Late Pleistocene Glaciations of the Snag-Klutlan Area, Yukon Territory

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ABSTRACT. Two late Pleistocene limits of glaciation were delineated in the Snag-Klutlan area. Radiocarbon dates, surficial characteristics of its drift, and the palynology of overlying sediments imply the older glaciation (Mirror Creek) is early Wisconsin in age; the younger glaciation (Macauley) is late Wisconsin in age and culminated c. 13,700 B.P. The stratigraphy of deposits within the Macauley glacial limit implies that deglaciation between the two glaciations was minimal.

RÉSUMÉ. *Glaciations fini-pléistocènes dans la région de Snag-Klutlan, Territoire du Yukon.* On a retracé dans la région de Snag-Klutlan deux limites fini-pléistocènes de glaciation. Les datations au radiocarbone, les caractéristiques superficielles de sa moraine et la palynologie des sédiments de recouvrement impliquent que la plus ancienne glaciation (Mirror Creek) est d'âge wisconsinien ancien; la glaciation plus récente (Macauley) est d'âge fini-wisconsinien et a culminé vers 13,700 A.P. La stratigraphie des dépôts englobés par la limite glaciaire de Macauley laisse supposer que la déglaciation interglaciaire a été minime.

РЕЗЮМЕ. *Позднеплейстоценовое оледенение в районе Снаг-Клутлан (Юкон).* Были определены границы позднеплейстоценового оледенения в районе Снаг-Клутлан. Датировка радиоуглеродным методом, изучение поверхностных характеристик ледниковых наносов и пыльцевой анализ отложений позволили установить наличие двух стадий оледенения ранне- и поздневисконсинского возраста.

INTRODUCTION

During the summers of 1965-67, and the spring of 1968, field investigations were conducted in the Snag-Klutlan area of the southwestern Yukon (Fig. 1); the primary objectives being a reconstruction of its Quaternary geologic, vegetational, and climatic history (Rampton 1969). The field investigations were supplemented by air photo interpretation, pollen analysis and ^{14}C dating in the laboratory. The extent, chronology, and climatic environment during two late Pleistocene glaciations are presented in this paper. Evidence of earlier glaciations is present in the area, but is not abundant enough to allow a detailed reconstruction of them.

CLIMATE, PERMAFROST, AND VEGETATION

The Snag-Klutlan area has a cool continental climate (Kendrew and Kerr 1955; Boughner and Thomas 1960). The Icefield Ranges, which are the largest group of peaks in Canada and range up to 19,850 feet in elevation (Bostock 1948), act

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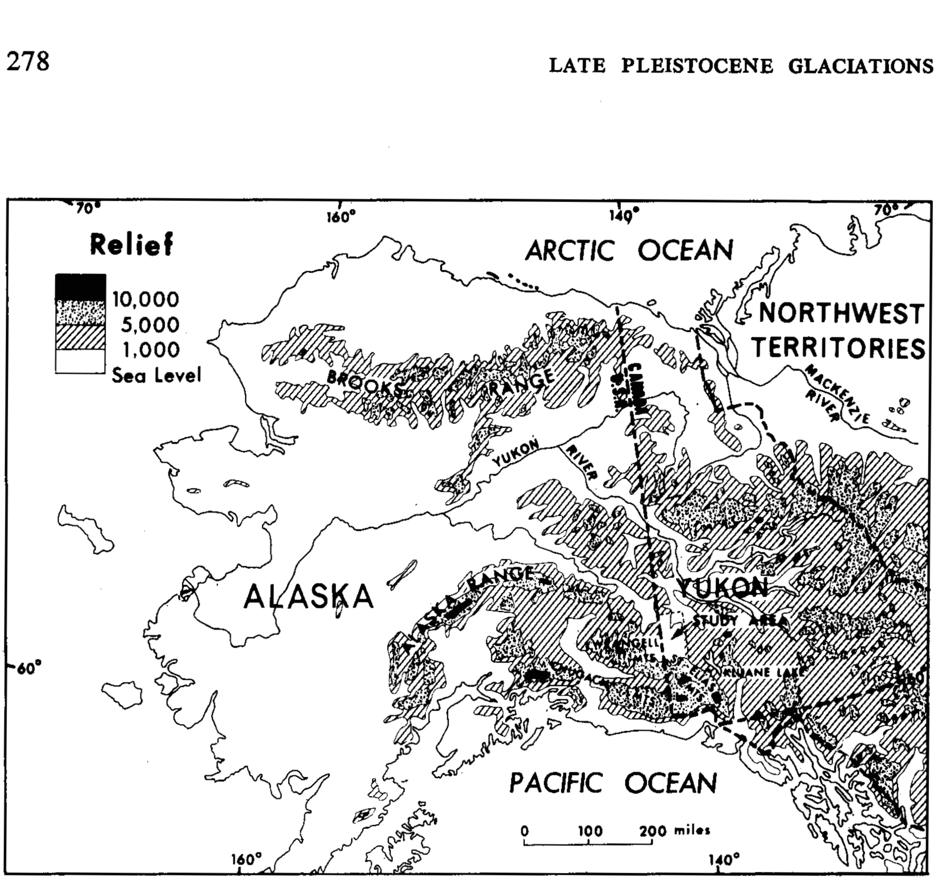

FIG. 1. Index map showing relief.

as a strong barrier to the maritime influence of the nearby Pacific Ocean. Winter temperatures are variable but generally are low (January mean at Snag is −14°F.). Summers are short and warm (July mean at Snag 57°F.). Spring and fall are very short seasons. The mean annual precipitation at Snag is 14.1 inches with no pronounced wet or dry season, although most precipitation occurs during summer at Snag.

The Snag-Klutlan area lies in the zone of widespread discontinuous permafrost (Brown 1967a, 1967b). All sediments except recently deposited fluvial sediments and possibly the more permeable glaciofluvial sediments are permanently frozen, as indicated by patterned ground, solifluction lobes, and thermokarst lakes.

Tree line is between 4,000 and 4,400 feet elevation at present. Black spruce forest is the dominant forest type below tree line. Other forest types, e.g. depauperate black spruce forest, white spruce-aspen, balsam poplar, are present on sites governed by special edaphic or hydrologic conditions. Above tree line, shrub tundra prevails to 4,800 ft. Most of the area between 4,800 and 5,500 feet is covered by tussocks and prairie-like mixtures of grasses, sedges, and flowering perennials. Above this, only fell field and rock desert are present.

PHYSIOGRAPHY

The bedrock geology and physiography have been described recently by Bostock (1948, 1952) and Muller (1958, 1967), and only a brief description of the

