

THE SURFACE VELOCITY OF THE YAKATAGA GLACIER, ALASKA*

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ABSTRACT. The Yakataga Glacier occupies a steep-walled valley in the Robinson Mountains on the north coast of the Gulf of Alaska. The main trunk of the glacier descends from 1130 to 150 m. in a distance of 21 km. A rock fall at the head of the glacier formed a moraine of distinctive shape which advanced at an average rate of 114 m./yr. from 1938 to 1954. The surface velocity of the glacier at fifteen stations below the firn line was calculated from the displacement of the rock-fall moraine and other less conspicuous features that are shown in two sets of vertical aerial photographs, taken in 1948 and 1954. For this time interval the average surface velocity along the medial line of the glacier ranged from a maximum of about 90 m./yr. at a station 14 km. above the terminus to zero at a station 2.3 km. above the terminus. The technique of photogrammetric measurement of surface velocity by using natural features on the surface of a glacier has wide application in Alaska, where many glaciers have been rephotographed from the air after intervals of a few years to as many as thirty years.

ZUSAMMENFASSUNG: Der Yakataga Gletscher nimmt ein von steilen Mauern eingezäuntes Tal in dem Robinson Gebirge an der Nordküste des Golfes von Alaska ein. Der Hauptgletscherstrom fällt innerhalb 21 km von 1130 m auf 150 m. Durch einen Felssturz bildete sich am Kopf des Gletschers eine besonders geformte Moräne, die sich von 1938 bis 1954 mit einer Durchschnittsgeschwindigkeit von 114 m pro Jahr vorwärts bewegte. Die Oberflächengeschwindigkeit wurde an 15 Stellen unter der Firnlinie von der Veränderung der Felssturz-Moräne und von anderen weniger ins Auge fallenden Merkmalen berechnet, wie in zwei Sätzen vertikaler Serien-Photographien, die in den Jahren 1948 und 1954 aufgenommen wurden, gezeigt wird. In dieser Zeitspanne erstreckte sich die Durchschnittsoberflächengeschwindigkeit der mittleren Linie entlang von einem Maximum von ungefähr 90 m pro Jahr an einer Stelle 14 km über dem Gletscherende bis Null an einer Stelle 2,3 km über dem Gletscherende. Von der Technik photogrammetrischer Messung der Oberflächengeschwindigkeit durch Benutzung natürlicher Merkmale an der Oberfläche eines Gletschers wird in Alaska, wo viele Gletscher von der Luft aus nach Zwischenräumen von einigen Jahren bis so viel wie 30 Jahren wiederphotographiert worden sind, weitläufig Gebrauch gemacht.

I. INTRODUCTION

The following observations on the surface velocity of a valley glacier are a by-product of petroleum investigations in southern Alaska. In 1944 Matt Walton and C. E. Kirschner, members of a United States Geological Survey party working in the Yakataga district, noted an unusual forklike moraine pattern on the Yakataga Glacier. They mapped the morainic feature by compass-pace traverse and from distant trimetrogon aerial photographs, and later described the feature to the writer. Vertical aerial photographs taken in 1948 showed that the morainic feature had been carried down-glacier about 610 m. (2000 ft.) and had changed considerably in shape since 1944. These photographs suggested to the writer that the morainic feature originated as a rock fall and that it afforded a convenient means of measuring the surface velocity of the glacier. Two other views of the rock-fall moraine were found among oblique aerial photographs taken in 1938. In 1952 the writer and R. C. Ellis re-examined and photographed the rock-fall moraine and plotted its new position. A further set of vertical aerial photographs of the Yakataga district were taken in 1954 by Aero Service Corporation. These photographs gave still another position of the rock-fall moraine and also afforded a means of measuring the amount of movement of other, less conspicuous, features on the glacier during the previous six years.

The three objectives of this paper are: to record the mode of origin, characteristics and several positions of an easily recognizable, unusual morainic feature which has provided a measure of the surface velocity of the Yakataga Glacier since 1938; to record the average surface velocity at fifteen stations on the Yakataga Glacier and its tributaries from 1948 to 1954; to call attention to a simple photogrammetric technique for study of glacier movement which is applicable in Alaska and other regions.

