PLEISTOCENE GEOLOGY OF THE SOUTH-WEST YUKON TERRITORY, CANADA

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Abstract. A morainal sequence in south-west Yukon Territory, Canada, records at least four major, successively less extensive glaciations from ice fields in the St. Elias Mountains south of the glaciated area.

The Nisling Moraine flanks the Klondike Plateau in a belt 1 km. wide to an altitude of 1,040 m., 12 km. north-east of Snag. The northernmost lobe of this moraine terminates at the junction of the Donjek and White Rivers, 120 km. from the nearest source of ice, Klutlan Glacier. 11 km. north-east of Snag, the prominent front of the Donjek Moraine lies 180 m. below the front of the Nisling Moraine. The northernmost lobe of the Donjek Moraine terminates 106 km. north of Klutlan Glacier and occupies the lower courses of canyons cut into the Nisling Moraine. The front of the Snag Moraine crosses the White River valley 210 m. below the front of the Donjek Moraine and 96 km. north of Klutlan Glacier. The Tchawsahmon Moraine, 38 km. north-west of Klutlan Glacier, consists of a series of concentric ridges, the oldest of which impounded Tchawsahmon Lake.

Provisional correlations suggest that the Nisling Moraine is pre-Illinoian; the Donjek, Illinoian; the Snag, pre-classical Wisconsin; and the Tchawsahmon, classical Wisconsin.

Résumé. *Pleistocène geologie du Territorie du Yukon du sud-ouest, Canada.* Dans une succession de moraines dans le sud-ouest du Territorie du Yukon (Canada), on reconnait au moins quatre stades glaciaires principaux, mais de moins en moins étendus, à partir des champs de neige des Monts St. Elias, au sud de la zone étudiée.

La Nisling Moraine forme une zone de 1 km de large le long du Klondike Plateau, jusqu'à 1040 m d'altitude, à 12 km au nord-est de Snag. Le lobe extrême-nord de cette moraine se termine au confluent des rivières Donjek et White, à 120 km de la source de glace la plus proche, le Klutlan Glacier. A 11 km au nord-est de Snag, le front très marqué de la Donjek Moraine se trouve à 180 m en-dessous du front de la Nisling Moraine. L'extension vers le nord de la Donjek Moraine se termine à 106 km du Klutlan Glacier et occupe les cours inférieurs de canyons creusés dans la Nisling Moraine. Le front de la Snag Moraine coupe la vallée de la White River 210 m en-dessous du front de la Donjek Moraine et à 96 km au nord de Klutlan Glacier. La Tchawsahmon Moraine, à 38 km au nord-ouest de Klutlan Glacier, est formée d'une série de crêtes concentriques dont la plus ancienne retient les eaux du lac Tchawsahmon.

Une étude préliminaire de leurs corrélations semble indiquer que la Nisling Moraine date d'avant l'Illinois, la Donjek de l'Illinois, la Snag d'avant le Wisconsin classique et la Tchawsahmon du Wisconsin classique.

Zusammenfassung. *Pleistozäne Geologie des südwestlichen Yukon-Territorium, Canada.* Eine Schargestaffelter Moränen im südwestlichen Yukon Territorium, Canada, lässt die Abfolge von mindestens vier grösseren Vergletscherungen erkennen, die in sukzessiv abnehmender Ausdehnung von den heutigen Firneisfeldern in den St. Elias Mountains nach Süden hin ausgingen.

Die Nisling Moräne flankiert das Klondike-Plateau mit einem etwa 1 km breiten Gürtel bis in 1040 m Seehöhe, 12 km nordöstlich von Snag. Ihr nördlichster Ausläufer endet am Zusammenfluss von Donjek und White River, rund 120 km vom nächsten Eisnährgebiet, dem Klutlan Gletscher, entfernt. 11 km nordöstlich von Snag und 180 m unterhalb der Nisling Endmoräne befindet sich die Stirn der Donjek-Moräne, deren nördlichster Ausläufer Rand 106 km nördlich des Klutlan-Gletschers liegt und welche die Unterläufe von Canyons einnimmt, die in die Nisling-Moräne eingeschnitten sind. Die Stirn der Snag-Moräne kreuzt das White-River-Tal 210 m unterhalb des Donjek-Moränenzuges, ca. 96 km nördlich des Klutlan-Gletschers. Die Tchawsahmon-Moräne, 38 km nordwestlich des Klutlan-Gletschers, besteht aus einer Serie von konzentrischen Rücken, deren ältester den Tchawsahmon Lake einschliesst.

Vorläufige Zuordnungen deuten darauf hin, dass die Nisling-Moräne dem Pre-Illinoian, die Donjek-Moräne dem Illinoian und die Snag-Moräne dem Pre-Classical Wisconsin entspricht, während die Tchawsahmon-Moränenserie mit der klassischen Wisconsin-Vereisung parallelisiert werden kann.