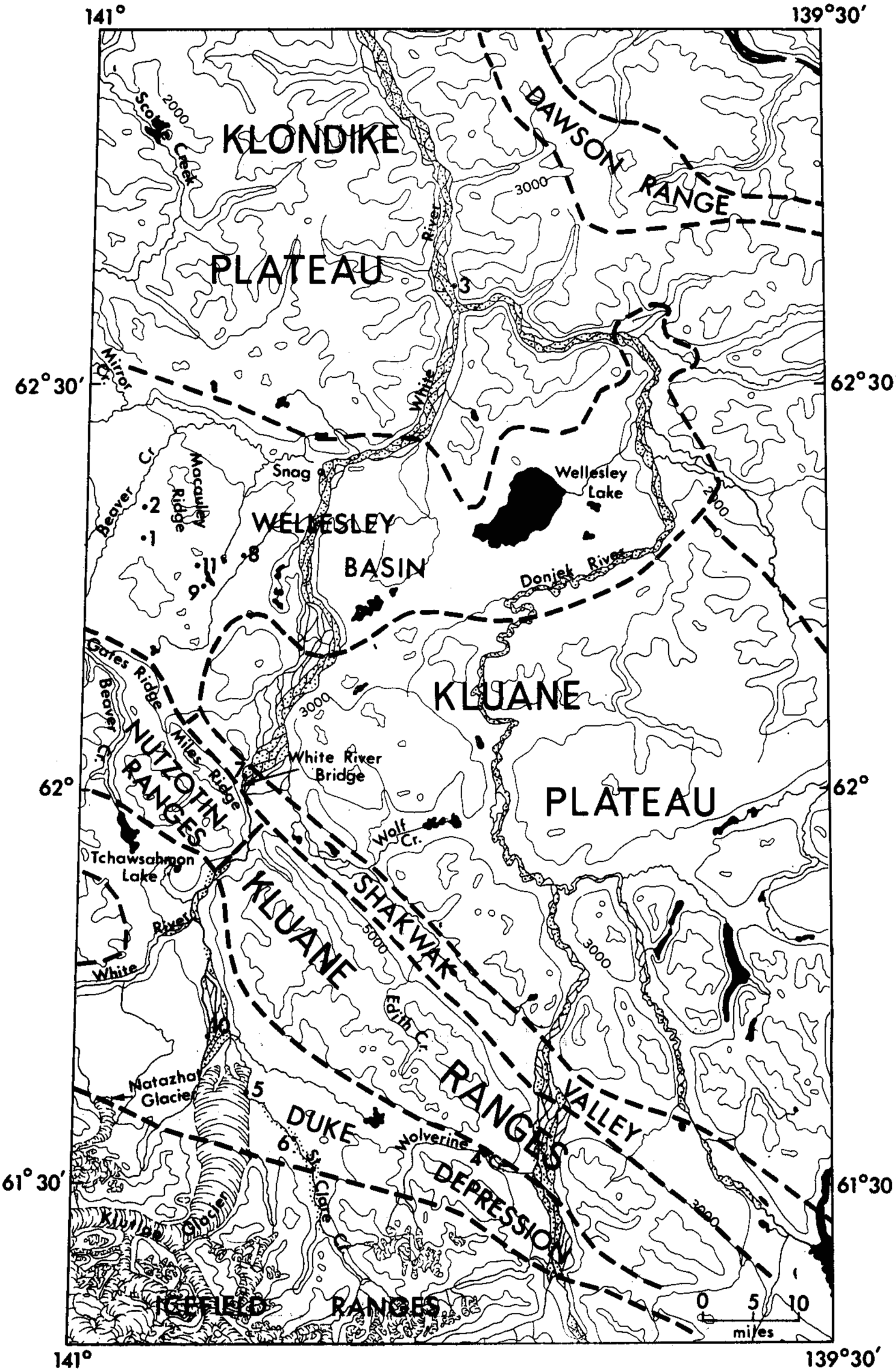

FIG. 2. Physiographic divisions of the Snag-Klutlan area (adapted from Bostock, 1948). Numbered localities and place-names mentioned in the text are also shown.

physiography will be given here. As can be seen from Fig. 2, the Snag-Klutlan area is divided into two distinct physiographic regions by the Shakwak Valley, which is probably of fault origin. To the south are the northwest-southeast aligned Kluane Ranges, Nutzotin Ranges, Duke Depression, and Icefield Ranges. The Kluane and Nutzotin Ranges border the Shakwak Valley and have peaks ranging in elevation between 6,000 and 7,500 feet. The Duke Depression is a "plateau-like belt characterized by broad smooth slopes", which consists of a broad steep-walled inner valley flanked by a plateau in the Snag-Klutlan area (Bostock 1948). The Icefield Ranges are the largest group of high peaks in North America and range up to 19,500 feet in elevation. At the northern edge of the mountains peaks range up to 13,500 feet in elevation; the higher peaks being covered by small ice-fields and alpine glaciers. North of the Shakwak Valley are the Kluane and Klondike plateaux, the Wellesley Basin, and the Dawson Range. The Kluane Plateau consists of peaks from 4,000 to 6,000 feet in elevation that are connected by broad undulating ridges. Its upper surface is dissected by broad glaciated valleys. The Klondike Plateau is "a maze of deep, narrow valleys separated by long, smooth-topped ridges whose elevations are very uniform" (Bostock 1948). The crests of these ridges are between 3,000 and 5,000 feet in elevation except in the Dawson Range where they rise to over 5,000 feet. The Wellesley Basin is a broad trench whose floor lies between 2,000 and 2,500 feet in elevation except where it is broken by large bedrock ridges and hills up to 5,000 feet high.

PREVIOUS INVESTIGATIONS

Reports of glacial phenomena in the area were recorded as early as 1892 (Hayes). However no attempt was made to outline the details of the maximum limit of Pleistocene glaciation until 1948 (Bostock 1948, 1952).

In 1962 Krinsley (1965) made a reconnaissance of the Pleistocene geology of the area and proposed a chronology of the glacial deposits. A series of moraines were mapped (Fig. 3) and tentatively assigned ages ranging from Kansan to Recent. Between 1950 and 1957 reconnaissance bedrock mapping was carried out by Muller and Christie. Muller (1967) mapped a number of glacial limits (Fig. 3) and outlined the Pleistocene geology for the southern part of the area on the basis of air photo interpretation and observations made during his bedrock mapping.

GLACIAL GEOLOGY

Terminology

Two Pleistocene limits of glaciation can be traced throughout much of the Snag-Klutlan area (Fig. 4). Within each glacial limit, moraines are present that commonly have distinctive geomorphic characteristics reflecting their relative ages. Because of the distinctiveness of the moraines, and the fact that stratigraphic units can only be chronologically distinguished where they can be related to ^{14}C dated sediments or surface features, glaciations have been defined on the basis of morphostratigraphic features rather than rock-stratigraphic units. Formal names for these glaciations presented in this paper were first used by Rampton in 1969.

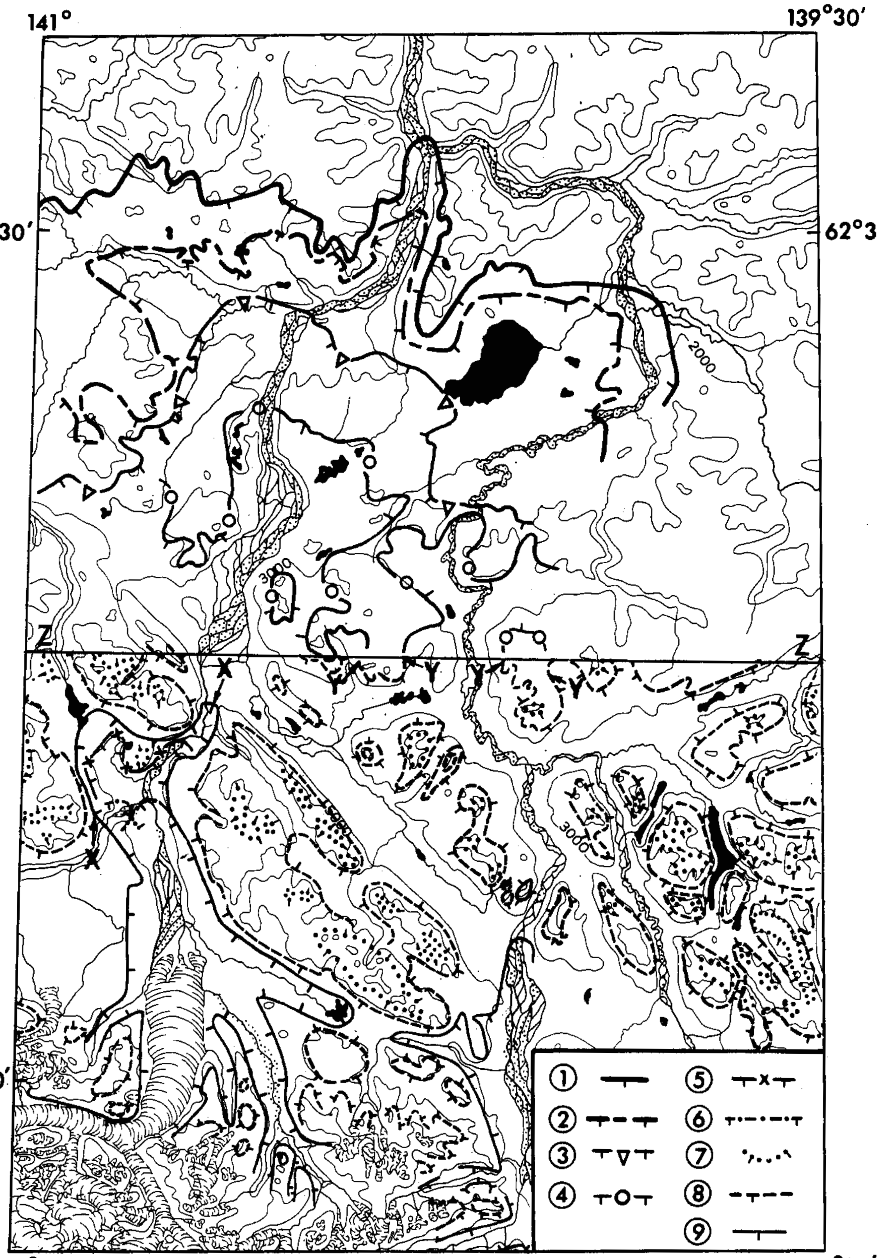

FIG. 3. Glacial limits according to and adapted from Krinsley (1965) and Muller (1967). 1: Krinsley's Nisling Moraine, 2: Krinsley's Donjek Moraine, 3: Krinsley's Snag I Moraine, 4: Krinsley's Snag II Moraine, 5: Krinsley's Tchawsahmon II Moraine, 6: Krinsley's Tchawsahmon III Moraine, 7: Muller's Nisling glacial limit, 8: Muller's Ruby glacial limit, 9: Muller's St. Elias glacial limit. X-X marks portion of Muller's St. Elias glacial limit that coincides with Krinsley's Tchawsahmon I Moraine. Y-Y marks portion of Muller's Ruby glacial limit that coincides with Krinsley's Snag II Moraine. Z-Z marks northern limit of Muller's mapping.