II. THE YAKATAGA GLACIER

The Yakataga Glacier occupies a steep-walled valley in the Robinson Mountains on the north coast of the Gulf of Alaska, at lat. 60° 10' N., long. 142° 08' W. (Fig. 1, p. 127). The Robinson Mountains lie between the great piedmont lobes of the Malaspina and Bering Glaciers and

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themselves give rise to a major part of the Guyot Glacier and to many smaller valley glaciers. The Yakataga Glacier basin and the adjoining region are shown on the Bering Glacier quadrangles (A-3 and A-4 on scale 1:63,360; and 1:250,000).

The main trunk of the Yakataga Glacier is 21 km. (13 mi.) long and from 0.8 to 3.6 km. wide; it descends at a uniform slope from 1130 m. altitude to 150 m. The terminus is 9 km. inland from the nearest point on the coast. The rock and ice divides at the head of the glacier basin (Fig. 2, p. 124) have an average altitude of about 2100 m. and a maximum altitude of 2573 m. The total drainage area of the Yakataga Glacier basin is about 236 km.² (91 sq. mi.), of which about 72 km.² is covered by ice below the firn line and about 60 km.² is covered by ice and permanent snow above the firn line. The average altitude of the firn line from 1948 to 1954 ranged from about 1065 m. (3500 ft.) on north-facing slopes to about 1280 m. on south-facing slopes.

Pertinent weather data for two stations on the Gulf of Alaska are summarized in Table I.

TABLE I. SUMMARY OF WEATHER RECORDS AT THE YAKATAGA AND YAKUTAT STATIONS, ALASKA (From "Climatological data; Alaska" and unpublished records of U.S. Dept. of Commerce, Weather Bureau)

YAKATAGA AIRFIELD, 1944-54						
<i>Temperature</i>						
Av. annual temp.	..	..	..	..	..	4.3° C. (39.7° F.)
Av. days/year with min. temp. 0° C. or below	..	..	..	..	..	162
Av. days/year with max. temp. 0° C. or below	..	..	..	..	..	38
<i>Precipitation</i>						
Av. annual total precipitation	..	..	..	..	..	284 cm. (112 in.)
Av. annual snowfall	..	..	..	..	..	274 cm. (108 in.)
YAKUTAT AIRPORT, 1949-54						
Av. clear days/year	..	..	..	..	..	41
Av. partly cloudy days/year (sky cover 40-70 per cent)	..	..	..	..	..	45
Av. cloudy days/year	..	..	..	..	..	279

The Yakataga Airfield is located on the coast at an altitude of 8 m. and 15 km. south-west of the glacier terminus. Data on cloudiness are given for Yakutat, which is on the coast and about 160 km. south-east of the Yakataga Glacier. In the upper part of the Yakataga Glacier basin the mean annual temperature is undoubtedly lower and the snowfall higher than at the coastal weather stations; however, the total precipitation and the percentage of cloudiness may be slightly lower than on the coast.

In the summer and early autumn, narrow bands of morainic debris appear just below the firn line on the main trunk and some tributaries of the Yakataga Glacier (Fig. 2). From a distance the lower two-thirds of the main trunk appear to be almost completely veneered by an ablation moraine. Much clear ice is exposed except in the lowest 3 km. of the glacier, which is largely covered by scattered low bushes to dense brush and a spruce forest near the terminus (Fig. 3, p. 124). On the inner face of the terminal moraine and adjacent part of the glacier are 30 cm. (12 in.) diameter spruce trees, indicating that the lower end of the glacier has been inactive for at least the past fifty years. It is known that the Guyot and Bering Glaciers attained maxima near the end of the last century and that their fronts have retreated intermittently since about 1904.