Location

The south-west Yukon Territory referred to in this paper covers an area of 7,240 km.^{2} and extends eastward from the United States–Canadian border at long. 141° to 139°15′ W., and southward from lat. 62°40′ to 61°35′ N. (Fig. 1). This area is traversed from north-west to south-east by the Alaska Highway. A narrow road connects the Alaska Highway with the unsurfaced airfield at Snag (Fig. 2).

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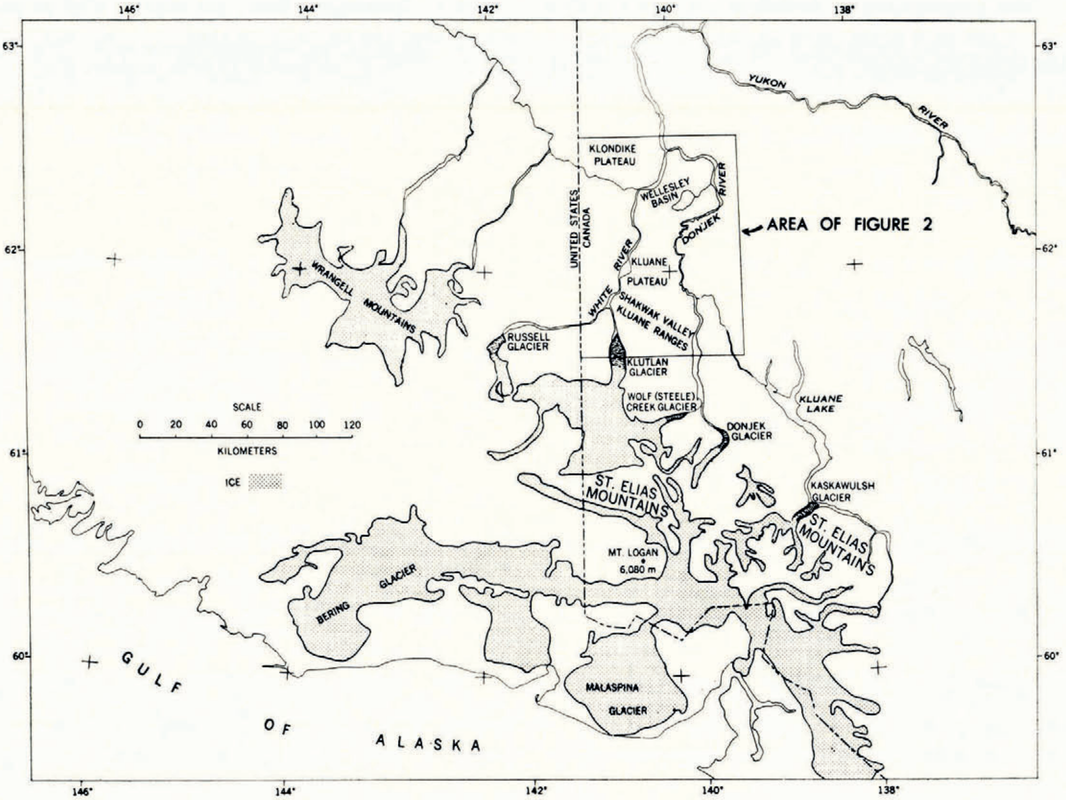

Fig. 1. Index map of the south-west Yukon Territory, Canada

Field Work

Geologic mapping began in June 1962 as part of a joint United States–Canadian terrain study of the south-west Yukon Territory. Helicopters were used for 6 weeks to visit many otherwise inaccessible locations. Field observations have been augmented through the use of aerial photographs, pebble counts and dendrochronology.

Previous Studies

The first observations on glaciation of the area were made by Hayes (1892, p. 157) who recorded "boulder clay" on the divide between the Nisling and Kluane (Kluanta) Rivers and correctly assumed that he was near the limit of glaciation. In 1898 Brooks (1900, p. 474), on a trip up the White River, observed the gorge of this river below the Donjek (Klotassin), and the glaciated, broadened White River valley above. McConnell (1906) explored the headwaters of the White River in 1905. In 1913 Cairnes (1915[b], p. 105) explored and mapped the surficial deposits of the "Upper White River district" and recorded the upper limits at which glacial erratics were observed.

Brooks (1906, pl. 22), Capps (1910, p. 39), and Tarr and Martin (1914, map 1) compiled maps of the "northern limit of former glaciation". These maps were based on scattered observations.