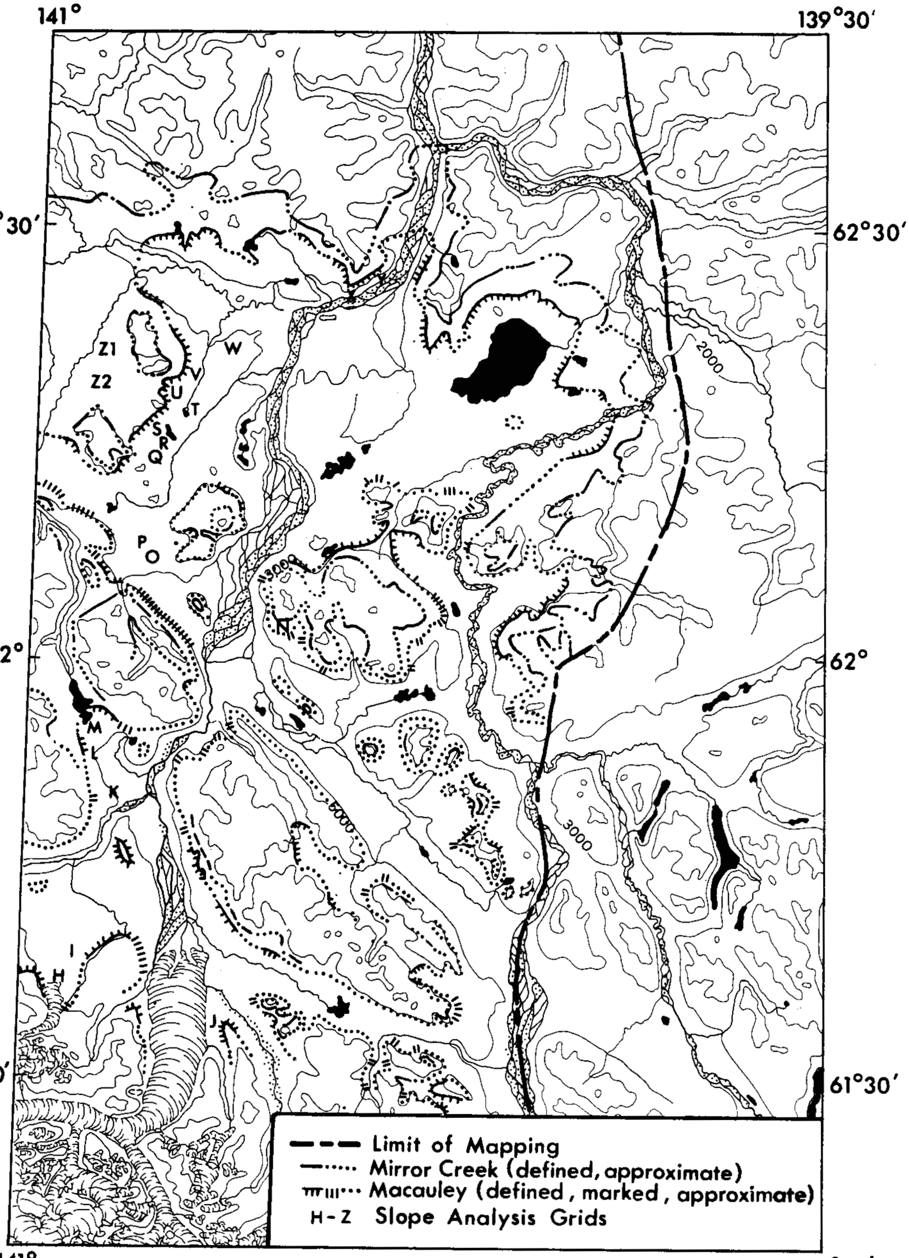

FIG. 4. Mirror Creek and Macauley glacial limits.

The glacial advance that produced the most extensive of these two glacial limits has been named the Mirror Creek glaciation. Moraines typical of this glaciation are not present near Mirror Creek, but the outermost limit of glaciation, which appears to correspond with the Mirror Creek limit of glaciation north of the

Shakwak Valley, does cross the Alaska Highway just north of Mirror Creek. Non-oriented moraines (nomenclature of moraines follows Prest 1968) typical of this glaciation are present north and east of Wellesley Lake beyond the glacial limit of the subsequent Macauley glaciation and between Beaver Creek and Macauley Ridge (Fig. 5). Terminal moraines typical of this glaciation are present in the Klondike Plateau north of Snag and along the edges of the White River valley.

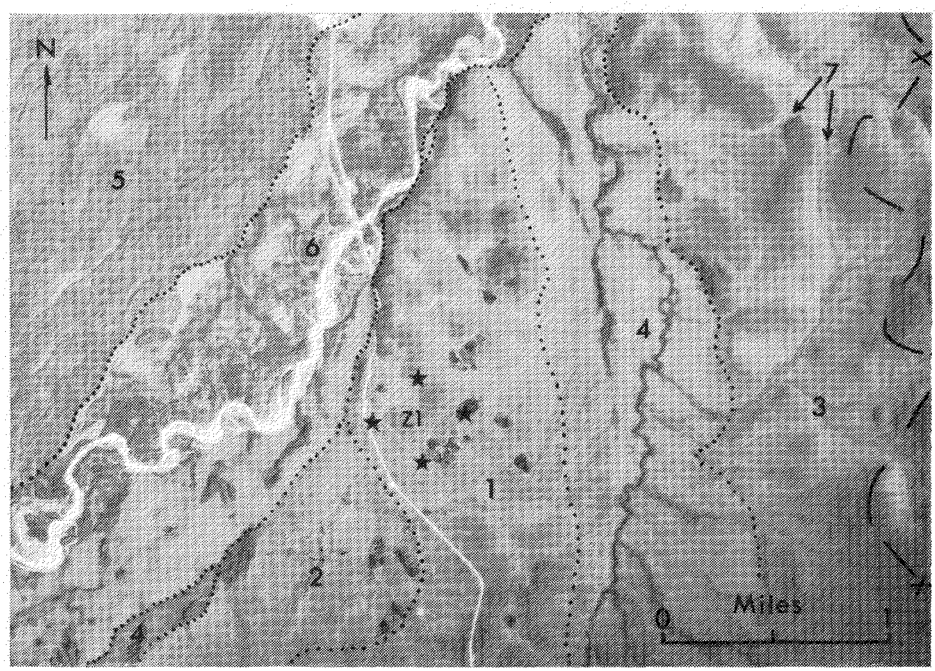

FIG. 5. Aerial photograph showing Mirror Creek glacial features. Unit 1 is a Mirror Creek disintegration moraine; 2 is underlain by Mirror Creek glaciofluvial deposits; 3 is mainly underlain by Mirror Creek drift, although bedrock hills covered by thin deposits of drift and colluvium are present (the southern edges of the hills are dark grey on the photo, as they are covered by forest); 4 and 5 are Macauley glaciofluvial deposits; 6 is post-Macauley fluvial deposits; 7 is Mirror Creek meltwater channels; X-X is approximate Mirror Creek glacial limit. Much of units 1, 3, and 6 and most of units 2 and 4 have fairly thick peat covers. Sample grid Z1 is outlined by 4 stars. Junction of Alaska Highway and Beaver Creek is located near the centre of photo. (Air photograph A14798-63; EMR, Ottawa.)

The maximum limit of the Mirror Creek glaciation corresponds closely with a glacial limit that Krinsley (1965) outlined in the northern part of the Snag-Klutlan area and called the Nisling Moraine (Fig. 3). However, Krinsley believed that the Nisling glaciation covered all of the southern part of the Snag-Klutlan area, whereas I have traced the maximum limit of the Mirror Creek glaciation throughout much of the area (Fig. 4). The maximum limit of the Mirror Creek glaciation also corresponds with a glacial limit that Muller (1967) outlined in the Kluane Plateau and called the Nisling glacial limit. However, south of the Shakwak Valley Muller has traced his Nisling glacial limit far above the maximum limit of the Mirror Creek glaciation. The term "Nisling" has been discarded because

Krinsley (1965) and Muller (1967) applied it to two different glacial limits, and because the results of this investigation suggest both were incompletely, and in part incorrectly, outlined. Application of "Nisling" to a third glacial limit and the glaciation that produced this limit would have added further confusion, even though the Mirror Creek and Nisling glacial limits correspond in some parts of the Snag-Klutlan area.

The later less-extensive glacial advance has been named the Macauley glaciation, as terminal and disintegration moraines typical of this glaciation clearly define its limit on the eastern and northeastern flanks of Macauley Ridge (Fig. 6).

