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NEOGLACIAL CHRONOLOGY, NORTHEASTERN ST. ELIAS MOUNTAINS, CANADA

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ABSTRACT. In the northeastern St. Elias Mountains, Yukon, Canada, drift morphology and stratigraphy, combined with thirteen C^{14} dates, suggest the following Neoglacial and pre-Neoglacial chronology for the Donjek and Kaskawulsh Glaciers: (1) About 12,500 B.P. (Y-1386) ice of the Kluane glaciation (= classical Wisconsin by C^{14} dating) receded from near Kluane Lake and about 9780 B.P. (Y-1483) withdrew behind the position presently occupied by Kaskawulsh Neoglacial moraines. (2) During the Slims nonglacial interval (basically Hypsithermal), glaciers maintained retracted positions; the Kaskawulsh terminus was located at least 13.7 miles up-glacier from its present position. (3) The initial Neoglacial advance, represented by onset of loess deposition, began shortly before 2640 B.P. (Y-1435). (4) Continuous loess deposition suggests that throughout the Neoglaciation glaciers maintained positions more extensive than those occupied during the Slims interval. (5) The youngest major Neoglacial advance, the most extensive of the last 9780 years (Y-1483), occurred through the last few centuries and is bracketed by seven C^{14} dates. Glacier retreat from this maximum began before A.D. 1874 (Donjek Glacier) and A.D. 1865 (Kaskawulsh Glacier).

Comparison of northeastern St. Elias events with those elsewhere supports the concepts that (1) the initial widespread Neoglacial advance shortly antedated 2600 to 2800 B.P. and (2) at least some major Neoglacial events were essentially synchronous throughout the Northern Hemisphere.

INTRODUCTION

The purpose of this study was (1) to establish a firmly dated Neoglacial chronology of glaciers in the northeastern St. Elias Mountains and (2) to use this chronology to test and complement existing concepts of widespread Neoglacial fluctuations in the Northern Hemisphere.

The term Neoglaciation is used here in the sense proposed by Sharp (1960, p. 321) as "a short convenient designation for a readvance of ice subsequent to shrinkage during the Hypsithermal interval". In this sense the Neoglaciation (1) is basically equivalent to the "little ice-age" of Matthes (1939, p. 519-520; 1940, p. 398-403; 1942, p. 212-214) and (2) includes all glacier fluctuations during the sub-Atlantic time of northwestern Europe.

The St. Elias Mountains are located in southwestern Yukon Territory, northwestern British Columbia, and southeastern Alaska (fig. 1); the international boundary between Alaska and Canada passes through the mountains. Much of the central part of the mountains, which includes many of the highest peaks in Cordilleran North America, is presently mantled with an extensive intermontane icefield which is drained on all sides by long outlet valley glaciers. The Neoglacial history and chronology of two of the largest of these, the Donjek (pl. 1) and Kaskawulsh

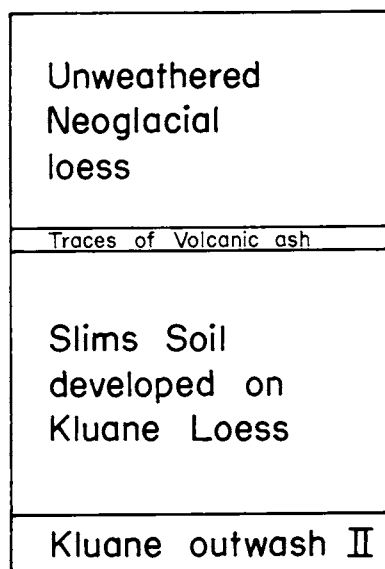
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Glaciers, are discussed here. Both glaciers are located within the Yukon Territory on the northeast flank of the mountains (fig. 1). In addition, the Neoglacial history of the Silver and Cairnes Glaciers,¹ two small valley glaciers on the northeast border of the mountains, is described.

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PREF-NEOGLACIAL DRIFT AND EVENTS

In the northeastern St. Elias Mountains, Yukon Territory, drift morphology and stratigraphic relations of drift sheets and weathering



¹In order to facilitate the following discussion, the names Silver and Cairnes Glaciers are used for two small unnamed valley glaciers located on the northeast flank of the St. Elias Mountains (see fig. 4).



A.



B.

PLATE I

Neoglacial features, northeastern St. Elias Mountains. A. Aerial photograph of Donjek Glacier terminus and St. Elias Mountains. Photograph taken in summer of 1941 by Walter A. Wood. B. Loess sequence showing, from top to bottom, Neoglacial loess, traces of volcanic ash, Slims Soil developed in Kluane loess, and the upper surface of Kluane outwash II. Interpretation of section is on p. 578.

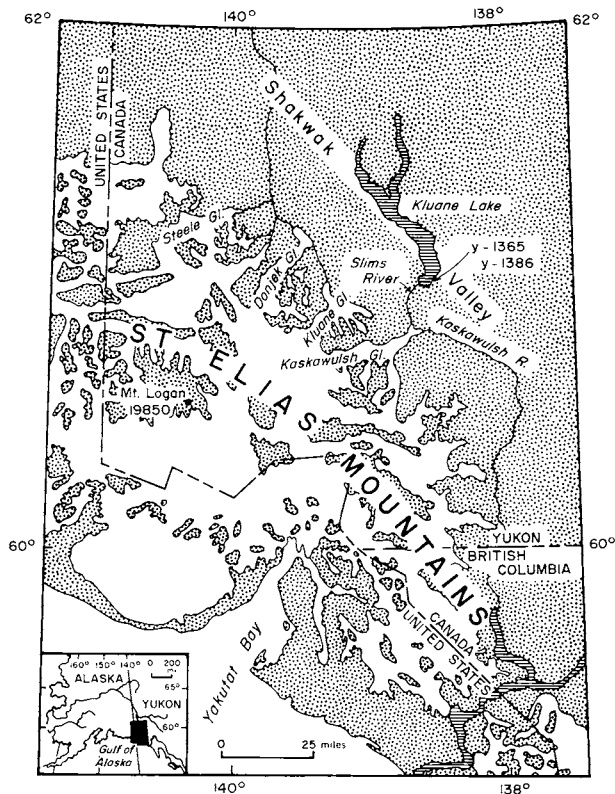


Fig. 1. Index map.

zones indicate that the Neoglaciation was preceded by at least three glaciations and three nonglacial intervals (Denton, ms; Denton and Stuiver, in press). All three glaciations included ice advances substantially more extensive than those of the Neoglaciation. A summary of these pre-Neoglacial events, with bracketing C^{14} dates, is given in table 1.

Ice of the Kluane glaciation had receded to the vicinity of the mouth of Slims River Valley shortly before 12,500 B.P. as indicated by organic matter from the base of a Kluane kettle (Y-1365) and by 9780 B.P. had withdrawn behind the position presently occupied by Neoglacial moraines fronting the Kaskawulsh Glacier as indicated by grass buried in place at the base of Kluane loess near these moraines (Y-1483). During this recession a widespread layer of loess derived from active Kluane outwash bodies was deposited on all older units of Kluane Drift. This Kluane loess varies in thickness from 14 to 40 inches. Subsequent withdrawal of glaciers into the St. Elias Mountains caused these active outwash bodies on the outskirts of the mountains to become nearly or totally inactive and covered with vegetation. With the source of silt

thus removed, deposition of loess ceased or nearly ceased, allowing weathering of the upper 12 to 16 inches of Kluane loess throughout the region. This weathering produced the Slims Soil (pl. 1).