Sharp (1951, fig. 2) mapped moraines of Wisconsin age in the valley of Steele (Wolf) Creek Glacier and summarized the local glacial chronology (Table I). The most complete

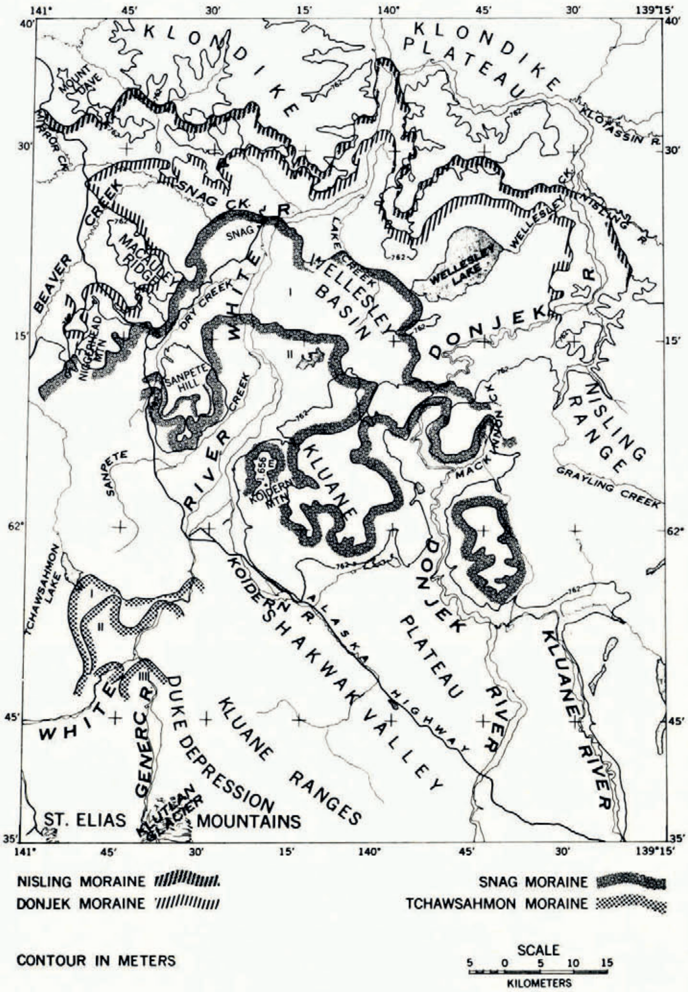

Fig. 2. Map of south-west Yukon Territory, Canada, showing moraine systems

observations to date have been made by Bostock (1948, 1952); his geologic map of the north-west Shakwak Valley (Bostock, 1952, map 1012A) includes the limits of the "last major glaciation", based on the absence of glacial erratics above certain altitudes.

General Setting

The south-west Yukon Territory is dominated by the St. Elias Mountains whose peaks are almost 6,080 m. above sea-level within 80 km. north of the Gulf of Alaska (Fig. 1). Most of the moisture-laden air from the gulf is trapped by the mountains and this huge source of precipitation nourishes extensive ice fields drained by numerous glaciers. The snow line fronting on the Gulf of Alaska has been recorded at 610 m. (Hayes, 1892, p. 153), 670 m. (Miller, 1961, table 1, p. 836) and 700 m. (Flint, [1947], p. 55). North-east of the St. Elias Mountains, within the precipitation shadow, the snow line has been recorded at 1,920 m. at Russell Glacier (Hayes, 1892, p. 153 (author's interpretation)), 2,590 m. at Steele (Wolf)

Creek Glacier (Sharp, 1951, p. 98) and 1,828 m. at Kaskawulsh Glacier (personal communication from M. M. Miller). Today, as in the Pleistocene epoch, most of the ice accumulates and drains southward, where it either discharges into the sea along broad calving ice cliffs or is slowly wasted in huge piedmont glaciers such as the Malaspina and Bering. During the major glacial expansions of the Pleistocene, the coastal glaciers spilled seaward and their huge floating fronts probably were rapidly eroded by waves generated by winds acting through the immense fetch of the Gulf of Alaska. The unstable glacier fronts and the rapid dispersion of morainic debris through great ocean depths were not conducive to the establishment of submerged morainal ridges that might be identified as boundaries on hydrographic charts. Only the most recent fringing moraines on the narrow coastal strips along the gulf can be identified and dated (Plafker and Miller, 1958). Less dramatic and less extensive glacial advances have occurred on the north-east slope of the St. Elias Mountains; the deposits of these glaciations are generally intact in broad valleys where low precipitation and permafrost have contributed to their preservation.

The principal glaciers of the north-east slope of the St. Elias Mountains are Russell, Klutlan, Steele (Wolf) Creek, Donjek and Kaskawulsh. Russell Glacier, the source of the White River, terminates 45 km. west of the Canadian–Alaskan border. Kaskawulsh Glacier terminates 19 km. from Kluane Lake, whose waters now cover much of the glacial deposits of the previously expanded glacier. The largest glacier, Klutlan, is drained by the Generc River and terminates 21 km. from the confluence of the White and the Generc Rivers. Steele (Wolf) Creek and Donjek Glaciers are the principal sources of the Donjek River and both terminate 50 km. south of the Donjek River bridge.

The two major streams, the White and Donjek Rivers, flow through all of the physiographic units in the area (Bostock, 1948) except the Nisling Range (Fig. 2). The Donjek River, whose tributaries include the Kluane, Nisling and Klotassin Rivers, joins the White River 30 km. north-east of Snag (Fig. 3, D). The White River enters the Yukon River 105 km. below the mouth of the Donjek River.

