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GLACIERS OF THE GANNETT PEAK-FREMONT PEAK AREA, WYOMING

by

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INTRODUCTION

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Geographic Location

Gannett and Fremont Peaks are located in the north-central Wind River Mountains, which form the Continental Divide in west-central Wyoming (Fig. 1). The glaciers studied are located on both sides of the divide and extend from about 2 miles north of Gannett Peak south and east to Knife Point Mountain. They all may be contained in a rectangle 9 miles long and 5 miles wide (Fig. 2).

Physiographic Description of Area

The Wind River Range is the highest mountain mass in the State of Wyoming; in fact no other ranges in the country north of Colorado or the Sierras include as much area above 13,000 feet in altitude. For a distance of about 30 miles the lowest col in the Continental Divide is nearly 11,900 feet above sea level, and for 9 miles the divide is almost continously above 13,000 feet. The highest elevation in Wyoming is Gannett Peak (13,785 feet), and the maximum relief in the area around this mountain is more than 4,000 feet. Although remnants of old erosion surfaces are evident in some locations, intense Pleistocene glaciation has so modified the topography that the area around Gannett

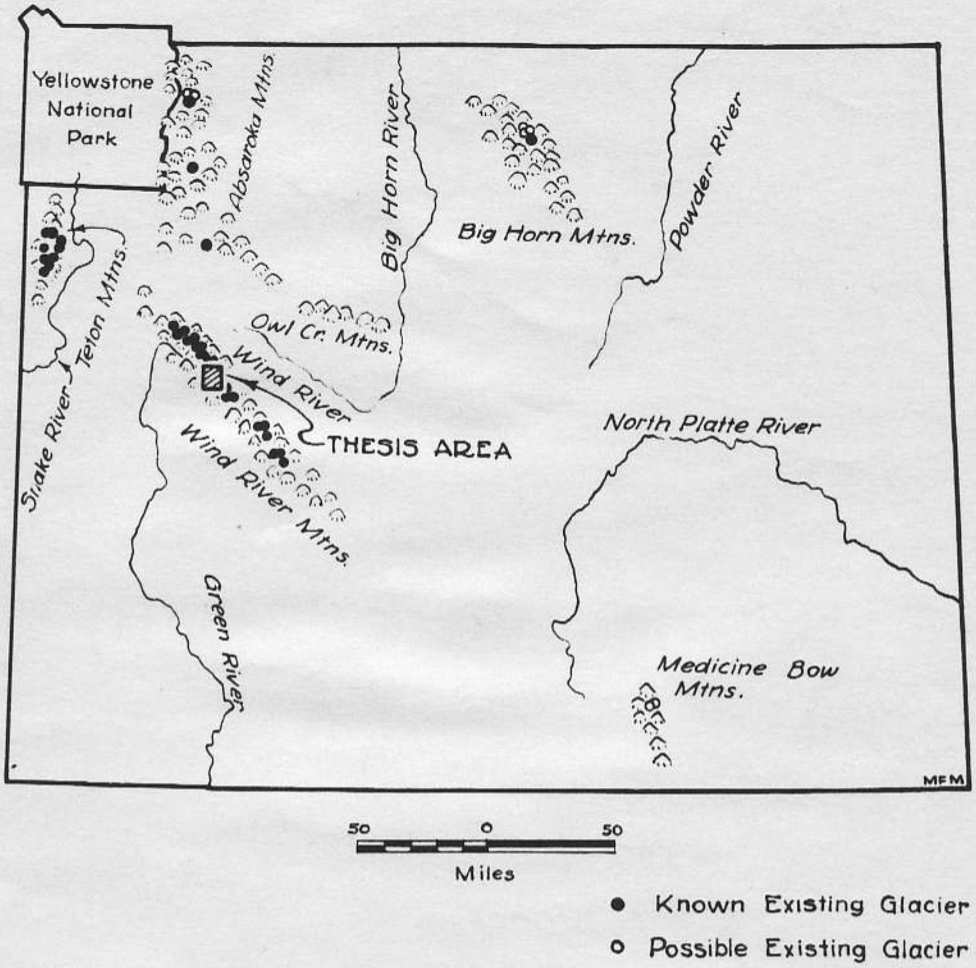
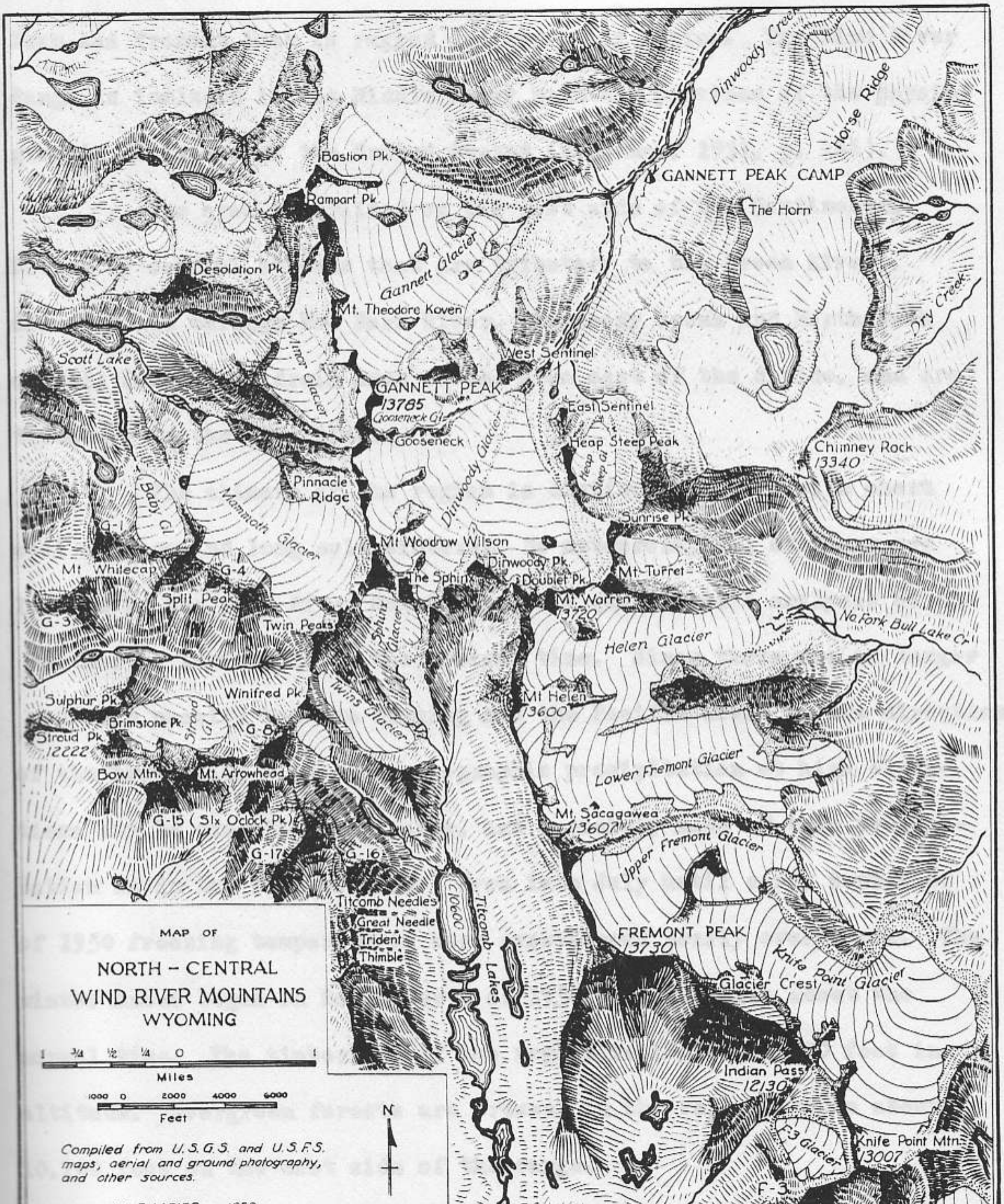


FIG 1 - INDEX MAP OF THE STATE OF WYOMING



map courtesy The Iowa Climber

Fig. 2

Peak and Fremont Peak is rugged and typically alpine. The Wind River Range is included in the Middle Rocky Mountain province of the physiographic divisions of the United States (Fenneman, 1931, p. 166).

The area is drained on the west side of the Continental Divide by several streams that are tributary to the Green River directly and through New Fork River. Dinwoody Creek and North Fork of Bull Lake Creek drain much of the area east of the divide, and are tributary to the Wind River.

The climate of the region is distinctly alpine with short cool summers and long cold winters. No meteorological stations are located in the Wind River Mountains, so a quantitative analysis of the weather is impossible at the present time. Since there are no larger mountain massifs between Wyoming and the Pacific Coast in the direction of the prevailing winds, the orographic precipitation at high elevations may be exceptionally large, and certainly much of this precipitation is in the form of snow. From late July until early September of 1950 freezing temperatures were experienced nearly every week. The winter snows began on September 9 of 1950 at apparently about the normal time. The timberline of the region is 10,500-11,000 feet in altitude. Evergreen forests are present in the valleys up to about 10,100 feet on the east side of the range.

Access to the Area

Travel in this area is difficult because of the absence of roads or good trails. The easiest approach to Gannett Peak is by way of a jeep or truck road from near Burris, Wyoming. This road terminates at the boundary between the Shoshone Indian Reservation and the Shoshone National Forest, at an elevation of about 9,800 feet. From this point a good horse trail leads over Horse Ridge (about 11,000 feet in altitude) to a tent camp in Dinwoody Valley, a distance of about 15 miles. A fair trail leads another 3 miles to the terminus of Dinwoody Glacier. The area can be approached from the northwest by way of the Green River lakes, or from the southwest from the town of Pinedale, but these routes require longer trail journeys. There are no trails across the Continental Divide in the Gannett Peak-Fremont Peak area, but the divide may be crossed at several points without the use of specialized equipment.

Relation to other Glacier Areas

The largest glaciers in the United States are in the Cascade Mountains of Washington, especially around Mt. Rainier, Mt. Baker, and Glacier Peak. According to Wentworth and Dole (1931, p. 609), Mt. Rainier is covered with about 45 square miles of glacier ice, and Mt. Baker with about 24.7 square miles.

The ice masses of Glacier National Park are the best known of those farther inland. According to Dyson (1950, p. 2) the largest glacier in this park was only 330 acres in area, about 0.51 square miles. Dyson (1945, p. 95) mentioned that there were at that time not more than 8 glaciers with an area more than one-fourth of a square mile. The total area covered by glaciers in Glacier National Park is probably now only a fraction of the 25 square miles measured on maps drawn near the turn of the century (Wentworth and Delor, 1931, p. 611).

Small glaciers exist in many other Rocky Mountain ranges in Montana, Wyoming, and Colorado according to Dyson (1950). In no case are these glaciers comparable in size or total area to those of the Wind River Mountains.

It seems certain, therefore, that the Wind River Range contains the largest glaciers (Gannett Glacier has an area of 1.77 square miles) of any area in the Rocky Mountains south of the Canadian border. Probably there is more glacier ice here than in any area of comparable size in the Rocky Mountains of United States.

Previous Studies of the Glaciers

The first report of glaciers in the Wind River Range is credited to the Hayden Survey (1878, a, b). In 1885 I. C. Russell described several Wind River glaciers (pp.344-346), but several years later the same author only states that north of the Colorado border "perennial snow banks increase in number and extent toward the north, and true glaciers occur in Montana and adjacent portions of Canada." (Russell, 1897, p. 39).

The U. S. Geological Survey's Fremont Peak quadrangle, edition of 1909 (out of print), shows several of the glaciers but omits many and locates some in improbable places. The generalized mapping is most inaccurate west of the Continental Divide.

The first published scientific observations on these glaciers resulted from a three-day pack trip by C. K. Wentworth and D. M. Delo (1931, pp. 611-620). The authors described Dinwoody, Gooseneck, and Gannett Glaciers. Dr. Delo later revisited these same glaciers, and an abstract of his findings was published (Delo, 1940).

The Wind River glaciers have been mentioned briefly in several of the reports of the Committee on Glaciers of the American Geophysical Union (see Matthes, 1941, p. 1010; Matthes, 1942, pp. 314, 383; also Dyson, 1950, pp. 9-10).

C. L. Baker, while working on the general geology of the north-western Wind River Mountains, discovered and reported several glaciers west of Gannett Peak (1946, p. 593). He was apparently the first to recognize that many of the existing glaciers are not shown on the Fremont Peak quadrangle, for he stated that there were 9 glaciers and 3 glacierettes west of the divide and 13 glaciers east of the divide.

Gerald Richmond, in an article pertaining to certain periglacial features in the Wind River Range (1949, p. 143), states that there are over forty active glaciers in the high mountains, and that the largest of these is over 3½ miles long. In 1950 (personal communication) he stated that he had found 52 glaciers in the Fremont Peak quadrangle, of which 21 were west and 31 were east of the divide.

Purpose of this Investigation

As can be seen from the above discussion, there has been relatively little scientific study of the Wind River glaciers. The author was, in fact, unable to find a single published description of the important Bull Lake Glaciers, or of many glaciers in the Gannett Peak area. Other glaciers in the Rocky Mountains, such as those in Colorado, the Tetons, and Glacier National Park, have been studied by prominent geologists and glaciologists, but the largest accumulation of glaciers in the Rockies has been, in comparison, nearly completely neglected. One of the purposes of this study, therefore, is to provide a general description of these glaciers for comparison with glaciers of better-known regions.

Another purpose is to provide a starting-point from which periodic recession measurements can be made, for these data may have great climatic significance. Matthes (1946) has said:

> Therefore it behooves us to keep a close watch on our glaciers and to measure and photograph them at frequent intervals. They, more vividly than thermometers and snow gauges, tell us what is happening to the climate.

This study was also initiated to attempt to determine the regime of these high-altitude, continental, temperate glaciers for a glaciologic comparison with other regions. A general glaciological investigation of ice structure, minor features, etc. was another important aspect of this study.