The maximum limit of the Macauley glaciation corresponds closely to a glacial

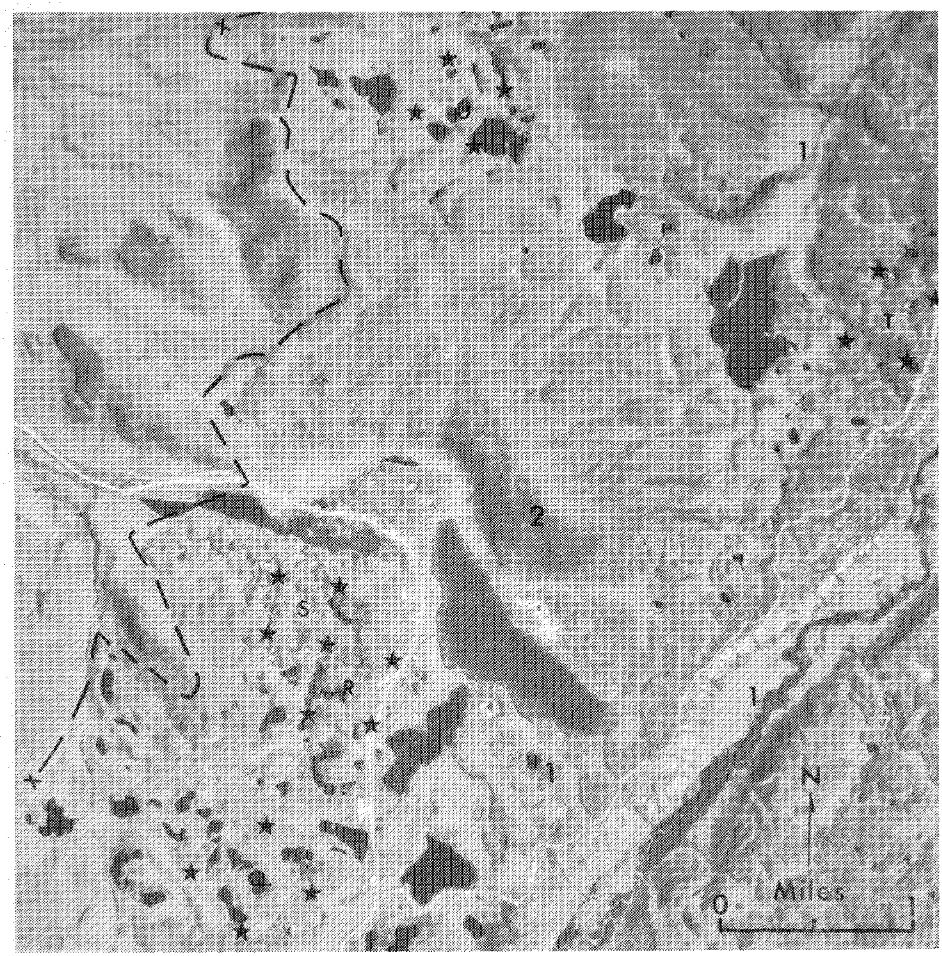

FIG. 6. Aerial photograph showing Macauley glacial features. Macauley disintegration moraines cover most of the area within Macauley glacial limit (X---X), except for areas underlain by glaciofluvial deposits (1) and bedrock highs covered by thin Macauley drift and colluvium (2). Beyond the Macauley glacial limit bedrock hills protrude through Mirror Creek and Macauley glaciofluvial deposits that are covered by peats. Sample grids Q-V are outlined by 4 stars. Junction of Alaska Highway and James Road in bottom of photo. (Air photograph A14798-69; EMR, Ottawa.)

limit that Krinsley (1965) outlined in the area between Macauley Ridge and the Donjek River and called the Donjek moraine. However, Krinsley did not recognize that this same glacial limit can be traced around the many nunataks in the area, and he outlined these nunataks with different glacial limits, which he called the Snag and Tchawsahmon moraines. To make these glacial limits continuous across the valleys and basins he mapped the outer edges of various disintegration moraines within the valleys and basins as parts of his Snag and Tchawsahmon moraines. The maximum limit of the Macauley glaciation also corresponds to a glacial limit that Muller (1967) outlined in the Kluane Plateau and northern part of the Kluane Ranges and called the Ruby glacial limit. Muller interpreted cer-

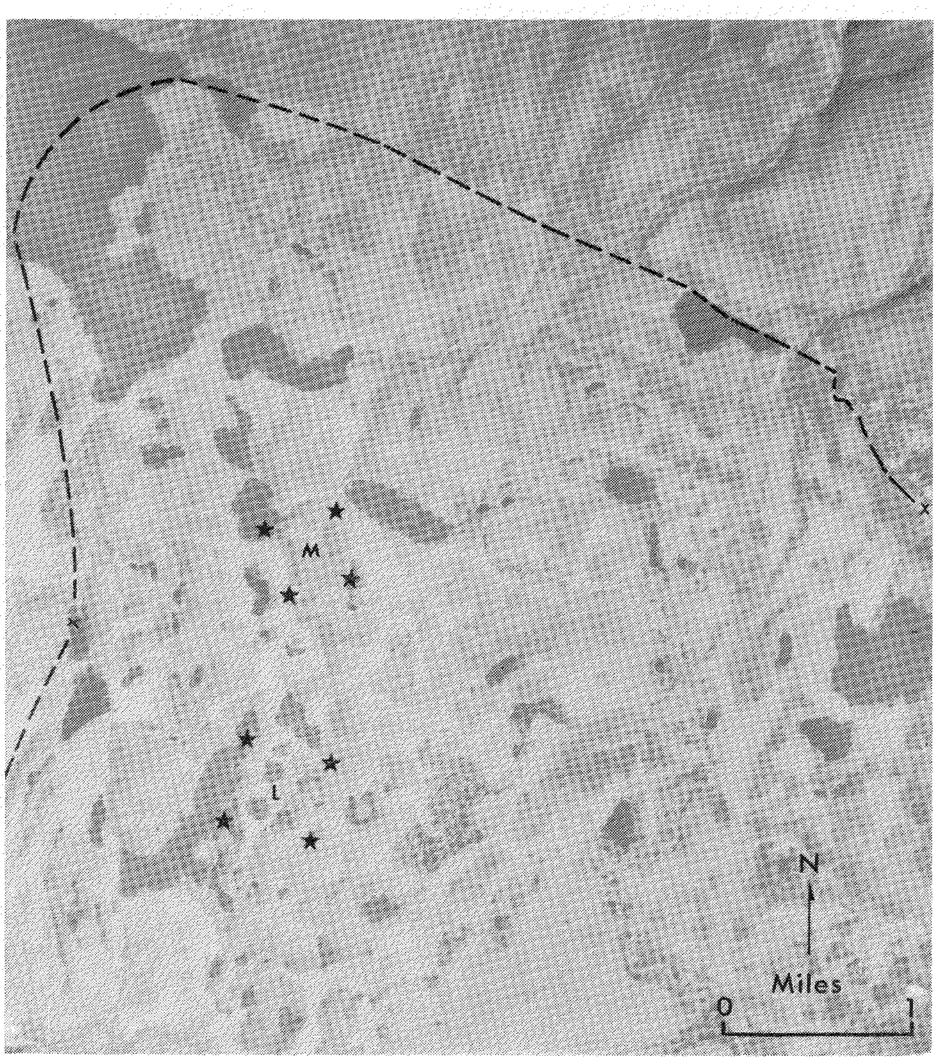

FIG. 7. Aerial photograph that shows non-oriented Macauley moraines and Macauley glacial limit near Tchawsahmon Lake. Sample grids M and L are outlined by 4 stars. (Air photograph A15491-49; EMR, Ottawa.)

tain features that define the same glacial limit south of the Kluane Ranges as marking another glacial limit, which he called the St. Elias glacial limit. Krinsley's (1965) and Muller's (1967) terms have been discarded because they traced their glacial limits incorrectly in part and assigned a multitude of terms to them. Application of any one of their terms to the Macauley glaciation would have added further confusion, even though the Mirror Creek glacial limits correspond to parts of Kringsley's Donjek, Snag, and Tchawsahmon moraines, and Muller's Ruby and St. Elias glacial limits.

Glacial Limits

The limit of the Mirror Creek glaciation is defined by large terminal and lateral moraines throughout much of the area north of the Shakwak Valley. In this area erratics have not been found above Mirror Creek terminal moraines, and the upper limits of meltwater channels and Mirror Creek terminal moraines are at corresponding levels where they are closely associated. It follows that the upper limit of erratics, patches of glacial drift, and meltwater channels probably mark the Mirror Creek glacial limit north of the Shakwak Valley, even where Mirror Creek terminal moraines are absent.

The Mirror Creek glacial limit is not so clearly defined south of the Shakwak Valley because of the sparsity of moraines and meltwater channels above the limit of the subsequent Macauley glaciation. The upper limit of erratics marks the Mirror Creek glacial limit only in the Kluane Ranges because high-level glacial drift from pre-Mirror Creek glaciations is present throughout most of the area south of the Shakwak Valley (Rampton 1969). An abrupt change from a U-shaped to a V-shaped valley marks the Mirror Creek glacial limit in the valley running parallel to the axis of the Nutzotin Ranges south of the Gates Ridge. In the Icefield Ranges, the Mirror Creek glacial limit is impossible to locate; either the Mirror Creek glacial features have been removed by postglacial erosion of the steep valley slopes, or the ice of the subsequent Macauley glaciation overrode or equalled the Mirror Creek glacial limit.

The limit of the Macauley glaciation throughout much of the area is clearly defined by terminal moraines and the frontal slopes of disintegration moraines having a distinctive morphology (cf. Figs. 6 and 7). Where terminal and disintegration moraines are absent, meltwater channels and lateral moraines are often present at elevations where the Macauley glacial limit might be expected. However, these glacial features are not significantly different from those of the Mirror Creek glaciation, and cannot be used as independent indicators of the Macauley glacial limit. The Macauley glacial limit is marked on some steep slopes by the limit of scouring, below which the bedrock is smooth and above which it is gullied and rough. On other steep slopes where meltwater channels, moraines, or scouring limits are absent the Macauley glacial limit cannot be precisely delineated. Most valley slopes in the Icefield Ranges fall in this category.

