and southeastern Alaska.

A new phase in the study of Quaternary glaciation in Alaska was initiated after World War II with increased use of aerial photographs and more intensive studies of unconsolidated deposits. Concentration of effort on the lowland areas and their adjacent highlands, revealed a complex glacial history. In these studies four distinct major Quaternary glaciations have been recognized.

The term glaciation is used to denote a glacial advance and retreat represented by deposits and land forms than can be distinguished from other glacial deposits of different ages. The term glaciation does not necessarily imply stadial or substadial rank. In general, the two youngest advances left festooned moraines in the lowlands; records of older glaciations, however, are scanty and only preserved high on the ridges of adjoining mountains or as till remnants remote from the mountain front.

Detailed work has been done in small areas, and broader regions have been mapped by ground and aerial reconnaissance; all phases were supplemented by intensive study of aerial photographs (pl. 1). The work of Fernald, Hopkins, Karlstrom, Krinsley, Muller, Wahrahaftig, and Péwé was supported in part by the Engineer Intelligence Division of the Corps of Engineers, U. S. Army. In the summers of 1949 and 1950, A. T. Fernald mapped the glacial deposits of the Alaska Range in the Upper Kuskokwim region (pl. 1). D. M. Hopkins studied the geology of the Seward Peninsula in 1947-50. T. N. V. Karlstrom studied the glacial deposits of the Upper Cook Inlet area during the field seasons of 1949-51. The southwest Kenai Peninsula was mapped by D. B. Krinsley during the field seasons of 1951-52. The glaciated lowland and hills surrounding Bristol Bay were mapped by E. H. Muller during the summer seasons of 1949-51. The area near Big Delta on the Tanana River and extending south into the Alaska Range was studied by

T. L. Péwé during the month of August 1949 and during the field seasons of 1951-52.

Clyde Wahrhaftig initiated his glacial studies of the Nenana River in the central Alaska Range in 1948 in connection with engineering geological studies along the Alaska Railroad. Parts of the seasons of 1949-52 were spent on this project.

R. L. Detterman mapped glacial deposits along the north flank of the Brooks Range between the Okpikruak and West Fork Shaviovik Rivers in 1949-52 in connection with a study of the petroleum geology of the area for the Office of Naval Petroleum Reserves, U. S. Navy.

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NORTHERN ALASKA PENINSULA AND EASTERN KILBUCK MOUNTAINS, ALASKA

By Ernest H. Muller

Four major glaciations are tentatively recognized in the northern part of the Alaska Peninsula. The distribution of glacial deposits derived from the Aleutian Range and the Kilbuck Mountains (pl. 1) suggests that the greater part of the Nushagak and Alaska Peninsula lowlands have been glaciated at one time or another. The piedmont ice sheet of the Aleutian Range and the glaciers of the Cook Inlet area were connected through low cols east of Iliamna Lake; and during the most extensive glaciation, the width of the ice sheet normal to the mountain front was more than 150 miles, from Iliamna Volcano southwest to the moraines west of Kvichak Bay.

Northern Alaska Peninsula

Alpine glaciers exist today in the higher portions of the Aleutian Range, particularly in the Cape Douglas and Katmai districts. Westward from the crest of the Aleutian Range, mountain summits decrease gradually in altitude across a belt transected by deeply scoured glacial basins. The eastern slope, on the other hand, descends steeply to the fiorded Pacific coastline. Deposits which date from more extensive glaciations lie below sea level on the Pacific side of the Peninsula but are well preserved in the Bristol Bay coastal lowlands.

Till exposed in bluffs on the west shore of Kvichak Bay opposite Naknek represents the earliest and most extensive glaciation. A low drainage divide trending approximately parallel to the coastline a short distance to the west is considered to be the much modified end moraine of this glaciation. Cobbles containing index fossils of the Jurassic Naknek formation occur both in the till of the bluffs and on the drainage divide, indicating that a part of the material was transported from the Aleutian Range about 75 miles to the east (Muller, 1952a, 1952b). The relative antiquity of this early glaciation is indicated by the altered topographic expression of the moraine, by the integrated drainage of the moraine belt, the partial induration of the till, the scarcity of exposed boulders on the surface of the drift, and by the remoteness of its terminal deposits from the glacial source.

A second early ice advance, or a major recessional phase of the preceding glaciation, is the Johnston Hill glaciation, named by Abrahamson (1949) for a prominent till ridge 12 miles southwest of Naknek. Bouldery outwash exposed in shore bluffs west of Johnston Hill and till in bluffs at the mouth of the Naknek River are considered to belong to this advance. Moraine knobs and ridges of this glaciation are so modified that it is difficult to differentiate between topography of the Johnston Hill and the preceding glaciations. Even the characteristic topographic expression of glaciated foothill summits, which were not subsequently overridden, has been destroyed; and the presence of erratic material is, in many cases, the only evidence that they were glaciated.

The Mak Hill glaciation was named by Abrahamson (1949) for a knoll composed of glacial till, 8 miles east of Naknek. Lateral moraines and glaciated bed-rock surfaces of the Mak Hill glaciation are well preserved below the summits of previously overridden hills and are more than 600 feet above marginal deposits of subsequent advances. West of the foothills, moraines of this glaciation are partly obscured and buried by later outwash, but where preserved they are characterized by partly filled kettle basins, incompletely integrated surface drainage and knobs, and ridges that have been considerably modified by subsequent mass wasting.

The Brooks Lake glaciation (Muller, 1952a), named for a large lake 36 miles east-southeast of Naknek, was the last major glaciation of the Aleutian Range. Moraine representing this glaciation near Brooks Lake was first mentioned by W. R. Smith (1925, p. 201). The name "Naknek moraine" suggested by Abrahamson (1949) is not retained here because of precedence of the name Naknek formation applied by Spurr (1900, p. 169-171) to Jurassic strata east of Naknek Lake. In the lowlands the moraine front rises prominently from a well-developed outwash plain. Clearly preserved push-moraines record minor fluctuations of the ice margin during a protracted stillstand. This morainic system controls the major drainage in the eastern portion of the lowlands and encloses the basins of Brooks, Naknek, and other large piedmont lakes. The moraines of this glaciation are the most prominent and the least modified in the lowland and in most cases are readily distinguished from older moraines and moraine topography. The frontal ridge of the moraine is nearly continuous; its knob and kettle topography are well preserved; boulders are abundantly exposed on the surface of the moraine and the drainage of the moraine belt is completely unintegrated, indicating a relatively short interval since recession of the glaciers from these positions.

A readvance of the ice front near the close of the Brooks Lake glaciation is inferred from a moraine which encloses Iliuk Arm, a headwater bay of Naknek Lake.

Moraines occupying similar positions in adjacent basins, and separating upper lakes or arms from the main lake in each basin, are believed also to mark the Iliuk advance.

Remnants of moraines within a few miles of the termini of present-day glaciers record minor oscillations of recent centuries, probably the greatest extent of glaciation since the Iliuk advance.