Method of Study

Because of the lack of roads or horse trails it was necessary to do all of the work on foot. Alpine camping equipment was backpacked. Most of the camps were above timberline. Supplies were carried to within 3 miles of Dinwoody Glacier by the Gannett Peak Camps, Inc. The author spent 10 days in the area in early August of 1948, and with the exception of one day was in the area continuously from July 22 to September 11 of 1950. The Fremont Peak topographic map was used only for general reference, and most of the mapping and location was done with the aid of aerial photographs. Photographs of the termini of the glaciers were taken from marked locations and prints were sent to the American Alpine Club and the Committee on Glaciers of the American Geophysical Union for filing.

Planimetric maps were constructed in the office from aerial photographs. Area distribution graphs (see Ahlman, p. 62) were plotted as an aid to the classification of the glaciers. It is realized that these diagrams are not exact since they are not based on accurate topographic maps. However, the graph depends only on: (1) the shape of glaciers, represented by a planimetric map; and (2) the differences of slope over the surface of the glacier. The true size, the true differences in elevation between high and low points, and the average slope do not enter into the calculations. The main source of error is the determination of changes of slope. The surface configuration of the ice was sketched first from the Fremont Peak map. This rough map was then altered by reference to: (1) direction of slope of the surface as revealed by the pattern of streams on the aerial photographs; (2) surface profiles determined from ground photographs; and (3) general reference to the author's observations and photographs. To test the accuracy of this method, area distribution diagrams were constructed of the complex Dinwoody Glacier according to: (a) a map drawn as accurately as possible; (b) the Fremont Peak map, unmodified; and (c) a map in which the contours were evenly spaced across the surface. The three graphs showed differences of up to 6 per cent at specific altitude intervals. However, they had a nearly equivalent shape, and all fell into the same category according to Ahlmann's classification. Although the results of this single test are by no means conclusive, area distribution graphs can probably be constructed by this method with sufficient accuracy to serve as a definite aid to classification.

Other characteristics of the glaciers were computed, including present area, maximum recent area, median altitude (altitude above 50 per cent of the area), firn limit altitude in 1945 (from aerial photographs), percentage of ablation area in 1945, altitude of firn basin (taken as half way between the median altitude and the maximum altitude, (see page), percentage changes in area in recent years. From these data it was possible to give a comparative description of each glacier. Ablation measurements on Dinwoody Glacier were compiled and analyzed so that an estimate of the regime during the 1950 season was obtained. From these data conclusions were reached about the general behavior of these glaciers in recent years.

GENERAL DESCRIPTION OF THE GLACIERS

Location of Glaciers in the Range

Glaciers occur throughout the Wind River Mountains, especially in the northern third of the range, but only those south of Bastion Peak (Lat. 49° 12' 56" N.) and north of F-3 Mountain (Lat. 49° 5' 41" N.) were studied in detail. South of this area the glaciers are small and rather sparse, but there are many large glaciers north of the area along the Continental Divide. The greatest accumulation of ice, however, seems to be in the Gannett Peak-Fremont Peak area (Fig. 2, p. 3).

In general the glaciers are found either in cirques facing north or east or on broad uplands at high altitudes near the Continental Divide. Very few glaciers are located more than 1½ miles from the divide, and none are farther than 3 miles. Most of the glaciers are on the eastern slope of the range, probably a consequence of the prevailing westerly winds.

The termini of the larger glaciers descend usually to between 11,000 and 11,300 feet above sea level, and the neves extend to nearly 13,600 feet in altitude. The firn limit of the glaciers is found usually at around 12,000 feet, although it may be as low as 11,400 feet on some favorably located cirque glaciers. The regional snow-line, as defined by Matthes (1942, p. 378), is probably at about 13,600 or 13,700 feet at the present time; ten years ago it was somewhat higher. A more thorough discussion of the regional snow-line is given later.

General Description

Most of the Wind River glaciers are small cirque glaciers, but three of the largest are valley glaciers and three others are complex in form. None of the glaciers are large by Alpine or Alaskan standards, for the largest is less than 2 square miles in area. Seven ice masses in the area are larger than the largest body of ice in other ranges of the Rocky Mountains of this country. Many small ice bodies are on the borderline between real glaciers and stagnant ice masses. Many of these may be termed "vestigial glaciers" (Fryxell, 1935, p. 387) or "glacierets" (Flint, 1947, p. 13).

None of the Wind River glaciers has a high rate of motion. Most of them show unmistakable evidences of movement, such as crevasses, dirt bands, medial moraines, and shear planes. That they are actively corraiding their beds is indicated by the quantity of suspended matter in the outlet streams. The presence of rock flour in the melt-water was regarded as an important criterion in this study for differentiating between real glaciers and stagnant ice masses. No bodies of ice are considered in this report that did not have turbid outlet streams. The milky color of the water in Dinwoody Creek after flowing about 29 miles and passing through several large lakes attracted the attention of Wentworth and Delo (1931, p. 606).

DESCRIPTION OF INDIVIDUAL GLACIERS

Gannett Glacier

Nomenclature

The name Gannett Glacier was apparently first applied by Henderson in 1933 (p. 355). The term "North Gannett Glacier" (Wentworth and Delo, 1931, p. 613) has not persisted in the local usage. This glacier is one of a group that has been known as the "Dinwoody Glaciers" because they are located at the headwaters of Dinwoody Creek. The name Gannett Glacier has not been specifically approved by the Board of Geographical Names, but it is the only name that is used by the local residents and the U. S. Forest Service, and has appeared in many publications.

Location

The glacier is located east of the Continental Divide north of Gannett Peak (Fig. 2). The direction of motion is generally east. The glacier now extends about 2½ miles north from Gannett Peak to a low divide northeast of Bastion Peak. When the Fremont Peak quadrangle was mapped (1906) ice was apparently continuous across this divide, joining the large glacier that lies west of Klondike Lake. At the southern extremity ice connects with Gooseneck Glacier through a high col. From a firn field elongated parallel to the divide several tongues of ice move eastward toward Gannett Creek, a tributary of

Dinwoody Creek.

Size

Gannett Glacier is more than 2½ miles in total width and the main lobe is about 1½ miles long. The area as measured in 1950, is 1.77 square miles or 1,130 acres. It is the largest of the glaciers studies. The highest firn extends to over 13,000 feet and the main lobe descends to about 11,000 feet in altitude. The median altitude (defined generally by hydrologists as the elevation above 50 per cent of the area, (Wisler and Brater, 1949, pp. 47-48) is 12,250 feet above sea level.

Classification

The peculiar shape of Gannett Glacier (Fig.3) makes it somewhat difficult to classify morphologically. Wentworth and Delo (1931, pp. 616, 619) considered it a palmate cirque glacier, and classified it according to Hobbs' system (Hobbs, 1911, pp. 41-58)as a radiating type of glacier.

This simple definition of cirque glacier has been ammended in recent years with the appearance of Ahlmann's graphical method of morphological classification (Ahlmann, 1948, pp. 59-67). In this method a graph of percentage of area a certain altitude interval is plotted against that altitude interval; the result is a curve which is characteristically different for different types of glaciers. Such a graph for Gannett Glacier (Fig. 3) is nearly identical with the

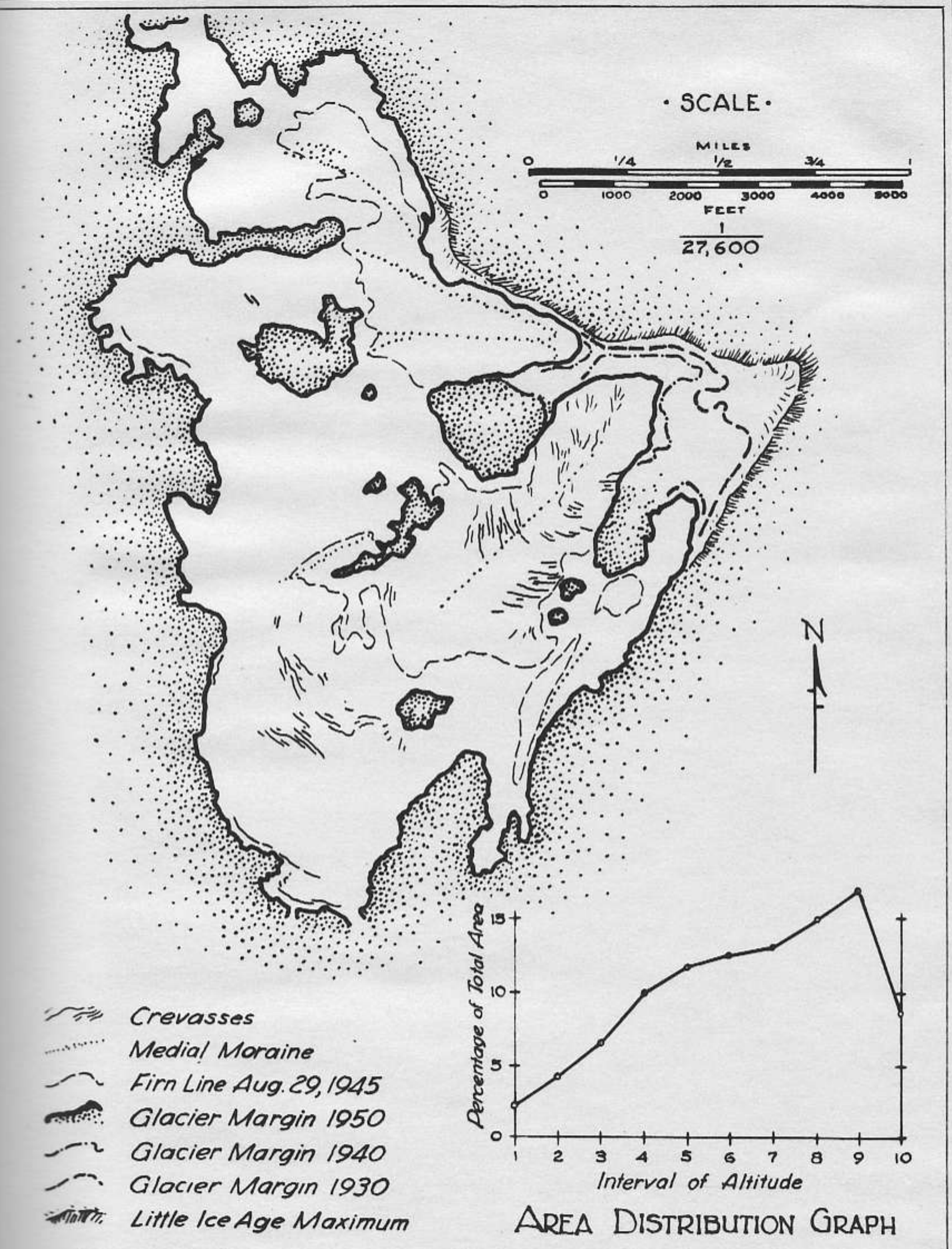


FIG. 3 — GANNETT GLACIER

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curve shown by Ahlmann for a valley glacier characterized by a large firn basin, and the graph is not at all like that of a normal cirque glacier.

This apparent discrepancy between the shape of the glacier and its area distribution graph can be resolved by dividing the glacier into its four independent tongues separated by ice divides. Figure 4 shows that the individual, independent parts all have the appearance of conventional valley glaciers characterized by large firn basins. Each of these parts has an area distribution graph similar to that of the composite glacier. Therefore, this glacier is best described as a system of contiguous valley glaciers, and is not properly considered a cirque glacier.

General Description

The common firn field that feeds the various tongues of Gannett Glacier is steep at its upper margin. Along the flank of Gannett Peak firn slopes at the exceptional angle of 50 to 60 degrees. Only below Gannett Peak and at several locations below Mt. Theodore Koven and Rampart Peak (see Fig. 2) is there a bergschrund. Below this steep apron is an irregular, gently rolling plateau of firn characterized by many large crevasses, especially in the upper regions of the main (center) lobe (see Fig. 5). One of these crevasses was reported by a local guide to be 50-60 feet wide. Below this firn plateau several rock nunataks channel the flow into three independent

