# GLACIERS OF THE WASHINGTON CASCADE AND OLYMPIC MOUNTAINS; THEIR PRESENT ACTIVITY AND ITS RELATION TO LOCAL CLIMATIC TRENDS

*By* RICHARD C. HUBLEY
(University of Washington, Seattle)

ABSTRACT. Between 1953 and 1955, 73 glaciers in the Olympic and Cascade Mountains of Washington State have been investigated to determine their present activity. 50 of these glaciers are now advancing at rates from 3 to 100 m. or more per annum. Of the remaining 23, 22 glaciers either demonstrate clear evidence of increasing thickness, or have remained so heavily snow-covered at the end of the ablation season that it has not been possible to locate their limits.

The present glacier growth, which appears to have started about 12 years ago, represents a radical change from conditions during the previous 20 years when glaciers of the Olympics and Cascades without exception were shrinking rapidly. An analysis of local climatic data demonstrates a present trend toward a cooler, wetter climate in western Washington. The ten year running mean annual temperature at Tatoosh Island off the Washington coast has decreased approximately 0·8° C. from the period 1934–1943 to the period 1945–1954. In the same interval of time the ten year running mean annual precipitation at Tatoosh has increased about 38 cm., and during the last decade has reached its highest value since the period 1898–1907.

ZUSAMMENFASSUNG. Zwischen 1953 und 1955 sind 73 Gletscher in den Olympic und Cascade Mountains des Staates Washington untersucht worden, um ihre gegenwärtige Tätigkeit festzustellen. Fünfzig dieser Gletscher bewegen sich jetzt mit einer Geschwindigkeit von 3 bis 100 m. oder mehr pro Jahr vorwärts. Von den übrigen 23 Gletschern zeigen 22 entweder ganz klar eine zunehmende Dichte auf, oder sie sind am Ende der Ablationssaison so tief mit Schnee bedeckt geblieben, dass ihre Grenzen nicht ausfindig gemacht werden konnten.

Das gegenwärtige Anwachsen der Gletscher, das vor etwa 12 Jahren begonnen zu haben scheint, entspricht einem radikalen Wandel der Zustände der vorherigen 20 Jahre, in denen die Gletscher der Olympic und Cascade Mountains ohne Ausnahme in schnellem Rückgang begriffen waren. Eine Analyse der lokalen klimatischen Verhältnisse lässt eine gegenwärtige Neigung zu einem kühleren, feuchteren Klima im Westen Washingtons erkennen. Die zehn Jahre laufende Durchschnittstemperatur auf der Insel Tatoosh gerade abseits der Küste von Washington hat seit der Periode 1934–1943 bis zur Periode 1945–1954 um ungefähr 0,8° C. abgenommen. In dem gleichen Zeitabschnitt hat sich der zehn Jahre laufende Durchschnittsniederschlag auf Tatoosh um 38 cm erhöht und hat im letzten Jahrzehnt seinen Höchstwert seit der Periode 1898–1907 erreicht.

## I. INTRODUCTION

Approximately ninety per cent of the total glacierized area in the continental United States is located in the Cascade and Olympic Mountains of Washington State in the north-west corner of the country. Glacier studies in the Cascades and Olympics have been very few and, in fact, the most heavily glacierized sections of the Northern Cascade ranges remain largely unexplored. In the last few years, interest in glaciers of this region has been aroused by discovery of growth of Nisqually Glacier on Mt. Rainier, and advance of Coleman Glacier on Mt. Baker[1, 2].

The purpose of this paper is to present preliminary results of two related investigations started in 1953: (1) To determine whether increased activity on Nisqually and Coleman Glaciers was an isolated, anomalous phenomenon, or was indicative of a general reversal in glacier activity from the widespread shrinkage of glaciers in the Olympics and Cascades which has been the pattern for the past several decades. (2) To analyze local meteorological data for any indications of recent climatic trends which might relate to the present glacier activity in the Olympic and Cascade Mountains.