The Slims Soil occurs on Kluane loess which overlies most pre-Neoglacial deposits below 4500 feet altitude. Near the Donjek and Kaskawulsh Glacier termini the soil is overlain by Neoglacial moraines; near presently active valley trains it is sharply overlain by nonweathered Neoglacial loess. Although the soil is absent on the Neoglacial moraines fringing the present Donjek and Kaskawulsh Glacier termini, it occurs widely on pre-Neoglacial deposits immediately adjacent to these moraines (figs. 2 and 3). Additionally, it is present on the west side of the Kaskawulsh Glacier as a nearly continuous sheet through 8 miles above the terminus and as discontinuous patches through an additional 5.7 miles (fig. 3). The last up-glacier occurrence of Slims Soil is on a bedrock knob 13.7 miles up-glacier from the present terminus and 15 miles from the outermost Neoglacial moraines that fringe the terminus.

The Slims nonglacial interval, which derives its name from the Slims Soil, is the time-transgressive interval that separated the Kluane glaciation from the subsequent Neoglaciation. Radiocarbon dates of the retreat of Kluane ice and the advance of succeeding Neoglacial ice bracket this interval between 2640 (Y-1435) and 9780 (Y-1483) to 12,500 B.P. (Y-1386) and indicate that it includes the Hypsithermal interval as defined by Deevey and Flint (1957, p. 182).

A minimum value of glacier retreat during the Slims nonglacial interval can be obtained from the areal distribution of Slims Soil and Neoglacial loess as follows: (1) all soil localities must have been evacuated by glacier ice, and (2) because Slims Soil formation was related to

TABLE I

Late Pleistocene glacial events, with bracketing C¹⁴ dates; northeastern St. Elias Mountains. Ages in C¹⁴ years B.P.

Neoglaciation
Start ~ 2640; still current
Slims nonglacial interval
Start ~ 12,500 to 9780; End ~ 2640
Kluane glaciation
Start < 30,100; end ~ 12,500 to 9780
Boutellier nonglacial interval
Start ~ 37,700; end < 30,100
Icefield glaciation
Start > 49,000; end ~ 37,700
Silver nonglacial interval
> 49,000
Shakwak glaciation
> 49,000

cessation of loess deposition resulting from deactivation of nearby valley trains, glaciers must have retreated from the immediate vicinity of all soil localities. Substantial retreat is indicated by the occurrences of Slims Soil sharply overlain by Neoglacial loess on the west side of the Kaskawulsh Glacier through 13.7 miles up-glacier from the present terminus. For the vicinities of its occurrences, this loess-and-soil sequence (pl. 1) implies (1) loess deposition, (2) cessation of loess deposition, and (3) renewed loess deposition. These events are in turn related to withdrawal of the Kaskawulsh Glacier terminus more than 13.7 miles up-glacier from its present position, followed by renewed advances subsequent to soil formation. This argument for substantial retreat is supported by the continuous, well-defined nature of the soil bordering the lower Kaskawulsh Glacier, which suggests lack of a nearby active valley train during soil formation. A similar argument applies to the Donjek Glacier, where large areas of well-developed soil fringing the terminus suggest retreat during soil formation.

NEOGLACIAL DRIFT

Neoglacial drift, the youngest drift in the northeastern St. Elias Mountains, occurs as loess near presently active valley trains, as well-preserved end-moraine sediments near glacier termini, as small bodies of lacustrine sediment, and as active outwash bodies extending downstream from glacier termini. In the following discussion the terms Donjek, Kaskawulsh, Silver, and Cairnes drifts are used informally to apply to Neoglacial end-moraine, outwash, and lacustrine sediments surrounding and extending downstream from the termini of these glaciers.

Volcanic ash.—A distinct layer of white volcanic ash described in detail by Capps (1916), Bostock (1952, p. 36), and Stuiver, Borns, and Denton (1964) appears at the base of or within Neoglacial loess. In the area of the Donjek and Kaskawulsh Glaciers, the ash ranges in thickness from 0.5 to 1.0 inch. Because it is everywhere synchronous, the ash affords a means of correlating and determining the relative age of Neoglacial drift. Radiocarbon dates (Y-1364 and Y-1363) bracketing the ash indicate that it was deposited about 1425 ± 50 B.P. (Stuiver, Borns, and Denton, 1964).

*Loess*².—Wherever observed, Neoglacial loess (pl. 1) rests on the Slims Soil developed on underlying Kluane loess. The contact is sharp except in a few places where redistribution has resulted in mixing of the two loess units. Because deposition is continuing, Neoglacial loess is not overlain by other sediments, except locally where Donjek and Kaskawulsh end-moraine sediments overlie the basal part of the loess.

Sedimentary and mineralogical characteristics of Neoglacial loess are nearly identical with those of nonweathered Kluane loess. Neo-

² Neoglacial loess was informally called Slims Valley silt by Sticht (ms, p. 94) and Slims River Silt by Johnson and Raup (1964).

glacial loess consists of well-sorted silt and fine sand; the mineralogy of the particles is complex and reflects the wide variety of bedrock lithologies traversed by the glaciers. Neoglacial loess is not weathered, in sharp contrast to the weathered upper part of the underlying Kluane loess. Along the southeast shore of Kluane Lake, Neoglacial loess is duned and commonly contains buried stumps of white spruce (*Picea glauca*) in growth position. Neoglacial loess is thickest in valley bottoms, thins on gentle valley slopes, and is generally absent from valley walls above about 4500 feet. Although rarely present on the Neoglacial moraines, the loess forms a blanket averaging 30 inches thick on all pre-Neoglacial deposits adjacent to the Donjek and Kaskawulsh Glacier termini and averaging 6 to 15 inches thick on the Slims Soil bordering the west side of the Kaskawulsh Glacier (fig. 3). Additionally, Neoglacial loess covers all pre-Neoglacial deposits fringing the upper Kaskawulsh River and the entire Slims River; average thickness decreases from 30 inches near the Kaskawulsh Glacier to 10 inches near the delta of Slims River. The thickness of Neoglacial loess in Shakwak Valley decreases both northwest and east from the Slims River delta. Northwest, along the southwest shore of Kluane Lake, the average thickness decreases from 5 to 2 to 0 inches over distances from the delta of 4, 10, and 12 miles, respectively. East, it decreases from 14 to 6 to 3 inches over distances from the delta of 5, 8, and 12 miles, respectively. Thus the blanket of loess is thickest near the present termini of the Donjek and Kaskawulsh Glaciers, is slightly thinner in Slims River Valley, and in Shakwak Valley thins rapidly with increasing distance from the Slims River delta. Neoglacial loess presently being deposited near the Donjek and Kaskawulsh Glacier termini in Slims River Valley and in Shakwak Valley is derived from the Donjek and Slims valley trains. The above relations strongly suggest that the source of the loess was, and still is, active valley trains of large glaciers draining the Icefield Ranges.

Near the termini of the Donjek and Kaskawulsh Glaciers, Neoglacial loess 10 to 30 inches thick occurs beneath the volcanic ash, although 30 inches is exceptional. The thickness of Neoglacial loess underlying the ash decreases with distance from the Kaskawulsh terminus until it reaches zero in Shakwak Valley. This relationship indicates that Neoglacial loess deposition began near the present terminus of the Kaskawulsh Glacier before it began in the lower Slims River and Shakwak Valleys.

Its relation to active valley trains and its stratigraphic position sharply overlying the Slims Soil imply that Neoglacial loess represents post-Slims reactivation of valley trains resulting from renewed glacier expansion. Thus Neoglacial loess records one or more advances that began at, or slightly before, the start of burial of Slims Soil and continued to recent times. No evidence of significant time breaks in Neoglacial loess deposition has been seen, and accordingly loess stratigraphy does not provide a more detailed record of glacier fluctuations.