The Rock-fall Moraine

The earliest known record of the "rock-fall moraine" feature is an oblique aerial photograph taken in 1938 (Fig. 2). At some unknown time before 1938 a large mass of sedimentary rock fell from the cliffs at the glacier head on to its surface. A closer range aerial photograph taken in October 1938 provides the earliest record suitable for plotting the position and shape of the rock-fall moraine, which then consisted of a debris tongue 1300 m. long and 300 m. wide. A

conspicuous ridge formed the front of the tongue and extended back along the lateral margins for at least half the length of the tongue. Low longitudinal ridges extended from the root to the lateral margins and nearly to the front of the tongue. The photograph shows faintly what appear to be low concentric ridges inside the marginal ridge at the tip. The shape of the rock-fall moraine at *this stage, the preservation of the longitudinal and crescentic ridges formed when the debris slid out on the ice, and the fact that the debris still extended to or nearly to the base of the cliff, all indicate that the rock fall occurred not more than one or two years before the 1938 photographic record.*

In 1948 the rock-fall moraine shown on vertical aerial photographs consisted of an elongate, teardrop-shaped, debris-covered ridge enclosing a relatively flat debris-covered area, about 1340 m. long and 260 m. in maximum width. These photographs show strikingly the superposition of the rock-fall moraine on the normal medial moraine pattern of the glacier.

When the writer and R. C. Ellis re-examined and photographed the rock-fall moraine in