The large number of glaciers in the Olympic and Cascade ranges precludes the possibility of investigating each glacier individually. For this reason, small but diversified groups of glaciers representative of the high Cascade volcanoes, the Northern Cascade ranges, and the Olympic Mountains were selected for observation.

## II. GENERAL DESCRIPTION OF GLACIERS AND THEIR PRESENT ACTIVITY

1. *High Cascade Volcanoes.*—Glaciers of the high volcanoes * cover an aggregate area estimated at 190 $km.^2$. In general, the glaciers are very active, steep gradient valley tongues originating from high *névé* fields at elevations from 2700 to 4200 m. above sea level. These glaciers appear

* These include Mt. Baker, 3287 m.; Glacier Peak, 3211 m.; Mt. Rainier, 4394 m.; and Mt. Adams, 3754 m. See Fig. 1, p. 670.

https://doi.org/10.3189/002214356793701938 Published online by Cambridge University Press

to be particularly sensitive to meteorological conditions during the warm part of the year. With their steep slopes and elevated positions above surrounding topography, all but the north-facing glaciers are well exposed to solar radiation. During a particularly wet year, however, the higher parts of these glaciers continue to receive snow accumulation throughout the summer months.

Since 1953, at least five glaciers on Mt. Rainier and six on Mt. Baker have been visited by various observers. Two glaciers on Mt. Rainier, and four on Mt. Baker have been found advancing. Although their termini are not yet advancing, the remaining three glaciers on Mt. Rainier and two on Mt. Baker all demonstrate growth through such qualitatively observable evidence as expansion of icefalls, and the rise of ice surface levels relative to lateral bedrock faces.

In September 1955, the nine largest glaciers on Glacier Peak were aerially photographed, and the positions of their termini compared with termini positions shown in 1950 aerial photographs taken of Glacier Peak by the U.S. Geological Survey. Eight of the nine glaciers are advancing. The ninth glacier was so deeply buried under firn in both the 1950 and 1955 photographs that it

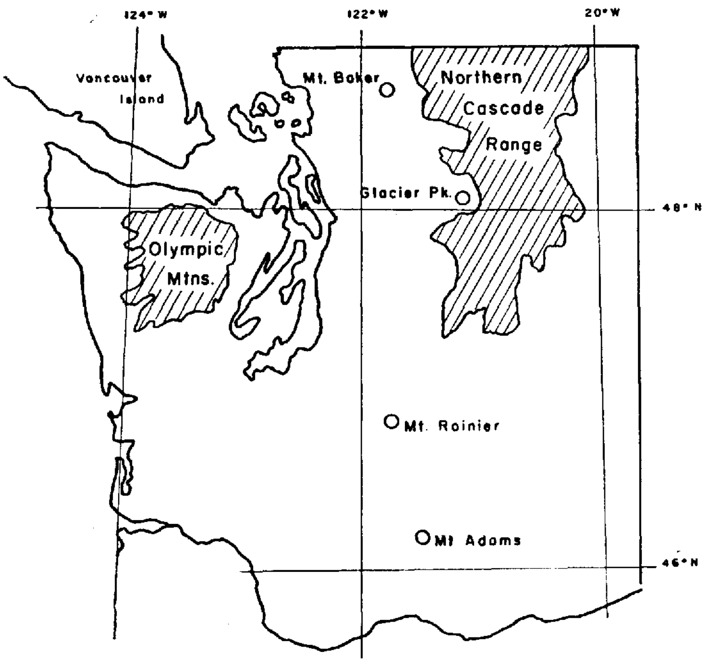



*Fig. 1. Part of Washington State showing the locations of the high volcanoes, Northern Cascades and Olympic Mountains*

was not possible to locate the positions of the terminus during those years. It was possible to locate four of the positions of the termini with sufficient accuracy in both the 1950 and 1955 photographs to compute their advances. The least of the four showed 180 m. advance for the five year period, while the greatest, measured for the Chocolate Glacier (Figs. 2 and 3, p. 678) was 400 m.