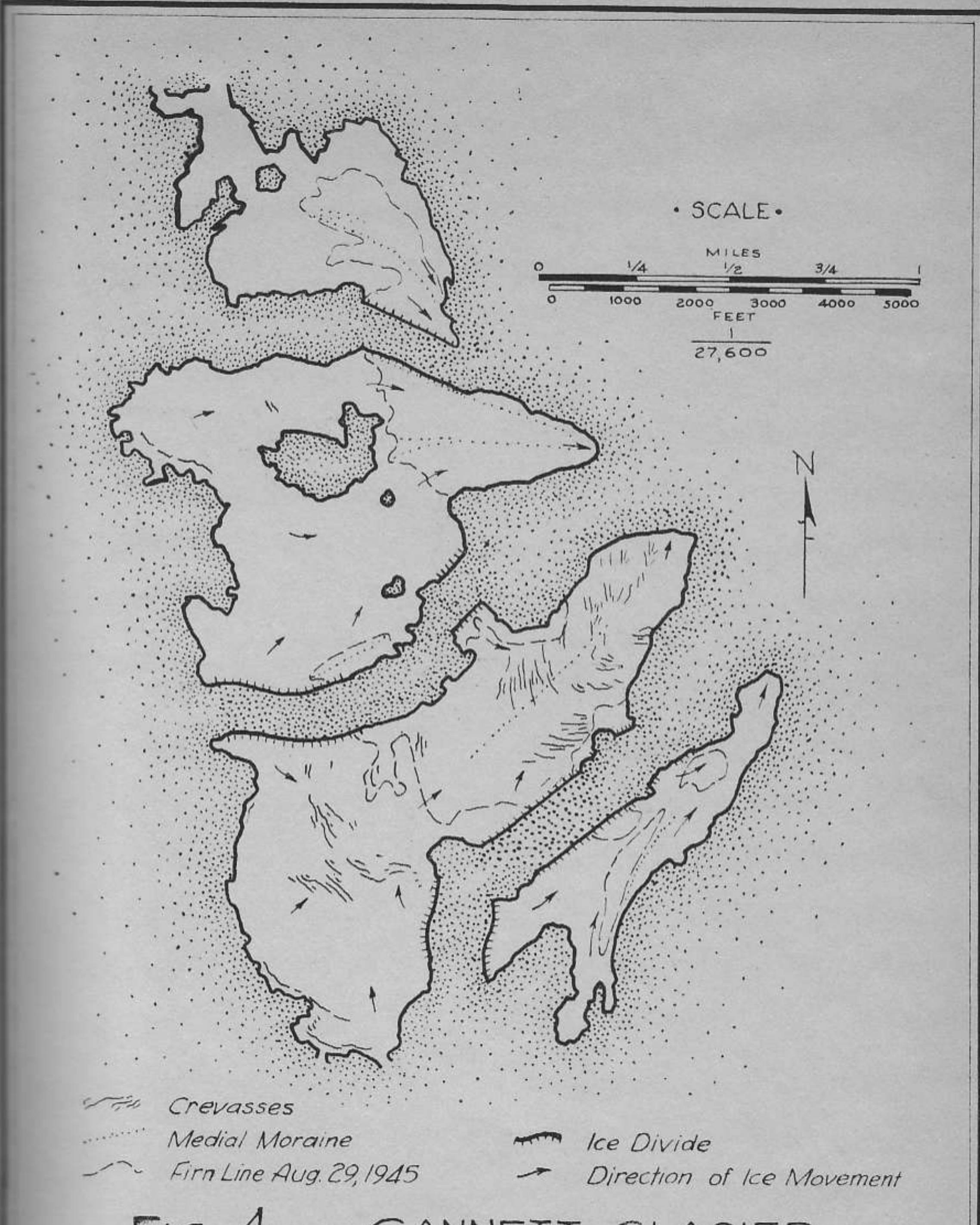


FIG. 4 - GANNETT GLACIER, INDIVIDUAL TONGUES ISOLATED

tongues or lobes. The more northerly of these has two separate source regions (Fig. 3). The ice tongues slope as much as 35 degrees near their termini, and the surface has a different appearance. Here, below the firn line, much debris is seen on the ice, and medial moraines are noticeable in the lee of nunataks. The main tongue is characterized by a perfect arrangement of marginal crevasses. The ice is thin in the lower parts of the tongues, and two high points in the bedrock come to the surface near the terminus of the main lobe (Fig. 6). The author made no attempt to determine the depth of ice in the central portions of Gannett Glacier, but Wentworth and Delo (1931, p. 617) estimated a thickness of 500 to 600 feet.

Gannett Glacier has considerable surface debris in its medial moraines, but compared with near-by Dinwoody Glacier the surface is quite clean. This is probably because Gannett Glacier is not continuously surrounded by high cirque walls. Many glacier tables were noticed both in 1948 and 1950, but Wentworth and Delo (1931, p. 618) make no mention of any.

In 1945 the firn limit on Gannett Glacier was at about 12,100 feet in altitude. An estimated 340 acres was at that time included in the ablation zone, therefore the ratio of ablation area to total area was about 0.30.

Moraines

A prominent fresh moraine exists just below the present

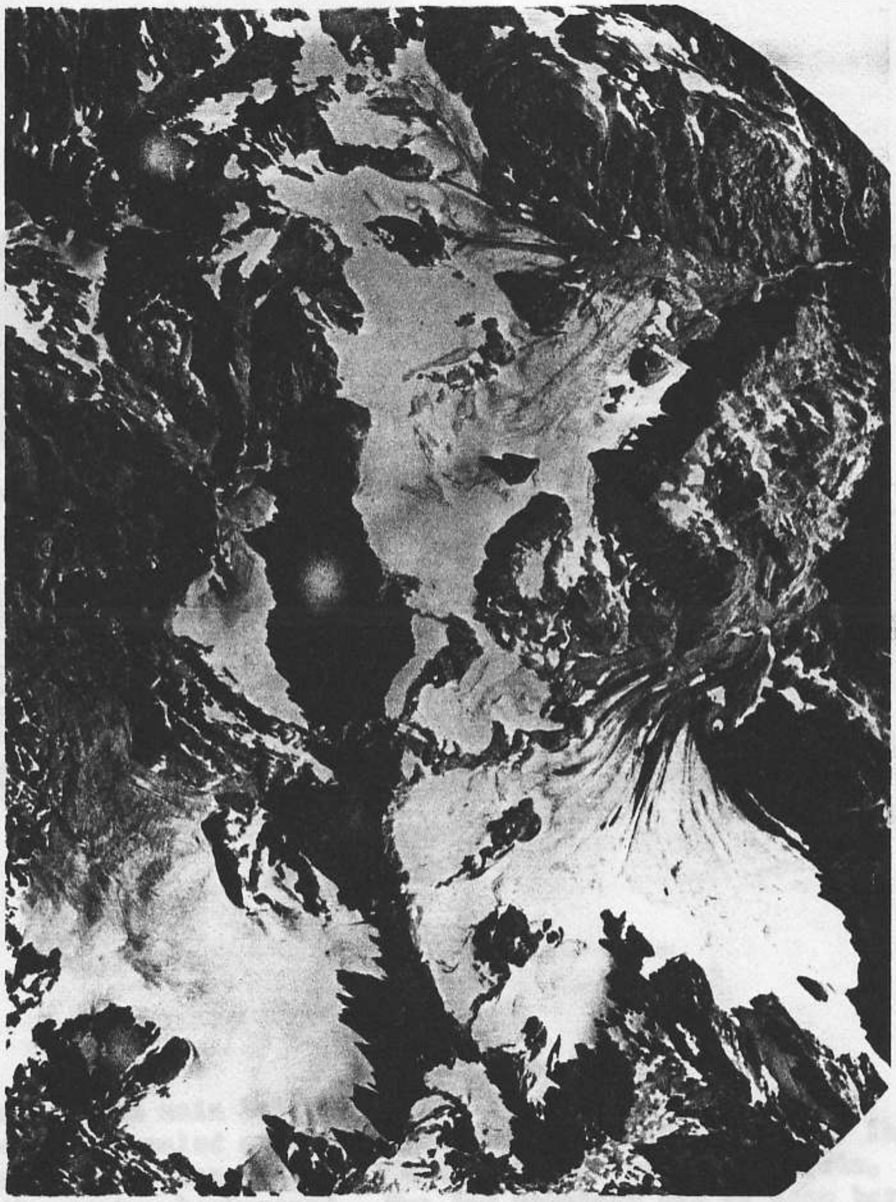


Fig. 5

Aerial photograph showing Gannett, Dinwoody, Mammoth, Minor, and Gooseneck Glaciers. Note the prominent crevasses and generally clean appearance of the surface of Gannett Glacier. North is to the top of the page, approximate scale 1:41,000.

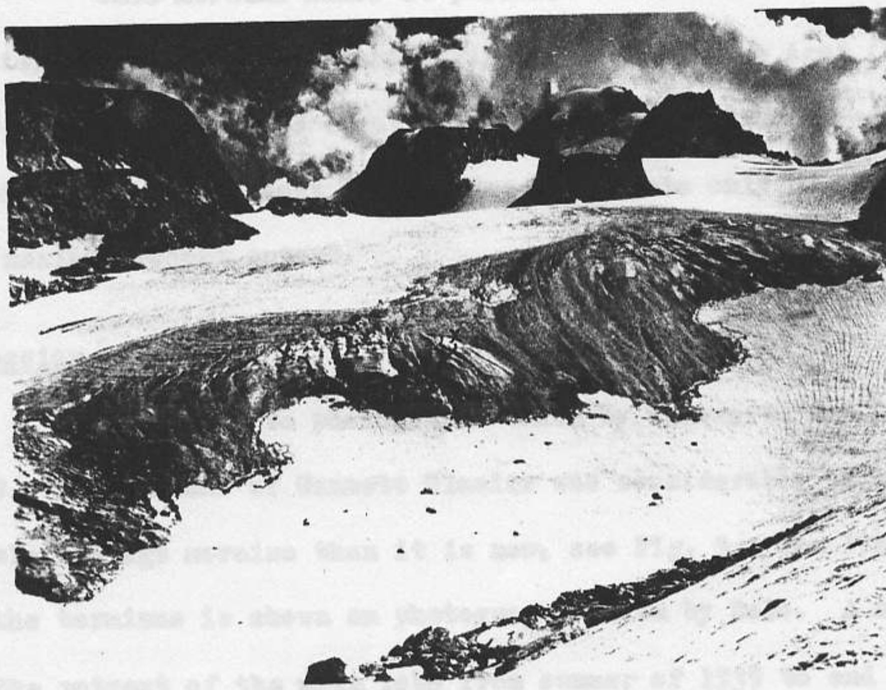


Fig. 6

Terminus of the main lobe of Gannett Glacier. Actual toe of the ice is concealed under snow at the bottom of the valley in the foreground. Gannett Peak, with its prominent snow crown, is in the center background. Two low nunataks can be seen barely protruding through the thin ice of the snout. At the places marked with an "x" it was possible to walk back under the ice for a considerable distance.

margin of Gannett Glacier, probably representing a terminal moraine which dates from a time when the three lobes coalesced. This ridge extends north and west for more than a mile. Nowhere is the moraine higher than about 50 feet.

This moraine makes it possible to estimate the area of the glacier at its maximum extent during the "Little Ice Age" (Matthes, 1940, p. 398). This is about 2.17 square miles (1387 acres). In other words, the present area of ice represents only 82 per cent of the maximum recent extent.

Recession

According to photographs taken by Wentworth and Delo in 1930, the terminus of Gannett Glacier was considerably closer to the Little Ice Age moraine than it is now, see Fig. 3. The 1940 position of the terminus is shown on photographs taken by Delo. A measurement of the retreat of the main lobe from summer of 1939 to end of the summer 1940 is given by Floyd Wilson in Matthes, 1941, p. 1010. The terminal recession of the margin of the main lobe between the years 1948 and 1950 was difficult to measure because of snow cover, but from the terminal thinning a linear retreat has been estimated. The approximate linear and area changes in recent times are given in the following tabulation:

Period of Time	Linear Recession of Main Lobe		Area Decrease		
	ft.	ft./yr.	acres	acres/yr.	per cent
L. I. A. max. to 1930	1100	--	~~166~~ 143	---	~~12.1~~ 12.4
1930 to 1940	600	60	68	6.8	4.9
1939 to 1940	87	87	--	---	---
1940 to 1950	200	20	19	1.9	1.4
1948 to 1950	30	15	--	---	---

These figures are, of course, only to be regarded as approximations. Nevertheless, the difference in the amount of retreat between the 1930-40 decade and the 1940-50 decade does seem to be significant. These figures are consistent with the general trend of the recession measurements made on other Wind River glaciers.

Dinwoody Glacier

Nomenclature

Dinwoody is the most accessible and is the most often visited of the Wind River glaciers. For many years the glacier was known along with several of its neighbors as the Dinwoody Glacier. Wentworth and Delo (1931, p. 613) proposed instead the name "East Gannett Glacier." This name has not persisted, and the name Dinwoody has continued in the literature and the local usage. Although not specifically sanctioned by the Board of Geographic Names, the name is accepted by the U. S. Forest Service and appears on many of their signs in the area.

General Description

Dinwoody Glacier is separated from Gannett Glacier only by the small Gooseneck Glacier which prior to 1936 was a tributary to Dinwoody (see Fig. 2). The glacier lies in a large compound cirque opening to the northeast. Jagged cirque walls form the Continental Divide from Gannett Peak to Mr. Warren. The glacier is of a palmate shape: several tributary glaciers (fingers) come together forming a large basin of ice, from which a stubby tongue reaches only a short distance (Fig. 7). The glacier is nearly two miles wide, but only a little over a mile and a half long. As measured by maps constructed in 1950, the glacier has an area of 1.34 square miles (860 acres), and is the fourth largest of the glaciers studies. Altitudes on the glacier range from 11,200 feet to 13,200 feet, and the median altitude is about 12,200 feet.

The area distribution diagram (Fig. 7) shows that the glacier may be classified as a cirque glacier according to Ahlmann (1948, p. 62). Wentworth and Delo (1931, p. 614) also considered this a palmate cirque glacier.

The tributary fingers of ice and firn that feed the main part of Dinwoody Glacier are quite steep at their highest margins. The ice cascade between Mr. Warren and Mt. Doublet averages over 45 degrees for nearly 1,000 feet (Fig. 8). These tongues of ice are generally crevassed where they pass over an irregularity in the bed (Fig. 9). In places these crevassed zones approach the condition of

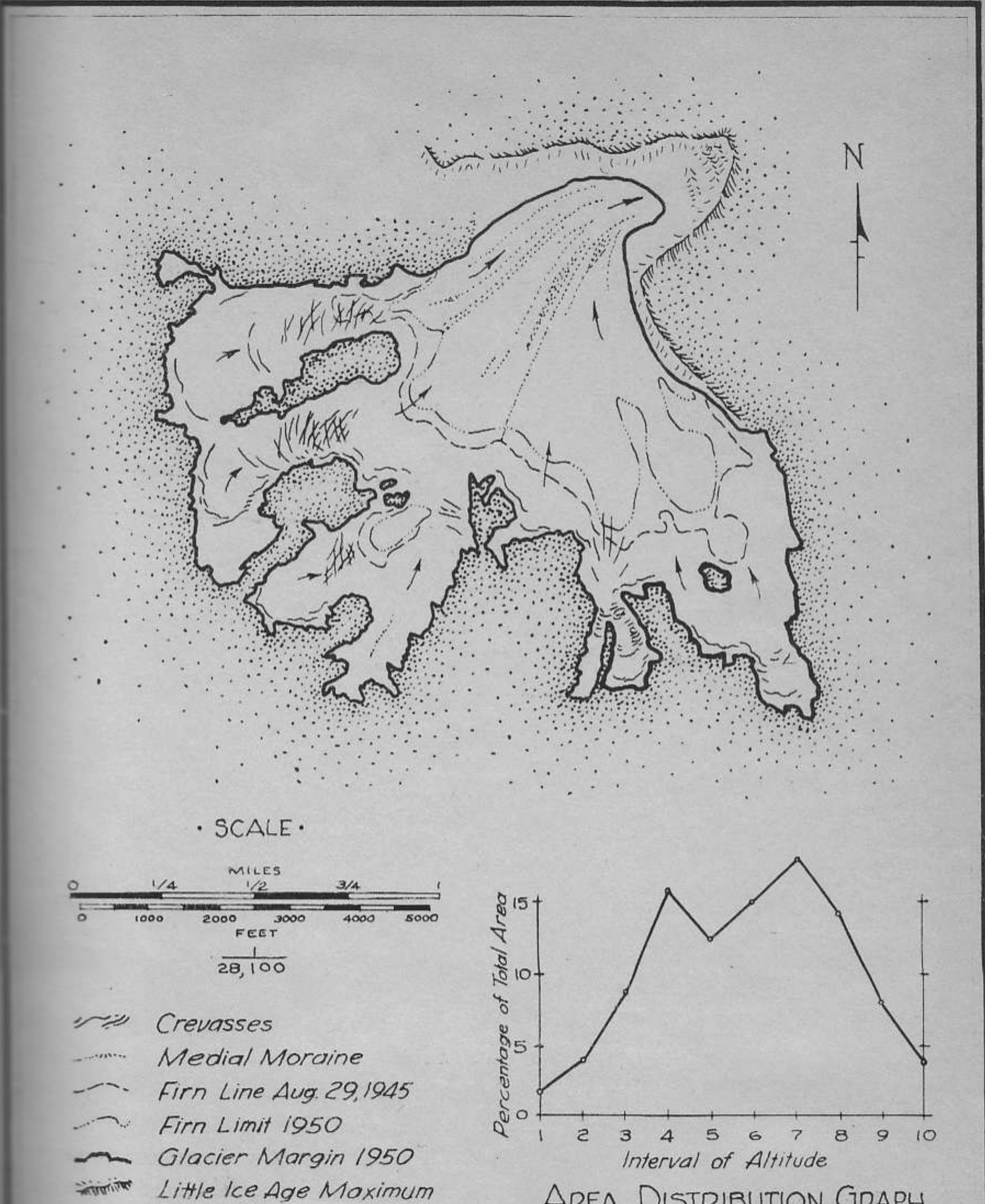


FIG. 7 - DINWOODY GLACIER

an ice fall. Very little, if any, coarse debris is seen on the surface of these tributary tongues, for most of this area is above the firn limit.