Nisling Moraine

The oldest drift in the south-west Yukon Territory forms a lateral moraine which can be traced on aerial photographs from the United States border north of Mirror Creek eastward to the White River valley, north-east of Snag, at an altitude of 1,040 m. (Fig. 3, A), then northward to Ten Mile Creek whose drainage was impounded during deposition of the moraine (Fig. 3, B). Strand lines of "Ten Mile Lake" are preserved along the lower south slope of "Ten Mile Valley". Ten Mile Creek is diverted 1 km. northward around the moraine where it enters the White River valley. The moraine lobe terminates northward 3·5 km. below the mouth of the Donjek River. Along the east side of the White River valley above the mouth of the Donjek River the moraine has impounded or diverted the tributary streams. North of Wellesley Lake the moraine decreases in altitude from 1,040 m. to 550 m. at the Nisling River. This old moraine, here named the *Nisling Moraine*, rises to about 1,220 m. along the west flank of the Nisling Range (Fig. 2).

Till of the Nisling Moraine, containing striated boulders and pebbles of greenstone, andesite, granite, limestone, amygdaloidal basalt, diabase, hornblende-gneiss and schist, is exposed in a gravel pit north of the Alaska Highway and 1·6 km. from Mirror Creek. The till is a silty and sandy pebble gravel mantled with 30 cm. of loess. Thick exposures of till were not observed and numerous bedrock outcrops in the vicinity suggest that the till cover is generally thin. There was no evidence of deep weathering.

The Nisling Moraine was deposited by ice from the greatly expanded glaciers of the St. Elias Mountains; the ice spilled through the Kluane Ranges into the Shakwak Valley and then northward through the Kluane Plateau into the Wellesley Basin. The principal ice streams from Beaver Creek, White River and Donjek River coalesced in a broad lobe which was confined against the south flank of the Klondike Plateau. The broad valley 16 km. west of Mount Dave was blocked by ice and the impounded drainage formed a lake, the level of which may have risen to an altitude of 762 m. (Fig. 2). A large ice tongue spread northward 3·5 km. beyond the mouth of Donjek River. The east-flowing tributaries of the White River were diverted westward into the Tanana drainage and large lakes were impounded in the

Fig. 3. Aerial view of the Klondike Plateau and White River Valley looking north-east from an altitude of 5,487 m. over the Wellesley Basin. A. Nisling Moraine; B. Nisling Moraine at mouth of Ten Mile Creek valley; C. Donjek Moraine; D. Junction of Donjek and White Rivers. (Photograph by U.S.A.F., 1941, R-24, R74)

adjacent valleys of the Klondike Plateau. The eastern tributaries of the Donjek River (which probably flowed north-west and into Lake Creek) were impounded and their rising lakes to the south gave rise to north-east outlets ahead of the advancing ice. Water from Mackinnon Creek first spilled north into Wellesley Basin, then north-east into Grayling Creek. By these diversions the water of Donjek River was moved north-eastward to the Nisling River. An extensive area at the mouth of Klotassin River is currently occupied by lakes, ponds and bogs. The position of this poorly drained area suggests that the mouth of the Donjek was dammed sufficiently during the Nisling maximum to impound the drainage and to form a lake which was, no doubt, short-lived.

Donjek Moraine

The second oldest drift in the area forms an extensive moraine 2 km. north-east of Snag. The prominent front of this moraine, 11 km. north-east of Snag, lies 180 m. below the front of the Nisling Moraine (Fig. 3, C). The lower younger moraine can be traced north-westward around the east flank of Macauley Ridge from an altitude of 914 m. to a terminal position at the Alaska Highway at an altitude of 610 m. (Fig. 2). The moraine extends eastward to the White River valley at an altitude of 790 m. and then terminates 8·5 km. above the mouth of the Donjek River. From the south shoulder of the Klondike Plateau, the moraine, here named the *Donjek Moraine*, extends eastward in a broad belt around Wellesley Lake to the Donjek River at an altitude of 610 m. On the west flank of the Nisling Range the Donjek Moraine is at an altitude of 730 m.

Till of the Donjek Moraine, containing striated boulders and pebbles of granite, limestone, hornblende-gneiss, amygdaloidal basalt, quartzite and andesite, is exposed 12 km. north-east of Snag. It is mantled with 31 cm. of loess. The soil is leached to a depth of 34 cm., and the low temperature (2° C.) of the deepest material (90 cm.) suggests that permafrost is at shallow depth.