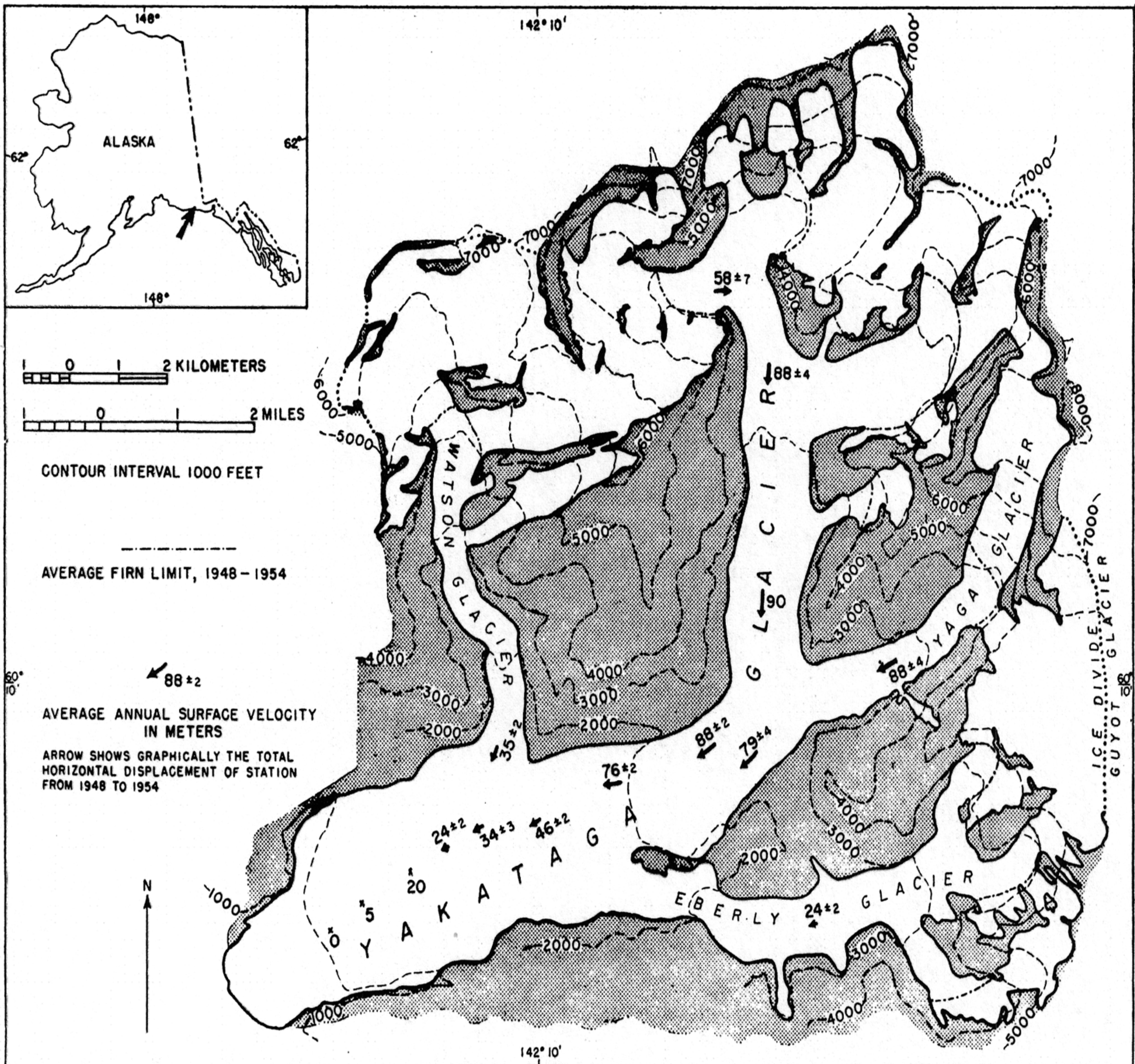


Fig. 1. Map of the Yakataga Glacier showing average annual surface velocity from 1948 to 1954. The land areas in the extreme north of the map are approximate only. Contour interval 1000 ft. (304.8 m.)

July 1952 it had about the same size and shape as in 1948, although it had moved about 365 m. farther down the glacier. The enclosing ice-ridge, thinly mantled by debris, in 1952 stood 3-12 m. above the general level of the glacier surface. The rock debris on and within the ice ridge was much coarser in average size than the debris forming the medial moraine ridges on which the rock fall was superimposed.

The vertical photographs taken in August 1954 provide the most recent record suitable for plotting the position of the rock-fall moraine. These, together with an oblique aerial photograph (Fig. 4, p. 124) taken a month later by the writer, show little change in the appearance of the rock-fall moraine, except that it was becoming more crescentic in shape as it was carried around a pronounced bend in the glacier.

Fig. 5 (p. 129) shows the outline of the rock-fall moraine as it appeared on 26 October 1938 and 17 August 1954. The relative positions of the front of the rock-fall moraine on 6 September 1944, 12 September 1948 and 20 July 1952, are also indicated.

III. SURFACE VELOCITY

During a period of nearly sixteen years the front of the rock-fall moraine moved a total horizontal distance of 1.8 km. (1.1 mi.), at an average rate of 114 m. (374 ft.) per year. The average surface velocity during the four intervals of observation was as follows:

	<i>Rate of Movement</i>
1938-44	114 meter year
1944-48	152 "
1948-52	97 "
1952-54	72 "

The apparent large increase in velocity from 1944 to 1948, compared with the average rate, may be due to incorrect location of the front in 1944, which was established by the compass-pace method and without the aid of accurate control points. However, it is certain that the moraine front advanced more rapidly from 1938 to 1948 than from 1948 to 1954. Whether this is due to change in position on the glacier or to change in velocity of the entire upper part of the glacier is not known.

The availability of two sets of good vertical aerial photographs and a detailed topographic map makes it possible to measure photogrammetrically the total movement or displacement of other less conspicuous features on the surface of the Yakataga Glacier. On Fig. 1 are plotted the total horizontal displacement and average annual rate of movement (surface velocity) of fifteen stations for the period 12 September 1948 to 17 August 1954. Many features on the main trunk glacier could be identified with certainty on both sets of photographs. Those used for the calculation of surface velocities include the front of the large rock-fall moraine, the front of a small rock-fall moraine (background of Fig. 4), small distinctive irregularities in medial moraines, ogives (middle foreground of Fig. 2) and clumps of brush near the glacier terminus.

The results of the measurements for the interval 1948-54 are summarized graphically in Fig. 6 (p. 129), which shows the average surface velocity and longitudinal profile along the medial line of the main trunk and west fork of the Yakataga Glacier from the terminus to the firn line. The surface velocity in the upper half of the main trunk was fairly constant, but it decreased rapidly from 88 m. per annum to zero in the part 2.3 km. to about 11 km. above the terminus. The surface of the lower 2.3 km., which is covered by brush and trees, showed no appreciable movement during this interval.

IV. METHOD OF MEASUREMENT

The rates of movement given in Fig. 1 were measured by a simple method suggested by B. H. Kent, photogeologist of the U.S. Geological Survey. For each feature that was used as a

station one or more reference lines were drawn on each set of photographs between valley-wall points identifiable on both the 1948 and 1954 photographs. The terminal points for each reference line were located near the margins of the glacier at approximately the same altitude as the station on the glacier, and as far as possible were so located that the connecting line was normal to the direction of movement of the station and fell between the 1948 and 1954 positions of the station. On each set of photographs the horizontal distance of the station from the reference line was measured to the nearest hundredth of an inch. These measurements at the photograph scales were then converted to true scale using ratios determined by measuring the photograph distance and map distance between two points in the vicinity of and at approximately the same altitude as the station.