Eastern Kilbuck Mountains

Evidence of only three major glaciations of the Kilbuck Mountains (pl. 1) has been recognized so far. Although small cirque glaciers exist today only on Mount Waskey, the much greater extent of former glaciations is indicated by major glaciated basins which transect the eastern Kilbuck Mountains and by moraines which occur on the lowlands far from the mountain front.

The earliest glaciation recognized in the lowlands drained by the Nushagak River is represented by moraine preserved at 800- to 1,000 feet above sea level on two groups of isolated bedrock hills 10 to 20 miles east of the mountain front. On the slopes of these hills the drift is coarse textured and is characterized by much subdued knobs and nearly filled kettle depressions. At lower elevations to the east, the moraine is recognizable only as low, rounded till ridges.

A subsequent glaciation is indicated by moraine west of the isolated bedrock hills, where deposits at altitudes of a few hundred feet form subdued knobs and partly filled kettle depressions and have a poorly integrated surface drainage. At lower altitudes the relief of the moraine as a whole has been reduced because it was partly buried by later outwash at a time when the ice front stood a few miles to the west.

In the mountain basins a system of younger moraines encloses deep glacial lakes and controls the regional drainage near the edge of the lowlands. Temporary drainage channels through the moraines were abandoned as the retreating ice edge exposed lower outlets into adjacent basins. The knob and kettle topography is undissected and only slightly modified by mass wasting. Many boulders are exposed on the surface of the moraine, and at altitudes of over 500 feet the moraine is mantled with rubbly soil material and sparse vegetation. These moraines resemble the Brooks Lake moraines of the Alaska Peninsula and are tentatively correlated with them.

Submerged thresholds which enclose deep headward embayments of the major glacial lakes suggest a subsequent stillstand or even a readvance of short duration during final recession of the ice, analogous to the Iliuk advance in the Aleutian Range (Mertie, 1937, p. 223; 1938, p. 66).

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UPPER COOK INLET REGION, ALASKA

By Thor N. V. Karlstrom

At least four major Quaternary glaciations are recognized in the Upper Cook Inlet area (Karlstrom, 1952, p. 1269). During the alternate expansion and contraction of icecaps centered in the adjacent mountains, the Cook Inlet trough was filled successively with ice to different altitudes. The bordering mountains still retain extensive icecaps and alpine glaciers.

The summit level of Mount Susitna, a 4,396-foot rounded knob of granite in the southern Susitna lowland, and other high-level surfaces are cited by Capps (1935, p. 77-78) as evidence for the last major glaciation of the Cook Inlet trough. These and related surfaces with apparent ice-scoured forms lie above truncated spurs and marginal deposits of subsequent glaciations and record the oldest glaciation, the Mount Susitna, recognized in the area. Aerial reconnaissance indicates that scattered boulders and a thick veneer of unconsolidated material are present on some of these high-level surfaces. Gross morainal form is present locally, but in general the unconsolidated deposits are intricately dissected and extensively modified by mass wasting.

During the Mount Susitna glaciation, icecaps blanketed the surrounding mountains, except perhaps for a few high peaks, and coalesced to fill Cook Inlet trough to altitudes greater than 4,000 feet. Projection of the inferred ice surface indicates extensive connections with ice in the Copper River basin across low cols in the upper valley of the Susitna River and in the head of Matanuska Valley (Capps, 1940, p. 152-153) and with ice in the Bristol Bay lowland across low cols in the Aleutian Range east of Iliamna Lake. The Cook Inlet ice in this and succeeding glaciations apparently spilled out into the Pacific Ocean through Shelikof Strait and the straits between Kenai Peninsula and Kodiak Island.

The Caribou Hills glaciation is represented by ice-scoured benches, truncated spurs, and drift on protected slopes below the level of the Mount Susitna glaciation but above the deposits of the subsequent glaciation. The Caribou Hills glaciation was originally differentiated from the succeeding glaciation by features that are well displayed on the till-covered, unnamed piedmont surface north of Tustumena Lake. The name comes from the Caribou Hills in the adjoining part of the Kenai lowland where remnants of the same surface form the summits. Deposits of the Caribou Hills glaciation only locally retain a distinct hummocky morainal form, with filled kettle depressions and subdued knobs. Along the mountain fronts the marginal deposits of this glaciation reach an average altitude of slightly more than 3,000 feet. Thus, during the Caribou Hills glaciation, the Cook Inlet area was again completely under ice except for isolated nunatoks such as Mount Susitna in the Cook Inlet trough. Topographic relations and the difference in the degree of dissection and mass wasting of the Mount Susitna and Caribou Hills drifts strongly suggest a long interval of time between glaciations. In the absence of other evidence, however, it is not feasible to eliminate the possibility that the Caribou Hills glaciation represents a major stillstand or minor advance during the retreat of the Mount Susitna ice.

The next glaciation, the Swan Lake, is represented by a distinct moraine near Swan Lake in the northwest part of the Kenai Mountains and by discontinuous lateral moraines that are found along the lower slopes of mountain fronts, generally 1,000 to 2,000 feet above sea level, and in the major mountain valleys. The moraines are much "sharper" in topographic expression than the older Caribou Hills deposits. The Swan Lake drift, in general, retains its hummocky aspect, but kettle depressions are partly or completely filled with an intermixture of organic silt and peat.

During the Swan Lake glaciation, ice tongues flowed down the Susitna, Matanuska, and Turnagain valleys and partly or completely coalesced near the axis of the trough with ice from the Alaska Range and Kenai Mountains. In the northern part of the Kenai lowland the retreat of these converging ice tongues resulted in a complex system of interlobate deposits which, near Pt. Possession, overlie till and outwash presumably of Caribou Hills age. Large icecaps were limited to mountain areas that today support alpine glaciers, and trunk glaciers reached the Cook Inlet trough through largely ice-free mountain areas that previously were ice covered. Valleys not glaciated at this time have subaerially modified forms which contrast sharply with the essentially unmodified U-shape of valleys that were glaciated. Many of the older tributary valleys were left hanging suspended by renewed downcutting in trunk valleys, and a few were beheaded by glaciation of transverse canyons that apparently were cut largely by melt water streams following the retreat of the Caribou Hills ice. The geomorphic features within the mountains record a long interval of subaerial erosion and perhaps complete deglaciation of the mountains between the Caribou Hills and Swan Lake glaciations. On the piedmont north of Tustumena Lake, Swan Lake moraines within canyons cut through Caribou Hills till demonstrate the retreat of the Caribou Hills ice far back into the mountains followed by an interval of canyon cutting prior to the readvance of the Swan Lake ice into the Inlet trough. This interval of subaerial erosion marks a major break in the glacial chronology of the area separating the two oldest from the two youngest glaciations recognized. Radiocarbon dating indicates that the Swan Lake glaciation retreated from the inlet trough more than 18,000 years ago.