The Donjek Moraine occupies the lower courses of canyons which had been cut into Nisling till in the White River valley. These relations suggest a major retreat of the Nisling ice southward, followed by a long period of erosion prior to the advance of the Donjek ice to the mouth of Ten Mile Creek. The subdued rounded form of the Nisling Moraine contrasts sharply with the steep hilly terrain of the Donjek Moraine and further suggests a considerable intervening period of interglacial erosion. Bostock (1936, p. 9–10, 48–49, 58) described a blue boulder clay first reported by Cairnes (1915[a], p. 25) at Nansen Creek, the head of Nisling River. This boulder clay is well beyond the generally recognized glacial limit in the Carmacks area. It is overlain by well-oxidized sand and gravel, which suggests a long interval of inter-glacial weathering. This boulder clay may be contemporaneous with the Nisling till. The long interval of time required for oxidation of the sand and gravel above the boulder clay may be equivalent, at least in part, to the Nisling-Donjek interglacial stage.

During the Donjek glaciation the Wellesley Basin was once more occupied by ice, which, however, was less extensive than the ice of the previous glaciation. Niggerhead Mountain (Fig. 4, B) and Macauley Ridge stood above the ice and thick glacial outwash was deposited on the large previously glaciated area of Beaver Creek Flats. Drill records at Beaver Creek indicate that the area is underlain by a minimum of 43 m. of sand and gravel. As the Donjek ice retreated, its east marginal drainage sought lower levels until the present channel of the Donjek River became stabilized south-east of Wellesley Lake.

Snag Moraine

The terminus of a conspicuous moraine crosses the White River valley at an altitude of 580 m., 210 m. below the front of the Donjek Moraine (Fig. 2). This post-Donjek moraine can be traced north-eastward from its prominent front east of Beaver Creek (Fig. 4, A) to the White River 3 km. north east of Snag, and then south-east to Wellesley Lake where it has impounded the lake behind a large till ridge. The moraine is traceable south-westward around a high hill and to a point where it crosses the Donjek River 12 km. south of Wellesley Lake. This moraine, here named the *Snag Moraine*, diverts Snag Creek 5·5 km. north-east to form an elbow in the valley axis in the vicinity of Snag. This diversion suggests a glacial advance of at least 5·5 km. The northern tributaries of Lake Creek that were diverted north-eastward and the push moraine impounding Wellesley Lake also suggest glacial advance. The Snag Moraine is only slightly rougher than the Donjek Moraine, but the drainage system of the Snag Moraine is less perfectly developed and its loessial mantle is thinner and less weathered than those equivalent features of the Donjek Moraine.

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Adjacent to Snag Road 15 km. south of Snag, an exposure of Snag till containing striated boulders up to 2 m. in cross-section and pebbles of granite, greenstone, hornblende-gneiss, amygdaloidal basalt, quartzite and andesite is mantled with 20 cm. of loess. The soil is oxidized to a depth of 25 cm. and permafrost is present locally 32 cm. below the ground surface.

Fig. 4. Aerial view of the prominent front of the Snag Moraine east of Beaver Creek, looking north-east from an altitude of 5,334 m. A. Snag Moraine; B. Niggerhead Mountain; C. Beaver Creek. (Photograph by U.S.A.F., 1941, R-20, R75)

During the Snag glaciation the lower part of Wellesley Basin was filled with ice. The lower Snag Creek drainage which was established following the retreat of the north-west lobe of Donjek ice was diverted north-eastward and temporarily impounded 2 km. north of Snag. Wellesley Lake, which had been girdled by the Donjek Moraine and which had drained into Lake Creek, was then impounded from the west.

The thickness of the ice mass during the Snag glaciation may be reconstructed by examining the ice gradients of a prominent morainal system whose terminus lies 12 km. behind the Snag front (Fig. 2). This moraine, which shows evidence of moderate pulsation in the form of push-moraine lobes at Sanpete Hill and evidence of impoundments in the Kluane Plateau at an altitude of 1,220 m., is considered to be a recessional moraine deposited during the general withdrawal of Snag ice. It is the freshest, highest and best delineated moraine in the Kluane Plateau. From the White River terminus of this recessional moraine, at an altitude of 610 m., to its position at Koidern Mountain 25 km. to the south the moraine rises to an altitude of 1,370 m. The ice gradient at the time of deposition was 30 m./km. If an ice gradient of 25 m./km. corresponds to the 40 km. distance from the terminus of the Snag Moraine, at an altitude of 580 m., to Koidern Mountain (1,656 m.), then the Snag ice reached to within 76 m. of the summit.

On the basis of this analysis it seems reasonable to assume that the Kluane Plateau, as well as most of the Kluane Ranges (2,292 m. maximum altitude in the study area), was overridden by ice during the Nisling and Donjek glaciations. Bostock (1952, p. 13), on the basis of the disappearance of glacial erratics, placed the upper limit of glaciation on Koidern Mountain at 1,400 m. Ground examination above this altitude corroborates the absence of erratics, but rock benches with reverse slopes (towards the mountain) are cut into the generally massive altered gabbro which forms the southern flank and marginal channels are sub-parallel to the slope. In addition, large boulders of altered gabbro are in isolated positions which would seem to preclude their transportation by an avalanche. Under conditions similar to those during the Nisling and Donjek glaciations of Koidern Mountain, erratics would be scarce in high ice fields where nunataks, if present, would contribute little debris to the slowly moving ice.