2. *Northern Cascade Ranges.*—Northern Cascade glaciers cover an aggregate area conservatively estimated at 320 km.[2]. This group includes many hundreds of small cirque and hanging glaciers, and a few very large cirque glaciers and ice aprons, some with valley tongues (Figs. 4 and 5, p. 679). The glaciers originate at elevations from 1950 to 2700 m., and vary considerably in steepness and rates of movement. During the past decades of retreat, many glaciers in these mountains disappeared entirely, or became totally stagnant. With the onset of a period of glacier growth, therefore, many of these glaciers must first build up an appreciable thickness of ice before advance can occur.

In September 1955, aerial photographs were taken of 48 glaciers in the Northern Cascades. Most of the 48 glaciers appear in aerial photographs taken in 1950 by the U.S. Geological Survey,

https://doi.org/10.3189/002214356793701938 Published online by Cambridge University Press

and the remainder were photographed from the ground in 1953: Comparison of the earlier and later photographs show that 33 of the 48 glaciers are advancing. Of the remaining 15 glaciers, one terminates on a steep slope, and is avalanching into the valley below; eight glaciers are nearly or completely covered with firn so that the positions of their termini cannot be determined; and six are as yet stagnant. It was possible to fix the distances over which four glacier termini advanced in the past five years. Values are given in Table I.

TABLE I

| *Glacier* | *Length in 1950 (Km.)* | *Area in 1950 (Km.²)* | *Advance between 1950 and 1955* (Meters)* |
|---|---|---|---|
| *Northern Cascades* | | | |
| Ladder Creek | 1·5 | — | 60 |
| Inspiration | 4·8 | 11·5 | 180 |
| N.E. side of Eldorado Peak (unnamed) | 1·8 | 2·6 | 235 |
| Boston | 6·7 width<br>2·4 max. length | 8·3 | 560** |
| *Glacier Peak* | | | |
| Kennedy | 3·0 | — | 180 |
| West side of peak (unnamed) | 3·0 | — | 200 |
| Tower | 3·3 | — | 220 |
| Chocolate | 4·7 | — | 400 |

* The values given here are believed to be correct within ten per cent.
** The amount of advance varies considerably from one part of the 6·7 km. wide front to another. The tabulated value is the maximum.

3. *Olympic Mountains*.—Although the glacierized area in the Olympic Mountains is very small (estimated 65 km.²), the Olympic glaciers are in some ways the most unique and interesting in the United States. Unlike the Cascades, the Olympic ranges do not form an elongated chain of mountains; rather they are massed in the center of a peninsula with the Pacific Ocean to the west, the Straits of Juan de Fuca to the north, Puget Sound and its lowlands to the east, and a low, broad river valley to the south (Fig. 1). Winters in the Olympics are mild but extremely wet. Summers are very cool and generally damp. In this highly maritime environment, glaciers are formed at lower elevations than elsewhere in the Northern Hemisphere at similar latitudes. The largest Olympic glaciers head at elevations from 1800 to 2250 m. and have low gradient, dynamically active tongues terminating at elevations from 1000 to 1350 m. There are also many cirque glaciers in the Olympics, several of which lie entirely below 1500 m.[3]. Because of their low altitudes, these glaciers are particularly sensitive to wintertime temperature fluctuations. During exceptionally warm winters, the atmospheric freezing level frequently rises above the glaciers so that precipitation, though it be plentiful, falls as rain and the glaciers suffer from lack of accumulation.

In the last year, five glaciers in the Olympics have been observed for activity. Three of these are advancing, though at very low rates, and one shows positive evidence of considerable increase in ice thickness up-glacier from its terminus. Insufficient data are available on the fifth glacier to draw any conclusions as to its activity. Many of the small cirque glaciers in the Olympics, as well as in the Cascades, have remained completely snow covered throughout the past three ablation seasons.