The youngest major glaciation, the Naptowne, is represented by a conspicuous spatula-shaped end moraine (crossed by the Stirling Highway near Naptowne on the Kenai Peninsula) and by similar morainal belts at the mouth of the Matanuska Valley (Karlstrom, 1950) and on the margin of the lowland in front of trunk valleys heading in glaciers of the Alaska Range and the Kenai Mountains. Along the lower slopes of these trunk valleys, marginal moraines and fresh ice scour features occur nearly continuously about 1,000 feet below Swan Lake moraines. The moraines have little modified knob and kettle topography and kettle lakes are common. Extensive deglaciation back into the higher mountain areas, during an interval sufficient for several feet of peat to accumulate and for appreciable oxidation of Swan Lake till before deposition of Naptowne till, is indicated by stratigraphic relations between Naptowne and underlying Swan Lake deposits exposed locally in the lowlands and in mountain valleys close to present ice sources.

Finely stratified silt and sand overlying older deposits in front of the Naptowne end moraine near Anchorage and on the Kenai lowland indicate that the piedmont glaciers fronted extensive lakes (or lake) in the upper Cook Inlet trough. This ponded water was apparently controlled largely by an ice dam across the lower part of the inlet trough. The upper and broader part of the inlet trough was partially ice free, whereas the narrower southern part was ice filled because of proximity to higher ice sources and because precipitation is heavier near the Pacific Ocean than inland. This ice was continuous and presumably filled Shelikof Strait which reached the Pacific Ocean around the margins of Kodiak Island. Capps (1937, p. 162-164), on the basis of geologic evidence, argues for the possibility that Kodiak and adjacent islands were tied to the mainland by glacial ice presumably of Wisconsin age.

During retreat of Naptowne ice, a compound morainal system was deposited; in the Kenai lowland the system consists of as many as six festooned morainal belts behind the terminal position. One of these inner moraines is especially prominent and consists of till that differs in texture and composition from the till, partially buried in outwash, of the outer-most morainal belts. This moraine is a record of either a distinct glacial advance or a major stillstand following retreat of the Naptowne ice and represents the Nicolai Creek glaciation named for a locality in the southwest part of the Kenai lowland.

Correlations of the morainal system at the mouth of Matanuska Valley with the glaciation in the Kenai lowland is based on the topographic position and expression of the glacial deposits. This correlation is substantiated by radiocarbon dating (Kulp, 1951, 1952) suggesting that topographic criteria in general are valid throughout the area. Lignitized peat beneath Naptowne till collected from two separate localities near Anchorage date 14,300 ± 600 and 19,100 ± 900 years old respectively. Two analyses of lignitized wood collected in outwash stratigraphically beneath Naptowne till near Tustumena Lake indicate ages of 15,800 ± 400 and 15,200 ± 500 years. Basal peat collected from an 8-foot peat section overlying clay and silt deposited in front of the Naptowne moraine near the Anchorage International Airport is 5,340 ± 300 years old. Basal peat from a 16-foot thick organic silt and peat section exposed near Boulder Point on the Kenai Peninsula overlies silt and sand deposited in front of the Naptowne moraine and is 8,200 ± 300 years old (written communication from J. L. Kulp to H. E. Suess, June 10, 1952). Thus on the basis of radiocarbon dates, the Naptowne glaciation, as represented by end moraines near Anchorage and on the Kenai Peninsula, advanced into the lowland between 14,000 and 8,000 years ago. The Swan Lake glaciation, as represented by deposits beneath the dated peat beds underlying Naptowne till, retreated from the lowland more than 18,000 years ago. The Swan Lake-Naptowne interglacial interval, therefore, was more than 4,000 years in duration. Post Naptowne represents a time interval of more than 8,000 years and less than 14,000 years duration (average— 11,000 years duration).

A threefold sequence of end moraines near the fronts of existing glaciers indicate at least three recent glacial fluctuations, presumably within the last few centuries. This threefold sequence is present locally in all the surrounding mountain ranges. Rock glaciers and talus accumulations of different ages, as indicated by differences of vegetation cover and dissection, may be correlated with the recent glacial advances. Wood from trees buried in the innermost of two recent moraines bordering the front of Tustumen, a glacier on the Kenai Peninsula, are interpreted as being 400 ± 150 years in age (Kulp, 1952, p. 412).

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SOUTHWEST KENAI PENINSULA, ALASKA

By Daniel B. Krinsley

The southwest part of the Kenai Peninsula was glaciated three or more times during the Quaternary period. During the oldest recognized and most extensive glaciation, ice flowing westward from the Kenai Mountains (pl. 1) overrode the entire piedmont including the Caribou Hills highlands south of Tustumena Lake and coalesced with a broad ice stream moving south through the Cook Inlet trough. During each of the younger, successively less extensive glaciations, the Caribou Hills were not ice covered; and the glaciers were diverted into the Tustumena trough to the north and into the Kachemak trough to the southeast.

The Kenai Mountains, the chief source area, are today partly covered by the Harding ice field. Glaciers descend to altitudes as low as 200 feet along the northwest slope, and several glaciers on the southeast coast calve into the sea.

The oldest recognized glaciation, here named the Caribou Hills glaciation, is represented by drift and associated marginal ice features which are found in the highest parts of the Caribou Hills. Till of the Caribou Hills glaciation is exposed near the heads of gullies in the high ridges of the Caribou Hills, which are mantled with rubble that contains graywacke and granite erratics. Frost action and running water have removed much of the fine material and have modified the original topographic expression of the Caribou Hills drift.

The ice summit and ice-carving of the Caribou Hills suggest a westward and southwestward flow of ice from the Kenai Mountains during the Caribou Hills glaciation.

A series of successively lower marginal channels with linear lakes, lateral moraines, and kame terraces found on the Caribou Hills above an altitude of 2,000 feet is a record of several retreatal phases of this glaciation.

The Swan Lake glaciation is represented in the southwest part of the Kenai Peninsula by moraines on the flanks of the Caribou Hills at altitudes lower than the Caribou Hills drift. The moraines consist of low, rounded till hills, partly buried by outwash. Some kettle lakes persist, but many of the original depressions are filled with peat and organic silt. Where the drift is thin or absent, marginal channels indicate the extent of this glaciation. The till ranges in mechanical composition from boulder clay to cobble gravel, and contains granite, graywacke, and greenstone fragments. Generally it is covered by 1 to 3 feet of loess.

At the maximum extent of the Swan Lake glaciation, the Caribou Hills were completely surrounded up to an altitude of 2,000 feet by southwest flowing ice from Cook Inlet and Tustumena Valley and by ice from the Kachemak trough that spilled westward through the summit valleys of the highlands on the west side of the troughs. These major ice streams joined northwest of Homer. In the Caribou Hills between altitudes of 2,000 to 1,000 feet successively lower marginal channels were carved during retreatal phases of the Swan Lake glaciation.

The Naptowne glaciation is represented in southwest Kenai Peninsula by conspicuous moraines along the north, east, and south margins of the Caribou Hills, where Naptowne drift locally overlies drift of the Swan Lake glaciation. Moraines of the Naptowne glaciation are the most continuous and best preserved glacial deposits in the Kenai Peninsula. The knob and kettle topography is little modified, and drainage is imperfectly integrated. In places the drift is extremely coarse and contains large deposits of cobble gravel. In the Anchor Point-Homer area a loessial cover of from 1 to 2 feet thick contains several volcanic ash layers. Relatively unmodified channels below an altitude of 1,200 feet in the bluffs north of Homer are a record of marginal ice positions.