Tchawsahmon Moraine

A distinct moraine can be traced north from an altitude of 1,220 m. above the upper canyon of White River to Tchawsahmon Lake at 915 m. (Fig. 5, A). It flanks the Kluane Ranges to an altitude of 1,036 m. and terminates in the lower canyon of White River at an altitude of 731 m. (Fig. 2). This extremely fresh unweathered moraine impounds the south end of Tchawsahmon Lake and is named the *Tchawsahmon Moraine* (Tchawsahmon I). Closely associated with this prominent end moraine are two inner morainal loops (Tchawsahmon II and III) which lie 4 and 14 km. behind the Tchawsahmon terminus and 152 and 91 m., respectively, below its lateral position at upper White canyon. These two morainal loops are considered to represent minor glacial re-advances within the Tchawsahmon glaciation. The small morainal loops at the mouth of the upper White Canyon record a bifurcation of the Tchawsahmon lobe into distinct ice tongues of Russell Glacier and Klutlan Glacier. These moraines are considered to be contemporaneous on the basis of proximity, accordant levels, topographic expression and similar degree of erosion by headward-cutting streams. There is some topographic evidence that a fourth morainal loop (tentatively named Tchawsahmon IV and not mapped) crossed the Generc valley at an altitude of 823 m., approximately 12 km. from the present front of Klutlan Glacier.

Till containing coarse angular blocks of granite, and cobbles and pebbles of andesite, diabase, amygdaloidal basalt, limestone, chert, hornblendite, hornblende-gneiss and sandstone is mantled with 20 cm. of loess in cut banks at the south end of Tchawsahmon Lake. No leaching or oxidation of the soil was recognized. Permafrost lies 20 cm. below the surface.

Recent Glaciations

A morainal complex which has not been examined lies between the innermost Tchawsahmon moraine (Tchawsahmon IV) and the present front of Klutlan Glacier, a distance of 12 km. A large ablation moraine occupies the terminal 12 km. of Klutlan Glacier. This moraine is ice-cored and stagnant (Sharp, 1949, p. 293), as evidenced by the presence of collapse features, recently drained closed depressions and ice exposures. The low brush and small trees on this moraine contrast sharply with the adjacent mature spruce forest growing on an older moraine (possibly Tchawsahmon IV) which was truncated by the ice now stagnating beneath the ablation moraine. The mature spruce forest extends 10 km. up Klutlan valley. The forest must have developed when the natural timber line was higher and when the glacier was up-valley from the forest. This suggests that the front of Klutlan Glacier receded at least 10 km. behind its present position prior to its most recent advance. Sharp (1951, p. 105) made a similar observation in the Steele (Wolf) Creek valley and suggested that this recession may have coincided with the post-Wisconsin altithermal (xerothermic) period. McConnell (1906, p. 20) reported that in 1905 a ridge of fresh uncovered ice appeared to be overriding the ablation moraine in the upper central part of Klutlan Glacier.

Fig. 5. Aerial view of Tchawsahmon Moraine, looking south-west from an altitude of 5,130 m. A. Front of Tchawsahmon (I) Moraine at Tchawsahmon Lake; B. Moraine from Russell Glacier at the mouth of upper White Canyon, equivalent to Tchawsahmon III; C. Post-Snag valley moraines and tarn lake (1,400 m.) 4·5 km. west of lower White Canyon. (Photograph by U.S.A.F., 1941, R-20, L64)

At Kaskawulsh Glacier a composite end moraine at an altitude of 823 m. lies 150 m. up-valley and 81 m. below an older moraine covered with a mature spruce forest. The younger end moraine, which consists of three distinct zones, extends northward from the glacier in a belt 500 m. wide. It is separated from the present stagnating ice front by a drainage depression 600 m. wide. The stagnating ice front is mantled by a 500 m. wide unvegetated belt of ablation moraine. Nine cross-section samples from the composite end moraine were taken from the largest living trees in each of the three zones. Of the two species collected, balsam poplar (*Populus tacamahacca*) and white spruce (*Picea glauca*), the former was not sampled at the outermost zone. The innermost zone, closest to the stagnating ice, contains a morainal ridge 12 m.