Donjek drift.—The Donjek Glacier heads in the Icefield Ranges at 9000 feet and flows 35 miles northeast to terminate at 3500 feet in a lobe projecting into and nearly across Donjek River Valley. The lobe is 6.7 miles long and 1 to 3 miles wide. Meltwater issuing from the Kluane Glacier, 14 miles farther up the Donjek River Valley, and from the Donjek Glacier itself flows northwest along the valley and covers the valley floor in many localities.

In addition to the loess previously mentioned, Neoglacial drift surrounding the terminus of the Donjek Glacier consists predominantly of fresh end-moraine sediments, which extend 0.5 to 1.7 miles from the ice front, and of active outwash sediments, which surround and extend downstream from the end-moraine sediments (fig. 2). Inclusions of local Slims Soil, early Neoglacial loess, and volcanic ash are embedded in the outermost end moraine (fig. 2, site 1), indicating that the end-moraine sediments postdate these included units and suggesting that the end-moraine sediments may locally overlie both Slims Soil and early Neoglacial loess. Also it is inferred that the end-moraine sediments overlie Neoglacial outwash, which must have been deposited in front of the advancing Donjek Glacier. Only traces of Neoglacial loess overlie the end-moraine sediments.

Slims Soil, developed on Kluane loess and overlain by Neoglacial loess, partially surrounds and locally borders the moraines (fig. 2). This relationship indicates that the outer limit of the moraines marks the maximum Neoglacial extent of the Donjek Glacier, for any more extensive advance would have destroyed or covered with till the surrounding Slims Soil.

On the basis of morphology and vegetation, Donjek drift is divided into an older drift A and younger drift B (pl. 2). The changes in characteristics across the boundary between these two drifts is nearly everywhere sharp. Drift A includes the outer end-moraine sediments which fringe the entire glacier terminus and which are partly covered with vegetation. This drift is comprised of a massive end moraine, consisting mainly of till, on which are superimposed many small end moraines, small outwash fans, and lacustrine sediments in drained kettles. The massive end moraine rises 60 to 100 feet above the Donjek valley train, whereas the small end moraines, many of which are cross cutting, average 30 feet wide, 8 feet high, and 400 feet long. Several fresh cracks associated with nearly vertical till faces suggest that the massive end moraine is at least partly ice cored. Furthermore, comparison of air photographs taken in 1935, 1961, and 1963 shows that a system of lakes on the northwest portion of the moraine is growing, perhaps due to melting and settling of an ice core. The morphology of drift A, although quite fresh, is more subdued than that of drift B; most slopes are stable, and the crests of the small end moraines are rounded. The surface of drift A is unweathered and very bouldery, with all boulders in stable positions.

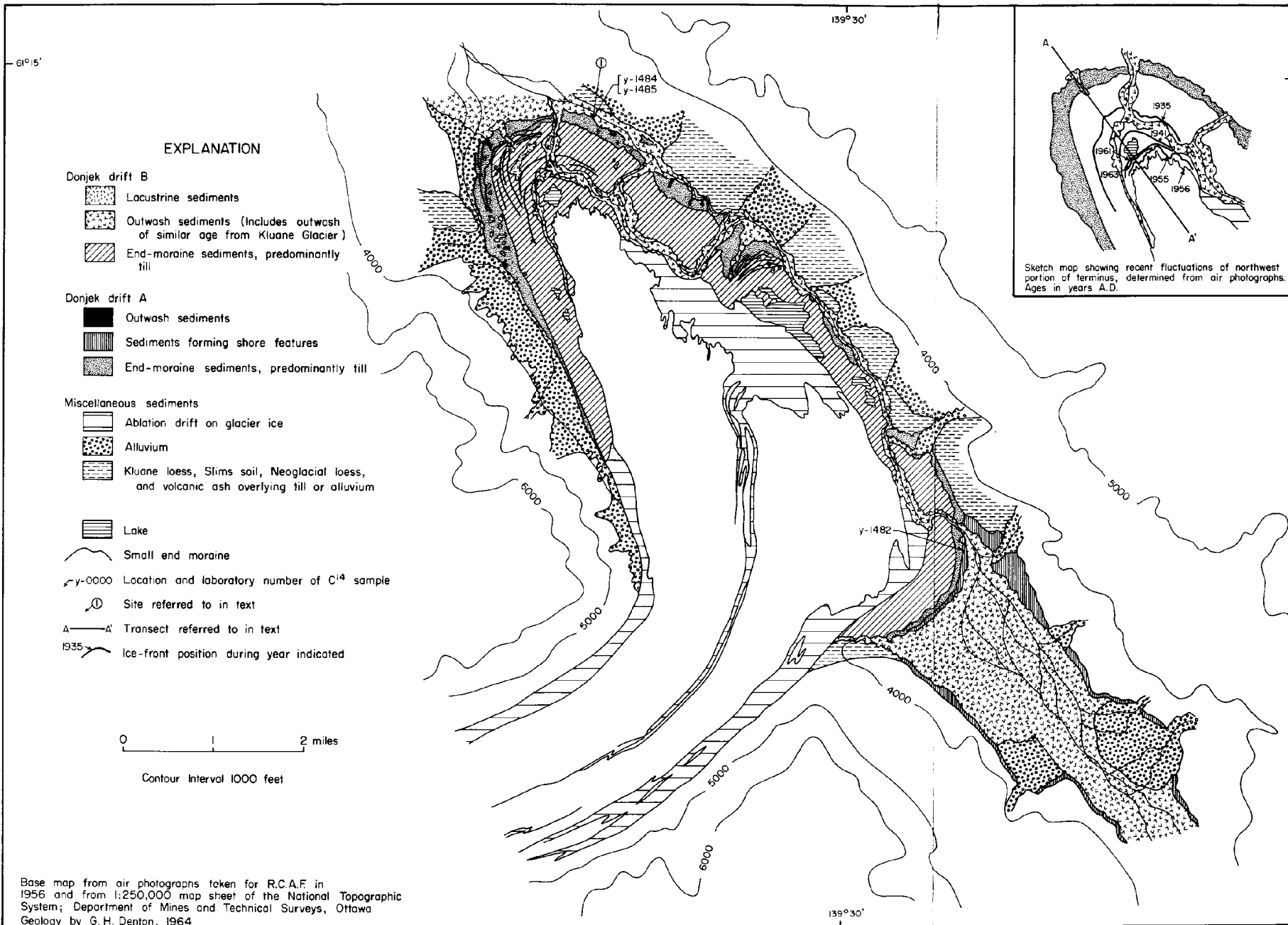


Fig. 2. Glacial features in terminal area of Donjek Glacier.

