The margin of the ice cap in east Greenland is not well known, but from the photographs appearing in recent publications of *Meddelelser om Grønland*[3] it would appear that many of the glaciers of east Greenland have high rock thresholds at the ice cap margin. If this proves to be the case, the starvation of these glaciers by a process of being cut off from their ice cap source may be a much more important factor in their recent recession than has been previously recognized. The geophysical work of the British North Greenland Expedition has confirmed the presence of mountain ranges beneath the ice cap, parallel to the western mountain range of Dronning Louise Land, and as our knowledge of the sub-glacial topography of the ice cap increases, we will be better able to understand the nature of the escape routes of the ice as it makes its way eastwards and through the coastal mountains.

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ACTIVITY OF THE COLEMAN GLACIER, MT. BAKER, WASHINGTON, U.S.A., 1949–1955

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Abstract. The Coleman Glacier on Mt. Baker in the State of Washington began to advance about 1949 after a long period of rapid retreat. Since that year the terminus has advanced continuously a total of about 300 m. and considerable thickening of the entire glacier has occurred. The continued advance of the Coleman Glacier and other evidence are interpreted as manifestations of a trend during the last decade towards a slightly cooler and moist climate in the north-west of the United States.

Zusammenfassung. Der Coleman Glacier auf Mt. Baker im Staate Washington begann um 1949 herum nach einer langen Periode rapiden Rückgangs vorzurücken. Seit 1949 ist die Spitze ununterbrochen bis auf ungefähr 300 m. vorgerückt, und der ganze Gletscher ist beträchtlich dicker geworden. Das anhaltende Vorrücken des Coleman Glacier und weitere Tatsachen werden als Manifestation dafür ausgelegt, dass sich im letzten Jahrzehnt im Nordwesten der Vereinigten Staaten ein etwas kühleres und feuchtes Klima entwickelt hat.

I. Environment

The Cascade Mountains of north-western Washington State, U.S.A., comprise a range the principal axis of which runs roughly north and south with summit elevations for the most part between 2000 and 2800 m. Severe glacial erosion during former periods of intensive glaciation is partially responsible for the extremely rugged terrain which prevails throughout the range. Rising above the range at various points are volcanoes which have maintained their activity into comparatively recent times. Mt. Baker is such a volcano which to-day rises to an elevation of 3270 m., dominating the Northern Cascade Range.

During the winter months the area receives much precipitation from cyclonic storms moving in from the Pacific Ocean. It also receives some precipitation from the same source during the summer, although most such storms pass well to the northward during the summer months. The area is far enough north that nearly all of the winter precipitation comes in the solid form at elevations above 1000 m. Ample snowfall and cool summers permit existence of small glaciers

Fig. 2. A corrie on the north wall of the upper Budolfi Glacier (Isstrøm)

Fig. 3. Small glaciers spilling from the ice cap through mountain passes on the north side of the Budolfi Glacier (Isstrøm)

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Fig. 1. Composite photograph from Bastile Ridge. Pt. D lies just east of south. Mt. Baker is on the extreme left. The Coleman Glacier terminus is on the right, that of Roosevelt Glacier is on the left. The dotted line shows the approximate position of their termini in 1949. Grouse Ridge is the high snow-covered ridge above Pts. A and D

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Fig. 3(a). Coleman Glacier photographed in 1949 looking approximately north from Pt. A in Fig. 1.

Fig. 3(b). View from the same place taken in 1955. The terminus and the other features are obscured by ice on the north sides of higher ridges at the present time, as well as extensive glacierization on the higher peaks. Mt. Baker itself is completely covered at all times of the year with snow and ice except where glacial erosion has resulted in the formation of interglacial ridges or cleavers of such high relief that snow does not remain on them. The average annual temperature at the Mt. Baker Lodge, elevation 1280 m., is about 4·8° C. and the average annual precipitation is roughly 280 cm. of water [1]. An estimated 80 per cent of the annual precipitation occurs in the solid form at this elevation.

II. Glacierization

Glaciers in the area have, at least until very recently, been following the pattern in evidence the world over—rapid retreat. At the termini of virtually all glaciers on mountains in the area there are large, unvegetated zones which obviously have been very recently cleared of ice. Fresh and unweathered moraines, in favored locations where they have not been destroyed, stand some distance from present termini. In proximity to some of the larger glaciers there are bodies of melting stagnant ice covered with detrital material, and in some cases, vegetation.