At the elevation (usually between 12,200 and 12,400 feet) where the tributary fingers of ice join the central basin, the surface of the glacier takes on a different appearance. The crevasses are closed here, only a thin slit or line of dirt marks their position. On the central portion of the glacier the slope averages less than 10 degrees. Superglacial streams incise channels to 10 feet deep in the ice. These streams are fairly straight where the surface gradient is gentle, but meander both horizontally and vertically (somewhat in the manner of a toboggan run) where the gradient is steeper. In places where the stream drainage is not well developed, "snow swamps" form, consisting of several inches to a foot of water and slush often masked by a thin layer of snow. The slush is formed either from melted snow or perforated "rotten" ice which has been riddled with dust wells. This latter condition is noticed most often in relatively clean ice early in the season.

Although some of the streams on the central basin disappear into moulins, many streams flow on the surface continuously until reaching the steeper terminal part of the glacier. Throughout the 1950 field season this lower portion was buried under snow, and the superglacial streams flowed out onto the surface of this permeable, partially firnified snow. The load of slush which is a characteristic

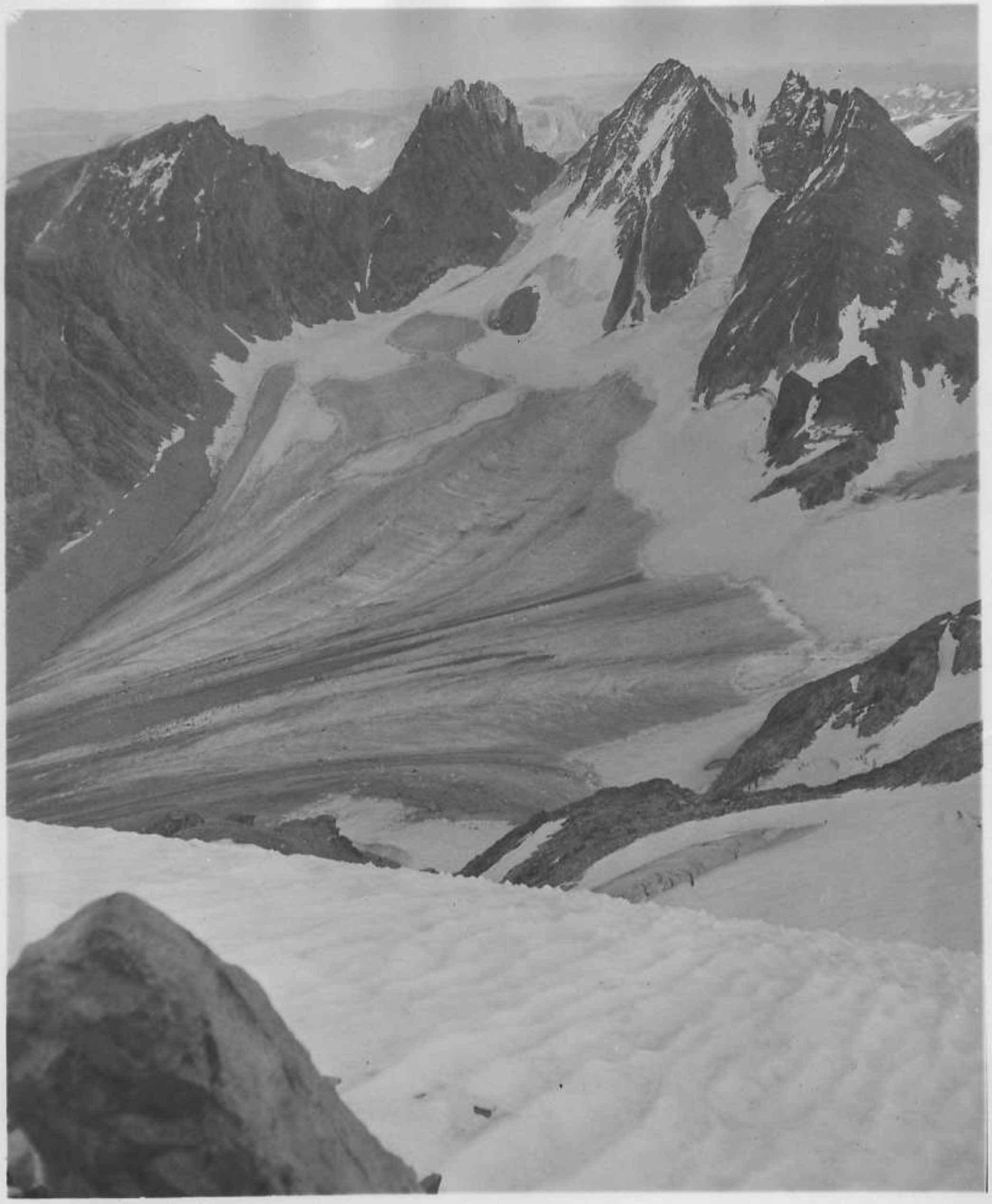


Fig. 8

Dinwoody Glacier, as viewed from the summit of Gannett Peak. The mountains in the background are (left to right) Sunrise, Turret, Warren, and Doublet. Note the exceptionally steep ice tongue between Mts. Warren and Doublet. The firn on the side of the glacier in the background (east) is considerably higher in altitude than anywhere else on the glacier. Photograph taken Sept. 5, 1950.

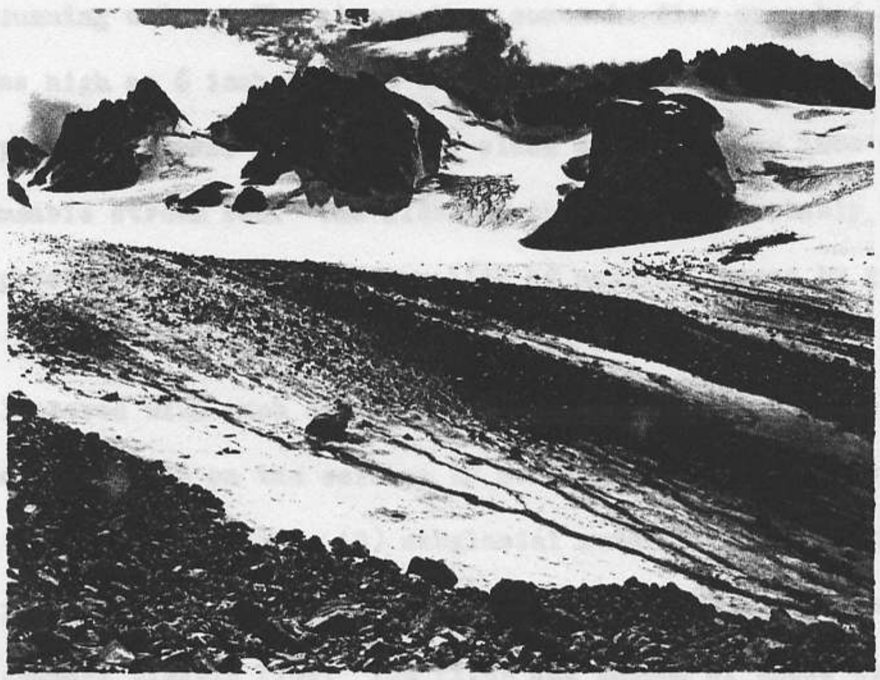


Fig. 9

Dimwoody Glacier, as seen from a point on the Little Ice Age moraine south of the terminus. The mountains in the background (Sphinx, Woodrow Wilson, and Pinnacle Ridge) are over 1¼ miles distant. Note the clean, crevassed surface of the tributary ice streams and the dirty, uncrevassed surface of the ice in the foreground. The gentle floor of the central basin is barely visible at the left center. The abrupt change in slope from the central basin to the sloping terminus is shown.

feature of these streams could not percolate down through the snow and was left on the surface. These accumulations of slush formed dams over and through which the water had to flow. The slush dams move slowly down slope by deposition on the downstream side and push of the running water. The stream thus comes to flow on a bed of slush often as high as 6 inches above the snow surface (Fig. 10). Diurnal freezing probably serves to cement the slush accumulations into a nearly impermeable stream bed. The sides of this bed are probably built up by a process similar to the formation of natural levees by graded rivers.

The surface of the central basin of Dinwoody Glacier is littered with much coarse debris (Fig. 8) derived from: (1) direct accumulation on the surface by avalanches from the surrounding cliffs; (2) medial moraines; (3) subglacial material brought up along shear planes; and (4) subglacial material delivered to the surface by homogeneous plastic flow. The first and second of these are probably the most important.

The lowest part of Dinwoody Glacier was not observable during the 1950 season because of the abnormal snow cover, but the author was able to observe the terminus in 1948. The snout of Dinwoody Glacier (Fig. 11) is considerably steeper than the central basin (the abrupt change in slope can be seen in Fig. 10). The ice is very dirty, and from a distance appears even darker than the nearby moraines. Only where streams have picked out the debris and cleaned the ice does the ice appear light in color. This terminal is probably

Fig. 10

Superglacial stream on snow, near terminus of Dinwoody Glacier. The stream is on snow for over 1000 feet, and is here elevated above the snow by about 6 inches. Medial moraine in the immediate background.

nearly stagnant.

Moraines

At either side and extending below the present snout of Dinwoody Glacier are morainal ridges which are continuous with medial moraines on the ice surface (Fig. 11). These consist of a surface concentration of debris mantling glacier ice. Their presence seems to confirm the idea that the terminal ice of Dinwoody Glacier has only very slow motion.

An extensive moraine dating back to the maximum advance of the glacier during the Little Ice Age surrounds the terminus of Dinwoody Glacier. It stands more than 100 feet above the outlet stream, and extends 900 feet from the present snout. In the low areas between the snout of the glacier and the crest of the moraine much sand and finer material has accumulated. Probably the moraine has a core of ice (it was so reported by Wentworth and Delo, 1931, p. 616). Ice in the moraine could be found in 1950 only near the glacier and could have been formed from melt-water. The size and the instability of the moraine suggest an ice core at some distance beneath the surface.

Recession

The terminus of Dinwoody Glacier is rather complex since the active ice is masked by nearly stagnant terminal ice and moraine, so this glacier does not lend itself readily to precise recession measurements. When Wentworth and Delo visited the glacier (1930)

Fig. 11

Terminus of Dinwoody Glacier. The snowfield in the foreground is in the lee of a bedrock knob, and is not underlain by moving ice. The nearest ridge of rocks is a short medial moraine, probably overlying stagnant ice. The tongue of snow just behind this moraine obscures the terminal ice. Beyond the snow tongue is a high medial moraine, consisting of a veneer of debris not more than 3 to 5 feet thick overlying glacial ice. Behind this medial is another tongue of snow covering more terminal ice which is probably stagnant. The large block in the left center of the picture measures about 60 by 40 by 25 feet. In 1930 Gooseneck Glacier descended into the upper left hand corner of the picture. The present terminus of the glacier is hidden in the cloud.

active ice extended nearly to the farthest moraine, and since then the snout has retreated considerably. This is about all that can be said about the recession of the terminus, and it is not possible to give a quantitative evaluation of the retreat.

Fortunately, many photographs exist that can be used to obtain an estimate of the position of the firn limit for a number of years in the last two decades. T his information is given in the following tabulation:

Year	Firn Line and Date	Estimated Firn Limit	Source of Photographs
1930	12,350, Sept. (?)	12,400	C. K. Wentworth
1937	12,700, Aug.	12,750	C. L. Baker
1940	12,400, Sept.	12,400	D. M. Dole
1941	12,350, about Aug.10	12,600	S. J. Ebert
1945	12,150, Aug. 29	12,250	Aero Service Corp.
1946	12,300, about Aug.15	12,450	author
1950	12,050, Sept. 9	12,050	author

The ratio of ablation area to accumulation area corresponding to each of these estimated firn limits has been plotted in Fig. 12. It is noticeable that the percentage ablation area has decreased somewhat in the last few years, although the data are not sufficiently precise or complete to prove a definite trend. It can be also noted that for most of these years there was a larger area of ablation than accumulation. If the accumulation and ablation were related linearly this would indicate that the regime was negative in all the years save 1950 and possibly 1945. This would suggest that recession has been the general rule since 1930.