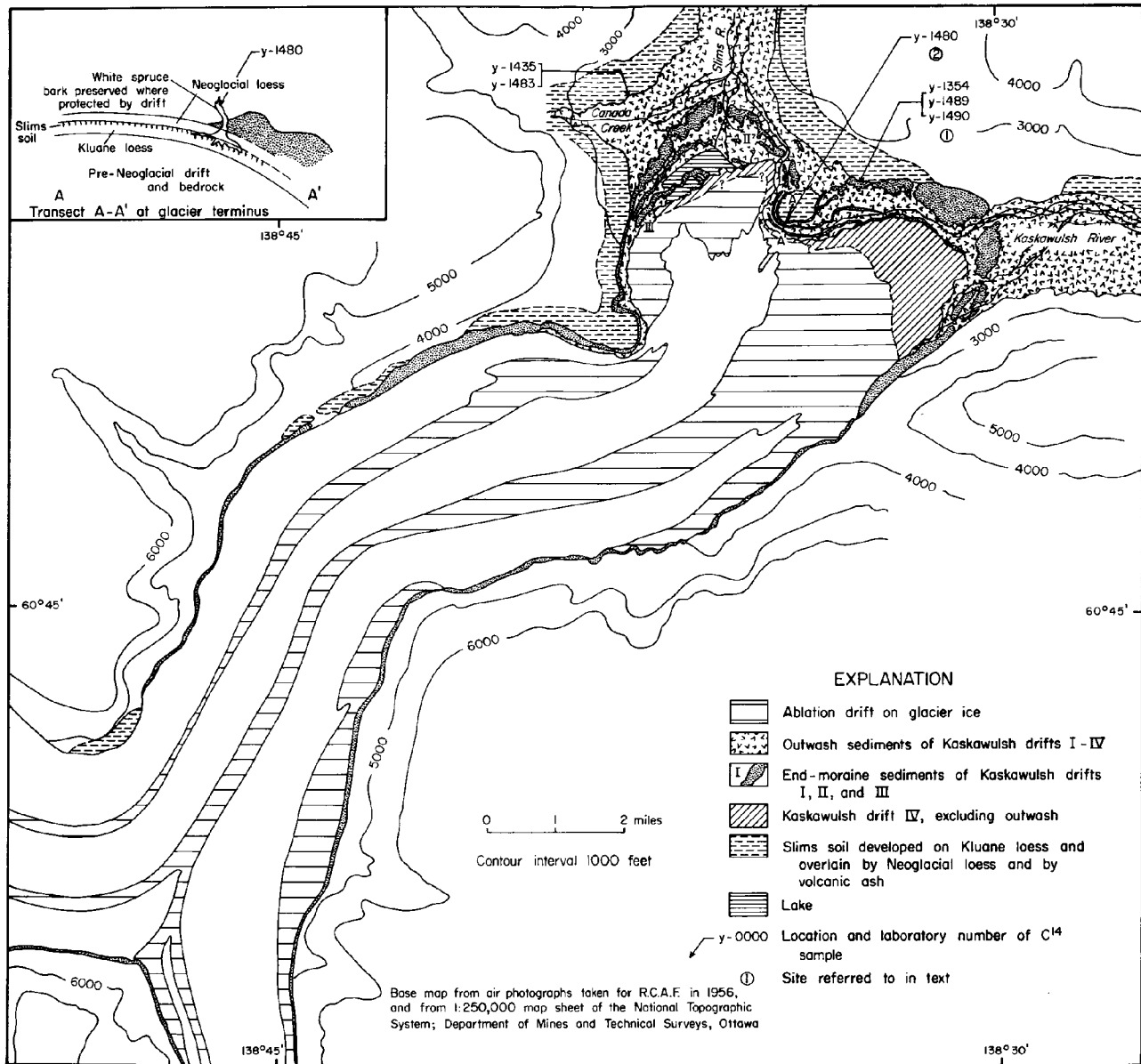


Fig. 3. Glacial features in terminal area of Kaskawulsh Glacier. Position of end-moraine sediments I, II, and III adapted from Borns and Goldthwait (1966).

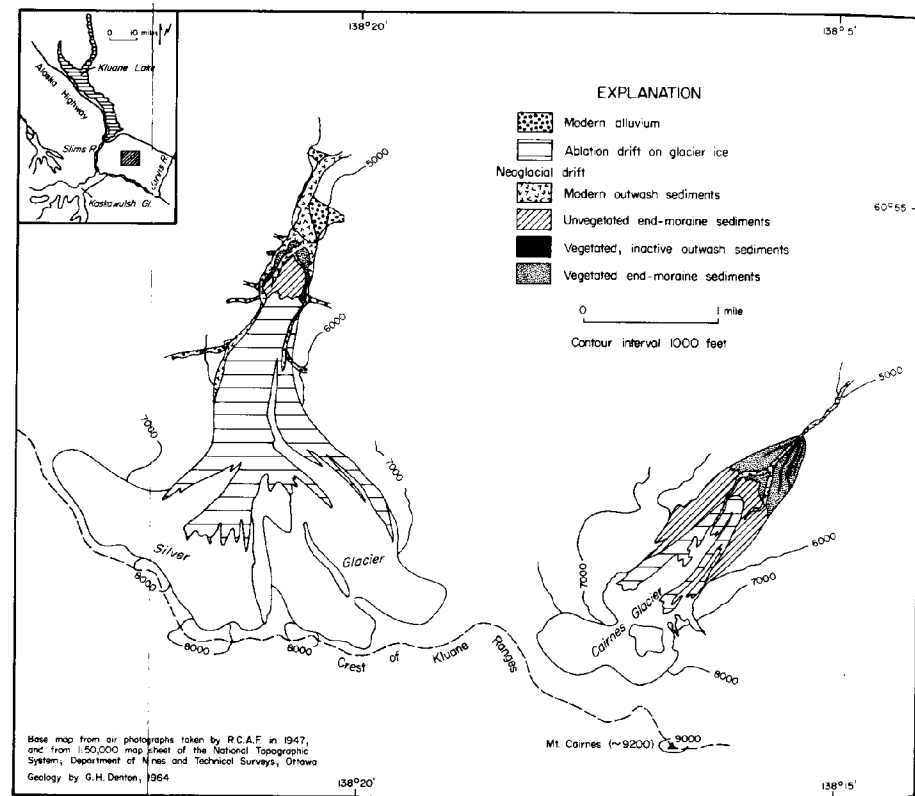
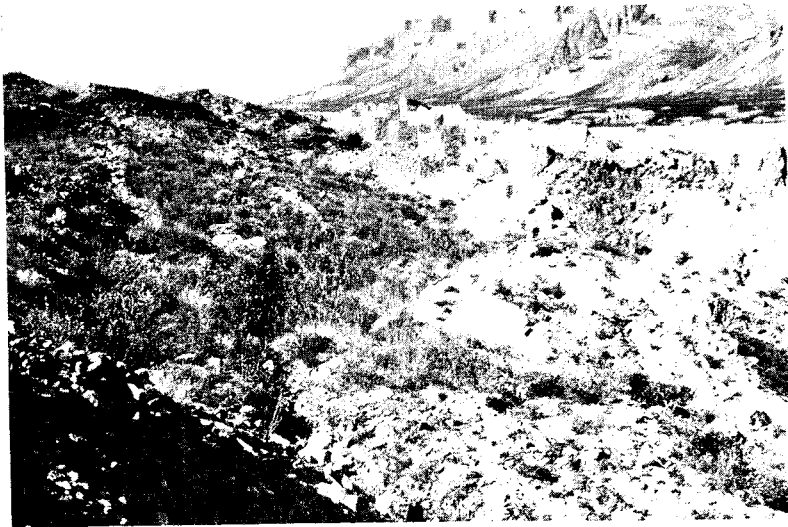
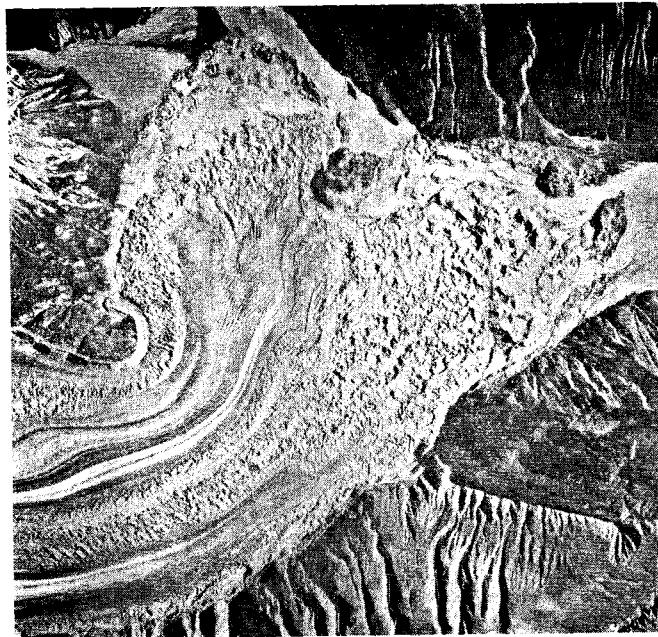


Fig. 4. Glacial features surrounding Silver and Cairnes Glaciers.