On the north-west side of the present summit cone of Mt. Baker and rising to an altitude of about 2900 m. lie the remnants of an earlier, much dissected volcanic cone. The remnants of this cone and older argillaceous rocks beneath it form a long ridge extending radially in a north-westerly direction from the present summit of the mountain with gradually decreasing altitude. The Coleman Glacier mainly occupies the natural depression on the north at the joining of the two cones and also the north side of the radial ridge, known as Grouse Ridge. The Coleman is now separated on the east from the Roosevelt Glacier by a wedge-shaped bedrock ridge dividing their two termini, but the division is somewhat arbitrary because the two glaciers are continuous higher on the mountain and at the turn of the century they were entirely continuous. The entire area appears in the composite photograph of Fig. 1 (p. 710), taken from Bastile Ridge at an elevation of 1500 m.

That part of the Coleman Glacier originating in the saddle between the two volcanic cones and the highest part of the radial ridge comprised, in 1949, the active part of the glacier, and was sufficiently active in 1949 to send moving ice down to an altitude of 1400 m. That part of the glacier originating on Grouse Ridge below about 2400 m. was stagnant in 1949 although it had been moving in the very recent past, as indicated by fresh striations and other ice markings in very easily weathered black shale. The Roosevelt Glacier was also active in 1949, but its terminus was at a higher elevation on the mountain than that of the Coleman.

The Coleman and Roosevelt Glaciers, like other North Cascade glaciers, have until very recently undergone rapid reduction in volume. As recently as 1900 ice filled the major part of the deforested valley shown in Fig. 1; relict ice covered with detrital material and vegetation was still to be seen in this valley in 1955. The termini of both glaciers were feather-edged in 1949 and appeared to be melting back rapidly. Remains of trees protruding at various points from lateral moraines now undergoing dissection by rain water show, however, that this retreat was not the first in recent time.

III. Measurements

In 1949 it was decided to attempt to obtain more quantitative information regarding glacial recession than could be obtained from simple photographs or verbal description by making a periodic survey of the Coleman Glacier. The Coleman Glacier was chosen for the survey in preference to other North Cascade glaciers because it was the most accessible, it was large enough to present little likelihood of complete disappearance, and there existed immediately adjacent to it on the west side up to elevation 1852 m. a ridge of bedrock very convenient for the establishment of permanent fixed points. Only a very small amount of work could be undertaken at the beginning because of the limited resources available, but in the summer of 1949 brass markers of the same

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general type as those employed by the U.S. Geological Survey were embedded in the rock along this ridge at elevations of 1852 m. above sea level at Point "D" and 1504 m. at Point "A" (see Fig. 1). The elevations of these points were carefully determined by means of aneroid altimeters and are believed to be accurate to ±10 m. These points were established as reference points to permit determination of the glacier surface elevation along a line normal to the apparent direction of ice flow, using transit and rod.

Photogrammetric methods were used to map part of the Coleman by Dr. Walther Hofmann in 1952, and the necessary stereoscopic pairs of pictures for mapping the entire glacier by photogrammetry were obtained by the author in 1955. A base line 201·8045 m. in length was established on Bastile Ridge east of the Coleman for this purpose, and it is planned to use photogrammetric methods exclusively in future surveys. Photographs comprising Fig. 1 were taken near the west end of the photogrammetric base line.

The cross profile of the glacier surface at Point "D" has been determined every year since 1949 except 1951 and 1955, and the cross profile at Point "A" has been determined every year except 1951. The cross profile at "D" could not be determined in 1955 because advancing ice had overwhelmed the reference point. All cross profiles obtained for Points "D" and "A" are shown in Fig. 2 (p. 713). It is seen that the elevation of the glacier surface at the upper station has remained essentially constant during the years it has been measured, whereas the elevation of the surface at the lower station has steadily increased. Increase in elevation at the lower station corresponded with advance of the terminus, but no measurements of the terminus position have been made because it lies in an area not safely accessible. The approximate position of the terminus in 1949 is indicated by the dotted line of Fig. 1. The approximate total linear advance since 1949 has been about 300 m. for the main tongue of the Coleman. The thickening in the vicinity of Point "A" can be appreciated by consideration of both Fig. 2 and Fig. 3 (p. 710).