Glacial Deposits

Mirror Creek glacial deposits, i.e. glaciofluvial, glaciolacustrine, and morainal deposits, cover most flat and gently-sloping areas that lie between the Mirror Creek and Macauley glacial limits. Steep slopes are rare on any glacial deposits of Mirror Creek age, and the deposits generally support depauperate black spruce forest or muskeg.

Exposures of deposits that are presumed to be Mirror Creek in age because of their relationship to surface features have been examined along the Alaska Highway where it parallels Mirror Creek, on the southeast bank of Beaver Creek west of Macauley Ridge, and along the east bank of the White River beyond the Macauley glacial limit. Most exposures along the Alaska Highway near Mirror Creek are on hill slopes, and the glacial deposits are very thin and covered by colluvium and solifluction deposits. The Mirror Creek glacial deposits on Beaver Creek and the White River are of variable thickness. The till in these exposures is up to 110 feet thick, and generally appears to be conformably underlain by glaciofluvial deposits. Along the east bank of the White River beyond the Macauley glacial limit the till is interlayered with and underlain by glaciolacustrine deposits. Proglacial gravels are exposed 2 miles below the Mirror Creek limit on the east bank of the White River. The Mirror Creek glacial deposits do not appear to be deeply weathered. The thickness of oxidation zones was found to be irregular. In one test pit in the Mirror Creek morainal deposits, the till was oxidized 1.1 foot whereas in a second test pit the till was not oxidized. Granitic clasts from test pits dug in the Mirror Creek drift are slightly more weathered than those in the Macauley drift. Although some Mirror Creek glacial deposits are not leached, at one test pit more than 1.7 foot of till was leached.

Macauley glaciofluvial, glaciolacustrine, and morainal deposits cover most of the lowlands within the Macauley glacial limit. Glaciofluvial deposits also cover a large area in the western part of the Wellesley Basin beyond the Macauley glacial limit. Rock glacier debris of Macauley age is present along some valley walls and within some cirques in the southern part of the area. A layer of loess of probable Macauley age blankets much of the lowland. Macauley glacial deposits support a variety of vegetation types because of their relative youthfulness, i.e. relative to Mirror Creek deposits they have a greater variety of slopes, and textural differences in the sediments have not been masked by vegetational succession.

Exposures of Macauley glacial deposits are common along stream cuts within the Macauley glacial limit. Macauley glaciofluvial and morainal deposits commonly exceed 100 feet in these exposures. Glaciolacustrine deposits are thinner, 30 feet being the maximum thickness noted. Macauley loess is up to 2.5 feet thick. Macauley glacial deposits are only slightly weathered. Thick sections of loess are often incompletely oxidized. Glaciofluvial deposits are generally oxidized only to a depth of 1 to 2 feet, although at one locality they were iron-stained to a depth of 4 feet. The maximum depth of oxidation measured in till was 0.5 foot. These measurements do not include observations made near the Natazhat Glacier where the brown colour of all tills and glaciofluvial deposits makes it difficult to distinguish oxidized from unoxidized deposits. Some presumed Macauley deposits along a tributary of St. Clare Creek also are deeply oxidized but they may be merely re-worked older drift (Rampton 1969). Most profiles on Macauley deposits examined were leached of lime to a depth of about 1.5 feet. At one locality 4.5 feet of leached glacial deposits are present. The depth of oxidation and leaching is probably governed by the depth of the active layer, which is very shallow in the Snag-Klutlan area.

Moraines

Mirror Creek morainal deposits are represented geomorphically by featureless ground moraines, non-oriented hummocky moraines, and terminal moraines. Streams have become incised in these moraines only on sloping areas and near escarpments. Postdepositional modifications of the non-oriented hummocky moraines make it difficult to determine whether they were originally low-relief, hummocky ground moraines or high-relief disintegration moraines. However, the spacing and size of partially filled depressions on most Mirror Creek non-oriented hummocky moraines are very similar to the spacing and size of those on younger disintegration moraines and suggest that the moraines were once morphologically similar (Figs. 5 and 6). Most former depressions on the non-oriented moraines are filled with silt and peat. Some of the silt may have been directly blown into the depression, but much has probably been transported into the depressions from the surrounding slopes by water flowing under and over the moss covering the slopes: the latter phenomenon can be observed at present on the Macauley moraines.

Macauley morainal deposits are represented geomorphically by featureless and drumlinized ground moraines and non-oriented hummocky moraines, most of which are high-relief disintegration moraines. Terminal and lateral moraines are not common. The moraines are incised by streams on sloping areas and near escarpments.

Quantitative slope investigations of moraines were undertaken to substantiate correlations of glacial limits that were outlined by air photo interpretation and field reconnaissance. This was particularly important in the Snag-Klutlan area as Krinsley (1965), Muller (1967), and I have outlined different sets of glacial limits for the area; the geomorphology of moraines within each glacial limit has been used by each of us as one of several criteria for establishing our glacial limits. Emphasis was placed on sampling non-oriented hummocky moraines with high-relief (disintegration moraines) because such moraines are common near the glacial limits that Krinsley, Muller, and I traced.

Grids, each comprising an area 2,000 feet on a side, were laid out on areas typical of the non-oriented hummocky moraine on which each was located. On each grid ten lines were run at 200 foot intervals, and the steepest slope at 20 points was measured along each line at 100 foot intervals. All lines and points were located by pace and compass. Points located in water were considered inaccessible, and no measurements were recorded. The steepest slope at each point was measured by aiming the sights of a Brunton compass at an eye-level mark on a pole positioned 10 feet up along the slope.

The K-S (Kolomogorov-Simirnov) test was chosen for testing differences in the population of the slope measurements because 1) it does not require normally distributed populations and 2) it allows for quick comparisons of many samples by graphical means. Slope measurements must be random variables if the sampled populations of several areas are to be compared by the test. In cases where samples are obtained by systematic sampling, such as in this investigation, the populations may be compared by the K-S test if the systematic samples were taken from populations that were in "random" order (Cochran 1963). Slope measurements taken at 100-foot intervals on disintegration moraines seem to have a random order. Evidently the topography of disintegration moraines is so chaotic that 1) serial correlation between measurements at successive sample points does not exist when sample points are 100 feet apart, and 2) no periodic variations in the population of slope angles are present. Disintegration moraines, in total, may be compared by the K-S test if the sample grids on these moraines are assumed to be representative of the moraines.

The mean slope of each grid on disintegration moraines of one age is a random variable obtained from the moraines. For regional comparison, the mean slope of grids on disintegration moraines of one age from one area can then be compared with those from another area by a t-test. The mean slopes should be normally distributed and the standard deviations of the populations of mean slopes should be similar for a valid test.

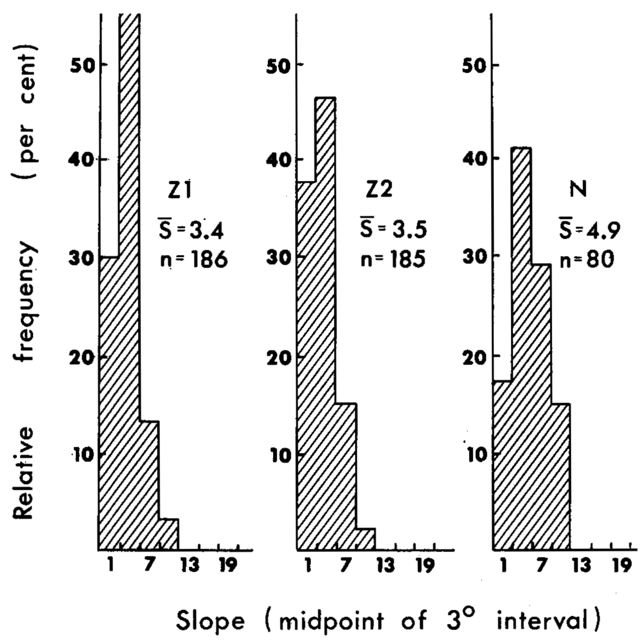

FIG. 8. Histograms of slope measurements of sample grids on Mirror Creek moraines. See Fig. 4 for locations. $\bar{S}$=mean slope. n=number of measurements.

The slope measurements of three sample grids located on Mirror Creek non-oriented hummocky moraines are shown in Fig. 8. Steep slopes are absent on these moraines, and the mean slopes of the samples are all very low. Sample grid N has slightly steeper slopes than grids Z1 and Z2. In fact, a K-S test at the 0.05 significance level calls for rejection of the hypothesis that the population from which sample N was drawn is the same as the population from which samples Z1 and Z2 were drawn. This discrepancy probably results from the fact that depressions on the disintegration moraines on which Z1 and Z2 are located are filled with silts, whereas the depressions on the disintegration moraine on which sample N is located are not. Grids Z1 and Z2 are located near a source of loess (Fig. 4), namely a large outwash plain, whereas grid N is located near the summit of a mountain, a site where loess deposition has probably been minimal.