For most stations from two to five sets of measurements were made from the same number of different reference lines. The resulting range of measurements about the average is indicated in Fig. 1 by the \pm figure. The variation in measurements by this method is believed to be due principally to errors in locating photograph reference points on the map.

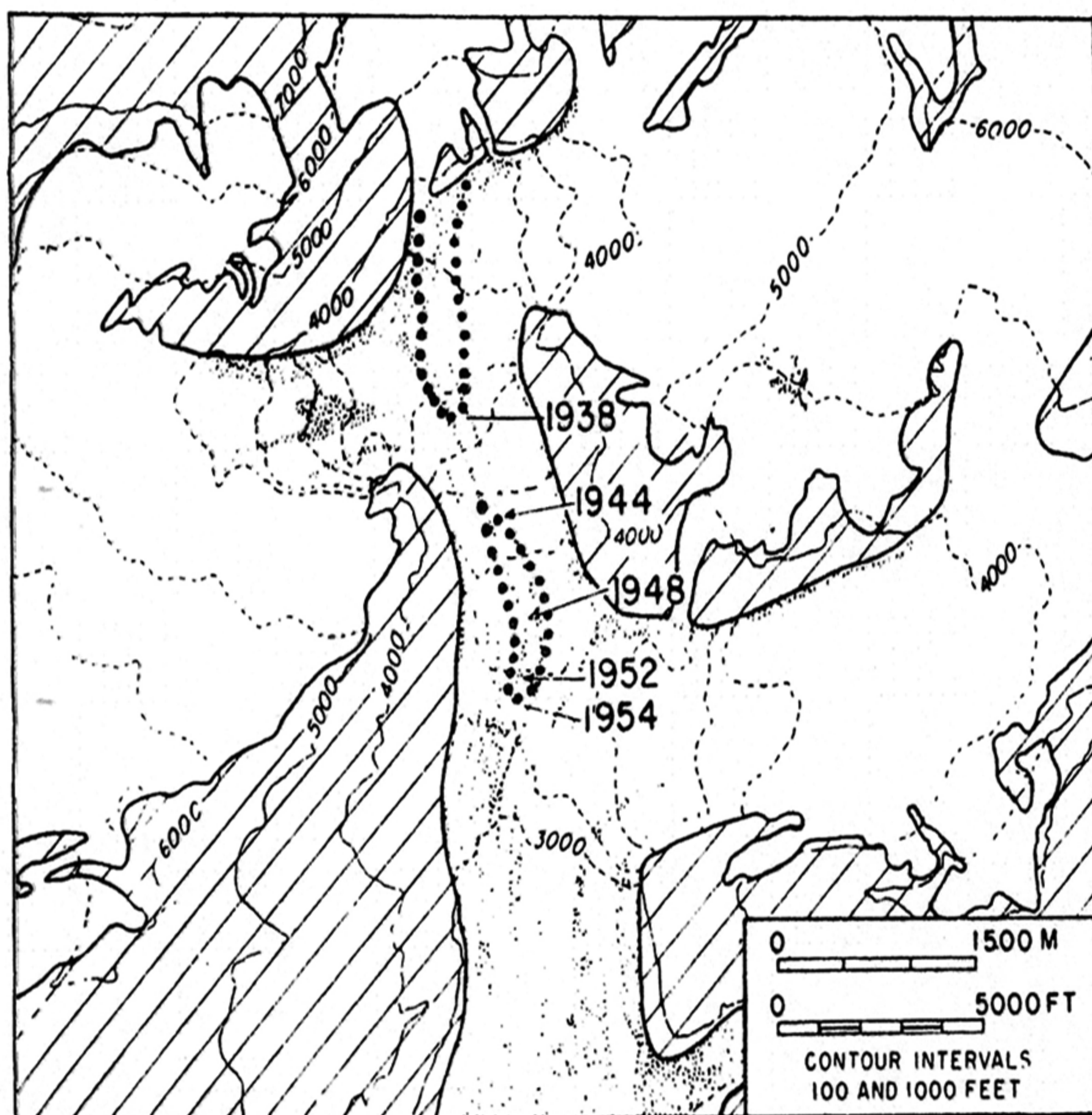


Fig. 5. Rock-fall moraine at the head of the Yakataga Glacier. Heavy dots represent the rock-fall moraine in 1938 and 1954; point of arrow shows position of the front in 1944, 1948 and 1952; light dots represent normal ablation moraine. The land areas in the extreme north are approximate only