A.



B.

PLATE 2

Neoglacial terminal moraines. A. Contrast between Donjek drifts A and B. B. Aerial photograph of Kaskawulsh Glacier terminus and Neoglacial moraines. Scale about 1:100,000.

Shoreline features, including beach ridges and wave-cut cliffs, occur on the outer slope of the southeast part of the outermost moraine of drift A up to 80 feet above the floodplain and also fringe the lower valley walls through 10 miles upstream from the glacier. These shoreline features record a lake, which was dammed when the Donjek Glacier at maximum Neoglacial extent impinged against the northeast wall of Donjek River Valley. The lake remained in existence while the outer moraine of drift A was constructed. It was drained after glacier retreat permitted breaching of this moraine. Because comparison of air photographs taken in 1935, 1949, and 1963 shows that modern breaching of moraines by the large quantities of meltwater from the Kluane and Donjek Glaciers is very rapid, drift A was probably breached shortly after withdrawal of the ice from the outermost Neoglacial moraine.

The surface of drift A is sparsely covered with vegetation. The amount of level terrain covered with vegetation decreases gradually and uniformly from about 60 percent on the outer part to about 30 percent on the inner part of drift A. The vegetation cover ceases abruptly at the contact between drifts A and B. Spruce (*Picea glauca*) and poplar (*Populus balsamifera*) trees presently grow only on the drift A end-moraine sediments that fringe the northwest part of the glacier terminus. On the outer part of drift A in this area, cores taken with a Swedish increment borer show that in the summer of 1964 the oldest spruce had from 70 to 86 annual rings whereas the oldest poplars had from 30 to 90 annual rings. On the inner part of drift B only poplars are present, and the oldest had from 20 to 30 annual rings in the summer of 1964. The ages of these trees afford minimum dates for recession of ice from the moraine sectors on which they are growing. Thus the Donjek Glacier had receded from the outer area of drift A, fringing the northwest portion of the glacier terminus, by at least A.D. 1874. (This estimate is obtained from the age of the oldest poplar.) A more accurate minimum date for retreat can be obtained if the time span required for establishment of trees on the moraine after ice recession is added to their age. However, information concerning this time span is very scarce, and only a crude estimate is possible. First, in view of the age of the oldest poplars (30 years in 1964) and of the lack of spruce on the inner part of drift A, it appears that there spruce trees require at least 30 years for establishment. Second, comparison of air photographs of the northwest Donjek terminus shows that an area of drift B, evacuated by glacier ice between 1935 and 1941, still lacks vegetation, indicating that there poplars require more than 23 years for establishment. When added to the age of the oldest poplars (30 years in 1964), this suggests that the inner portion of drift A has been ice free for at least 53 years and that spruce there take at least 53 years to become established. Addition of this estimate of minimum time required for spruce establishment to the age of the oldest spruce growing on drift A (86 years in 1964) suggests that the northwest Donjek

terminus receded from the outermost moraines of drift A before A.D. 1825.

Drift B includes (1) the end-moraine sediments that fringe the glacier terminus inside drift A and are bare of vegetation and (2) active outwash extending downstream from the terminus. The innermost end-moraine sediments are presently being deposited. The end-moraine sediments of drift B consist predominantly of till but also comprise outwash and small bodies of lacustrine sediments. The end moraines include (1) massive embankments of till and (2) small, well-defined ridges, some superimposed on the embankments. Most of the moraines contain ice cores very near the surface, are very bouldery with many boulders in unstable positions, and have steep, unstable slopes. Many features of drift B are continually changing because of glacier fluctuations and shifting of outwash streams.

The history of the Donjek Glacier since Kluane time can be ascertained from the deposits surrounding the glacier terminus and from a comparison of recent air photographs of the terminus. During late Kluane time the glacier withdrew into the Icefield Ranges sufficiently far to allow deactivation of the valley train, cessation of loess deposition, and formation of Slims Soil in the area of the present terminus. Renewed glacier activity following the Slims interval resulted in reactivation of the valley train and deposition of Neoglacial loess over the Slims Soil. During the subsequent Neoglacial advance or advances, the glacier overran Kluane loess, Slims Soil, Neoglacial outwash and loess, and volcanic ash as well as organic matter in these deposits. This organic matter included logs of spruce (*Picea glauca*) that still retain their bark where protected by drift. Because modern trees of the same species lose all their bark within 6 to 20 years after death (Mr. Donald Merrill, Forestry Superintendent, Yukon Forestry Division, written communication), the trees embedded in the moraine were alive or had been dead for only a very short time when they were overrun by glacier ice.

The Donjek Glacier had reached its maximum Neoglacial extent marked by the outer moraine of drift A, had dammed a lake in Donjek River Valley, and had probably begun to retreat by at least A.D. 1825. The lack of abrupt changes in vegetational characteristics on drift A suggests that over the area of drift A, the retreat, although marked by small fluctuations as shown by the cross-cutting moraines, was uninterrupted by major pauses or readvances. The marked contrast between drifts A and B indicates that steady but fluctuating retreat from the area of drift A was interrupted either by a major readvance that terminated at the outer limit of drift B or by a prolonged pause in recession. That the subsequent recession which resulted in deposition of at least the surficial part of drift B was punctuated by fluctuations is shown by cross-cutting moraines.

Recent fluctuations of the Donjek Glacier terminus can be ascertained from a series of air photographs taken at intervals from August

1935 to July 1964 (pl. 3). The following distances and recessions were measured along a transect of the northwestern part of the glacier (fig. 2, A-A'), where the ice terminus is clearly defined. Behavior of the rest of the terminus was probably similar but is harder to measure because ice tended to stagnate rather than waste back. In August 1935, the ice front was about 2640 feet behind the outer limit of the moraines of drift A. Between August 1935 and the summer of 1941, net retreat was about 1760 feet; between the summer of 1941 and the summer of 1955 it was also about 1760 feet; between the summer of 1955 and the summer of 1956 it was about 200 feet. At some time between the summer of 1956 and August, 1961, the ice front advanced to a position some 1380 feet in front of its 1956 position. From this position it had retreated about 120 feet by August 1961, 570 feet by August 1963, and 620 feet by July 1964 when the distances were measured.

Kaskawulsh drift.—Neoglacial drift near the terminus of the Kaskawulsh Glacier was studied both by Borns and Goldthwait (1966) and by the present writers, in part jointly and in part independently. The present writers are grateful for permission to cite their colleagues' work, which is the next article in this issue.

The Kaskawulsh Glacier, 45 miles long, flows northeast from the Icefield Ranges and terminates at 2700 feet altitude near the junction of Slims and Kaskawulsh Valleys. A bedrock knob divides the terminal portion of the glacier into two lobes, the Slims River lobe and the Kaskawulsh River lobe. Both lobes are fronted by Neoglacial drift (pl. 2) which, in addition to loess previously mentioned, includes (1) end-moraine sediments extending from 0.2 to 2.0 miles in front of active glacier ice and (2) active and inactive outwash sediments (fig. 3).