At the maximum extent of the Naptowne glaciation, ice from the Kenai Mountains spread around the eastern flanks of the Caribou Hills up to an altitude of 1,600 feet. Ice filled the Tustumena trough and extended west to the middle course of the Kasilof River, which drains Tustumena Lake. Ice from the Kachemak trough reached into Cook Inlet as far north as Anchor Point and probably coalesced with an ice lobe from the Aleutian Range to the west. This ice dam may have ponded Cook Inlet north of Anchor Point giving rise to a large lake. Stratified sandy silts and fine laminated blue silts occur in the upper section of the bluffs north of Anchor Point and suggest deposition in a standing body of water.

A prominent moraine near Nikolai Creek at Tustumena Lake is evidence of a glacial advance, here named the Nikolai Creek glaciation, during or after the general retreat of the Naptowne glaciation is recorded. The moraine can be traced south along the eastern flanks of the Caribou Hills and southwest along the northwest bluffs of Kachemak Bay to within 10 miles of Homer. Drift of the Nikolai Creek glaciation is thin; the till is generally coarse grained and contains numerous granite boulders.

Fresh morainal ridges near the fronts of most existing glaciers indicate minor advances during the last few centuries. The outermost moraines, presumably Recent in age, are about 3 miles from the present ice fronts and are covered with a spruce forest. The younger moraines are less than a quarter of a mile from the ice fronts and support scattered young alders, willows, and birches. Adjacent to the ice fronts, barren ablation moraines exhibit evidence of recent ice push and collapse.

ALASKA RANGE IN UPPER KUSKOKWIM REGION, ALASKA
By Arthur T. Fernald

Two major glaciations of the western part of the Alaska Range have been recognized in the Upper Kuskokwim region (pl. 1). During these glaciations, ice advanced down the three large valleys now occupied by the West Fork, the Middle Fork, and the South Fork of the Kuskokwim River. All the glaciers, except the younger one along the West Fork, extended onto the broad piedmont slope that flanks the range on the northwest and spreads out into distinct lobes. In part at least, the glaciers in the three valleys had a common source area south of the Upper Kuskokwim region in the higher part of the Alaska Range where many glaciers exist today. Glaciation of the western part of the range has been reported previously by Spurr (1900, p. 252-253) and Brooks (1911, p. 126).

All three of the above mentioned valleys show a similar sequence of glacial deposits: an older, greatly subdued end moraine at a maximum distance of 12 to 25 miles north of the range, and younger, well-preserved morainal deposits up to 20 miles from the mountain front. A major time break is thus indicated between the older and the younger drift. Along two of the valleys, the younger moraines exhibit a twofold division.

The correlation of the moraines from valley to valley in the area is based principally on similarity of sequence and on gross topographic expression. However, contrasting conditions from one moraine to another imposed by their physiographic setting and by differences in altitude have resulted in dissimilarities in topographic details and in amount of dissection. Mass-wasting processes, active today, have produced gentle slopes in a relatively short time on moraines above timberline; slopes have been stabilized at steeper angles on forested moraines at lower altitudes. The location of the moraines with respect to the Alaska Range determines in part the drainage and the degree of stream erosion.

The older glaciation along the West Fork is represented by high lateral moraines within the mountainous area and by a broad end moraine on the piedmont. The glacier extended 18 miles from the base of the Range. This older glaciation is here called the Selatna glaciation from a tributary of the Selatna River which originates in the end moraine. The moraine forms a nearly continuous arcuate belt, 2 to 4 miles wide, and is composed of till interbedded with gravel and sand and overlain by silty peat and loess. The original knob and kettle topography is greatly subdued. The vegetation is predominately white and black spruce, with numerous swampy areas. A broad outwash slope, dissected and standing high above the present streams, extends north and west downstream from the moraine. Upstream, the end moraine merges into a series of high lateral morainal ridges, subparallel to the broad valley of the West Fork. The ridge tops stand 500 to 1,000 feet above the present river. The lateral ridges are tundra covered and bear scattered erratic boulders.

The Selatna glaciation along the Middle Fork is represented by an irregularly shaped, tundra-covered area of greatly subdued morainal topography on the piedmont, 10 to 12 miles north of the range. The moraine is not connected to the mountain front.

Evidence of the Selatna glaciation along the South Fork consists of scattered remnants of a lone arcuate moraine, which extends to a maximum distance of 25 miles from the range. This moraine has been greatly dissected and in part has been buried by outwash of the younger glaciation. The vegetation cover is open forest, and the knob and kettle topography is greatly subdued.

Along the West Fork a bed of compacted peat mixed with some silt overlies till of the Selatna glaciation. Ten feet of loess, overlying this organic layer, is correlated with the younger drift. The peat probably was deposited during the interval between the older and the younger glaciation.

The younger glaciation is represented by prominent moraines along the South Fork near Farewell and is termed the Farewell glaciation. The deposits of this glaciation consist of a slightly subdued end moraine 20 miles from the range and an area of fresh moraine extending 15 miles northward from the mountain front. The outer arcuate moraine has been dissected in several places and ranges from ½ to 2 miles in width. The inner morainal area consists of extensive areas of knob and kettle topography, a series of recessional moraines in its eastern sector, and locally, smooth outwash slopes which contain prominent ice-block depressions. More than half of the rim of this inner morainal area is outlined by a high ridge that rises 150 feet above the surrounding terrain. The moraine is fresh and little dissected. Both the outer and inner moraines are predominately forested, and the slopes are fairly stable.

Two young moraines also are present along the Middle Fork. The outer loop extends 4 to 8 miles beyond the range and has subdued knob and kettle topography, poor surface drainage, and numerous lakes. It lies on a gentle piedmont slope. The inner morainal loop extends 4 miles out from the base of the range, has good surface drainage, and lies on a moderately steep piedmont slope. Its knob and kettle topography is better preserved than that of the outer moraine. Both of these moraines are above timberline at altitudes 500 to 600 feet higher than the equivalent, forest-covered moraines along the South Fork. Mass-wasting processes, principally those associated with frost action, are more active on the moraines of the Middle Fork, and consequently the modification of the glacial topography is greater.

The Farewell glaciation is represented along the West Fork by a single V-shaped moraine which lies in the broad open valley within the mountainous area. This young moraine can be traced 15 miles on both sides of the valley and forms terracelike ridges on the inner flanks of the moraine of the Selatna glaciation and knob and kettle topography on the valley bottom. The change in altitude between the upper and lower ends of this moraine is about 1,000 feet, and the vegetation is both forest and tundra. The morainal topography is generally fresh and little modified.

The twofold division of the Farewell glaciation, which is well displayed on the piedmont slope along the South Fork and Middle Fork, may represent two distinct glaciations; but for the purposes of this paper they are grouped as the products of a single glaciation. This twofold division is not found in the valley of the West Fork, because of the physiographic setting of the moraine in this area, which would make such a division difficult to detect.