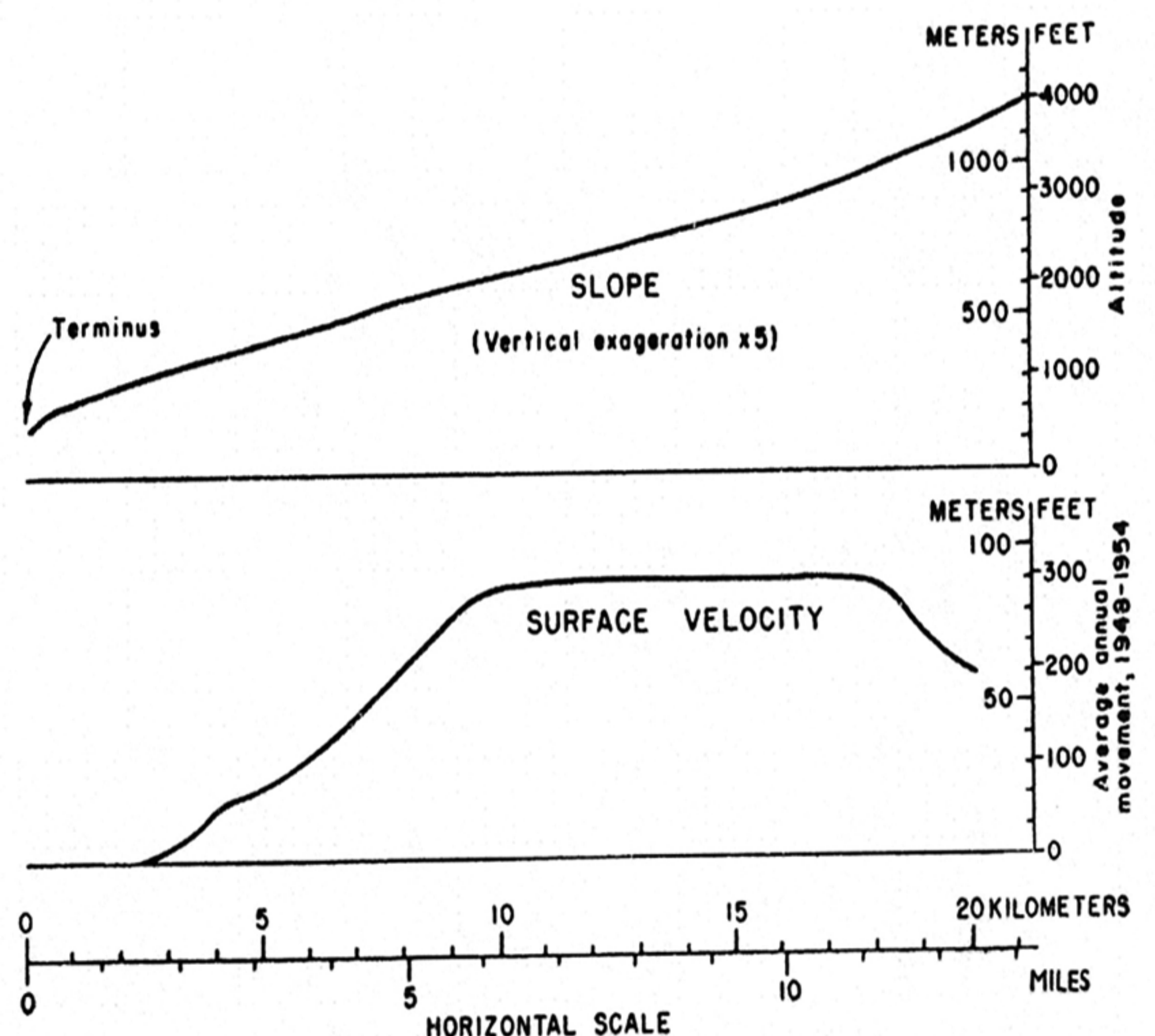


Fig. 6. Longitudinal profiles of the Yakataga Glacier. (Average surface velocity from 1948 to 1954, compared with slope.) The firn line is at 4000 ft.