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high and 100 m. wide at its base. The oldest tree growing at the protected base of the north slope was 21 yr. old. A second zone consists of a morainal ridge 12 m. high and 80 m. wide, which merges at its north base with a less well-defined hummocky moraine that occupies an additional width of 200 m. The oldest trees in both protected and exposed positions at either end of the second zone were 45 yr. old. Zone three consists of a morainal ridge 15 m. high and 120 m. wide at its base. Its oldest tree, growing at the protected base of the north slope, was 97 yr. old. Lemmon (unpublished data), who measured and graphed the tree-ring growth rates, found that the intervals of minimum growth culminated in 1897, 1917, 1937 and 1957. The oldest tree sampled started growing in 1865 at the protected north base of the outermost morainal ridge. If 25 yr. were required for the development of an ablation mantle of sufficient thickness to support the growth of conifers (Bray, 1964), then the outermost moraine was deposited by a glacial advance which culminated about 1840. The oldest tree in the second morainal zone started growing in 1917, 20 yr. after a nadir in the rate of tree growth. Zone two, therefore, was deposited by a glacial advance which culminated about 1897. The oldest tree on the innermost morainal ridge started growing in 1941, 24 yr. after the 1917 nadir in the rate of tree growth. Wood (personal communication) reported that the last advance of Kaskawulsh Glacier ended approximately in 1939. That year would represent the time at which the outermost ablation moraine ceased all forward movement and stagnation of the present ice front was initiated. This date would best correspond to the 1937 nadir of minimum growth. The 1957 period of minimum tree growth has not been recognized to date in terms of a specific physical manifestation of glacial pulsation.

Valley Glaciations

Four kilometers north of the Nisling Moraine, at the south-west base of Mount Dave, a roadcut exposes rock rubble of cobble and pebble size in a silty sandy matrix. The rocks consist of locally derived schist, quartzite, limestone and granite, some larger fragments of which are striated. The soil mantle is leached to a depth of 46 cm., which is the deepest leaching recorded in the area by the author. Examination of aerial photographs reveals that the unsorted material is part of a single lobate feature with a distinct front which heads in a wide valley occupied by an underfit stream. Two additional lobes are north-west and adjacent to the lobate feature; their valleys display gently rounded contours which suggest greatly modified cirque-like forms. At an altitude of 610 m. all three valley floors have a "step" which is about 300 m. wide and which slopes gently away from the steep base of Mount Dave at 640 m. The valleys are interpreted as old cirques that developed when the snow line was at an approximate altitude of 610 m. The depth of weathering of the soil, the presence of a single morainal loop and the proximal position of the cirques to the Nisling glacial front suggest that small glaciers occupied the south-west flank of Mount Dave during or at the culmination of the Nisling glaciation. Similar features north of the Nisling Moraine occur 5 km. north of Mount Dave and along the north slope of Donjek Valley 15 km. above its mouth.

Four discrete composite morainal ridges occupy a tributary valley 4·5 km. west of lower White canyon (Fig. 5, C). The highest (youngest) morainal ridge, behind which a tarn lake is impounded, is at an altitude of 1,400 m., an elevation below the level of the Snag ice. Therefore, these valley moraines are post-Snag. The cirque behind the youngest moraine is currently ice-free but it was cut into the mountain at a time when the snow line* was at an altitude of approximately 1,400 m. The distances between the morainal ridges from oldest to youngest are 200, 600 and 250 m., respectively, or a ratio of 4 : 12 : 5. The distances between the Tchawsahmon morainal loops from oldest to youngest are 4, 14 and 7 km., respectively.

* Based on the excavation of the cirque floor.

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Both moraine systems are post-Snag and their agreement in number and grouping of moraine ridges strongly suggests that they are contemporaneous.

There are no morainal ridges nor rock glaciers between the valley head and the tarn lake, nor is there evidence for any morainal development down-valley from the lowest (oldest) morainal ridge. The evidence suggests that after the retreat of the Snag ice there was another period of glacial advance during which time the Tchawsahmon basin was partly filled with ice and valley glaciers occupied the north slopes of the Kluane Ranges. At that time the local snow line was at an altitude of somewhat less than 1,400 m. During the last phase of the Tchawsahmon glacial advance the local snow line was at an altitude of approximately 1,400 m. There has been no post-Tchawsahmon glaciation of the Kluane Ranges within the study area.

Summary of Glacial Stratigraphy

Thick sections of the Nisling and Donjek tills have not been observed either together or separately, nor have deep-weathering profiles been found. The presence of permafrost at shallow depth and the low rate of precipitation during the current phase of interglacial erosion suggest that similar conditions were prevalent in previous periods of interglacial erosion. Permafrost prevents the downward movement of what little moisture is available in the area and may account for the lack of deep-weathering profiles. The following stratigraphy has of necessity been based primarily on topographic position, comparative morphology and erosional characteristics, and relationships of the moraine systems. Eight pebble counts of 100 or more pebbles each included 33 different rock types. Of these rock types, only hornblende-gneiss and amygdaloidal basalt were considered sufficiently restricted to the upper White Valley to use as indicators. These rocks diminish in the following whole-number ratios of their average lowest occurrence, from 9 to 6 to 4 to 1 from the Tchawsahmon to the Snag to the Donjek to the Nisling tills, respectively. These data suggest a longer interval of time between the deposition of the Nisling and Donjek Moraines than between the Donjek and Snag Moraines, and are of corroborative use in establishing the older glacial sequence. The deepest weathering profile observed in the soil mantle was 46 cm. in material considered to be contemporaneous with Nisling till. Leaching depth was 33 to 37 cm. in Donjek soil and 20 to 25 cm. in Snag soil. No leaching was observed in soil of Tchawsahmon age.

