Institute of Polar Studies
Report No. 1

Changes in Blue Glacier, Mount Olympus, Washington

by
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Institute of Polar Studies

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INSTITUTE OF POLAR STUDIES

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CHANGES IN BLUE GLACIER, MOUNT OLYMPUS, WASHINGTON

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Institute of Polar Studies, to the
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I. INTRODUCTION

The purpose of this study has been to prepare two maps on a scale of 1:5000 showing the changes in the height of the surface of the Blue Glacier between specified dates and from these to calculate the change in volume of the glacier. One map represents the change between 1939 and 1952 (Fig. 1), and the other the change between 1952 and 1957 (Fig. 2). The comparative changes in the height of the ice surface and the volume are given in Table 1. This is a preliminary report primarily to make the maps and data in the table available to interested research workers.

The Blue Glacier is a temperate valley glacier situated on the northeastern slope of Mount Olympus (2,424 m.), the highest point of the Olympic Mountains, in the State of Washington. In 1957 the glacier was roughly 4 km. long and about 1 km. wide at the firm limit, descending from a maximum elevation at the foot of West Peak of 2375 m. to a minimum of 1265 m. at the snout. For convenience in studying the glacier it was divided into five sections: (1) the south basin, a cirque, and (2) the north basin and snowdome form the major accumulation areas and (3) from these, two ice falls coalesce to form (4) the valley section of the glacier with (5) the snout which is divided into two by a bedrock ridge (Fig. 3).

The topographic maps used for this work were prepared by the Department of Geodetic Science at The Ohio State University, under the supervision of Dr. A. Brandenberger. Three maps were constructed from aerial photographs taken on 25 September 1939, 3 October 1952, and sometime in September 1957 on a scale of 1:5000 with a contour interval of 5 m. The quality of the photographs for the construction of the 1952 and 1957 maps was very good and the accuracy of the finished maps was within 1-1/2 m. linear scale and 1 m. vertically for the contours. The 1939 photographs were not so good and the accuracy correspondingly less, about 2-1/2 m. linear and 1-1/2 m. vertically. The firm line was not plotted as this appears as a rather indistinct region, so it has only been possible to sketch in an approximate position.

II. CALCULATING CHANGES IN THICKNESS AND VOLUME

A. METHODS

The two basic methods are (a) cartographic and (b) by the use of formulae. The cartographic method involves overlaying two topographic maps and obtaining the height change for a number of closely spaced points over the whole glacier and from these obtaining the mean height change to multiply by the area used to give the volume change. The second method has been used by Finstervalder (1953, p. 307-309) on a number of Alpine Glaciers and Haumann (1960, p. 96-102) on the Salmon Glacier, British Columbia. The area between a selected pair of contour lines on one map
Diagram to illustrate changes in height and volume by using formulae. Figures denote areas in square meters. Solid line ——— 1939; dashed line ——— 1952. Scale is approximate.
is measured and compared with the area between the same two contour lines on the second map. Using the interval between the two contours, the mean height change is obtained. The volume change is then obtained by a comparison of the same two areas and the use of the mean height change.

B. TEST AREA

A test area was selected on the valley portion of the glacier on the maps of 1939 and 1952 between the 1575 m. and 1600 m. contours where there appeared to be least modification of the contour lines by crevassing and where there had been an appreciable change in volume (diagram facing page). The following comparative results were obtained.