V. APPLICATIONS OF TECHNIQUE

Measurement of the surface velocity of a glacier by photogrammetric determination of the amount of displacement of natural features on the ice surface relative to the valley walls provides a useful tool for studying the rate and nature of glacier movement in Alaska and possibly in other areas where glaciers extend into a zone of relatively temperate climate. Hitherto time-lapse ground or aerial photography has been utilized in Alaskan glacier studies mainly to determine changes in the surface height of a glacier or its terminal position. This gives a measure of the balance between forward movement and wastage rather than the rate of movement.

The first systematic aerial photography in Alaska was carried out in 1926 by the U.S. Navy in co-operation with the U.S. Geological Survey¹. Since that time, largely in conjunction with the accelerated mapping program during World War II and the postwar period², virtually all of the approximately 20,000 square miles (52,000 km.²) of Alaska that are covered by glaciers have been photographed from the air, and much of this area has been photographed two or more times. Therefore for many Alaskan glaciers there are now available two or more sets of aerial photographs taken over intervals ranging from a few years to as many as thirty years. These photographs, supplemented by ground photographs and measurements made in the field, afford many opportunities for applying the technique described here.

VI. ACKNOWLEDGEMENTS

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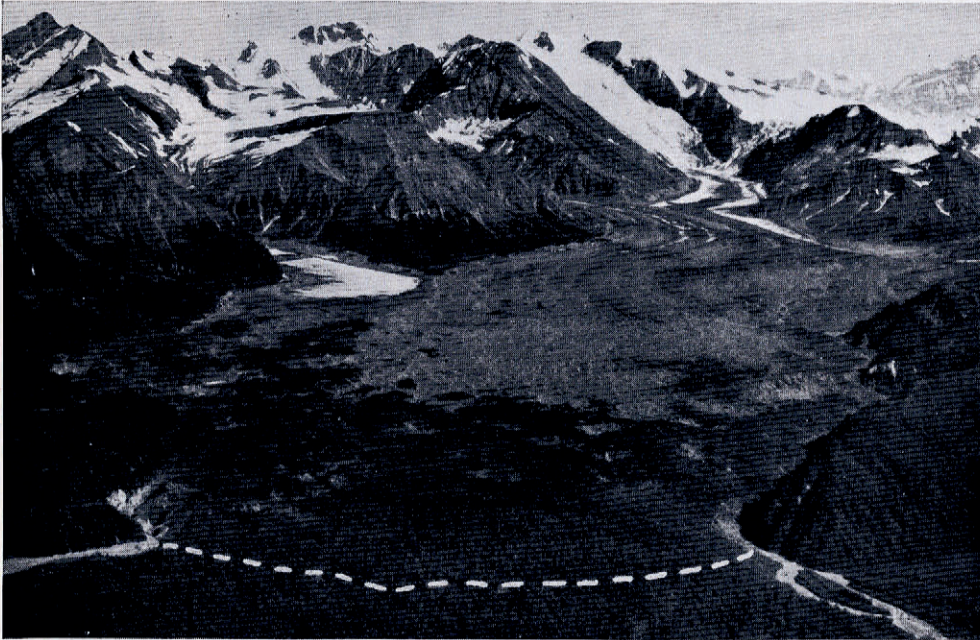


Fig. 2 (top). Upper part of the Yakataga Glacier. View north showing rock moraine superimposed on medial moraine base of steep cliff in middle view. The valley walls are composed of folded Tertiary sediments. (Photograph by Bradford Washburn, 1938)

Fig. 3 (centre). Lower part of the Yakataga Glacier showing ice surface covered with vegetation and ablation moraine. Terrain outlined by dashed line in foreground. (Photograph by Bradford Washburn, 1938)

Fig. 4 (bottom). Oblique aerial view of rock moraine on the Yakataga Glacier. (Photograph by Bradford Washburn, September 1954)