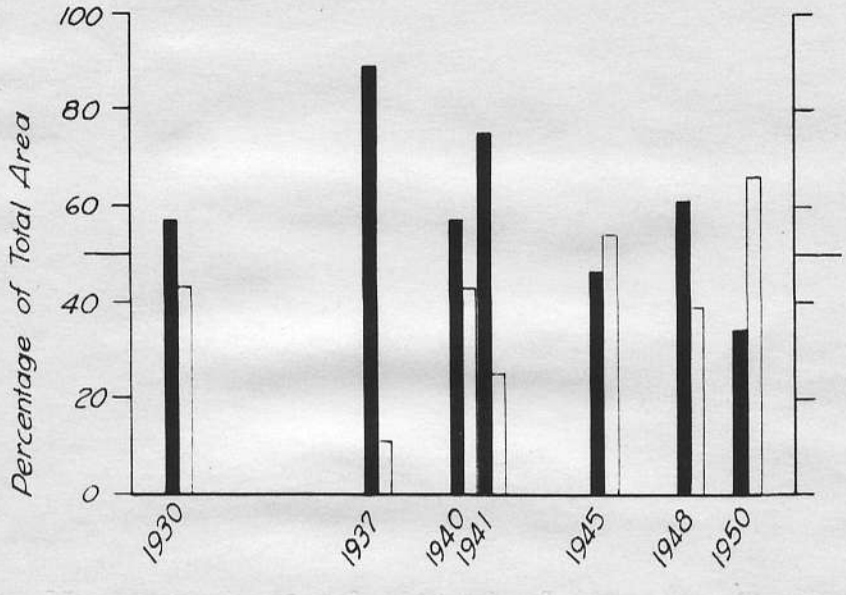


Fig. 12

Approximate relation of ablation area to accumulation area of Dinwoody Glacier since 1930. Black bars indicate per cent of total that is ablation area, white bars indicate accumulation area. Accumulation probably exceeded ablation only in 1945 and 1950.

The total area of the glacier at its maximum recent extent is somewhat difficult to compute, since at that time Dinwoody and Gooseneck Glaciers coalesced. An approximation of the maximum area not including the area of Gooseneck Glacier is 1.48 square miles or 950 acres. This represents a decrease of 9.5 per cent to the present.

Mammoth Glacier

Nomenclature

This glacier was referred to as "West Gannett Glacier" by Wentworth and Delo (1931, p. 613), and as the "Wells Creek Glacier" by Baker (1946, p. 593). The term "Green River Glacier" is often applied since this glacier is the largest of several glaciers which form the headwaters of the Green River. The name in present usage by most parties which visit the higher regions (Mammoth Glacier) was apparently first suggested by Hendersons in 1933 (p. 356).

General Description

Mammoth Glacier is located south and west of Gannett Peak and is the only large glacier in the area studied west of the Continental Divide (Fig. 2, p. 3). Meltwater from this glacier flows northwest to form Wells Creek, a tributary of the Green River. The glacier has an area of about 1.55 square miles (990 acres). Its length is about 2 1/8 miles and the average width about 3/4 of a mile. The highest snowfields extend to nearly 13,000 feet in elevation, and the snout is at about 11,300 feet. The median altitude is about 12,400 feet.

The area distribution graph (Fig. 13) shows that this glacier falls into the class of valley glaciers characterized by large firn basins as defined by Ahlmann (1948, p. 62), and its shape is that of a typical valley glacier.

A characteristic feature of Mammoth Glacier is the large firn field. This basin is more or less semicircular and dish-shaped. The central portion is nearly flat and featureless. This large firn basin is encircled by a ring of mountains (Fig. 14).

From this firn basin a 3/4 mile wide tongue extends northwest. Several subsidiary feeders deliver ice to the tongue from mountains along the south margin of the glacier. The slope of the tongue is here very gentle, and the center of the tongue is at about the same level as the sides. (Fig. 15) Toward its terminus the tongue is only 1,500 feet wide. The direction of motion is diverted from northwest to north. Here at the lowest part of the glacier the gradient is rather steep (up to 25 degrees at the terminus) and the profile is strongly convex.

Character of Surface

Mammoth Glacier is crevassed both in the upper reaches of the firn basin and in the tongue. In general the firn field is rather free of crevassing except along the southeast and south margins, where a non-continuous bergschrund exists. The tongue of the glacier exhibits a typical system of marginal crevasses. These generally intersect the margin at an angle of about 45 degrees with the acute

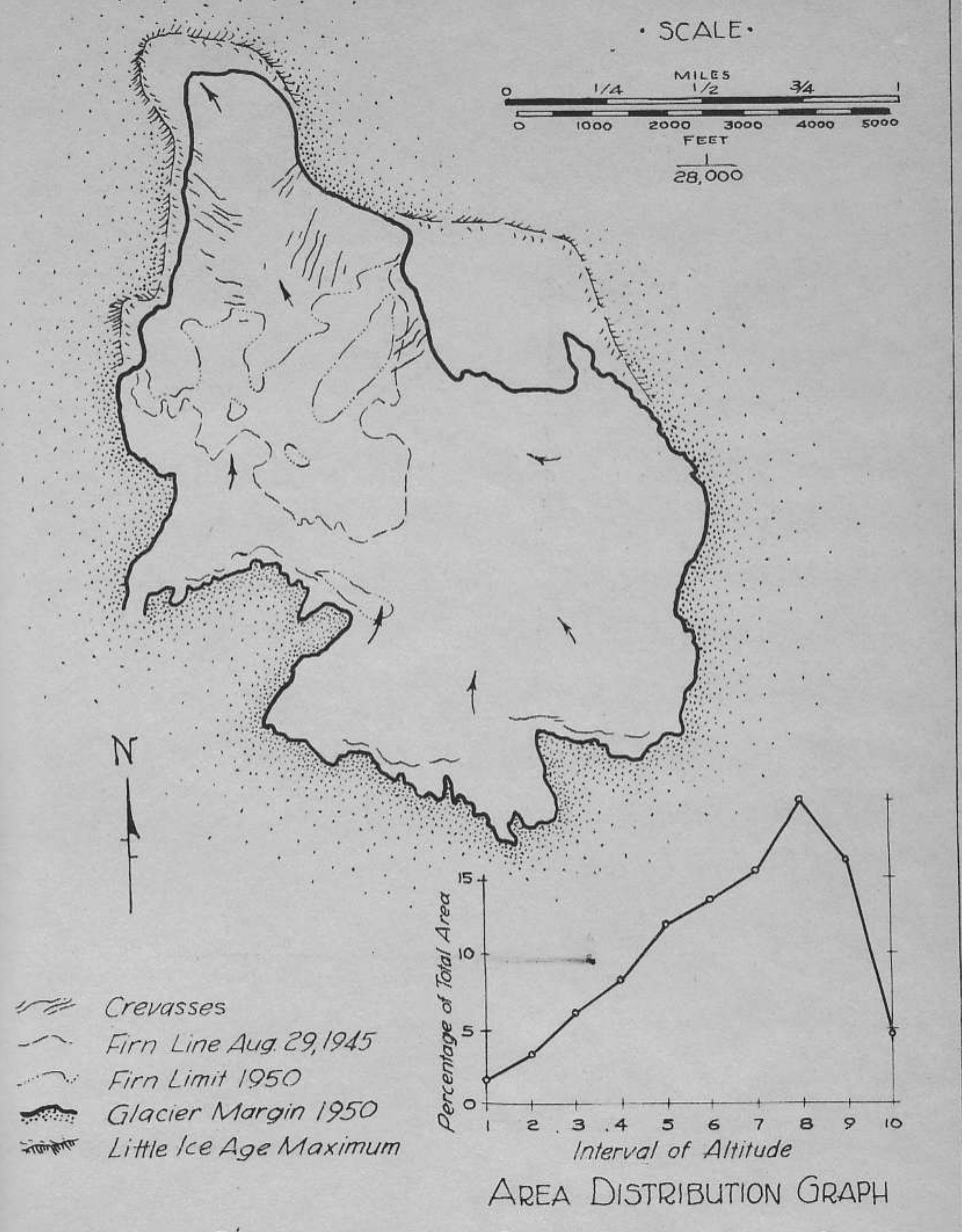


FIG. 13 - MAMMOTH GLACIER

angle up-glacier. These marginal crevasses are formed by the shearing drag of the valley side on the ice. The general character of the tongue and several of these marginal crevasses can be seen in Fig. 15.

No large superglacial streams were observed on Mammoth Glacier. Most of the meltwater was transported in a series of parallel channels only a few inches deep, and much of this water disappeared into crevasses after flowing only a short distance.

The surface of Mammoth Glacier differs markedly in appearance from either Gannett or Dinwoody Glaciers because of the nearly complete absence of coarse debris. Debris is chiefly of silt and sand sizes, imparting an even, gray color to the surface. Very few glacial tables were observed. The scarcity of large blocks is probably due to the lack of high cirque walls overlooking the glacier.

In 1945 about 320 acres were contained below the firn limit, so the ablation area embraced about 32 per cent of the total area. The low firn limit in 1950 is visible in Fig. 15.

Moraines

Immediately below the snout of Mammoth Glacier is a small lake, about 400 feet long, encircled by an extensive moraine which represents the maximum extent of the glacier in the Little Ice Age. This moraine consists of large blocks mixed with a considerable amount of very fine material. This fine debris (flour) probably serves both to cement the moraine and to preserve any ice which might be buried

Fig. 14

Firn basin of Mammoth Glacier, as seen from the west end of the ridge on the southwest side of Minor Glacier. The peak at the extreme left is Mt. Woodrow Wilson, and the two on the right side of the picture are Twin Peaks and Winifred Peak. Note the nearly featureless surface of the firn basin. This picture is almost panoramic with Fig. 15.

Fig. 15

Part of the tongue of Mammoth Glacier, as seen from the summit of Gannett Peak at the end of the summer. The firn basin is out of view to the left, and the terminus extends off to the right. Marginal crevasses and several types of dirt bands are seen below the firn line. Baby Glacier, at the foot of G-1 Peak, is seen in the upper right corner.

beneath. Consequently the moraine is nearly impermeable. The lake stands to within a few feet of the crest of the moraine.

No medial moraines of any sort were observed on Mammoth Glacier, but a prominent lateral moraine occurs along the western margin. It is continuous for about 4,600 feet. At a point about 1000 feet from the southern extremity of the moraine there is a depression in the bedrock. The moraine bulges out into this depression, forming a sort of rudimentary terminal moraine around a slight salient in the side of the glacier.

Recession

The maximum extent of the glacier in the last several centuries can be determined from a study of the moraines. Apparently the glacier once extended as thin ice over a large area now bare of ice directly south of Gannett Peak. Because of this the reduction in area since the Little Ice Age is somewhat greater than that which would be expected on the basis of terminal recession alone. According to maps drawn in 1950 the glacier once extended over about 1125 acres (1.76 square miles), and the decrease to the present amounts to about 12 per cent.

Unfortunately the author was unable to procure any photographs showing the position of the terminus in recent years. The Fremont Peak quadrangle shows the glacier extending along one margin nearly to Gannett Peak, but does not show the lower tongue at all.

Photographs supplied by C. L. Baker show the marginal lake along the northeast side of the glacier (see Fig. 15) nearly surrounded by glacier ice in 1937, whereas in 1950 this lake was bordered by ice only on one side. From this it appears that the thin ice overlying the area southeast of Gannett Peak mainly disappeared during the years 1937 to 1945. Aerial photographs show that the terminus has receded about 80 feet in the interval 1945 to 1950.

It is indeed unfortunate that this glacier has not been visited by many people, for the simple configuration of the terminus makes it an unusually good one for recession study. The glacier can be reached from the Green River Lakes without too much difficulty. Probably this glacier lends itself to glaciological study more easily than any of the other Wind River Glaciers. It is vigorous, has a simple configuration, and is not dangerous to work on. The snout is simple, clean, rests on polished bedrock, and is not masked by any accumulations of debris or moraines.

Helen Glacier

General Description

The name of this glacier was first suggested by Henderson (1933, p. 356). The Heyden Survey (1878) party viewed the northern margin of this glacier from the summit of Fremont Peak, but did not propose a name.

Helen Glacier is the most northerly of the Bull Lake Glaciers.

The glacier originates in an imperfect cirque between Mt. Helen and Mt. Warren and moves straight east for about 1½ miles (Fig. 2, p. 3). The average width is about a third of a mile. This glacier is the smallest of the seven larger glaciers studied, for it has an area of only 0.61 square miles (393 acres). The median altitude is about 12,160 feet. The long narrow shape and the area distribution diagram indicates that this is a valley glacier of the normal type.

The cirque at the head of Helen Glacier is rather imperfectly developed. The ice surface at the north edge of the cirque is not over 12,700 feet in altitude and receives most of its accumulation by avalanching from the southern slopes of Mt. Warren. On the south side of the cirque firn extends continuously to the summit pyramid of Mt. Helen, an elevation of over 13,000 feet.

Below this cirque is a constriction which narrows the width of the glacier down to about 1,000 feet. Below this neck the glacier receives considerable ice from a firn slope that connects over a high divide (12,500 feet) with adjacent Sacagawea Glacier. At the other side of the glacier a tongue of neve extends up to "Elsie's Col" at 13,000 feet.

Below the junction of these two tributary neve tongues the main glacier moves east for about 3,000 feet, then turns abruptly to the northeast for another 2,000 feet. The average width of the lower tongue is only about 1,000 feet, and the slope averages about 7 degrees. The maximum slope at the terminus is not more than 18 degrees.