The moraines of the Farewell glaciation are mantled with loess and organic accumulations of variable thickness, locally up to 40 feet thick. A broad outwash slope fronts the moraines along the South and Middle Forks.

Morainal remnants near present glaciers in the western part of the Alaska Range represent minor glacial oscillations of recent date. These features have not been investigated on the ground.

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NENANA RIVER VALLEY, ALASKA

By Clyde Wahrhaftig

Four distinct glacial advances separated by marked ice withdrawals are recognized along the Nenana River, a north-flowing stream through the central Alaska Range (pl. 1). Deposits assigned to any single glaciation may represent two or more separate advances.

Deposits of the Browne glaciation, the earliest recognized, are granite blocks, the largest of which are 40 feet in length. These rest on terraces 500 feet above the Nenana River at Browne, 1,000 feet above the river near Ferry, and 2,500 feet above the river at Lignite Creek, 6 miles north of Healy. The blocks are strikingly similar to granite that crops out in an area between the Nenana and Yanert Glaciers and are presumably derived from that body. They indicate that an ancient glacier extended down the Nenana River from a point near these glaciers at least as far as the northern edge of the foothills of the Alaska Range (Capps, 1932, pl. 1). Near Lignite Creek the glacier was at least 16 miles wide.

Tilting of the Alaska Range proceeded concomitantly with the early glaciations. During the interval between the Browne glaciation and the next glaciation, the northward inclination of the Alaska Range was increased by about 2.5 feet per mile, and the range was uplifted 700 feet at Healy. In response to this uplift, stream sculpture and periglacial processes produced, below the upland surfaces on which the Browne deposits lie, a topography that differs markedly from glacial topography.

The Dry Creek glaciation is represented by a lake deposit on post-Browne topography at Dry Creek, 5 miles west of Healy, and by drift between McKinley Park railroad station, 10 miles south of Healy, and Windy, 20 miles further to the south. The lake deposit is 600 feet higher than the end moraine of the next younger Healy glaciation, which stands immediately above the mouth of Dry Creek. The Dry Creek drift is likewise several hundred feet above ice-contact deposits of the Healy glaciation. A terrace with 100 feet of outwash gravel, which is probably the outwash plain of the Dry Creek glaciation, extends along the sides of the Nenana River valley northward from Lignite Creek about 400-600 feet above the outwash terraces of the Healy glaciation and 500-1,700 feet below the deposits of the Browne glaciation. The Dry Creek deposits indicate that a glacier advanced down the Nenana River to a terminus near Dry Creek. The height and slope of its outwash terrace indicate an additional increase in the northward inclination of the Alaska Range of about 17 feet per mile between the Dry Creek and Healy glaciations and uplift at Healy of about 500 feet.

The end moraine of the Healy glaciation is a prominent curved compound till-ridge on a terrace about 450 feet above the Nenana River 2 miles northwest of Healy. A U-shaped gorge between Healy and McKinley Park railroad station was occupied by Healy ice but not by later ice. The spurs of this gorge were truncated by Healy ice, but no small scale glacial abrasion features are preserved. Modified lateral moraine ridges and patches of till, preserved on gently sloping topography, identify the position of the upper surface of this glacier. Elsewhere deposits of the Healy glaciation were removed before the next glacial advance. No lakes dating from the Healy glaciation have been preserved.

The outwash terrace of the Healy glaciation is about 470 feet above the Nenana River near the end moraine and slopes northward to 85 feet above the river at the north edge of the foothills.

A proglacial lake held in by the end moraine occupied the U-shaped gorge between McKinley Park station and Healy and was subsequently filled with varved silt, clay, and delta gravel. Building of alluvial cones by tributaries from the west forced the Nenana River, flowing on the lake sediments, to the east wall of the downstream half of the U-shaped gorge, where the river now has a superposed course in a narrow rock-walled canyon about a quarter of a mile east of the sediment-filled U-shaped gorge.

Drift attributed to the Riley Creek glaciation is much better preserved than the older deposits. The end moraine forms a ridge along the south bank of Riley Creek near its mouth at McKinley Park station. Lateral moraines and ice-contact deposits have been traced for several miles up the valleys of the Yanert Fork and Nenana Rivers as irregular pond-pocked embankments. The ground moraine has well-preserved drumlinoid hills, medial moraine ridges, and numerous lakes.

The outwash plain of the Riley Creek glaciation extends downstream to the north edge of the foothills as a set of terraces—the highest, 200-250 feet above the river—with outwash gravel 10-160 feet thick. Riley Creek outwash rests unconformably on eroded lake deposits between McKinley Park station and Moody, 5 miles north. North of Moody the terraces are in the canyon of the superposed Nenana River. River bluffs, truncating terraces graded to the Riley Creek outwash on Healy Creek, which enters the Nenana River from the east at Healy, reveal only alluvium from creek level to terrace top, indicating that prior to the Riley Creek glaciation, Healy Creek, and probably also the Nenana River, flowed at or below their present gradelines.

An end moraine near Carlo is associated with a valley outwash train which forms a gravel terrace 200 feet high that occupies a canyon cut in Riley Creek till and outwash. This end moraine and its associated outwash suggest a readvance of the ice after the Riley Creek glaciation. No other river valley observed in the central Alaska Range shows evidence of a similar glacial advance. The end moraine and associated outwash might also be explained by assuming that the retreating Riley Creek ice left near Carlo a proglacial lake which was drained by erosion of its drift dam a few miles north of Carlo. The removal of the drift dam was possible because the river draining the lake was not overloaded with debris, for the debris from the glacier was deposited as a proglacial delta at the head of the lake. Once the lake was drained, a new valley train was built by the again over-supplied meltwater stream in the canyon cut through the Riley Creek till and outwash. A short readvance of the glacier pushed forward the proglacial delta to form an end moraine, and the valley train which was being formed was graded to this end moraine. This readvance may have coincided with similar readvances reported from southern and western Alaska.

Evidence of two, more recent, minor cold intervals is found in two rock glaciers at the head of Clear Creek. The older rock glacier, now stabilized and overgrown, has been dissected with deep gullies into which the younger rock glacier is now moving. Presumably rock glaciers are active during cold periods and dissection takes place during intervening warm periods (Wahrhaftig, 1949, p. 216).

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BIG DELTA AREA, ALASKA

By Troy L. Péwé

At least three major Quaternary glaciations, each successively less extensive than the former, are recorded at the north end of the Delta River pass, a 40-mile long, north-south canyon which separates the eastern Alaska Range from the central part and connects the Copper River basin south of the range with the Tanana River valley to the north (pl. 1). The moraines at the north end of the Delta River pass were formed by large trunk glaciers fed in part from the south side of the range.

Glaciers on the north side of the range were considerably less extensive than those on the south because they received less precipitation and had smaller collecting area (Capps, 1912, p. 37). It long has been held by Moffit (1912, p. 52) that part of the great accumulation of Quaternary ice in the Copper River basin found egress to the north through the Delta River and other low passes in the Alaska Range, as well as to the south through the Chugach Mountains and to the west into Cook Inlet.