The distributions of slopes on the Macauley moraines were examined in detail, because Macauley moraines have been chronologically separated by Krinsley (1965) and Muller (1967). The slopes of the disintegration moraines have been sampled at various sites throughout the area (grids H-K, O, Q-Y); a few non-oriented hummocky ground moraines were also sampled (grids M and P). The distribution of slopes and the mean slopes of the sample grids on the disintegration moraines are variable (Figs. 9 and 10). Indeed, K-S tests at the 0.05 significance level call for rejection of the hypothesis of identical distributions in a few cases, e.g. grids Q, R, and S, and grids U and V. These cases, in which

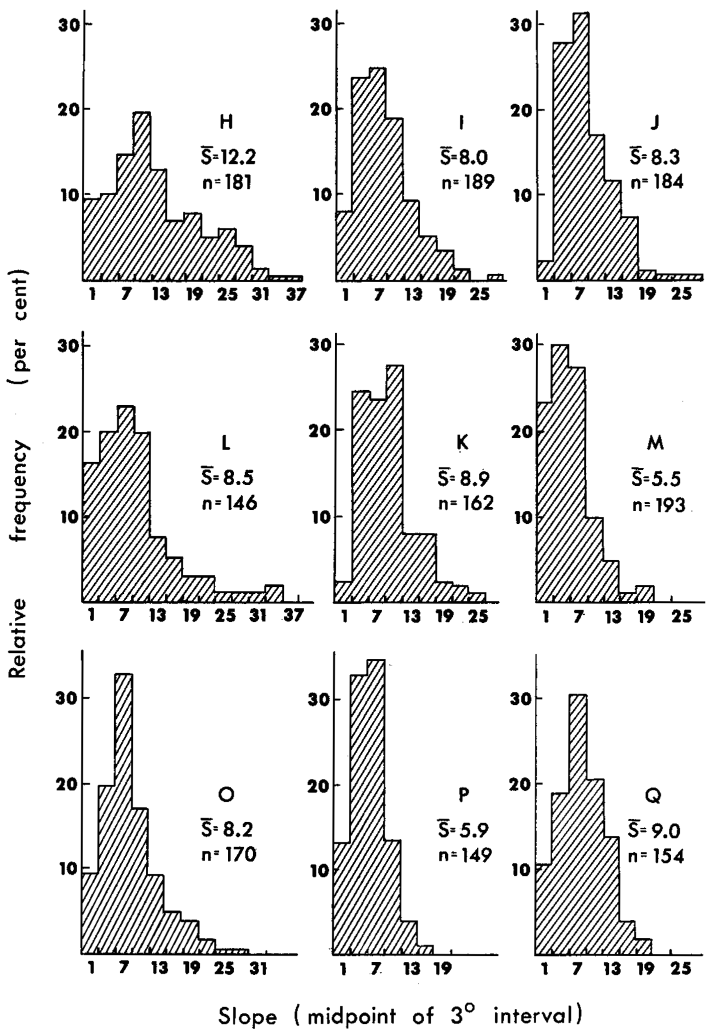

FIG. 9. Histograms of slope measurements of sample grids H-M and O-Q on Macauley moraines. See Fig. 4 for locations. S̄=mean slope. n=number of measurements.

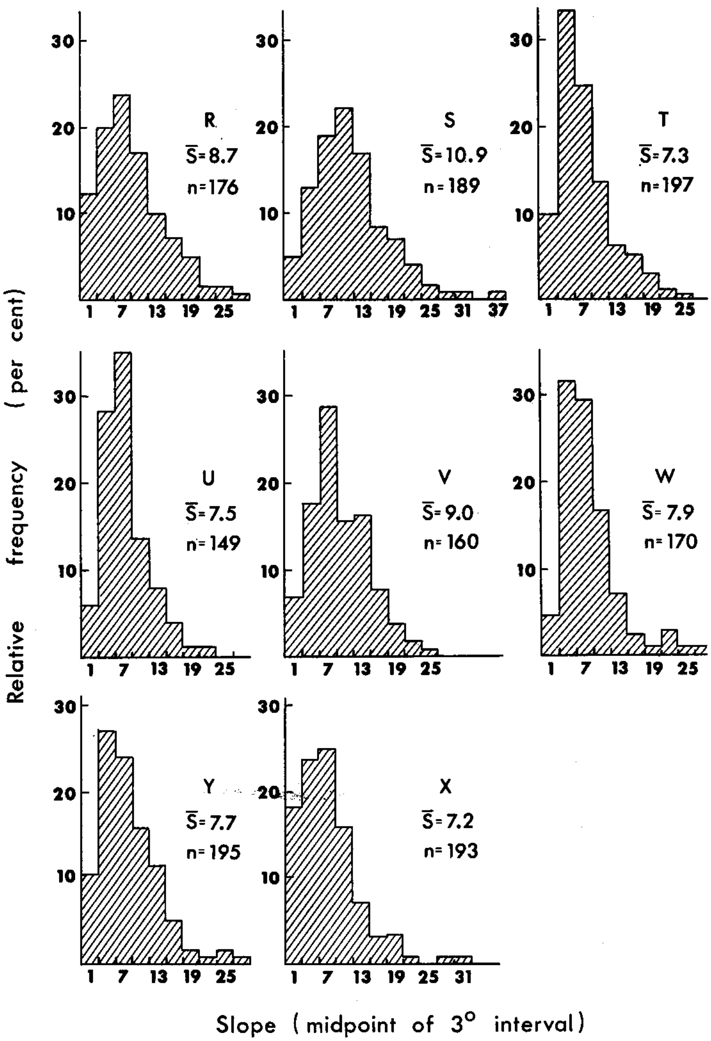

FIG. 10. Histograms of slope measurements of sample grids R-X on Macauley moraines. See Fig. 4 for locations. n=number of measurements. $\bar{S}$=mean slope.

different distributions are located on the same or adjacent disintegration moraines (Fig. 4), may be explained by variation in the original distribution of slopes from one part of the moraines to another. The greater ruggedness of grid H relative to grid I may have resulted from a late Macauley advance of the Natazhat Glacier or from the thick debris deposited by the Natazhat Glacier upon the glacier occupying the White River valley: grid H is located on a spatulate-shaped disintegration moraine that lies near the Natazhat Glacier's Neoglacial moraines; grid I is located on a disintegration moraine that was deposited by a glacier that moved east along the White River valley.

All moraines that Krinsley (1965) and Muller (1967) differentiated morphologically and chronologically have been sampled (Figs. 3 and 4). Grids U, V, X, and Y lie on moraines within Krinsley's Donjek glacial limit, grids O-T, and W lie on moraines within Krinsley's Snag glacial limit, grids K-M lie on moraines within Krinsley's Tchawsahmon glacial limit and within Muller's St. Elias glacial limit, and grids H-J on moraines within Muller's Ruby glacial limit. These grids were not located in any systematic manner and the mean slope of each grid is for all practical purposes a random variable. The hypothesis of a difference in mean slopes of samples grids located on the different moraines can be tested by a t-test if the means of each group are assumed to have equal variances. A difference in the mean slopes of sample grids located on moraines within Krinsley's Donjek, Snag, and Tchawsahmon glacial limits and within Muller's Ruby and St. Elias glacial limits would be rejected at a 0.05 significant level. No significant difference exists between any of these populations.

Source and Flow of Glaciers

The slope of the Mirror Creek glacial limit suggests that most of the glacier ice entered the Snag-Klutlan area from the southeast via the Donjek and Shakwak valleys, and then flowed northwest along the Shakwak Valley and north along the broad valleys dissecting the Kluane Plateau. Upon reaching the Wellesley Basin, the valley glaciers coalesced to form a large piedmont glacier. Tongues from this mass of ice moved into the head of Scottie Creek and down the White River to the mouth of the Donjek River. Mirror Creek glacial features along the Duke Depression between the Donjek and White Rivers suggest that the ice flowed northwest along the inner valley of the Duke Depression. The ice was probably joined by local ice flowing north out of the Icefield Ranges. Presumably, ice also flowed northwest along valleys within the Kluane and Nutzotin Ranges that parallel their axis.

The source of glacier ice during the Mirror Creek glaciation along the upper reaches of Beaver Creek is not clear; partly because the Mirror Creek glacial limit is not clearly marked in this vicinity, and partly because the glacial history of the Nutzotin Mountains in adjacent Alaska is unknown. Meltwater channels suggest that the ice surface sloped to the northwest south of Tchawschomon Lake. However, high-level meltwater channels along the upper reaches of Beaver Creek suggest that ice was overflowing into Beaver Creek valley through passes in the Nutzotin Mountains from the head of the White River and from ice accumulation areas in the eastern Wrangell Mountains of Alaska. Capps (1916) proposed similar glacial flow patterns during his early investigations of this area. Meltwater channels south of Gates Ridge suggest that the glacier in the Beaver Creek valley not only flowed parallel to the Creek but also flowed through a gap in the Nutzotin Ranges to the southeast of Gates Ridge to join the large piedmont glacier in the Wellesley Basin to the north.