The photograph shown in Fig. 3(a) of the terminus area was taken from Point "A" in 1949, the terminus area being readily visible from "A" at that time. The photograph shown in Fig. 3(b) was taken in the same direction from the same point in 1955. Absence at Point "D" of the spectacular thickening observed at "A" is explained by the thickening responsible for increased activity having reached "D" prior to the first measurement in 1949 and by the increased ice velocity at "D" which surely has accompanied the general thickening. There appeared to have been considerable thickening at "D" since 1954, and it is unfortunate that quantitative measurements could not be made there in 1955.

It is difficult to predict how long or how far the advance will continue. Visits to the upper areas of the mountain in 1954 showed that the accumulation of *névé* was greater than on any previous visit. The photographs making up Fig. 1 were taken on 25 September 1955; they show the glacier to be covered with *névé* above about 1800 m. elevation. About 75 per cent of the area of the glacier has therefore enjoyed a net positive budget for 1955, as very little further rise of the *névé* line will occur this year. Conditions in 1948, 1954, and several other years have been the same or slightly better. Sounds of ice movement were often heard while the photogrammetric work was in progress or when the glacier was being crossed en route to or from the photogrammetric base line. Several very large avalanches at the termini of both the Roosevelt and Coleman were observed as huge ice seracs tumbled to the base of the cliffs now below the termini; the avalanche debris can be seen in Fig. 1. If anything, the advance can be expected to accelerate during the coming year.

IV. Interpretation

Increased activity on the part of other glaciers in the Cascade Range has been noted by the author and several other observers [2, 3, 4]. Some of the increased activity has been as pronounced as that of the Coleman, although no other actually advancing glacier in the Cascades has been observed for as long as has the Coleman. That the increase in activity has been more or less general and that at least in the case of the Coleman it has been sustained over a period of years rules out explaining the increased activity as being due to strictly local weather phenomena, earthquakes, or other local causes. The increased activity must be due to climatic change, affecting an area the extent of which is at present unknown.

Unfortunately no long-term, dependable meteorological records are available for any point near Mt. Baker. The nearest meteorological station at which records have been kept is near the city of Bellingham, Washington, at sea level west of the Cascade Range and about 75 kilometers from Mt. Baker. Even here, variation in technique of taking meteorological readings over the years, change in location of the meteorological station, and the unknown meteorological effects of encroaching civilization make confidence in any conclusion derived from a study of the records impossible. Hubley [2] used meteorological records for Tatoosh Island, Washington, to explain increased activity of the Blue Glacier in the Olympic Mountains and other glaciers in the Cascades. He found the disturbing effects mentioned above to be absent at this station and did find evidence of a distinct cooling trend during the last decade together with a pronounced increase in precipitation for the same period.

It was observed by the author that during the years 1948, 1949, 1950, 1951, 1953, 1954 and 1955 weather conditions in the Cascades were such as to result in an unusually heavy amount of snow remaining on the ground at elevations above 1200 m. at the end of the accumulation period.

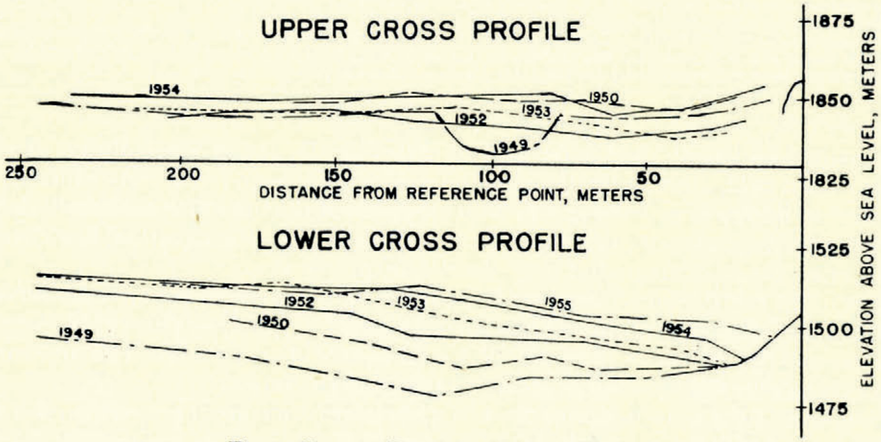

Fig. 2. Cross profiles of the Coleman Glacier

There also seemed to be a superabundance of cool, cloudy weather during the summers of most of the same years.

During the last decade the climate of the State of Washington, and perhaps of a greater area, has become cool and moist enough so that the Coleman Glacier has ceased retreating and has advanced a considerable distance. The change in climate causing the advance has not been great, and the regime of this glacier is such that an extremely small climatic change could result in either accelerated advance or a return to conditions under which recession would take place.

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