1. Change in Height

According to Finsterwalder and Haumann

\[ dh = \frac{dF_1 + dF_2}{F_1 + F_2} \cdot \Delta h \]

where

\[ dh = \text{mean decrease in height} \]
\[ \Delta h = \text{contour interval (25 m.)} \]
\[ F_1 = D_2 D_3 C_3 C_2 \]
\[ F_2 = B_2 B_3 A_3 A_2 \]
\[ dF_1 = D_2 D_3 B_3 B_2 \]
\[ dF_2 = C_2 C_3 A_3 A_2 \]
\[ dh = 17.475 \text{ m.} \]

Using cartographic method (a) 5 m. isometapach* interval \( dh = 17.89 \text{ m.} \)

(b) 1 m. isometapach* interval \( dh = 17.65 \text{ m.} \)

*lines showing equal change in thickness
2. Change in Volume

According to Finsterwalder

\[ dv = \frac{dF_1 + dF_2}{2} \cdot \Delta h \]

\( dv = \) change in volume

where

\[ dF_1 = D_1 D_1 B_4 B_1 \]
\[ dF_2 = C_1 C_4 A_4 A_1 \]
\[ \Delta h = 25 \text{ m.} \]

\( dv = -4,177,411 \text{ cu. m.} \)

According to Haumann

\[ dv = Fm \cdot dh \]

\( dv = \) change in volume

\[ Fm = D_2 D_3 C_2 C_2 + B_1 B_4 A_4 A_1/2, \text{ i.e. mean of original surface area + new surface area} \]

\( dh = \) average decrease in height

\( dv = -4,172,852 \text{ cu.m.} \)

Using the formula \( dv = F_2 \cdot dh \)

\( dv = \) change in volume

\[ F_2 = B_1 B_4 A_4 A_1, \text{ i.e. original surface area} \]

\( dh = \) average decrease in height

\( dv = -4,802,797 \text{ cu. m.} \)

Using cartographic method

(a) with 5 m. isometapach interval \( dv = -4,660,894 \text{ cu. m.} \)

(b) 1 m. isometapach interval \( dv = -4,595,958 \text{ cu. m.} \)
It can be seen from the above that the cartographic method gives very similar results to the methods used by Finsterwalder and Haumann. It was decided to use the former method since it has the added advantage of producing a map to show the variations of ice thickness at all points on the glacier and not just average values for large sections, as is the case with the latter method.

The small differences obtained by the various methods are probably due to errors in the assumptions which are made in obtaining the formulae used by Finsterwalder and Haumann, such as that in the measured area, the glacier retreats at a uniform rate parallel to the original surface.

III. CHANGES IN BLUE GLACIER

A. PROCEDURE

The two topographic maps in question were overlaid and all points were marked where the 5 m. interval contour lines of one map crossed those of the other. This gives the points where the height of the surface has changed by zero or by a multiple of 5 m. Wherever the contours on the topographic maps were sufficiently well spaced, one-meter changes were interpolated. Isometapachs were then constructed from these points to give a map showing the change in ice thickness for the whole glacier from 1939 to 1952 (Fig. 1). The same procedure was followed in comparing the maps of 1952 and 1957 (Fig. 2). In some places near the margins of the glacier, and particularly in the comparison of the 1939 and 1952 maps, it was only possible to approximate the thickness change because of the limitations in the original photographs.

Excluding the inaccuracies in the elevations on the topographic maps, the 5 m. isometapachs are accurate to within ± 1/2 m. and the interpolation of the 1 m. isometapachs probably to within ± 1-1/2 m. Considering also the inaccuracies in the original maps, the indicated values of change in height may be in error by as much as 3 m. However, the relative error between neighboring points is smaller than this so that the general pattern of ice thickness changes will not be affected. Over the whole area of the glacier the mean error is likely to be much smaller than three meters.