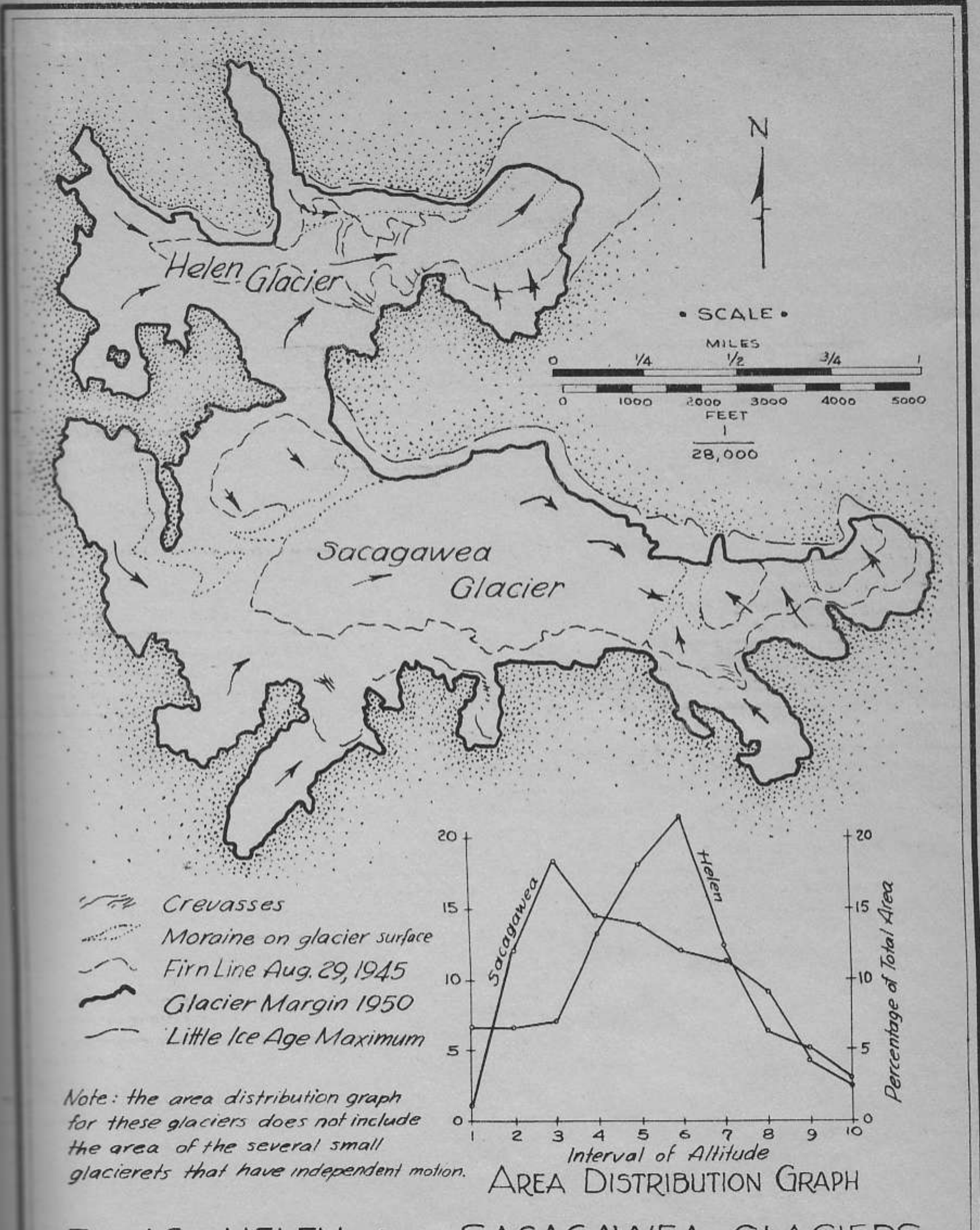


FIG. 16 - HELEN AND SACAGAWEA GLACIERS

The firn limit in 1945 was estimated at 12,300 feet. When the glacier was visited on August 28, 1950, only a very small area of ice was exposed (Fig. 17). The area below the firn limit in 1945 was estimated to be 150 acres or 39 per cent of the total area.

Surfical Features

Helen Glacier has a normal system of marginal crevasses where the tongue narrows below the confluence of ice from Elsie's Col and Mt. Helen. A nearly uncrossable bergschrund exists just below Elsie's Col, but this is the only place where a bergschrund is prominent.

Meltwater from surface ablation is carried off the glacier in many small streams flowing in parallel channels only a few inches deep and several feet apart. Since debris is washed from the ice in these channels and because the stream beds often contain much slush and perforated ice, these channels appear as parallel white lines on the gray surface of the glacier when seen from a distance. Note this effect in the lower left corner of Fig. 17, and also in Fig. 48, page .

Moraines

Several medial moraines exist on this glacier. One originates as a separation between the Elsie's Col tongue and the main glacier and continues throughout the length of the glacier and for several hundred feet beyond. This moraine, however, is very close to

Fig. 17

Helen Glacier. The high peak on the right is Turret Peak and in the center of the picture is Mt. Warren. A small vestigial glacier existed just below the facing cliff of Turret Peak during the Little Ice Age, note the prominent moraine. Elsie's Col is between Mt. Warren and Turret Peak, but is not visible.

the north margin of the glacier, and nearly takes on the appearance of a lateral moraine. Another, more prominent, medial moraine separates the main tongue of Helen Glacier from the small vestigial glacier which is south of the terminus. This medial is high and ice-cored. A third medial moraine originates about 850 feet from the present terminus and forms a prominent feature in the lower part of the glacier. This is probably caused by a bedrock knob under the glacier some distance back from the point of emergance of the moraine. The postulated bedrock knob must be deep under the glacier, for its presence is not indicated by crevasses or other surface features.

Below the glacier is a large accumulation of morainal debris which probably indicates the maximum extension of the ice during the Little Ice Age. This moraine does not stand high, and probably is everywhere less than 100 feet bedrock. Between the crest of the moraine and the toe of the glacier is much reworked morainal material, mainly sand and gravel with some larger sizes.

Below the Little Ice Age moraine is a large sand (and quicksand) flat which measures about 1,600 feet wide and 2,000 feet long. The meltwater from the glacier forms anastamosing channels on either side of this flat.

<u>Recession</u>

During the greatest extension of Helen Glacier in recent times the area of the glacier was about 530 acres. The present ice represents only 85 per cent of that area. The linear recession of the terminus is about 1,100 feet.

In 1945 the glacier extended somewhat farther than it did in 1950, but the exact amount is difficult to estimate. It is probably about 50 feet.

Since Helen Glacier is only very rarely visited, the author was unable to find any ground photographs that show the position of the terminus in recent years, and little can be said about the size variations of this glacier in the last several decades.

Sacagawea Glacier

Nomenclature

The only published reference to this large glacier that the author could find was Henderson (1935, p. 356) who assigned the name "Lower Fremont Glacier." However, the Hayden Survey (1878, b) applied this name to a completely different glacier, and this original usage has priority. Since this glacier originates in the vicinity of Mt. Sacagawea the name "Sacagawea Glacier" is here proposed. Richmond (1950, personal communication) also suggested this name.

General Description

This glacier is one of the Bull Lake Glaciers. It heads between Mt. Helen and Mt. Sacagawea and flows east for nearly 2¼ miles (Fig. 2, page 3). The glacier has an average width of about 3,000 feet and a total area of about 1.47 square miles (940 acres) . It is the third largest of the glaciers studied. Altitudes range from 11,700 feet to 13,200 feet, and the median altitude is about 12,150 feet.

The area distribution diagram for this glacier (Fig. 16) is transitional between a Type III (characterized by absence of a large firn field) and Type IV (large lateral tributaries) valley glacier as defined by Ahlmann (1948, p. 62). The lack of a large firn basin is particularly noticeable.

Sacagawea Glacier is fed by several small tongues of neve, one from high on Mt. Helen (see Fig. 19), and two others from Mt. Sacagawea.

Directly east of Mt. Helen is a mass of ice that appears to have motion independent of the main glacier. This glacieret is separated from Sacagawea Glacier proper by a terminal moraine which, unfortunately, was not visited in 1950.

The largest part of Sacagawea Glacier is a broad tongue of ice (Fig. 18) that slopes very gently (less than 6 degrees) from about 12,500 feet to 11,900 feet in altitude. The northern margin of this tongue is blocked at its east end by a bedrock knob which forces the glacier to the southeast.

The snout is a rather complex combination of small, independent ice masses separated by considerable morainal debris. The actual terminus is difficult to locate. When the glacier was visited on August 28 and 29 of 1950 the whole area was deeply covered by snow. The mapping of this complicated mass of divergent ice motions would

Fig. 18

View of the flat, broad tongue of Sacagawea Glacier. The peak to the left of center is Mt. Sacagawea (13,607 feet).

--photo by C. F. Darling

Fig. 19

Mt. Helen and the upper part of Sacagawea Glacier. Note the large, high-level moraine parallel to the Continental Divide (skyline to the left of Mt. Helen) and glacieret below the peak.

not have been possible without the aid of the 1945 aerial photographs.

The existence of these vestigial glaciers at altitudes below the true snout of the glacier is a consequence of an exceptionally favorable topographic location. The main glacier is generally unprotected from the sun, but these glacierets are nestled under a steep northward-facing cliff, and receive direct sunlight for only a few hours during the day. The topographic position also suggests that snow might drift to considerable depths here, and this would contribute to the existence of these small glaciers at such a low altitude.

The firn limit on Sacagawea Glacier in 1945 was at about 12,400 feet in altitude, including about 440 acres in the ablation zone, or 47 per cent of the total area. The per cent of ablation area is significantly higher than for the Dinwoody Glaciers. The firn limit could not be observed in 1950, but it was noticed that by August 29th nearly one-third of the total area was beneath the firn line.

<u>Surficial Features</u>

Sacagawea has a low gradient and is therefore nearly free from crevassing. A discontinuous bergschrund exists along the southern margin of the glacier, and a few crevasses occur at the foot of the neve slope beneath Mt. Sacagawea. Because of the paucity of crevasses and the gentle slope, the surface is not drained well and "snow swamps" exists at several places.

Some large blocks, apparently relics of avalanches, occur on the surface (Fig. 18). Except for these the surface of the ice is very clean. Probably much debris is being carried englacially as fine particles, for the outlet stream is exceptionally milky.

Moraines

No medial moraines exist on Sacagawea Glacier, but the many lateral and terminal moraines form prominent features around the main glacier and the small glacierets. The lateral moraine that borders the tongue of firn that descends from Mt. Helen is a rather unique feature (see Fig. 19). This moraine is well over 100 feet high, 500 feet broad, and flat-topped, yet it occurs in the extreme upper reaches of the glacier at an altitude of from 12,600 feet to over 13,100 feet. The top of this moraine is at one place higher than the adjacent Continental Divide (Fig. 21).

Unfortunately, the author was not able to get to this moraine in 1950, and the reason for the existence of so large a moraine at such a high level is not known. The source of material must have been near the summit of Mt. Helen, but it is somewhat difficult to visualize the former, more extensive ice tongue that would have produced this interesting feature.

The eastern margin of Sacagawea Glacier is unusual. Here the ice is separated from the bedrock hill to the east although the general motion of the ice is almost directly toward this hill. Several hundred feet back from the edge of the ice is a low moraine (Fig.22).

One possible explanation for this feature is that the ice is very thin underneath the margin. The main mass of ice, then, would be deflected to the southeast well back from the margin, and the ice at the edge may have very little motion. Unfortunately the whole area was snow covered when visited in 1950, and it was not possible to determine the direction of motion of the ice at the extreme margin.

The complex arrangement of moraines at the snout (Fig. 16) is not being altered at the present time. It seems likely that these moraines were formed at the time of the maximum extent of the glacier during the Little Ice Age, and have not moved appreciably since then. Therefore the glacier probably did not extend far beyond the present ice in recent years, for these moraines border the present limits of ice.

Recession

The maximum Little Ice Age extent of the glacier covered about 1.59 square miles (1,010 acres) and the more recent retreat has uncovered less than 7 per cent of this area. Pronounced terminal thinning is noted by the high moraines, now standing nearly 100 feet above the ice surface. The terminus has shown negligible recession since 1943.

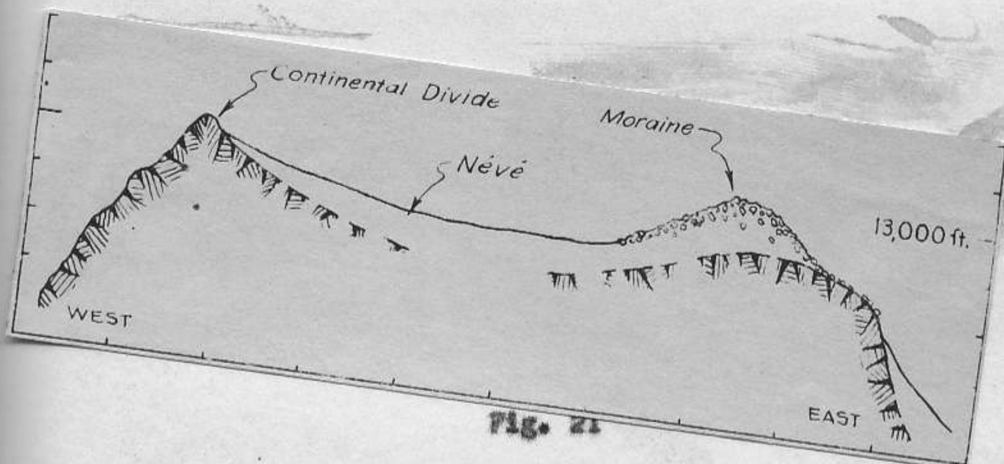


Fig. 21

East-west profile through high-level moraine at head of Sacagawea Glacier. Approximate scale: 1" = 400'

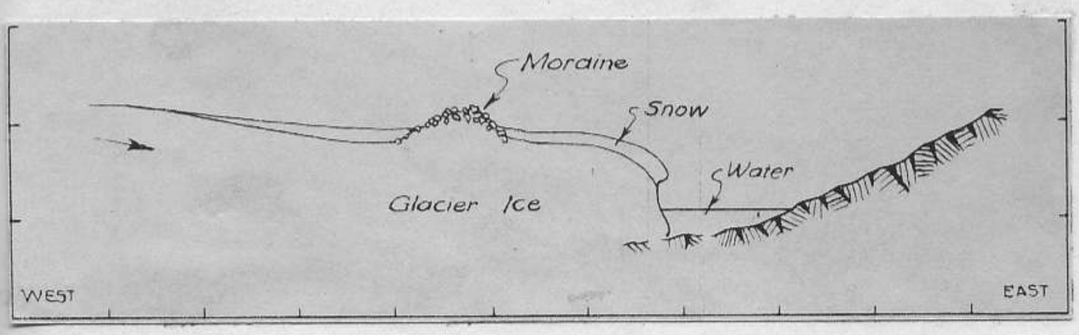


Fig. 22

East-west profile through eastern margin of Sacagawea Glacier northeast of terminus. Approximate scale: 1" = 400'

Fremont Glacier

Nomenclature

The first published reference to this glacier, apparently a report of the Hayden Survey (1878, b), contains a careful sketch of the view from the summit of Fremont Peak showing parts of this glacier. The ice mass just below the summit of the peak was named "Upper Fremont Glacier," and a lower ice mass was called "Lower Fremont Glacier." This usage will be followed here, and the two masses of ice, which are connected, will be referred to as "Fremont Glacier" collectively. Henderson (1933, p. 356) called this the "Upper Fremont Glacier" and referred to the next glacier to the north (Sacagawea) as "Lower Fremont Glacier." Richmond (1950, personal communication) suggested the term "North Fremont Glacier." The author was not able to find any consistent local usage.