The Delta River pass is ice free today although high mountains nearby support large glaciers on their flanks.

The earliest glacial advance recognized in the Big Delta area is the Darling Creek glaciation (Péwé, 1952a), named after an eastern tributary that enters the Delta River 40 miles upstream from its mouth. Isolated remnants of Darling Creek till occur on flat interfluves 2,000 to 3,000 feet above the floor of the Delta River valley. Boulders in the till have no fresh faces, and the drift retains no morainal form. No till of this advance has been found north of the Alaska Range in the Tanana Valley or the Yukon-Tanana upland. End moraines of this and possible other early advances have been completely destroyed or are buried beneath the great outwash aprons that extend from the Alaska Range to the Tanana River. The maximum extent of the Darling Creek glaciers is not known, but in the immediate area of Big Delta they probably abutted against the Yukon-Tanana upland and were deflected down the Tanana River valley perhaps as far as to the vicinity of Richardson.

The succeeding glacial advance is named the Delta glaciation (Péwé, 1952a) from the Delta River. A trunk glacier in the Delta River valley coalesced with smaller glaciers originating on the north side of the range to form a piedmont lobe that spreads about 30 miles beyond the front of the range almost to the Tanana River.

Strong winds swept northward over the outwash and floodplains only scantily covered with vegetation. Silt was picked up and deposited on the Yukon-Tanana upland, forming a thick loess blanket.

Moraines of the Delta glaciation are preserved in breached festooned belts about 15 miles farther north than moraines of the next younger glacial advance. Till of the Delta glaciation also occurs on spurs and flat areas in the Alaska Range, 1,500-1,800 feet above the floor of the Delta River valley. West of the Delta River, the end moraine extends northward to within 3 miles of the present Tanana River floodplain.

Moraines of this glaciation are dissected and considerably subdued. No sharp ridges exist and many of the kettle lakes are completely filled with sediment and organic material. Many granite boulders are friable, and schist boulders are rare. No ice-polished boulders remain, and striated boulders are uncommon at the surface although well-developed ventifacts are common. Boulder frequency, the numbers of boulders per unit surface area (Blackwelder, 1931), is low.

Following this glaciation, the northern part of the Delta River cut down as low, if not lower, than its present gradeline, and it is assumed that glaciers retreated at least as far back as they are today. The trunk glacier probably disappeared entirely from the Delta River Canyon.

The latest major glacial advance is named the Donnelly glaciation (Péwé, 1952a) after Donnelly Dome, a prominent rock knob 25 miles south of Big Delta, which was partially surrounded by ice of this advance. The ice lobe from the Delta River pass extended only about 15 miles north of the range. The glacier split into a major and a minor lobe near Donnelly Dome; the major lobe to the west extended 15 miles past the dome, but the minor lobe to the east stopped near the dome. Insufficient ice was present to produce a coalescent piedmont lobe in the Big Delta area, and distinct terminal bulbs spread northward onto the plain from the Little Delta River, Delta Creek, Granite Creek, Gerstle River, and Johnson River. The Johnson River glacier abutted against the Yukon-Tanana upland causing local rearrangement of streams flowing southward from the upland.

Again strong winds during the Donnelly glaciation spread a loess deposit over the south side of the Yukon-Tanana upland. This loess, as well as the earlier loess deposited during the Delta glaciation, has been recognized on the north side of the Tanana Valley (Péwé, 1952b).

Well-preserved, festooned end moraines of the Donnelly glaciation lie on the lowland at the base of the range. Only the axial part of the morainic lobe in the lowland at the mouth of the Delta River pass, like those on the Little Delta River, Delta Creek, Granite Creek, Gerstle River, and Johnson River, have been removed by the streams. To the south, Donnelly till mantles lower parts of the U-shaped valley. The upper limit of ice in the northern part of the pass is marked by kame terraces about 1,000 feet above the floor of the valley. Prominent moraines of the Donnelly glaciation are displaced by faults east of Donnelly Dome and east of Granite Creek.

End moraines of this glaciation are characterized by many lakes and by fresh knob and kettle topography. In contrast to older drift derived from the same source area, Donnelly till contains numerous schist cobbles and boulders. Striations and ice polish are well preserved on many boulders of fine-grained igneous rock, and boulder frequency is high. Ventifacts are less well developed and not as abundant as on the Delta moraine. Along the Delta River 5 miles southwest of Donnelly Dome, till of the Donnelly glaciation overlies outwash gravel. Overlying the till is 8 feet of loess of late Donnelly and post-Donnelly age. The Donnelly glacier in the Delta River pass disappeared with the diminution of supply from ice sources south of the range and with the dwindling of side-valley glaciers.

A readvance of the ice on the south side of the range deposited drift which holds in Summit Lake near the south entrance of Delta River pass. Deposits of the Summit Lake advance are characterized by fresh knob and kettle topography with little or no dissection.

Since the disappearance of the Delta River pass glacier, certain of its tributaries, notably Black Rapids, Canwell, and Castner glaciers have readvanced into the pass and withdrawn leaving conspicuous moraines. Black Rapids advanced entirely across the floor of the Delta River valley forcing the Delta River to carve a bedrock gorge around the front of the glacier. These advances occurred about 200-300 years ago (Péwé, 1951) and represent the greatest extension of these tributary glaciers since the disappearance of the Donnelly trunk glacier in the Delta River pass. Correlative advances are reflected by Gulkana, Gakona, and many other glaciers in the area. Rock glaciers in ice-free north-facing cirques also record presumably these same climatic fluctuations.

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SEWARD PENINSULA, ALASKA

By David M. Hopkins

Evidence of four Quaternary glaciations is recognized on Seward Peninsula. The Kigluaik, Bendeleben, and Darby Mountains (pl. 1) have been major glacial centers. Glaciers also have been present in the York Mountains and in higher parts of uplands elsewhere. Glaciated areas make up about 20 percent of the total area of the peninsula, and three small glaciers persist today in the Kigluaik Mountains.

The earliest glaciation—the Iron Creek glaciation—is represented by till and outwash encountered beneath till of the Nome River glaciation at Iron Creek (Smith, 1909, p. 316-319). Facetted spurs adjoining bedrock benches several hundred feet above stream grade in the Nome River valley and in nearby valleys are tentatively assigned to the Iron Creek glaciation. Neither till nor erratics were observed on the bedrock benches. Granite erratics found by Max White, geologist (personal communication), on the deformed marine terrace at the south front of the York Mountains (the York plateau of Brooks, and others, 1901, p. 52) may have been deposited during Iron Creek time. The extent of the Iron Creek glaciation can not be determined from present fragmentary evidence.

Organic deposits between outwash of the Iron Creek glaciation and overlying till of the Nome River glaciation are records of an interglacial interval during which the forests on Seward Peninsula contained trees which now grow no farther north than southeastern Alaska.