Volume changes were obtained by measuring, with a planimeter, the area between adjacent isometapachs and multiplying by the mean height change. Each area was measured twice with an accuracy of 0.064 sq. cm. (i.e., 16.1 sq. m. on the map scale). Thus, the error in the volume change for a small area of 1 sq. in. on the map for a height change of 10 m. could be as great as 30 percent. However, for a whole section, such as the South Basin, where there is a change in height from a loss of 15 meters to a gain of 15 meters, the height change errors will be largely compensating and the final volume change figure is probably correct to within 3 percent. For the whole glacier the figure is likely to be less due to compensating small errors.
The topography of the Ice Falls area was too complicated to allow work to be done on maps with a scale of 1:5000 and the maps of this area were enlarged to 1:2500. The irregularities of the contours on the topographic maps were due to the crevasse pattern, since in the construction of these maps the contours were continued down into the crevasses wherever possible. Thus, where there is intense crevassing or individual large crevasses on either of the topographic maps being compared, a false impression is given of the changes which have actually taken place in the over-all height change. A rounding of the contours is possible but this is very subjective and the resulting isometapachs are only accurate to within about ± 5 meters. The large increases and decreases in the Ice Fall area are, therefore, mainly a reflection of a changing crevasse pattern. However, the figure for the change in volume will not be greatly altered.

The marginal areas have for the most part been ignored in calculating the volume change since there has been very little change in the snow-rock or ice-rock contact. Moreover, the accuracy of the topographic maps is less at the margins of the glacier. However, in the snout section a separate calculation was made for the 1939-1952 comparison for that part of the glacier which had retreated from the rock ridge. Also in this comparison it was difficult to accurately draw in the contours for the west half of the north basin so that the calculation of height and volume change is by estimation.

B. RESULTS

1. Height and Volume

For the period 1952 and 1957 the mean height of the glacier increased by about 10 meters (Table 1). This is largely in the valley portion of the glacier and can probably in part be explained by the fact that in 1957 the snow line is much farther down glacier than in 1952. The 1952 photographs were taken late in the season on October 3, and it is likely that there had been considerable wasting of the ice surface then exposed. This ice was still snow-covered when the 1957 photographs were taken.

The figures for the 1939-52 comparison are far more variable than those for 1952-57 and show that, while the snout and valley portion of the glacier were diminishing, the upper part was increasing, particularly the Snow Dome area. According to Heusser (1957, p. 149), the snout of the glacier was still retreating in 1952 but it is quite likely that the increase in volume had already begun in the upper basins.

Comparing the two periods of measurement, the totals on Table 1 show a change from a strongly negative regimen, still causing retreat in 1939-52 to a positive regimen registered all over the glacier by 1952-57. These maps show the total change in the surface elevation in the periods under consideration. These changes include the effects of changing velocities and strain rates as well as the changes in the accumulation and ablation.
<table>
<thead>
<tr>
<th>Section</th>
<th>Area of section in sq. m.</th>
<th>1939-52 Av. ht. change in m.</th>
<th>Vol. change in cu. m.</th>
<th>Area of section in sq. m.</th>
<th>1952-57 Av. ht. change in m.</th>
<th>Vol. change in cu. m.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Snout</td>
<td>- 202,580</td>
<td>-20.71</td>
<td>- 4,195,000</td>
<td>a) 108,871</td>
<td>b) + 106,935</td>
<td>+11.06                +1,183,000</td>
</tr>
<tr>
<td>2. Valley Section</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>a) 1,788,706</td>
<td>+11.69                +20,891,000</td>
</tr>
<tr>
<td></td>
<td>a) 1,997,899</td>
<td></td>
<td></td>
<td>b) +1,787,093</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>b) -1,992,738</td>
<td>-16.68</td>
<td>-33,239,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. South Basin</td>
<td>a) 629,999</td>
<td></td>
<td></td>
<td></td>
<td>a) 731,192</td>
<td>+4.80                +2,665,000</td>
</tr>
<tr>
<td></td>
<td>b) + 273,870</td>
<td>+5.18</td>
<td>+1,919,000</td>
<td>b) + 555,160</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. North Basin and Snowdome</td>
<td>a) 1,458,707</td>
<td></td>
<td></td>
<td></td>
<td>a) 1,713,545*</td>
<td>+6.70                8,441,980</td>
</tr>
<tr>
<td></td>
<td>b) + 651,934</td>
<td>+5.90</td>
<td>+3,728,000</td>
<td>b) +1,259,997*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals excluding Ice Fall area</td>
<td>a) 4,289,185</td>
<td></td>
<td></td>
<td></td>
<td>a) 4,345,314</td>
<td>+8.94                +33,181,000</td>
</tr>
<tr>
<td></td>
<td>b) -1,289,514</td>
<td>-2.50</td>
<td>-32,287,000</td>
<td>b) +3,709,185</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Ice Falls</td>
<td>a) 1,442,416</td>
<td></td>
<td></td>
<td></td>
<td>a) 1,313,223</td>
<td>+11.78                +13,239,000</td>
</tr>
<tr>
<td></td>
<td>b) + 351,612</td>
<td>+4.40</td>
<td>+1,547,000</td>
<td>b) +1,123,869</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL FOR WHOLE GLACIER</td>
<td>a) 5,731,601</td>
<td></td>
<td></td>
<td></td>
<td>a) 5,658,537</td>
<td>+9.60                +46,420,000</td>
</tr>
<tr>
<td></td>
<td>b) - 937,902</td>
<td>-3.28</td>
<td>-30,740,000</td>
<td>b) +4,833,054</td>
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<td></td>
</tr>
</tbody>
</table>