## III. RECENT CLIMATIC TRENDS IN WESTERN WASHINGTON AS RELATED TO GLACIER GROWTH

The investigation of climatic trends is difficult in this region because few climatological stations have records over any appreciable time period. Furthermore, most station sites have been changed during the stations' periods of record. For the present work, one station was found to have a sufficiently long record unaffected by changes in station site for a reliable analysis of temperature and precipitation trends. This station is Tatoosh Island, located off the north-west coast of Washington near the mouth of the Straits of Juan de Fuca.

In Fig. 6 (p. 673) are shown the running ten year mean annual temperatures for Tatoosh Island from the beginning of the temperature record. In Fig. 7 are shown the running ten year mean annual precipitation amounts for Tatoosh from the beginning of the precipitation record.

It is not possible to relate quantitatively the observed glacier growth to the present precipitation and temperature trends at Tatoosh as glacier growth or shrinkage has no simple relationship with these two factors. Changes in wind speeds, prevailing wind directions, degree of cloudiness and other factors are also exceedingly important in causing changes in glacier regime. Qualitatively the present period of glacier growth corresponds to a period of decreasing temperatures and increasing precipitation in the Tatoosh meteorological record. This trend toward a cooler, wetter climate first appears in the Tatoosh records about 1943. The first sign of glacier growth was found by Arthur Johnson of the U.S. Geological Survey in 1944 on Nisqually Glacier[4].

Upper air temperatures measured by radiosonde and airplane flights were also used for analysis of climatic conditions associated with the present glacier activity. In Table II are given the number of months out of each year for the past two decades during which the free air temperature at 1500 m. over Tatoosh Island averaged 0° C. or lower, and during which the free air temperature at 1500 m. averaged 10° C. or higher. It is assumed that the pattern of monthly

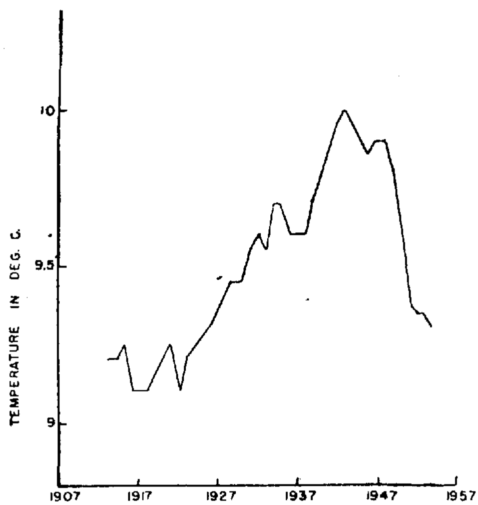
TABLE II

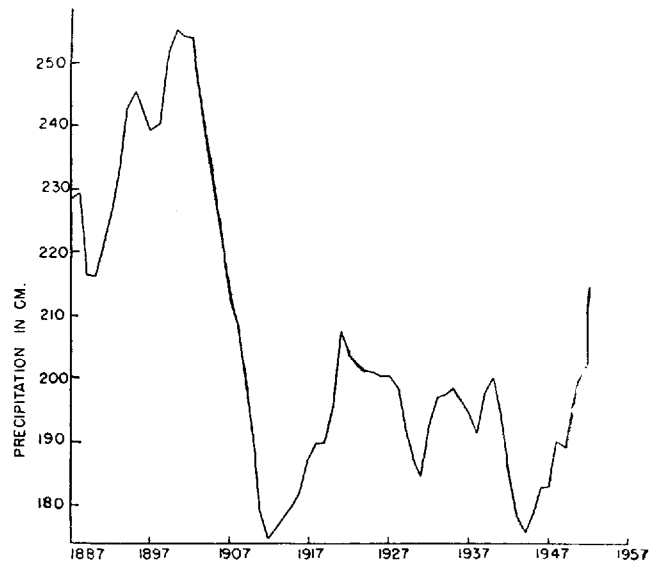
| *Year* | *No. of months av. temp. at or below* 0° C. | *No. of months av. temp. at or above* 10° C. | *Year* | *No. of months av. temp. at or below* 0° C. | *No. of months av. temp. at or above* 10° C. |
|---|---|---|---|---|---|
| 1935 | 1 | 3 | 1945 | 5 | 2 |
| 1936 | 3 | 2 | 1946 | 5 | 1 |
| 1937 | 3 | 3 | 1947 | 1 | 1 |
| 1938 | 2 | 4 | 1948 | 5 | 0 |
| 1939 | 2 | 3 | 1949 | 4 | 1 |
| 1940 | 1 | 3 | 1950 | 5 | 3 |
| 1941 | 2 | 2 | 1951 | 4 | 4 |
| 1942 | 3 | 3 | 1952 | 5 | 4 |
| 1943 | Missing | Missing | 1953 | 5 | 1 |
| 1944 | 4 | 3 | 1954 | 3 | 0 |