Deposits of the next recognized glaciation—the Nome River glaciation—are distributed widely and have been studied in detail in the Nome River valley. Most valleys in the York, Kigluaik, Bendeleben, and Darby Mountains were occupied by ice. End moraines are found 1 or 2 miles beyond the northern and western margins of the Bendeleben Mountains and 5 to 10 miles beyond their south fronts. Glaciers originating in the Kigluaik Mountains extended 15 to 25 miles south of the range, reaching Bering Sea at Nome (McNeil, F. S., and others, 1943, p. 72). Glaciers also were present in cirques throughout the uplands south and west of the Kigluaik Mountains and in a few other highland areas.

Outwash of the Nome River glaciation is interbedded with auriferous beach sand 70 feet above present sea level at Nome. End moraines are displaced by faults at the south front of the Bendeleben Mountains and at the north front of the Kigluaik Mountains.

Glacial topography of the Nome River glaciation is thoroughly modified by subsequent frost-riving, creep, and stream erosion. Higher parts of valley and cirque walls are mantled with rubbly soil, and little bedrock is exposed. Lateral moraines are preserved as inconspicuous, gently undulating convexities on valley walls. End moraines consist of series of broad, smooth ridges on which no characteristic glacial microrelief can be recognized. Drainage is relatively well integrated and lakes are scarce. Till generally is fresh in appearance, but in a few areas it is deeply weathered and cemented with calcium carbonate or iron oxides.

The differences between the topographic expression of deposits of the Nome River glaciation and of the succeeding Salmon Lake glaciation suggest that a relatively long time elapsed between the two glacial episodes. Peat and organic silt deposits which are found in stream valleys in unglaciated parts of Seward Peninsula and which contain remains of extinct mammals and of trees now found in the boreal forest of interior Alaska may have been deposited during this interglacial interval.

The Salmon Lake glaciation affected a much smaller area than the Nome River glaciation. Salmon Lake, a large lake a few miles southwest of Iron Creek (pl. 1), is dammed by a moraine marking the most advanced position of the Salmon Lake glaciation. Ice extended 5 to 6 miles into upland valleys south of the Kigluaik Mountains and 1 to 3 miles into the lowland north of the mountains. Salmon Lake ice in the Bendeleben and Darby Mountains was restricted to the upper parts of most valleys but reached the mountain front in one or two valleys draining particularly rugged areas in the Bendelebens. The Salmon Lake glaciation is represented in the York Mountains by rock glaciers, protalus ramparts, and moraines in a few valleys which drain the highest peaks. Moraines and freshly sculptured cirques of equivalent age also are found locally in the most rugged upland areas elsewhere on Seward Peninsula.

End moraines of the Salmon Lake glaciation consist of arcuate zones of slightly modified knob and kettle topography in which a few lakes are present, undrained depressions are abundant, and drainage is poorly integrated. Lateral moraines are readily recognizable embankments on valley walls but are breached by gullies and ravines. Where valley walls are low, slopes are mantled with rubbly soil; and little bedrock is exposed; however, where valley walls are high, they consist of rock cliffs interspersed with active avalanche chutes.

Moraines of the Salmon Lake glaciation are displaced by the young fault at the north front of the Kigluaik Mountains.

Deposits of a later glaciation—the Mount Osborn glaciation—are recognized on aerial photographs of the valley heading in the west wall of Mount Osborn (pl. 1) and in a few other valleys in the Kigluaik Mountains. Further study may result in recognition of the Mount Osborn glaciation in many other valleys and in other mountain ranges. Rock glaciers which bury lateral moraines of the Salmon Lake glaciation in many places are tentatively assigned to the Mount Osborn glaciation.

End moraines of the Mount Osborn glaciation are small, sharp-crested ridges that enclose portions of valleys in which talus accumulations are small and rock glaciers uncommon. Small lakes commonly are retained behind these end moraines.

A relatively short interglacial interval between the Salmon Lake and Mount Osborn glaciations is suggested by the small difference in degree of modification of moraines of the two glaciations.

Fresh moraines, snowbank ramparts, and active rock glaciers are noted on aerial photographs in many cirques in high mountain areas. These may be correlative with recently abandoned moraines a few hundred feet in front of living glaciers in the Kigluaik Mountains and may have formed during glacial fluctuations within the last one or two centuries.

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SAGAVANIRKTOK-ANAKTUVUK REGION, NORTHERN ALASKA

By Robert L. Detterman

Four Quaternary glacial advances have been recognized in the Sagavanirktok-Anaktuvuk district that comprises a part of the central Brooks Range and the adjacent portion of the foothills province to the north. Today the district is ice free except for small glaciers on north-facing slopes of the higher mountains and extensive aufeis fields in the floodplains of the major streams. During the four glaciations, ice occupied valleys in the central Brooks Range; and during at least the two early glaciations, coalesced to form piedmont lobes in the foothills along such major rivers as the Itkillik, Sagavanirktok, and Anaktuvuk.

Fragmentary evidence for the oldest glacial advance (the Anaktuvuk) is found at one place 40 miles from the mountain front (at least 10 miles north of the maximum extent of subsequent glaciations), about 30 miles above the mouth of the Anaktuvuk River. Schrader (1904, p. 88) found till at a point 10 miles above the mouth of the Anaktuvuk River. The present author's evidence consists of quartzitic conglomerate boulders on the hills 500-600 feet above the Anaktuvuk River and drift preserved as low, subdued, tundra-covered morainal hills that occupy an area of 100 square miles along the river. Weathering and wind erosion have destroyed all evidence of glacial striations, and a thin weathering rind occurs on the surfaces of these boulders. The till is considerably weathered and consists mainly of small rock fragments. Most of the kettle lakes have been filled or drained.

The oldest well-defined glacial advance, the Sagavanirktok glaciation, is named for morainal remnants that cover an area of 230 square miles along the Sagavanirktok River, 60 miles east of the Anaktuvuk. The remnants are considerably modified but retain recognizable knob and kettle topography. In a few places the terminal moraine is intact, but over most of the area it is covered by outwash of more recent glacial advances. Many of the kettle lakes have been filled or drained.

At the time of the Sagavanirktok advance a piedmont lobe probably was formed with a maximum extension 30 miles north of the mountains. Limestone and conglomeratic quartzite erratics, 1,500 feet above the valley floor, in the mountains, probably date from this advance. Limestone constitutes about 30 percent of the larger rock fragments of the Sagavanirktok drift but is rarely found in till of the Anaktuvuk glaciation and then only as highly weathered fragments.

A subsequent advance is called the Itkillik glaciation after one of the rivers in the central part of the area. Till of the Itkillik glaciation covers approximately 1,000 square miles, and the drift forms fan-shaped deposits at the mouths of major valleys. The greatest extent of this glaciation was about 20 miles north of the maximum advance of the next glaciation. 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. Terminal and lateral moraines are easily recognized, as well as the knob and kettle topography. Glacial features have been less modified by weathering than have the earlier Anaktuvuk and Sagavanirktok deposits. Numerous kettle lakes, a few tens of feet to half a mile in length, occur on the moraines. Relatively few have been filled or drained. Lakes up to several miles in length are enclosed behind the moraines in many of the stream valleys at the front of the range.