General Description

This glacier lies on the east and northeast flank of Fremont Peak (13,730 feet in elevation). It occupies a broad high shelf south of Sacagawea Glacier, and is adjacent to the larger Knife Point Glacier southeast of Fremont Peak (Fig. 2). This glacier has the highest median elevation of any glacier studied - 12,870 feet. Altitudes on the glacier range from 12,200 feet to over 13,600 feet.

The composite glacier has a total length of about 2 miles,

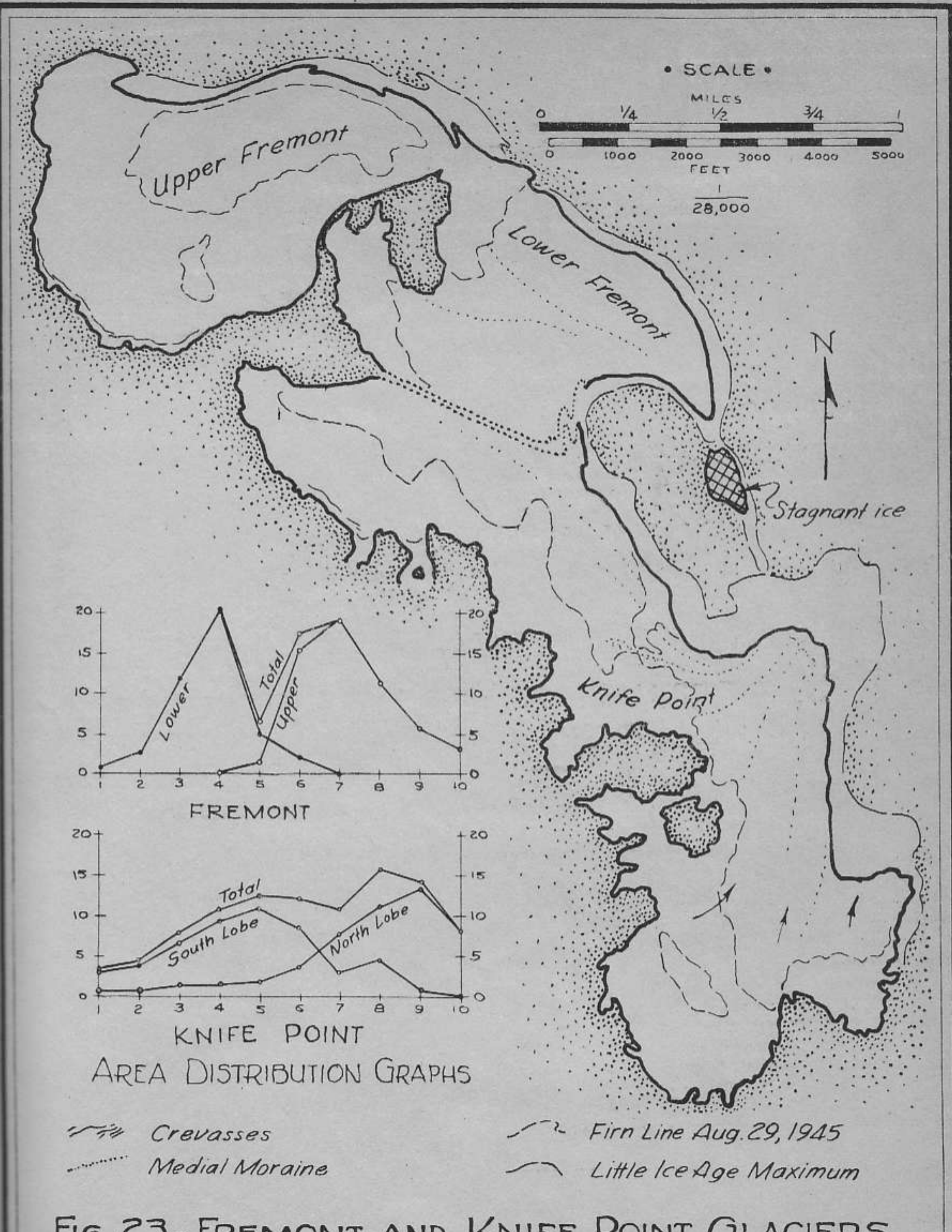


FIG. 23 - FREMONT AND KNIFE POINT GLACIERS

and the maximum width is about 7/8 of a mile. The total area is about 1.03 square miles or 660 acres. It is the sixth largest of the glaciers studied.

Since the glacier consists of two nearly separate parts, as seen in Fig. 23, the area distribution diagram is a two-peaked graph (Fig. 23). The diagram for either Upper Fremont or Lower Fremont Glacier shows, however, a shape characteristic of cirque glaciers (Ahlmann, 1948, p. 62). From this graph and from the general shape of the glacier it is seen that this glacier should be classified as a double (or tandem) cirque glacier.

Upper Fremont Glacier

Upper Fremont Glacier consists of a pear-shaped field of ice and firn. The broad end of the pear is the steep firn apron on the upper slopes of Fremont Peak. The other end of the glacier is a nearly flat and featureless plain of ice (Fig. 24). The slope here is less than 6 degrees. The bergschrund which forms a prominent feature at the head of Upper Fremont Glacier is continuous for nearly a mile, and occurs at an altitude of about 13,400 feet. The firn line in late August of 1945 extended up to as high as 13,200 feet. The snout of Upper Fremont Glacier is at about 12,800 feet, so it can be seen that the glacier has an abnormally high general altitude. In 1945 about 114 acres were included beneath the firn line. The ratio of ablation area to total area for this year was about 0.30. This

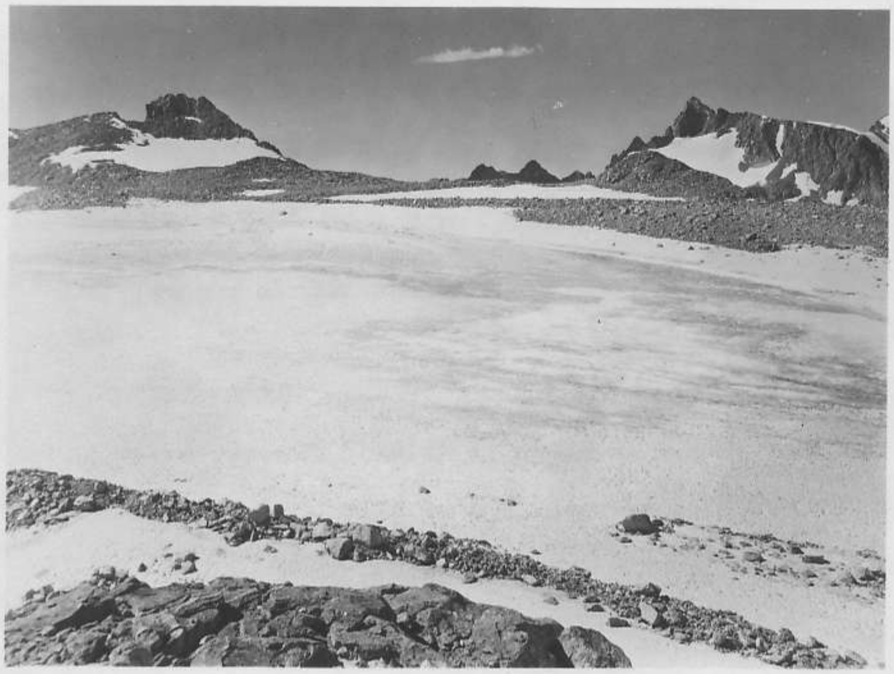


Fig. 24

Lower part of Upper Fremont Glacier. Note the flat, featureless surface and the slushy ice. Dirt bands, probably representing shear surfaces, can be seen below Mt. Sacagawea in the left background. Little Ice Age moraine is just beyond the ice on the right. View taken from the summit of unnamed peak between Upper and Lower Fremont Glaciers.

low figure is due, of course, to the decreased ablation at high altitudes.

The upper and lower parts of Fremont Glacier are now connected only by one narrow throat. This steep couloir was completely snow covered when visited in 1950. However, ice is probably being actively transferred through this constriction, as indicated by the following evidence:

(1) Faint indications of crevassing beneath the snow would not be expected if this was an ordinary snow couloir and suggest motion.

(2) The dirt bands on the exposed ice of Lower Fremont Glacier dip at a high angle (about 60 degrees) up-glacier and are separated by 10 to 15 foot intervals, although further down on the glacier similar bands dipping at the same angle are spaced at only 3 foot intervals. This would indicate that the velocity of the glacier is greatest just below the couloir, a fact that is consistent with the assumption that considerable ice is transferred to the lower glacier through the couloir.

(3) The percentage of ablation area of Lower Fremont Glacier is so low in comparison with other glaciers that it would seem probable that the glacier could not have maintained its present size unless it was supplied with ice from another source (Upper Fremont Glacier).

Several other smaller couloirs connect Upper and Lower Fremont Glaciers, but it is doubtful that there is any appreciable transfer of ice through them. In some cases overhanging cornices of old ice were observed, and these may have been connections between the glaciers at a time of greater ice thickness.

Lower Fremont Glacier

This glacier is somewhat smaller than Upper Fremont Glacier, for its surface area is only about 284 acres (0.44 square miles). The surface is also quite flat, averaging generally less than 10 degrees. The snout descends into a small valley for a short distance, but it was not possible to delineate accurately the ice terminus in 1950 because of snow cover. The ablation area in 1945 amounted to about 209 acres, 74 per cent of the total area. Probably in a normal year nearly the whole area is included in the ablation zone.

The ablation area for the composite glacier was about 320 acres, or 49 per cent of the total combined area, in 1945. This was the highest per cent ablation area recorded of the glaciers studied, and is in spite of the high altitude of this glacier.

Surficial Features

The surface of both Upper and Lower Fremont Glaciers is remarkably free from coarse debris, although some large blocks were observed on the ice below the unnamed peak between the two glaciers. The ice is generally clean, and is apparently transporting little debris. The outlet stream from Lower Fremont Glacier was observed to be carrying very little suspended matter. Because of the gentle slope and poor drainage, many "snow swamps" occur. Dirt bands, probably representing shear surfaces, were noticed on both Upper and Lower Fremont Glaciers.

<u>Moraines</u>

Upper Fremont Glacier is bordered on the north by a series of lateral moraines which rise less than 50 feet above the ice. These are compound, indicating several expansions and contractions of the glacier. Along the southeast margin of the ice is a rudimentary lateral moraine of no great height.

The south border of Lower Fremont Glacier is formed by a medial moraine which separates this glacier from the adjoining Knife Point Glacier. This moraine is low, probably less than 100 feet high, and is very straight throughout most of its length. The eastern end is marked by several tight folds. These may represent minor curvings or drag folds that were compressed and tightly folded against the bedrock and moraine beyond the glacier. If these folds started as drag folds, then it follows that Lower Fremont Glacier here flows faster than Knife Point Glacier. Beyond the folds the moraine merges with extensive morainal debris overlying bedrock, and becomes part of a large lateral moraine around the southeastern margin of the glacier. A similar lateral moraine exists on the northeast side of Lower Fremont Glacier.

<u>Recession</u>

The author was not able to locate any previous photographs of the terminus of Fremont Glacier. From a study of the moraines and the 1945 aerial photographs it seems probable that there has been little, if any, terminal recession in the last few years. The true snout of this glacier was heavily snow covered when visited in 1950, and the ice may possibly have retreated a slight distance from the moraine. In the valley below the snout some old glacier ice was observed, but this is probably a stagnant remnant of a small vestigial glacier which once existed in the confines of the valley.

The upper regions of the glacier have been observed by several parties, and the author was able to locate photographs or sketches of the glacier dating as far back as 1901 (Titcomb, 1939) and 1878 (Hayden, 1878, b.). No change could be detected in the margins or the thickness of Upper Fremont Glacier in the 1878-1901 interval. Comparison of the 1878 sketch and the 1945 aerial photographs shows some recent marginal thinning amounting probably to less than 100 feet, and a slight morainal development along the eastern margin of Upper Fremont Glacier. Considerably greater change, however, is noticed in those parts of Lower Fremont Glacier that were visible to the 1878 party. The glacier at that time stood even with, or possibly above, the crest of the moraine on the southeast edge of the glacier. At the present time this moraine stands over 100 feet above the ice surface, so the thinning since 1878 must have amounted to well over 100 feet.

Knife Point Glacier

General Description

The name Knife Point Glacier (from Knife Point Mountain) has been taken from Henderson (1933, p. 356). No other published name or any consistent local usage has been found.

This glacier is located on the east slope of the Continental Divide and extends southeast from Fremont Peak to Knife Point Mountain (Fig. 2). Only small glaciers and glacierets exist south of this glacier in the Wind River Mountains. Knife Point Glacier extends for over 2½ miles in its longest dimension, and has an area of about 1.16 square miles (740 acres). Firn reaches to about 13,100 feet and the snout is at about 11,300 feet in altitude. The median elevation is about 12,090 feet above sea level.

This glacier is somewhat difficult to classify morphologically. The area distribution diagram for the whole glacier (Fig. 23) does not fit any of Ahlmann's glacier types (Ahlmann, 1948, p. 62). However, when individual area distribution graphs are drawn for the north and south lobes, it is seen that the north lobe can be considered a typical valley glacier and the south lobe a typical cirque glacier.