Above data calculated from free air temperatures 1500 meters above Tatoosh Island.

temperatures at corresponding elevations in the mountains is similar to that shown in the free air data taken over Tatoosh. On this basis, the data indicate that: (*a*) the length of the ablation season has decreased; (*b*) monthly mean temperatures during the ablation season have decreased; and (*c*) the number of months during which snow accumulates on the glaciers has increased. The latter factor suggests that during the past several years the increase in snow accumulation on the glaciers has been greater than is indicated by the increase in annual precipitation alone.

An attempt was made to obtain a specific correlation between meteorological data from Tatoosh and annual rate of retreat of the Blue Glacier in the Olympic National Park, as measured by the National Park Service. If the terminal ice of a glacier is stagnant, i.e., transport of ice by glacier motion is zero at the terminus, the rate of retreat of the terminus will be a function only of ice thickness and rate of ice ablation at the terminus. If the thickness of ice at the terminus does not vary greatly from year to year, the rate of retreat can provide a significant record of changes in the net energy received from the sun and atmosphere at the terminus during the ablation season. Until 1954, the Blue Glacier had a retreating snout which fulfilled to some extent the above conditions. Fig. 8 (p. 673) demonstrates the relation between rate of retreat of the Blue Glacier snout and meteorological data from Tatoosh Island. Located in a deep canyon, the terminal region of this glacier is well protected from regional winds. Melting at the terminus is produced primarily by radiation and by turbulent transfer of heat from a well-defined, local down-glacier wind. Intensities of both the down-glacier wind and back radiation from atmospheric water vapor and clouds depend on difference between glacier temperature and free air temperature. There is, therefore, a basis to expect some correlation between melting at the terminus and free air temperature. The solid line in Fig. 8 shows annual rate of retreat of the Blue Glacier terminus from 1938 to 1954 in meters per year. The dashed line shows excess of free air temperature above freezing in degree-months at 1500 m. A direct correlation between rate of retreat and temperature excess is apparent up to the year 1947. Here the correlation breaks down. It is likely that after this time, increase in winter accumulation of snow over the terminal ice probably shortened considerably the period of