The slope of the Macauley glacial limit also suggests that major glaciers entered the Snag-Klutlan area via the Shakwak and Donjek Valleys, and then flowed northwest along the inner valley of the Duke Depression and the Shakwak Valley. This ice was reinforced by ice flowing north out of the Icefield Ranges, namely the Klutlan Glacier, and by ice flowing east from Alaska parallel to the upper reaches of the White River. Glacier lobes from the Shakwak Valley flowed into the main gaps in its valley wall, e.g. northward along the Donjek River, up Wolf Creek, and up Edith Creek. Glacier flow in the gap between the Kluane and Nutzotin Ranges occupied by the White River appears to have been southward during the Macauley maximum. At the junction of the Shakwak Valley and the White River, the glacier flowing northwest along the Shakwak Valley was split into glaciers that flowed through the gaps between the Nutzotin Ranges and isolated western hills of the Yukon Plateau. The main glacier that paralleled the White River spilled out as a large piedmont glacier in the central Wellesley basin. Lobes from this mass of glacier ice advanced up Beaver Creek to a point north of Macauley Ridge, down the White River, and east past Wellesley Lake where it coalesced with a glacier that was advancing down the Donjek River Valley. Drumlins and fluted bedrock on most of the main valley bottoms conform with the flow patterns inferred from the glacial limits; from this it is implied that no major changes in direction of flow occurred during deglaciation.

A very small amount of ice was added to the through-flowing valley glaciers by local valley glaciers that developed in the Kluane and Nutzotin Ranges during both glaciations, as indicated by cirques and lateral moraines in these mountains (Rampton 1969). During the Mirror Creek glaciation 3 or 4 very small valley glaciers between Wolf Creek and the Donjek River may also have joined the main trunk glaciers in that area. Terminal moraines in some of the valleys in the Kluane and Nutzotin Ranges indicate that not all valley glaciers joined the trunk glaciers during the Macauley glaciation.

Chronology

No ^{14}C dates have been obtained from materials stratigraphically beneath the Mirror Creek deposits, and ^{14}C dates from sediments overlying Mirror Creek deposits are beyond the range of ^{14}C dating (Table 1). The absence of deep weathering profiles on the Mirror Creek deposits and the presence of thick oxidation zones on other subsurface glacial deposits in the area and nearby areas (e.g. near Kluane Lake; Denton and Stuiver 1967) suggest that the Mirror Creek deposits have not experienced an interglacial interval and are early Wisconsin in age. Alternatively, weathering zones could have been removed from the surface of the Mirror Creek deposits by creep and solifluction.

Dates on materials below Macauley drift and in the lower Macauley deposits are beyond the range of ^{14}C dating (Table 2). The one exception is GSC-732 at

TABLE 1. ^{14}C dates from sediments overlying Mirror Creek deposits.

Sample Number	*Locality (Fig. 4)*	*Material and stratigraphic position*	*^{14}C age (years B.P.)*
GSC-959[1]	1	Peat and organic silt from top of 6.0+ ft. of silt that contains an abundance of peat lenses, especially near its top, and one ice wedge cast. Unit underlies 2.4 ft. of inorganic silt (loess) having a thin volcanic ash near its base	>38,000
GSC-496	2	Organic detritus from base of 12.6 ft. of silts and organic silts, which are overlain by 5.8 ft. of peat and underlain by pebbly silt, in bog	>36,000
GSC-960[1]	3	Peat from near base of 54+ ft. of organic silt, which overlies 29 ft. of gravel	>38,000

[1]Dates that have been reported in Lowdon and Blake (1970)

TABLE 2. ^{14}C dates related to the Macauley glaciation.

Sample Number	*Locality (Fig. 4)*	*Material and stratigraphic position*	^{14}C *age (years B.P.)*
A. ^{14}C dates on organic materials underlying Macauley drift and within the lower Macauley glacial deposits.			
GSC-919[1]	4	Organic clay from base of glaciolacustrine and glaciofluvial deposits (Table 5)	>35,000
GSC-962[1]	4	Twigs from glaciofluvial deposits (Table 5)	>40,000
GSC-799[1]	5	Peat from thin layer of peat and volcanic ash, which underlies 57 ft. of till and overlies 26+ ft. of till	>39,000
GSC-924[1]	6	Silty peat from base of 3 ft. of peat, which underlies 120 ft. of alluvium and 0-6 ft. of till, and overlies 2 ft. of till. Peat contains a thin layer of involuted volcanic ash	>41,000
GSC-552[1]	7	Organic silts from contorted sands and organic silts along unconformity between underlying gravel and overlying till, which contains an abundance of local angular clasts near its base. Till is 30 ft. thick and capped by 11 ft. of gravel.	>42,000
GSC-732[1]	7	Wood from partially cemented mud-flow deposit containing layers of woody and silty peat. Mud-flow deposit underlies slope deposit consisting mainly of slumped grey drift.	48,000 ± 1,300
B. ^{14}C dates from organic sediments directly overlying Macauley drift			
GSC-581[2]	8	Sedge peat from base of 12 ft. of peat, which overlies pebbly sand	4470 ± 150
GSC-580[2]	8	Gyttja and organic detritus from base of 3.2 ft. of organic lacustrine deposits, which overlie pebbly sand	4550 ± 150
GSC-544[2]	9	Organic detritus from base of 9 ft. of lacustrine deposits, which overlie gravel	6200 ± 150
GSC-777[1]	7	Wood from base of 11 ft. of woody peat, which overlies 90 ft. of gravel and till	7760 ± 170
GSC-776[1]	10	Lens of organic silt in upper part of till, which underlies 5.5 ft. of peat and volcanic lapilli. Till is 10 ft. thick and overlies 5+ ft. of gravel.	9360 ± 150
GSC-714[1]	7	Organic silt from base of 2 ft. of pebbly organic silt, which underlies 10 ft. of woody peat, and overlies 37+ ft. of gravel and till	11,000 ± 160
GSC-495[2]	11	Organic silt from base of 16 ft. of organic lacustrine deposits, which overlie laminated silt and sand	13,660 ± 180

[1]Dates that have been reported in Lowdon and Blake (1970)
[2]Dates that have been reported in Lowdon *et al.* (1967)

48,000 ± 1,300 B.P. However, this date may be a result of modern contamination of the analysed wood sample because it had been penetrated by modern rootlets. The log was dissected and the pieces scraped clean, but some rootlets may not have been removed. With the exception of the dates obtained from the Wolverine Creek section (Fig. 2) some time may have elapsed between the deposition of most dated materials and the beginning of the Macauley glaciation. At Wolverine Creek, the sequence of lacustrine and fluvial sediments (Table 3), from which ^{14}C dates GSC-919 and GSC-962 were obtained, represents deposition in front of a glacier advancing west along the Duke Depression. If only one till overlies these units and if it is Macauley in age as interpreted in Table 3, GSC-919 and GSC-962 should have given a close maximal estimate of the beginning of the Macauley glaciation. However, because ^{14}C date GSC-962 was greater than 40,000, it can only be stated that the Macauley glaciation began more than 40,000 years ago.

The Macauley glaciation probably culminated shortly before 13,500 B.P. A date of 13,600 ± 180 B.P. (Table 2) was obtained on the basal part of lacustrine sediments directly overlying Macauley deposits near the Macauley glacial limit (Fig. 4). The flatness of the area on which the lake is located suggests that the Macauley glacier covering this area had a relatively thin debris cover and melted rapidly at the end of the Macauley glaciation. A date of 13,500 ± 300 B.P. (GSC-1110) was obtained on organic silts overlying 2.5 feet of grey silts in a small lake west of Macauley Ridge (Locality 2, Figs. 2 and 5). Loess that blankets much of the area adjacent to Macauley outwash deposits west of Macauley Ridge is approximately the same thickness (Rampton 1969). This blanket of loess was deposited when the Macauley glaciers were near their maximum and outwash was being actively deposited on the plains west of Macauley Ridge. Therefore the top of the loess represents the retreat of the Macauley glaciers from near their maximum position.

TABLE 3. Wolverine Creek Section (locality 4, Fig. 2).

Unit	*Description*	*Thickness (ft.)*
1	Covered; upper 20 ft. appear to be gravel and lower 30 ft. appear to be till	50
2	Till, dark olive grey	30
3	Gravel, coarse; partially covered	15
4	Covered; probably gravel; possibly till	30
5	Sand and gravel, grey	35
6	Sand; fine sand is dark brown; coarse sand is dark greyish brown; cross-bedded; twigs and peat present; GSC-962 obtained from twigs and peat	20
7	Covered; probably similar to units 6 and 8	25
8	Clay, grey	5
9	Clay, organic, dark grey to black; contains shells, GSC-919 obtained from unit	2
10	Clay, silty, grey — base of Macauley glacial deposits —	0.5
11	Gravel, orange	0.25
12	Gravel, grey	2-5
13	Till, grey	10
14	Covered to creek level; colluvium suggests oxidized gravel and till underneath cover	70

Carbon-14 dates from sediments directly overlying Macauley drift and its correlatives of 11,000 ± 160 B.P. (GSC-714) from near the White River bridge, 10,900 ± 160 B.P. and 11,270 ± 200 B.P. from near the head of the White River (Stuiver 1969), 9,360 ± 150 B.P. (GSC-776) from near the Klutlan Glacier, and 12,500 ± 200 B.P. from near Kluane Lake (Denton and Stuiver 1967) suggest that deglaciation was rapid. Younger dates of 6,200 ± 150 B.P. (GSC-544), 4,500 ± 150 B.P. (GSC-580), and 4,470 ± 140 B.P. (GSC-581), obtained from lakes on Macauley drift, more closely relate to melting of buried ice blocks or to some later nonglacial events. The rugged spatulate-shaped moraine near the Natazhat Glacier is the only evidence of a major still-stand or readvance during the Macauley deglaciation. Other moraines that Krinsley (1965) has mapped within the Macauley glacial limit appear to be morainic areas isolated by melt-water activity during deglaciation and do not indicate glacial readvances.