The age relation of Kaskawulsh end-moraine sediments to surrounding drift units is identical with the comparable Donjek situation as shown by (1) inclusions of Slims Soil and Neoglacial loess in the outer moraine (fig. 3, site 1), (2) end-moraine sediments overlying *in-situ* Slims Soil, Neoglacial loess, and volcanic ash in which a sheared spruce (*Picea glauca*) is still rooted in growth position (fig. 3, site 2), and (3) traces of Neoglacial loess on the end-moraine sediments. Additionally, logs of spruce (*Picea glauca*) embedded in the end-moraine sediments (fig. 3, site 1) contain Slims Soil and Neoglacial loess in their roots.

The areal distribution of Slims Soil bordering the Kaskawulsh end-moraine sediments (see also Borns and Goldthwait, 1966) parallels the Donjek situation and likewise indicates that the outer end moraine marks the maximum Neoglacial extent of the Kaskawulsh Glacier.

Borns and Goldthwait (1966) have divided the end-moraine sediments and the associated inactive outwash and lacustrine sediments into Kaskawulsh drifts I, II, and III, mainly on the basis of three distinct end moraines fronting the Slims River ice lobe. The three drifts have a sparse cover of vegetation in comparison to surrounding



A.



B.

PLATE 3

Aerial photographs of the northwest part of the Donjek Glacier terminus showing recent fluctuations. A. Photograph taken August 1935. B. Photograph taken August 1963. Photographs by Walter A. Wood.

terrain. Between drift III and active glacier ice there is a deposit of thick, bare ablation drift covering ice which is probably inactive. In front of the Kaskawulsh River lobe, the moraines of drifts I, II, and possibly drift III merge to form an outer fringe of drift which is partly covered with vegetation and nestles around an extensive inner deposit of fresh drift, which is bare of vegetation. The inner drift is ice cored very near the surface and grades into thin ablation drift covering active glacier ice. The contact between the two drifts is sharp. This inner drift, and possibly the inner ablation drift fronting the Slims River lobe, is here called drift IV, following the terminology of Borns and Goldthwait (1966). Also included in drift IV is the active outwash extending downstream from the glacier terminus.

The Neoglacial history of the Kaskawulsh Glacier is revealed by drift and vegetation surrounding the ice. Following the Slims interval, Neoglacial advance(s) caused reactivation of the lower valley train, resulting in deposition of Neoglacial loess, first near the glacier and later in lower Slims River Valley and in Shakwak Valley. Spruce logs associated with Slims Soil and Neoglacial loess are embedded in the outermost moraine, indicating that the advancing ice overrode spruce forests growing on these deposits. Where protected by drift, the logs retain their bark, strongly suggesting that the trees were alive when overrun by ice. When it reached its maximum Neoglacial extent, the ice sheared off and partially covered with drift a tree whose stump is still rooted in growth position in Slims Soil, Neoglacial loess, and volcanic ash. Because its bark is still entirely preserved where protected by drift, the tree was probably alive when its top was removed by glacier ice. The total Neoglacial advance of the Kaskawulsh Glacier was at least 15 miles from the retracted position the terminus occupied during the Slims interval.

The most recent fluctuations of the Kaskawulsh Glacier during its general recession from the maximum Neoglacial position are represented by drifts I, II, III, and IV. On the Slims River lobe the moraine of drift I was deposited when the glacier stood at its maximum Neoglacial extent; the moraine of drift II was deposited during a readvance; the moraine of drift III was deposited either during a readvance or a pause in retreat (Borns and Goldthwait, 1966). On the Kaskawulsh River lobe these advances and/or pauses either are not represented or are recorded by the outer drift. Drift IV represents either a readvance or a stillstand during general recession. Ages of the oldest trees now growing on the outermost moraine suggest that retreat from the Neoglacial maximum began prior to A.D. 1865 (Krinsley, 1965).

Silver and Cairnes drifts.—The Silver and Cairnes Glaciers are small valley glaciers located on the northeast flank of the St. Elias Mountains. They head near 8000 feet and terminate at 6000 feet. Well-preserved end-moraine sediments, probably ice cored, surround their termini and active outwash bodies extend downstream from their

moraines (fig. 4). No deposits underlying the end-moraine sediments are exposed, and no deposits overlie them. The volcanic ash is absent on both the end-moraine sediments and the surrounding deposits. The latter situation can be interpreted as resulting from the fact that the surrounding deposits consist of active fan and gelifluction sediments that would have disrupted ash beds. On the other hand numerous flat surfaces on the end-moraine sediments afford ideal situations for preservation of the ash, and its absence is interpreted as indicating that the end-moraine sediments are younger than the ash and that they were therefore constructed subsequent to ash deposition dated at 1425 ± 50 B.P. Because Slims Soil is not present at the altitude of the moraines, its distribution cannot be applied to determination of the maximum Neoglacial extent of these glaciers. In view of the absence of more extensive moraines, it is assumed that the outer moraine probably represents the maximum Neoglacial extent of each of the glaciers. Both the Silver and Cairnes end-moraine sediments have a bipartite arrangement consisting of an outer fringe of drift partly covered with vegetation and an inner barren fringe of drift; in both cases the contact between the inner and outer drifts is sharp.

Only fragments of the Neoglacial history of the Cairnes and Silver Glaciers are revealed by deposits surrounding their termini. Both glaciers probably reached their maximum Neoglacial extent, marked by the outer limit of end-moraine sediments that surround the termini, after deposition of the volcanic ash. At the time of maximum Neoglacial extent, various glaciers now separated from the present Silver Glacier had coalesced to form one large valley glacier. Retreat from the maximum Neoglacial position began recently, as shown by the sparse cover of vegetation on the outer end moraines. The pronounced difference in vegetation cover of the inner and outer drifts indicates that general recession was interrupted by a readvance or a stillstand of the ice.

Østrem (1964; 1965) has shown that ice-cored moraines fronting short glaciers in continental areas may have been constructed during several advances spread over thousands of years. In such cases surface characteristics of moraines represent only the youngest advance. Because they are associated with small glaciers in a continental area, the ice-cored moraines fronting the Silver and Cairnes Glaciers may represent such a situation.

CHRONOLOGY

The similar Neoglacial history of the four glaciers studied (Donjek, Kaskawulsh, Silver, and Cairnes) probably represent the general situation for glaciers in the northeastern St. Elias Mountains. The termini of Donjek and Kaskawulsh Glaciers, and probably of the Silver and Cairnes Glaciers, assumed retracted positions during the Slims interval preceding the Neoglaciation. For the Kaskawulsh Glacier, this position was more than 13.7 miles behind its present terminus and 15 miles behind the outermost Neoglacial moraines. The oldest evidence of glacier