On the basis of the author's acquaintance with Cook Inlet glacial stratigraphy (Krinsley, 1952, p. 1272; 1953, p. 5) and Karlstrom's (1955, 1957, 1961) studies, a tentative correlation has been made between coastal Alaska and the Canadian Yukon (Table I).

The gross geomorphic relationships between the Caribou Hills and Eklutna Moraines of Cook Inlet are strikingly similar to those between the Nisling and Donjek Moraines in the south-west Yukon Territory. In both regions canyons cut in the old till were later filled in their lower courses by younger till. The older, rounded and modified moraine contrasts sharply with the steep, hilly terrain of the younger moraine. Morphological differences between the Eklutna and Knik, and the Donjek and Snag Moraines are less prominent, but the younger moraines are slightly rougher and their drainage systems are less perfectly developed. The Naptowne and Tchawsahmon Moraines show many similarities. In both cases the outermost moraine is sharp and well defined. At Tustumena Lake (Kenai Peninsula) as at Tchawsahmon Lake, the two outer moraines are close together, followed by a third morainal loop at a much greater distance from the outermost morainal belt. Capps (1916, p. 70–74) estimated that Russell Glacier had not advanced beyond an undisturbed peat bluff within 13 km. of the present terminus of the glacier. On the basis of his estimated rate of peat accumulation, the bluff was 8,000 yr. old. Fernald (1962, p. B29–30) dated a peat section by means of radiocarbon and substantiated Capps's conservative estimate for the rate of peat accumulation. The oldest moraine specifically identified as a direct deposit of Russell Glacier is at the mouth of upper White Canyon, 51 km. from the undisturbed peat bluff (Fig. 5, B). This

TABLE I. TENTATIVE CORRELATION OF GLACIAL SEQUENCES IN THE SOUTH-WEST YUKON TERRITORY AND COOK INLET

Standard	*South-west Yukon Territory (Krinsley)*			*Steele (Wolf) Creek (Sharp, 1951)*	*Cook Inlet (Karlstrom, 1955, 1957, 1961)*		
		VI	A.D. 1957				
		V	A.D. 1937	Present regime			A.D. 1930's
		IV	A.D. 1917				A.D. 1916
						Tunnel II	
Recent	Klutlan A.D. 1905						
					Alaskan		
	Kaskawulsh	III	A.D. 1897	Modern A.D. 1890			A.D. 1890's
		II	A.D. 1840	Advance A.D. 1840			A.D. 1850's
		I	Moraine with mature spruce (81 m. above 1840 moraine)			Tunnel I	A.D. 1000
						Tustumena I-III	2000 B.C.–A.D. 1
Altithermal	Retreat of Klutlan Glacier; development of mature spruce forest on moraine 150 m. above present ablation moraine			Retreat of Steele (Wolf) Creek Glacier; forest development			3500 B.C.
		IV	Pre-altithermal moraine 150 m. above Klutlan Glacier			Tanya	5000 B.C.
Late Wisconsin	Tchawsahmon	III	>6000 B.C.	Later glaciation; drift 15 to 300 m. above present glacier	Naptowne	Skilak	10,000 B.C.
		II				Killey	12,500 B.C.
		I				Moose Horn	16,500 B.C.
Early Wisconsin (Iowan)	Snag	II	(recessional)	Earlier glaciation; drift 262 to 492 m. above valley floor	Knik		55,000 B.C.
		I					
Illinoian	Donjek				Eklutna		100,000 B.C.
Kansan	Nisling				Caribou Hills		175,000 B.C.

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moraine is therefore older than 8,000 yr. and is considered to be contemporaneous with Tchawsahmon III. The age of the Tchawsahmon moraines, and their position and morphology, clearly suggest their contemporaneity with moraines of Naptowne age.

An older moraine at Kaskawulsh Glacier, 150 m. down-valley and 81 m. above the 1840 end moraine, has not been examined on the ground. In the absence of large-scale topographic maps and aerial photographs, the antiquity of the moraine cannot be judged definitively. It is obviously older than A.D. 1840 and may be as old as Tchawsahmon IV. The author tentatively places it in a post-altithermal position.

Dendro-climatic studies in Cook Inlet (Karlstrom, 1961) and at Kaskawulsh Glacier indicate a similar sequence of events. Intervals of minimum tree growth (advance intervals) at Cook Inlet centred about A.D. 1850, the late 1890's, 1916 and 1930–40. The 1897 advance at Kaskawulsh Glacier and the 1905 advance at Klutlan Glacier are reflected in dated (dendro-chronology) moraines near the fronts of numerous glaciers that advanced near the Gulf of Alaska during or just prior to 1898 and 1905 (Tarr and Martin, 1914). The 1937 advance at Kaskawulsh Glacier was contemporaneous with the dramatic advance of Black Rapids Glacier (Péwé, 1951) in the central Alaska Range.

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