On a stratigraphic basis, the Mirror Creek glaciation should probably be considered as an early stage of the Macauley glaciation, especially if 1) the base of the Macauley glacial deposits within the Macauley glacial limit marks the beginning of early Wisconsin time and 2) the Mirror Creek glaciation occurred in early Wisconsin time. The Mirror Creek glaciers may have retreated only a short distance behind the Macauley glacial limit following the Mirror Creek glaciation, and both glaciations may be represented by one till sheet within much of the area outlined by the Macauley glacial limit. However, the great difference in the morphology and age of the Mirror Creek and Macauley land forms, and the uncertainties in the age of the Mirror Creek glaciation and the beginning of the Macauley glaciation warrant giving them equal status at present.

Correlations

The Macauley glaciation is the correlative of the Donnelly Glaciation of the northeastern Alaska Ranges (Péwé *et al.* 1965), the McConnell glaciation of the central Yukon (Bostock 1966; Hughes 1968, Hughes *et al.* 1969), and the other glaciations throughout Alaska and the Yukon that culminated at about 13,500 B.P., e.g. the Itkillik glaciation of the Brooks Range (Porter 1964), and late Pleistocene glaciation of the Ogilvie Mountains (Terasmae and Hughes 1966; Vernon and Hughes 1966). Frontal slopes of the Donnelly Glaciation are reported to average 13 per cent (7.5°; Péwé *et al.* 1965). This value is somewhat lower than most of the average frontal slopes measured on Macauley moraines (14°, 15°, 16°, 33°).

The Mirror Greek glaciation is probably the correlative of the Delta Glaciation of the northeastern Alaska Ranges (Péwé *et al.* 1965) and the Reid glaciation of the central Yukon (Bostock 1966; Hughes 1968; Hughes *et al.* 1969). All moraines that are attributed to these glaciations have positions that are similar relative to later more positively correlated moraines. However, the average frontal slope of Delta moraines in the northeastern Alaska Ranges is 6.5 per cent (3.7°; Péwé *et al.* 1965) and is much lower than the average frontal slope at one locality on the Mirror Creek moraines (21.6°). However, Holmes (1965) has found that some Delta moraines have frontal slopes of 20 per cent (11.4°). Also, a more extensive sampling would probably show that 21.6° is not representative of Mirror Creek frontal slopes. The weathering profile on Mirror Creek drift is not as thick as that reported on the Delta drift, but this may be due to slightly different environments.

A special note should be made of possible correlations of the glacial history of the Snag-Klutlan area with that of an area near the southern end of Kluane Lake (Fig. 1) as part of glacier ice flowing into the Snag-Klutlan area during most glaciations probably came via the trench occupied by Kluane Lake. Denton and Stuiver (1967) have interpreted the glacial history for the southern end of Kluane Lake and have outlined the following glacial chronology, from youngest to oldest:

Neoglaciation — start approximately 2,640 B.P.
Slims nonglacial interval
Kluane Glaciation — end *c.* 12,500 – 9,780 B.P.
— start 30,100 B.P.
Boutellier nonglacial interval
Icefield Glaciation — end *c.* 37,700 B.P.
— start >49,000 B.P.
Silver nonglacial interval
Shakwak Glaciation — >49,000 B.P.

The maximum phase of the Macauley glaciation is the correlative of the Kluane Glaciation. However, earlier phases of the Macauley glaciation, during which lower parts of its drift were being deposited, may be correlative with the Icefield Glaciation. Indeed, if the Mirror Creek glaciation is early Wisconsin in age, and if its drift is indistinguishable from the Macauley drift within the Macauley glacial limit, it may also be the equivalent of an early phase of the Icefield Glaciation. Although the Mirror Creek glaciation definitely terminated before the Icefield glaciers completely abandoned the southern Kluane Lake area, local stagnation during the Icefield Glaciation had begun in the southern Kluane Lake area before 49,000 B.P. (Denton and Stuiver 1967). Alternatively, if the Mirror Creek glaciation is pre-Wisconsin in age, it is probably the correlative of the Shakwak Glaciation, even though the upper part of the Shakwak drift contains a thick oxidation zone.

Uncorrelated nonglacial sediments and drift that underlie the Macauley drift in most localities are probably the correlatives of deposits attributed to the Silver nonglacial interval and the Shakwak Glaciation by Denton and Stuiver, even though the drift underlying the Macauley drift is not as deeply weathered as the Shakwak drift. Carbon-14 dates from nonglacial sediments underlying and within basal Macauley drift and from the base of the Icefield drift suggest that the interval when the sediments underlying the Macauley drift were deposited does not correlate with the Boutellier nonglacial interval and Icefield Glaciation.

Evidence of major deglaciation in the Snag-Klutlan area during Denton and Stuiver's Boutellier nonglacial interval is lacking, even though the palynologic record of a core from near Niggerhead Creek suggests that some climatic warming occurred in the Snag-Klutlan area during this interval (Rampton 1969). This apparent paradox has two possible explanations: 1) Much of the Snag-Klutlan area was deglaciated during the Boutellier nonglacial interval, but datable nonglacial deposits have not been preserved or incorporated into the base of the Macauley drift. If this is true, an unconformity has been overlooked at the exposure on Wolverine Creek where glaciolacustrine and glaciofluvial deposits have been dated at >40,000 B.P. and assigned to the Macauley glaciation; 2) Deglaciation during the Boutellier nonglacial interval was minimal in the Snag-Klutlan area, i.e. glaciers were withdrawn inside the Macauley glacial limit, but not to the extent that the areas near the White River bridge and the Duke Depression were deglaciated. The latter explanation is supported by the fact that ^{14}C dates obtained from 4 localities on materials from directly below or from the base of the upper drift within the Macauley glacial limit all predate the Boutellier nonglacial interval. It is noteworthy that no dates between 38,000 B.P. and 30,000 B.P. have been reported from interstadial or interglacial sediments underlying till in central and northern Alaska and the Yukon. Moreover, Ferrians and Nichols (1965) do not believe that glaciers retreated enough in the Chugach Mountains during this time interval to allow the drainage of an ice-dammed lake in the Copper River basin, which lies to the north of the mountains.

If only minor deglaciation occurred in the Snag-Klutlan area during the Boutellier nonglacial interval, glacier ice had to be maintained there throughout the interval without receiving any ice along the Shakwak Valley from the Kluane Lake area. This is a possibility, as climatic warming may have been less intense in the Snag-Klutlan area during the Boutellier nonglacial interval than in the southern Kluane Lake area. Kluane Lake is closer and less sheltered from the maritime influence of the Pacific Ocean than is the Snag-Klutlan area (Fig. 1). Moreover, the southern Icefield Ranges and coast Mountains, which were the sources of late-Pleistocene glaciers that occupied the Shakwak Valley near Kluane Lake, would have been subjected to greater warming because they are closer to the Pacific Ocean than the northern Icefield Ranges, which are the source of the Russell Glacier, Klutlan Glacier, and the glaciers feeding the upper Donjek River valley.

CONCLUSIONS

1) Meltwater channels, terminal moraines, lateral moraines, and the frontal slopes of disintegration moraines delineate the maximum extent of two late Pleistocene glaciations in the Snag-Klutlan area, the outer limit being formed during the Mirror Creek glaciation, and the inner limit being formed during the Macauley glaciation. The outer limit of erratics and patches of glacial drift correspond with the Mirror Creek glacial limit in the area north of the Shakwak Valley.

2) Moraines within each glacial limit have distinctive geomorphic characteristics, which reflect their age. The average slopes on Macauley non-oriented hummocky moraines are steeper than those on Mirror Creek non-oriented hummocky moraines.

3) Slope measurements on moraines within the Macauley glacial limit indicate that the morphologic and chronologic differentiation of these moraines proposed by other investigators is invalid.

4) Most glacier ice flowed into the area from the southeast, and continued northwest via trunk valleys within the area during both glaciations. Some ice flowed north directly out of the Icefield Ranges and east from Alaska.

5) Mirror Creek glacial deposits do not appear to have experienced an interglacial interval, and the Mirror Creek glaciation is most probably early Wisconsin in age.

6) The Macauley glaciation seems to have begun more than 40,000 years ago.

Following its culmination probably shortly before 13,500 B.P., deglaciation of the region was very rapid.

7) Very little area within the Macauley glacial limit seems to have been deglaciated between the Mirror Creek and Macauley glaciations. Unconformities representing nonglacial intervals between the two glaciations cannot be positively identified within the Macauley glacial limit.

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