a) total area measured
b) net loss or gain
* includes part of ice fall area
2. Variations and Anomalies

On the two prepared maps, the largest decrease for 1939-1952 is in the snout section where the south snout has retreated over 200 meters and lost, at the tip, a maximum of 45 meters in thickness. Between 1952 and 1957 the advance of the snout of about 50 meters has been accompanied by an increase in thickness of about 10 meters.

Near the edge of the glacier there are a number of areas of large increase and decrease in height of ice surface. No distinction was made on the topographic maps between ice and snow; on examining the original photographs it appears that most of these marginal anomalies are associated with the presence or absence of snow drifts.

Below the Ice Falls the position of the snow line is reflected in the 1939-1952 map by the change from decrease to increase in the height of the ice surface. Between 1952-1957 this change is not so apparent but this is probably because the 1957 photographs were taken somewhat earlier in the season and the snowline had not retreated as far as in 1952.

Above the Ice Falls, in the accumulation basins, the areas of increase and decrease, which appear on both the maps, are probably a reflection of a change in the accumulation pattern by wind effects noticed by LaChapelle (1960, p. 20) in this area. On the 1939-1952 map there is a noticeable juxtaposition of an area of decrease next to an area of increase in the south basin. The decrease marks the position of a deep crevasse and the high area is probably a result of a change in the accumulation pattern by wind effects.

IV. CONCLUSION

The two maps which have been produced to show the changes in elevation of the surface of the glacier are based on topographic maps prepared from aerial photographs showing the configuration of the glacier at a specific time. The amount of ablation varies from year to year according to the climatic conditions, so that to determine whether the photographs represent similar states of the glacier, all available weather data would have to be examined. The contribution of the changes in strain rate and velocity should be assessed before an attempt is made to relate the changes in surface elevation to the climatic data. Changes in the strain rate in 1939-52 and 1952-57 are likely to produce changes in the elevation which are small compared with the changes due to variations in accumulation. The maps are of value in showing the general pattern of changing ice thickness, but in detail it would be appreciated that each map is a record of the difference between two specific times. More analysis can be done of the maps produced in conjunction with climatic observations, accumulation data, density measurements, and strain measurements.
This study was carried out at the Institute of Polar Studies under a grant from the American Geographical Society (Ohio State University Research Foundation Project No. 1278). I wish to thank Dr. Colin Bull for many discussions and advice in the writing of the report.

VI. REFERENCES CITED


VII. SELECTED REFERENCES


CHANGES IN BLUE GLACIER
MT. OLYMPUS WASH.
1939-1952

Figure 1
Figure 3. Map showing division of Blue Glacier into sections. Approximate boundary between sections, dashed line. Rock outcrop, shaded areas.