TABLE 2
C¹⁴ dates

Sample number	Location	Substance and stratigraphic position	C ¹⁴ age in years B.P.
Y-1482	Donjek Glacier (fig. 2)	Outer rings of spruce log buried in highest beach ridge of lake dammed by Donjek Glacier at Neoglacial maximum	< 100
Y-1485	"	Outer rings of spruce log embedded in outermost Donjek Neoglacial moraine	230 ± 80
Y-1484	"	"	290 ± 80
Y-1489	Kaskawulsh Glacier (fig. 3)	Outer rings of spruce log embedded in outermost Kaskawulsh Neoglacial moraine	110 ± 80
Y-1490	"	"	390 ± 80
Y-1354	"	" (see Borns and Goldthwait, 1966)	450 ± 100
Y-1480	"	Outer rings of sheared spruce stump in growth position rooted in Slims soil and Neoglacial loess and partly covered with end-moraine sediments	270 ± 60
Y-1365	Shakwak Valley (fig. 1)	Outer rings of spruce stump buried in growth position in Neoglacial loess immediately above volcanic ash (see Stuiver, Borns, and Denton, 1964)	870 ± 100
Y-1363	Kaskawulsh Glacier	Peat from immediately above volcanic ash (see Stuiver, Borns, and Denton, 1964)	1460 ± 70
Y-1364	Kaskawulsh Glacier	Peat from immediately below volcanic ash (see Stuiver, Borns, and Denton, 1964)	1390 ± 70
Y-1435	Kaskawulsh Glacier (fig. 3)	Grass buried in place 4 inches above base of 10 foot section of Neoglacial loess	2640 ± 80
Y-1483	Kaskawulsh Glacier (fig. 3)	Grass buried in place at base of Kluane loess	9780 ± 80
Y-1386	Shakwak Valley (fig. 1)	Organic matter from base of kettle in Kluane ice-contact stratified drift	12,500 ± 200

expansion following the Slims interval is Neoglacial loess, deposited initially near the present termini of the Donjek and Kaskawulsh Glaciers and later farther down-valley.

Lack of evidence of depositional breaks within the Neoglacial loess near the Kaskawulsh and Donjek termini suggests that throughout the

Neoglaciation these termini maintained positions farther down-valley than the positions occupied during the preceding Slims interval. Near the present Kaskawulsh Glacier terminus, a C^{14} date of grass buried in place near the base of a 10-foot section of Neoglacial loess provides a close minimum age of 2640 B.P. (Y-1435; fig. 3) for the initial Neoglacial advance(s) of the Kaskawulsh Glacier. Near the Kaskawulsh terminus as much as 30 inches of Neoglacial loess underlie the volcanic ash, whereas in Shakwak Valley near Kluane Lake only 0 to 2 inches underlie the ash. On the shore of Kluane Lake the outer few rings of a spruce stump buried in place in Neoglacial loess 3 inches above the volcanic ash provided a C^{14} date of 870 B.P. (Y-1365); the volcanic ash is dated at about 1425 ± 50 B.P. Thus loess deposition had begun in Shakwak Valley by at least between 870 B.P. and 1425 B.P.

During recent centuries the Kaskawulsh and Donjek Glaciers, and probably also the Silver and Cairnes Glaciers, reached their maximum Neoglacial extent, recorded in each case by the outer end-moraine sediments surrounding the present termini. Sharp (1951) has reported a similar advance of the nearby Steele (Wolf Creek) Glacier. A series of C^{14} samples is associated with this recent advance. In order to present a more realistic chronology and to facilitate correlation with historically dated advances elsewhere, the dates presented are corrected for variations in atmospheric C^{14} (see Stuiver and Suess, 1966). Both the corrected dates and the original C^{14} dates are presented in table 3.

All corrected dates are on stumps or logs of white spruce, the drift-protected parts of which still retain their bark, indicating that the trees were alive or had been dead only a short time when they were overrun by ice and incorporated into the drift. Radiocarbon dates of the outer few growth rings of logs embedded in Neoglacial

TABLE 3
Corrected young neoglacial C^{14} dates. All dates in years B.P.
Statistical errors not considered

Sample number	C^{14} ages, in years, B.P., based on 95 percent oxalic acid and a half life for C^{14} of 5568 years	Age range in calendar years B.P., when C^{14} ages are corrected for half life and for fluctuations in atmospheric C^{14} content. Corrections based on data from Stuiver and Suess (1966)
Y-1482	< 100	< 260
Y-1489	110	130 to 280
Y-1485	230	300 to 400
Y-1480	270	300 to 420
Y-1484	290	300 to 440
Y-1490	390	480
Y-1354	450	500

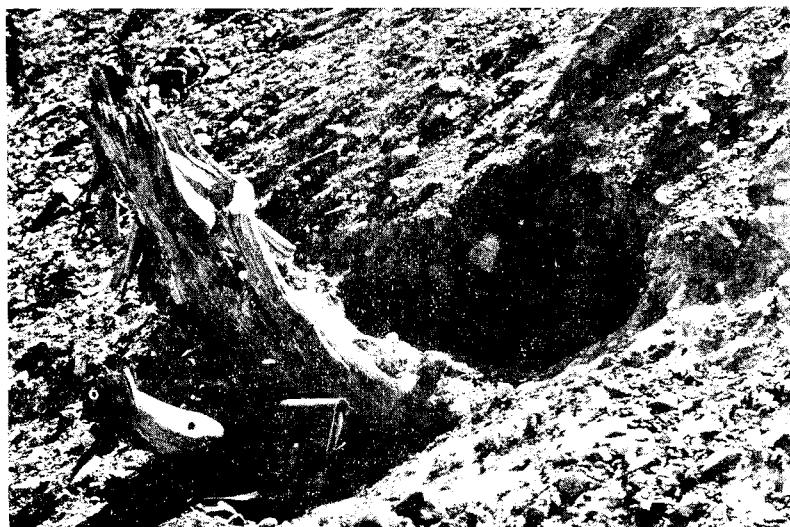
end moraines represent (1) a time when the glacier concerned was advancing and (2) a maximum date for construction of the part of the moraine involved. Corrected ages of logs in the outer Kaskawulsh end moraine (pl. 4) suggest that the Kaskawulsh Glacier was advancing about 500 B.P. (Y-1354) and 480 B.P. (Y-1490). The glacier subsequently reached its Neoglacial maximum between 300 and 420 B.P. (Y-1480), the range of corrected ages of the sheared stump at the bedrock knob separating the Slims River lobe from the Kaskawulsh River lobe. A corrected age (130 to 280 B.P. for Y-1489) on a log embedded in the outer moraine is either anomalous or suggests that different parts of the Kaskawulsh terminus reached maximum Neoglacial positions at slightly different times. During this Neoglacial advance the Kaskawulsh Glacier attained its greatest extent of at least the last 9780 years (Y-1483), the age of grass buried in place at the base of Klwane loess immediately outside the Neoglacial moraines.

The corrected ages of wood embedded in the outermost Donjek end moraine (pl. 4; Y-1484 and Y-1485 in table 2) establish possible dates when the Donjek Glacier was advancing and are maximum for construction of the moraine at the sample localities. These corrected ages range from 440 to 300 B.P. The number of annual growth rings of the oldest trees presently growing on end-moraine sediments imply a minimum date of A.D. 1874 (76 B.P.) for retreat of the northwest part of the Donjek Glacier terminus from its Neoglacial maximum. The date of retreat of the southeast part of the terminus can be estimated from the C^{14} age of a log buried in the highest beach ridge of a lake dammed by the Donjek Glacier at its Neoglacial maximum. The sample, Y-1482, gives a corrected age of <260 B.P. for the highest lake level. Drainage of the lake probably accompanied ice withdrawal from the maximum stand; hence this date suggests that retreat began after 260 B.P.

Retreat from the maximum position began by the Kaskawulsh Glacier before A.D. 1865, a date obtained from the age of the oldest trees now growing on the moraines (Kransley, 1965). In the case of the Steele Glacier, the Neoglacial advance is estimated to have culminated between A.D. 1840 and 1890 (Sharp, 1951, p. 107). The fluctuating retreat from the maximum Neoglacial extent of the Donjek, Silver, and Cairnes Glaciers, as well as of the Kaskawulsh River lobe of the Kaskawulsh Glacier, was interrupted by at least one major readvance or period of equilibrium, as shown by the bipartite division of drift surrounding the glacier termini. This major interruption in general recession is paralleled in the Steele Glacier, whose moraines also have a bipartite arrangement (Sharp, 1951, p. 107). Recession of the Slims River lobe of the Kaskawulsh Glacier was interrupted by four pauses or readvances, the last probably corresponding to the major pause, or reexpansion, in general recession of the other glaciers discussed above.