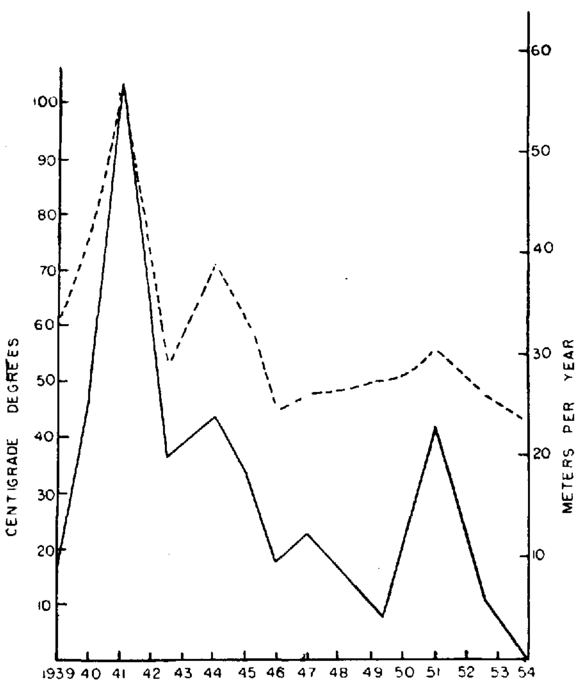




*Fig. 6 (above left). Running ten year mean annual temperatures at Tatoosh Island, Washington. Along the ordinate is plotted the last year of each ten year mean*

*Fig. 7 (above right). Running ten year mean annual precipitation values at Tatoosh Island, Washington. Along the ordinate is plotted the last year of each ten year mean*

*Fig. 8 (below). Annual rate of retreat of Blue Glacier as related to temperature. Solid line, annual retreat in meters. Dashed line, annual temperature excess over freezing in degree-months*



https://doi.org/10.3189/002214356793701938 Published online by Cambridge University Press

time each year during which the terminal ice was exposed to melting. An additional influence may well be change in the physiographic environment of the snout as it retreated up-valley, for the physiographic environment exerts a strong influence on the energy transfer at the ice surface. Changes in thickness of the terminal ice might also have been a factor. Had simultaneous measurements been available from other stagnant termini in the vicinity of the Blue Glacier, comparison of data might have allowed separation of fluctuations in retreat of termini related to general meteorological conditions from those resulting from local physiographic influences. Since 1954 the terminus of the Blue Glacier has advanced. The effect of this advance on further analysis of annual rates of change in position of the terminus will be greatly to complicate the situation. It will now be necessary to consider the amount of ice delivered each year to the terminus by flow from the upper portions of the glacier—a factor not necessarily related to meteorological conditions in a specific year.

## IV. Conclusions

Observations have clearly demonstrated that a period of general growth of glaciers in the Olympic and Cascade Mountains in Washington State is in progress. Analysis of climatic data from Tatoosh Island indicates that in the most general terms, the glacier growth is associated with a present trend which began about twelve years ago toward a cooler, wetter climate. The effect on glaciers of this trend has been to increase the length of the annual accumulation season and the rate of accumulation. Conversely, the length of the ablation season has decreased as have air temperatures during the ablation season.

The extent of the area along the Pacific Coast outside of Washington State within which general growth of glaciers is occurring is not definitely known. Positive evidence of glacier growth has been found to the south on Mount Shasta in northern California. Analysis of meteorological data from Juneau, Alaska, approximately ten degrees of latitude north of Washington State, has not shown any pronounced trend toward a cooling of the climate such as that found in the Tatoosh records. Firn limits in the Juneau Ice Field, however, have been observed to remain at unusually low elevations on the glaciers during the past two ablation seasons. Further reconnaissance surveys of glacier activity are needed, particularly in the Coast Range of British Columbia. In the meantime, groundwork has been laid during the 1955 summer field season for detailed, quantitative measurements of the regimen of the Blue Glacier in the Olympic Mountains. These studies include annual budget measurements and micrometeorological and glacier kinematics studies. Continuation of this program should lead to a much better understanding of what is happening to the glaciers in this area at present. Results of detailed studies on the Blue Glacier in 1955 will appear in a later paper.

## V. Acknowledgements

This work has been made possible by a grant from Agnes Anderson Research Funds, University of Washington.

Cooperation of the Olympic National Park Service on phases of this investigation carried out in the Olympic Mountains is gratefully acknowledged.