Till of the Itkillik glaciation is less weathered than that of the earlier advances and has a higher percentage of large rock fragments. Erratics with well-developed glacial striations are found on the moraines. A piedmont lobe was formed at the time of the Itkillik glaciation with glaciers coming from all the major valleys, and deposits of this advance are found throughout the area.

The last recognizable advance of the ice is here called the Echooka glaciation after the Echooka River, a major eastern tributary of the Sagavanirktok River. This advance was relatively minor, covering less than 50 square miles, and was confined to the major valleys of the Sagavanirktok River drainage area. At its maximum extent this ice did not reach the front of the range and formed independent valley glaciers.

The farthest advance of the Echooka glaciation is marked by well-developed end moraines and kame terraces along the valley wall. Knob and kettle topography of the moraine is relatively fresh. The till sheet is 30 to 50 feet thick, and boulders of limestone, sandstone, and quartzite are well striated and have fresh ice-polished surfaces. The kettle lakes and moraines are much smaller than those of previous glaciations. The lakes have not been filled with sediments, and streams from side valleys have not yet cut deep channels through moraines of this glaciation.

Glaciers in the range are receding today. A few have made minor advances of about half a mile within historic time and have built up boulder moraines in front of them. This period of activity probably has been within the last few hundred years.

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TENTATIVE CORRELATION OF GLACIATIONS IN ALASKA

By Troy L. Péwé and others

Similarities in the glacial deposits of eight areas in Alaska, mapped by Detterman, Fernald, Hopkins, Karlstrom, Krinsley, Muller, Péwé, and Wahrhaftig, representing several major geomorphic divisions, indicate that the areas have broadly similar glacial histories and justify the construction of a tentative correlation table (table 1). The table is proposed primarily as a working tool to facilitate completion and extension of the investigations reported above. Its preliminary nature must be emphasized, for further work may necessitate changes.

Most of the writers have observed glacial deposits in several of the areas, and they have discussed mutual problems and compared aerial photographs of all areas. The extensive use of photointerpretation requires considerable reliance on topographic expression as a criterion for correlation. Factors such as lithology, topographic position, and morphologic environment have been considered in comparing modification of moraines. These variables are so difficult to evaluate for the older glaciations that precise correlations are not attempted.

Several generalizations apply to all of the eight areas:

1. Each area contains evidence of minor glacial advances or intensified rock glacier activity within the last few centuries.

2. In each area fresh moraines of a late major glaciation appear comparable on the basis of position, prominence, and preservation of glacial microrelief. An important readvance or stillstand followed shortly after the late major glaciation in many areas, but this is not recognized everywhere.

3. Each area contains readily recognizable but modified moraines of an older, more extensive glaciation.

4. Seven areas contain, beyond the limits of subsequent glaciations, scattered remnants of still older glacially scoured surfaces that locally retain till or boulders and extremely modified morainal belts.

Moraines of the late major glaciation generally stand above well-developed aprons of coarse-grained outwash, except in the Cook Inlet area where they fronted a body of water. Generally these moraines are above the lake deposits. The moraine ridges control drainage patterns in the lowlands and are transected by few streams other than those along the axes of the major lobes. Lateral moraines on valley walls are less deeply gullied than are older moraines on upper slopes, and deflection of drainage lines at the morainal contact is common. Knob and kettle topography is well preserved, though kettle depressions are partly filled and knobs are somewhat rounded. Boulders are generally abundant and relatively fresh.

Deposits of the youngest major glaciation in Alaska are well preserved and similar in expression to glacial deposits in adjacent Yukon Territory (Bostock, 1936, p. 58; Sharp, 1951). It is suggested that deposits of this glaciation in Alaska are late Wisconsin in age. Radiocarbon dating of deposits of the youngest major glaciation, Naptowne, in the upper Cook Inlet area indicates that they are less than 14,000 years and more than 8,000 years old (Karlstrom, 1952) and presumably are late Wisconsin, the Mankato substage which attained its maximum advance in north central United States about 11,000 years ago (Flint and Deevey, 1951, p. 261).

Moraines of the next earlier glaciation are more subdued and generally are partly buried by outwash. In the lowlands, drainage through the morainal belts is better integrated and is controlled less closely by morainal ridges. Although deposits of this glaciation are distinctly more modified than those of the last

Table 1. —Tentative correlation of glacial sequences in Alaska, 1952

Standard	Kenai Peninsula [Karlstrom, Krinsley]	Alaska Peninsula [Muller]	Upper Kuskokwim [Fernald]	Nenana River [Wahrhaftig]	Big Delta [Péwé]	Seward Peninsula [Hopkins]	Brooks Range [Detterman]
Recent	Unnamed	Unnamed	Unnamed	Clear Creek	Black Rapids	Unnamed	Unnamed
late Wisconsin	Nikolai Creek	Iliuk		Carlo	Summit Lake		
	Naptowne (older than 8,000 yrs. younger than 14,000 yrs.)	Brooks	Farewell	Riley Creek	Donnelly	Mount Osborn	Eschooka
early Wisconsin	Swan Lake (older than 18,000 yrs.)	Mak Hill	Selatna	Healy	Delta	Salmon Lake	Itkillik
pre-Wisconsin	Caribou Hills	Johnston		Dry Creek	Darling Creek	Nome River	Sagavanirktok
	Mount Susitna	Earliest		Browne		Iron Creek	Anaktuvuk

major glaciation, they are much better preserved than the fragmentary remnants of still earlier glaciations. The next to the last major glaciation is probably early Wisconsin in age. Radiocarbon dating in the Upper Cook Inlet area indicates that the Swan Lake deposits are older than 18,000 years and may represent Cary and or earlier substages of the Wisconsin (Karlstrom, 1952).

The oldest glaciations are less amenable to correlation. The deposits are scanty and generally poorly preserved. They are found far out from the mountains or at high altitudes, well above the limits of deposits of the presumed Wisconsin glaciations. Most deposits at high altitudes owe their present positions to downcutting of valley bottoms since they were laid down. Their extreme modification and dissection suggest that a long time interval elapsed after they were deposited and before the deposits of the first of the two late major glaciations were laid down. In the Cook Inlet region, glacially beheaded and highly modified glacial valleys close to present ice-sources of the Kenai Mountains indicate a long period of subaerial erosion and complete or nearly complete deglaciations of the mountains during this interval. These lines of evidence suggest that the deposits of the early glaciations are pre-Wisconsin in age.

A flora recording a climate much warmer than the present is found between deposits of two early, presumably pre-Wisconsin glaciations on Seward Peninsula, indicating that two major glacial stages are represented.

These tentative correlations aid in establishing the broad framework of the Quaternary history of both glaciated and unglaciated regions in Alaska. They clarify the nature of the Alaskan environment at times when important floral and faunal changes took place in North America, and establish more precisely possible routes and periods of migration of man from the old world into the new.

It is expected that more intensive work in Alaska will permit a more refined subdivision and correlation of the glacial deposits within and between the present areas of study.

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