A.



B.

PLATE 4

Neoglacial C^{14} samples. A. Inclusion of Neoglacial loess, volcanic ash (A), and wood (W) embedded in outermost Donjek Neoglacial moraine. B. Spruce stump embedded in outermost Kaskawulsh Neoglacial moraine.

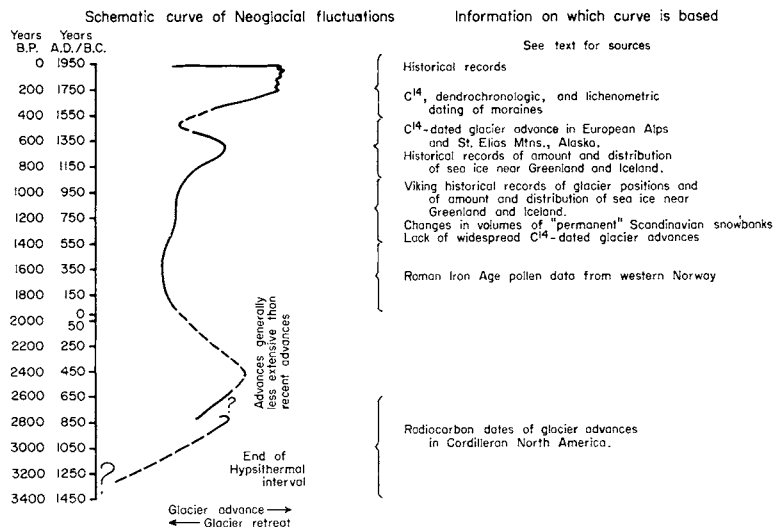


Fig. 5. Neoglacial glacier fluctuations. Most information from alpine areas. Horizontal axis has no absolute scale; known total Neoglacial advance ranged from more than 15 miles for Kaskawulsh Glacier to several miles or less for small Scandinavian glaciers. Although curve probably reflects general situation, for an individual glacier any of the Neoglacial advances represented may have been the most extensive.

CORRELATION

Because recently published information concerning the Neoglaciation has not been synthesized, a brief summary of dated events is presented here. Figure 5 shows a representation of dated Neoglacial fluctuations in the Northern Hemisphere, mainly of glaciers in alpine regions. The curve is based on a detailed synthesis by Porter and Denton (ms) of available Neoglacial data. The curve has several weaknesses. (1) Some of the information is from geographically restricted areas, and thus, if it is to represent the Northern Hemisphere, the curve involves the assumption that major Neoglacial events were synchronous throughout the Hemisphere. (2) Several C^{14} dates of glacier advances in Alaskan coastal mountains contradict the part of the curve representing the Middle Ages. However, neither the extent nor the geographic significance of these Alaskan advances are known, and thus the curve here is based on better-documented data from the North Atlantic region. (3) The horizontal axis of figure 5 has no absolute dimensions, and the extent shown for each period of glacier expansion is at best relative and represents only an interpretation of available literature.

Data for the timing of the initial Neoglacial advances come mainly from Cordilleran North America. Available C^{14} dates directly associated with glacier advances during the latter half of the Hypsithermal and during early Neoglacial time are shown in figure 6. The only C^{14} -dated

advance recorded during the Hypsithermal was that of South Cascade Glacier (Meier, 1964). At present it is not known to what extent this advance represents a regional trend, for the only other C^{14} evidence of a glacier advance of comparable age is from the European Alps where wood from a moraine fronting Oberaar Glacier dates from 4600 B.P. (Gfeller and others, 1961, p. 19). Otherwise, the oldest dates of glacier expansion cluster between 2800 and 2600 B.P. and come from areas of such diverse latitudes as the Brooks Range in north-central Alaska (Porter, 1964, p. 457-458), Glacier Bay (Goldthwait, 1963, p. 44), the Juneau district in southeastern Alaska (Heusser and Marcus, 1964, p. 84), and Utah (Richmond, 1962). Such broad areal distribution strongly suggests that widespread advances began shortly before 2800 to 2600 B.P. Evidence supporting this inference is given by the age of initial Neoglacial advance of glaciers on Mt. Rainier, bracketed between 3500 and 2000 B.P. by C^{14} -dated beds of volcanic ash (Crandell, 1965).

The best-documented information for the time span between the oldest Neoglacial expansion and the major advances of the last few centuries comes mainly from the North Atlantic region and is based on (1) Roman Iron Age pollen data (see Hafsten, 1960, p. 449-450), (2) historical records relating to relative glacier positions (see Ahlmann, 1953, p. 39) and to amount and distribution of sea ice in waters surrounding Iceland and southern Greenland (see Koch, 1945, p. 243-298), (3) changes in volumes of permanent snowbanks in Scandinavian mountains (see Hoel and Werenskiold, 1962, p. 57), and (4) C^{14} -dated advances about A.D. 1200 in the southern St. Elias Mountains (see Plafker and Miller, 1957) and in the European Alps (see Oeschger and Röthlisberger, 1961). Data concerning the widespread later Neoglacial advances of the last few centuries come from many sources and include historical records as well as C^{14} , dendrochronologic, and lichenometric dating of moraines.

Available data from the northeastern St. Elias Mountains agree closely with relevant parts of figure 5. The close minimum date of

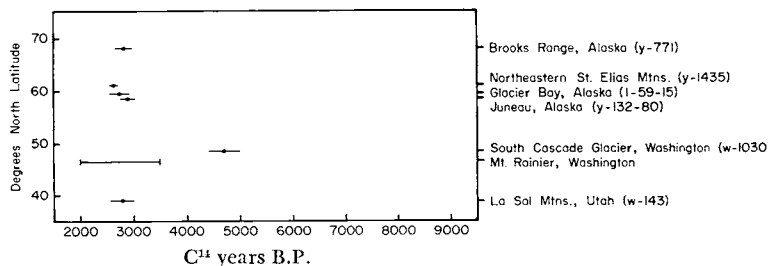


Fig. 6. C^{14} dates of glacier advances in Cordilleran North America during Hypsithermal and early Neoglacial times. —●— represents C^{14} date with statistical error. |—| represents limiting dates of initial Neoglacial advance as imposed by C^{14} -dated beds of volcanic ash. See text for sources.

2640 B.P. for the initial Neoglacial advance of the Kaskawulsh Glacier correlates with similar dates from elsewhere in Cordilleran North America and lends strong supporting evidence for the postulate that widespread, essentially synchronous, Neoglacial expansion began shortly before 2600 to 2800 B.P. Furthermore, glaciers of the northeastern St. Elias Mountains were advancing from about 500 B.P. until sometime shortly before A.D. 1874 (Donjek) or A.D. 1865 (Kaskawulsh). This timing agrees with the widespread Neoglacial advances throughout alpine areas of the Northern Hemisphere. Thus, as far as it is known, the St. Elias Neoglacial chronology fits closely with that of other areas and supports the concept that major Neoglacial events were essentially synchronous, at least in alpine regions of the Northern Hemisphere.

In addition, the St. Elias data add the following local dimensions to figure 5: (1) For the Kaskawulsh Glacier the total distance of advance from its retracted Hypsithermal position to its maximum Neoglacial extent, attained within the last few centuries, exceeded 15 miles. (2) For both the Donjek and Kaskawulsh Glaciers the major Neoglacial advance of the past few centuries was more extensive than any previous Neoglacial advance.

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