*MS. received October* 1955

## REFERENCES

1. Harrison, A. E. Fluctuations of the Nisqually Glacier, Mt. Rainier, Washington, since 1750. *Journal of Glaciology*, Vol. 2, No. 19, 1956, p. 675.
2. Bengtson, K. B. Activity of the Coleman Glacier, Mt. Baker, Washington, U.S.A., 1949–1955 [in press].
3. Earlier descriptions of the glaciers of the Olympics have been published in Matthes, F. E., *and others*. Report of Committee on Glaciers, 1945. *Transactions of the American Geophysical Union*, Vol. 27, No. 2, 1946, and in Danner, W. H. *Geology of Olympic National Park*. Seattle, University of Washington Press, 1955.
4. Harrison, A. E., *op. cit.*

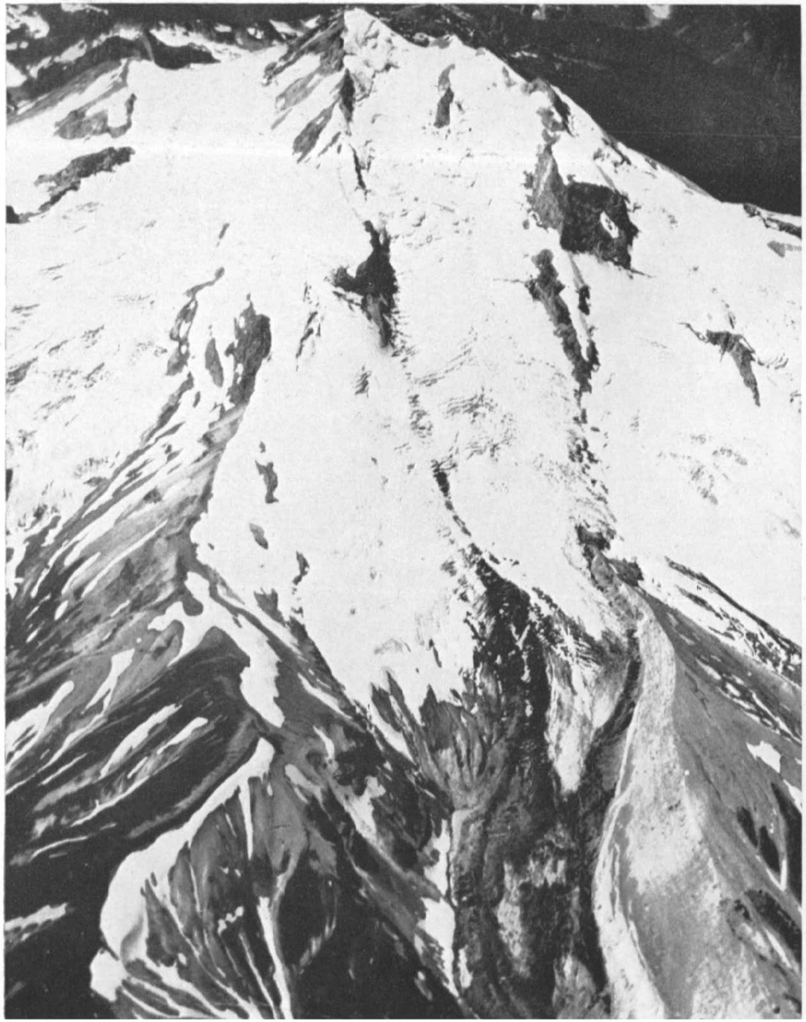


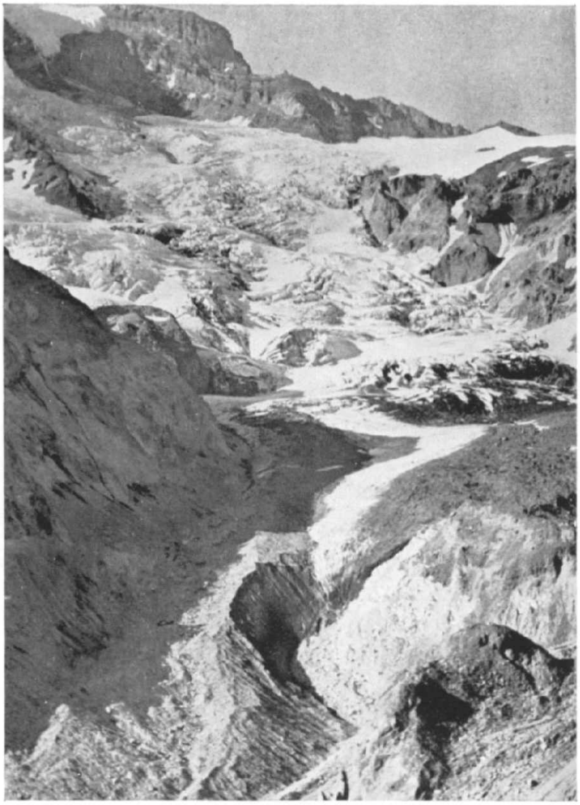
*Fig. 2. (See p. 670.) Chocolate Glacier in August 1939. By the late 1940's, the dirt covered, stagnant ice on the lowest part of the glacier had sloughed off, and was melting rapidly*

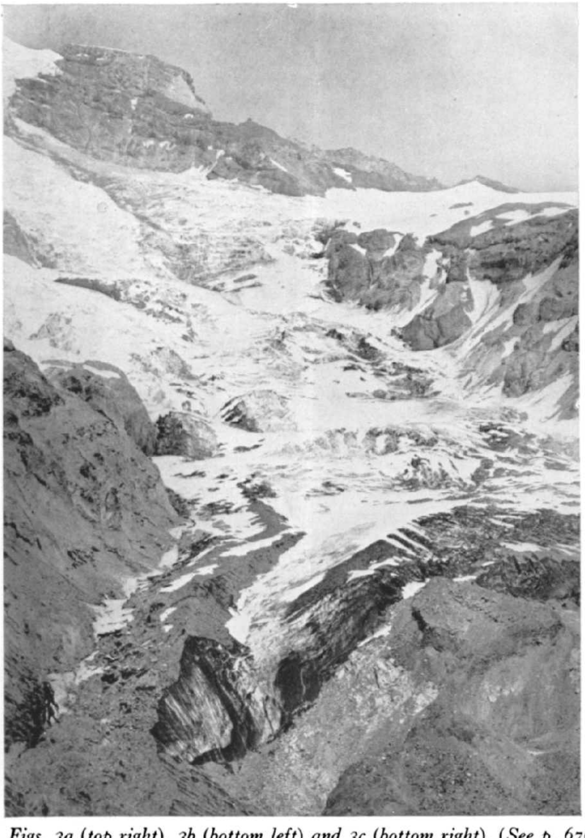
*Fig. 3. Chocolate Glacier in September 1955. With an average rate of advance of 80 m. per year from 1950 to 1955, the glacier terminus has moved forward to a position very near that occupied by the stagnant terminus in 1939*

*Fig. 4. (See p. 670.) Chikamon Glacier, Northern Cascades, in September 1955. The ice apron has advanced appreciably since the glacier was last visited and photographed in 1953. Activity on the icefall in the valley tongue has increased, however the terminus of the tongue is as yet stagnant*

*Fig. 5. (See p. 670.) Boston Glacier, Northern Cascades, in September 1955. The two visible tongues, one to the right and one to the left of the picture center have formed completely since 1950. Maximum advance of the glacier front was 560 m. between 1950 and 1955*

*Fig. 2. (See p. 675.) View of Mt. Rainier and the Nisqually Glacier from Nisqually Vista, a point on the rim of the canyon just above the terminus of the glacier*





*Figs. 3a (top right), 3b (bottom left) and 3c (bottom right). (See p. 676.) Telephoto views of the ice wave on the Nisqually Glacier in 1951, 1952 and 1953 respectively. [illegible] ped rock in the lower right corner in Fig. 3a*