The north lobe of Knife Point Glacier originates at the Continental Divide in a depression between Fremont Peak and Glacier Crest (Fig. 2). It moves first east, paralleling the adjacent Lower Fremont Glacier (Fig. 25), and then turns southeast and flows parallel to the divide for about a mile (Fig. 26). Near Indian Pass the lobe turns abruptly east and northeast, joining the snout of the south lobe. The slope of the north lobe is rather constant at from 6 to 10 degrees except where the glacier moves off a bench along the east side of Glacier Crest. Here, just west of the terminus, the ice is steepest and is probably thin, for several low nunataks project through to the surface.

The south lobe of Knife Point Glacier originates in a cirque, the walls of which form the Continental Divide from Indian Pass southeast to Knife Point Mountain. The ice moves in a generally northward direction toward the main terminus northeast of Indian Pass, although some ice is directed toward a rudimentary snout to the southeast. Next to the cirque walls the surface slopes up to 30 degrees. About one-third of the way down the surface slope changes to a much lower value (around 8 to 10 degrees), and at the terminus is again steep (about 15 degrees).

In 1945 the firn limit on Knife Point Glacier ranged from as high as 12,900 feet to as low as 11,900 feet in altitude. For this year the ablation area amounted to about 0.55 square miles, 48 per cent of the total area. When the glacier was visited in 1950 (August 30 and 31) only about 30 per cent of the area was below the firn line.

Except for a bergschrund on the north face of Glacier Crest (Fig. 25) and a discontinuous bergschrund east of Knife Point Mountain, no crevasses were seen on Knife Point Glacier. Some coarse debris

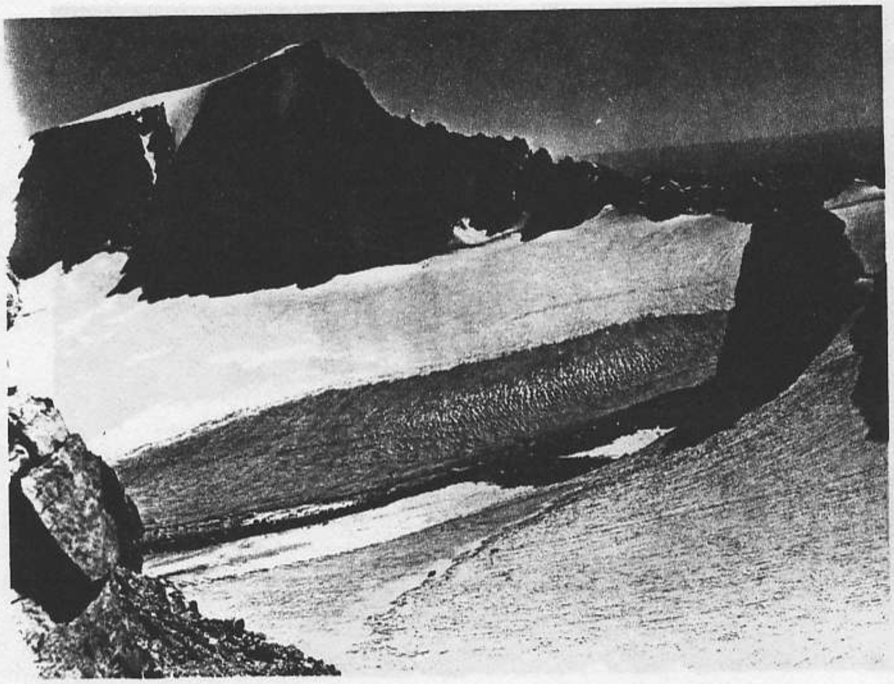


Fig. 25

Head of the north lobe of Knife Point Glacier. Glacier Crest is the high peak. Medial moraine and a small part of Lower Fremont Glacier in the foreground. This picture is almost panoramic with Fig. 26.

Fig. 26

Knife Point Glacier from the summit of the unnamed peak between Upper and Lower Fremont Glacier. The snow peak extending out of view to the right is Glacier Crest. In the center of the view the north lobe of Knife Point Glacier turns to the southeast, and then steepens abruptly before joining the south lobe, which is visible in the background. Note the folds in the medial moraine separating Knife Point Glacier from Lower Fremont Glacier (foreground). This view is almost panoramic with Fig. 25.

occurs on the surface, but not as much as on the Dinwoody Glaciers. The surface is fairly well drained, and few snow swamps were noticed in 1950. Dirt bands probably indicating shear planes were observed on the south lobe.

Moraines

The only medial moraine seen separates Knife Point and Fremont Glaciers (Figs. 25, 26, and discussion under Fremont Glacier).

A massive, fresh moraine marks the maximum extent of the glacier in the last century or so. This feature extends continously as a lateral moraine from near Fremont Glacier to the terminus of Knife Point Glacier where it takes the form of a large, high terminal moraine. This moraine probably contains the most material of any of the moraines that were visited in 1950. Some small kettles were seen on this moraine. Between the crest of the terminal moraine and the edge of the glacier is a quicksand flat, similar to the one at the foot of Dinwoody Glacier.

Recession

This glacier has retreated considerably from its maximum extent in the Little Ice Age. About 890 acres (1.39 square miles) were then covered by ice, and the present area represents only 83.5 per cent of that amount. The line retreat of the snout has been about 1,200 feet.

A sketch from the summit of Fremont Peak (Hayden, 1878, b.)

shows that ice extended nearly to the crest of the terminal moraine in that year. This suggests that most of the recession has taken place in the last 70 years. The same sketch shows that the neve on the north face of Glacier Crest has thinned by not less than 100 feet.

Very little change at the terminus could be detected between 1945 and 1950, but there was noticeable thinning on the steep part of the north lobe. If recession continues in a very short time this lobe of Knife Point Glacier will be cut in two at this point.

Gooseneck Glacier

General Description

This glacier was until 1935 or so a tributary of Dinwoody Glacier. Consequently, it has not needed an individual name until recently. Although no published name could be found, the name "Gooseneck Glacier" has been used by the local packing and guiding personnel. The "Gooseneck" is a peculiar pinnacle dominating the ridge between this glacier and Dinwoody Glacier.

Gooseneck Glacier lies in a small, imperfect cirque beneath the precipitous east face of Gannett Peak (Fig. 2). The glacier has a surface area of only about 87 acres. The length is about 2,700 feet and the average width about 1,400 feet. The snout is now at about 12,000 feet, firn extends to as high as 13,000 feet, and the median elevation is about 12,310 feet. The area distribution diagram shows this to be a typical cirque glacier (Fig. 27).

The upper portions of Gooseneck Glacier slope up to 30 degrees. Below this steep upper margin is a broad, irregular firn basin which slopes to the northeast. The glacier moves in an easterly direction, and the slope of the tongue is to the southeast. Thus, when viewed from the east the glacier has a "twisted" appearance. South of the present terminus is a pocket of ice which is no longer being fed from above and is, therefore, stagnant. The actual snout is on a rock slope so steep that little morainal material can lodge there.

The surface of the glacier is badly crevassed, probably from the irregular bed. The bergschrunds around the west margin of the glacier are large and imposing. One prominent system of crevasses exists in a semicircular bend just below the firn basin which is at the foot of the Gannett Peak cliffs. Below this area is an additional set of crevasses which intersect the above system at nearly right angles. These crevasses are apparently due to the "twisting" effect of the bed.

Very few well defined melt water channels exist on the surface of Gooseneck Glacier, for most of the water disappears into crevasses. Some coarse debris litters the surface, a result of avalanches from Gannett Peak.

In 1945 ablation exceeded accumulation over about 20 acres, so the ratio of ablation area to accumulation area for that year was about 0.24.

Very little morainal material is found in the immediate

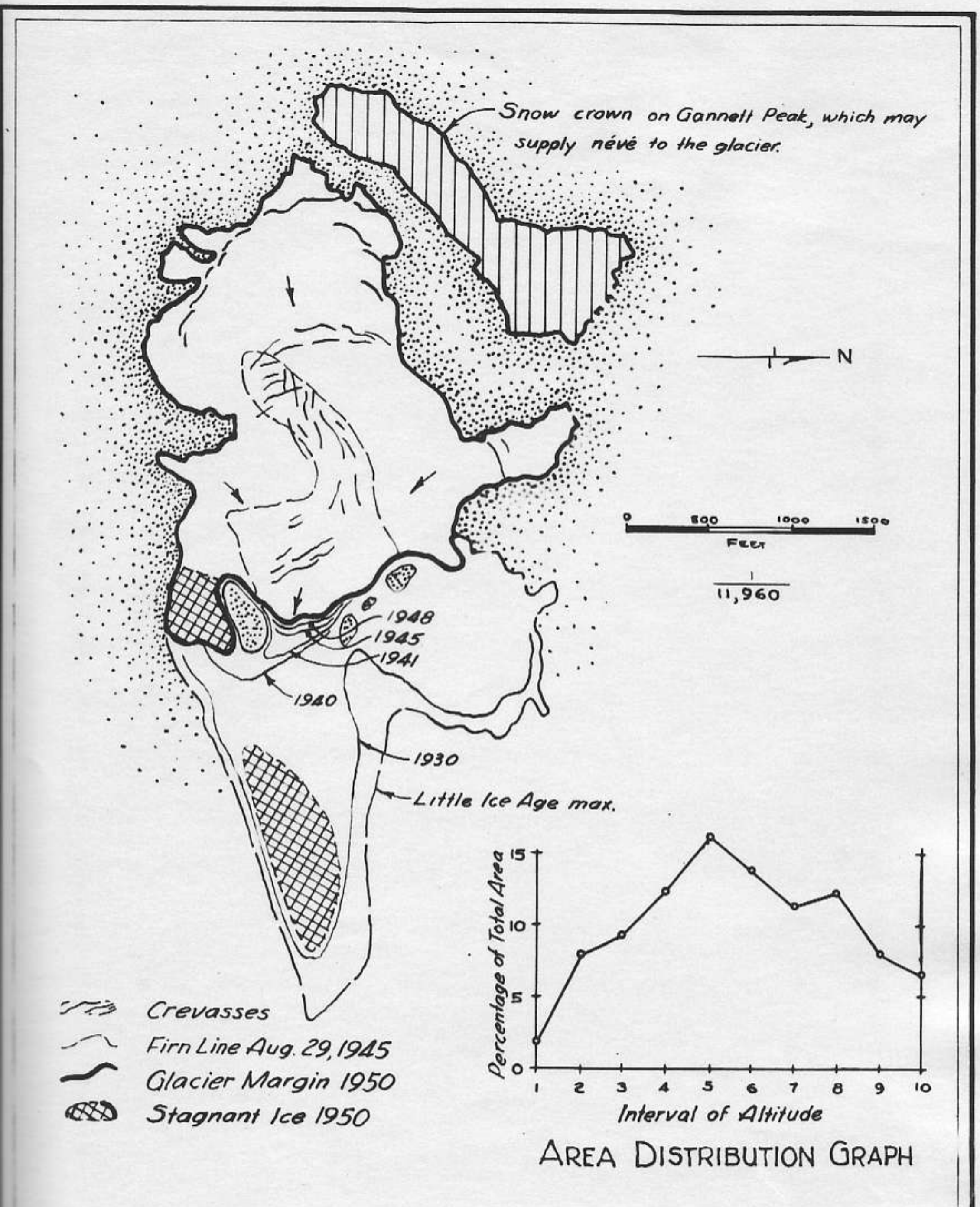


FIG. 27 - GOOSENECK GLACIER

vicinity of the present terminus. However, a prominent Little Ice Age moraine shows that the glacier was formerly much more extensive. This moraine stands over 100 feet high beneath West Sentinel, and is probably ice cored.

Recession

The maximum extent of the glacier in the last several centuries is difficult to estimate, since the glacier at its maximum extent coalesced with Dinwoody Glacier. However, it is estimated that the glacier at one time spread over 147 acres and the area reduction since this maximum is about 41 per cent. At the time of its maximum size the glacier extended over a considerable area to the northeast of its present position, and the terminus extended about 2,300 feet to the terminal moraine of Dinwoody Glacier. By 1930 it had retreated but slightly from its maximum position. However, at sometime between 1930 and 1939 the glacier had thinned to the point where the 1,700 foot section of the tongue which was connected to Dinwoody Glacier was cut off from the main part of the glacier (Fig. 28). This left a mass of stagnant ice which in 1950 amounted to about 9 acres. Since 1940 the retreat has been but a few per cent of the maximum area. The linear and area changes in recent years are summed up in the following tabulation:

Fig. 28

Position of the terminus of Gooseneck Glacier in the years 1930, 1940, 1941, 1945, 1948, and 1950. Note snow crown on Gannett Peak. Vertical relief from the snout of Gooseneck Glacier to the summit of Gannett Peak is slightly over 2,000 feet. View from near Heap Steep Glacier, looking west.

Period of Time	Linear Recession ft.	ft./yr.	Area Decrease per cent	per cent/yr.
L. I. A. max. to 1930	340	---	10.1	---
1930 to 1940	1,700	170	28.6	2.86
1940 to 1941	150	150	1.3	1.30
1941 to 1945	150	38	0.7	0.18
1945 to 1948	35	12	0.3	0.10
1948 to 1950	20	10	0.1	0.05
Total	2,395		41.1	

Minor Glacier

General Description

The name Minor Glacier was apparently first suggested by Henderson (1933, p. 356) by way of contrast to the nearby Mammoth Glacier (see Fig. 2, page 3). This name is commonly used locally.

Minor Glacier is directly beneath the sheer west face of Gannett Peak. It is contained on the south and west by a curving ridge which nowhere rises more than a few tens of feet above the present surface of the glacier. The direction of motion of the ice is slightly west of north. The glacier is about 4,700 feet long and generally about 2,000 feet wide. The present area is about 214 acres (0.33 square miles). It is the largest of the group of small cirque glaciers that were studied.

The form of this glacier (Fig. 39) is that of a small cirque glacier. An area distribution diagram could not be constructed for lack of sufficient photographic control.

The slope of the surface of Minor Glacier is rather constant

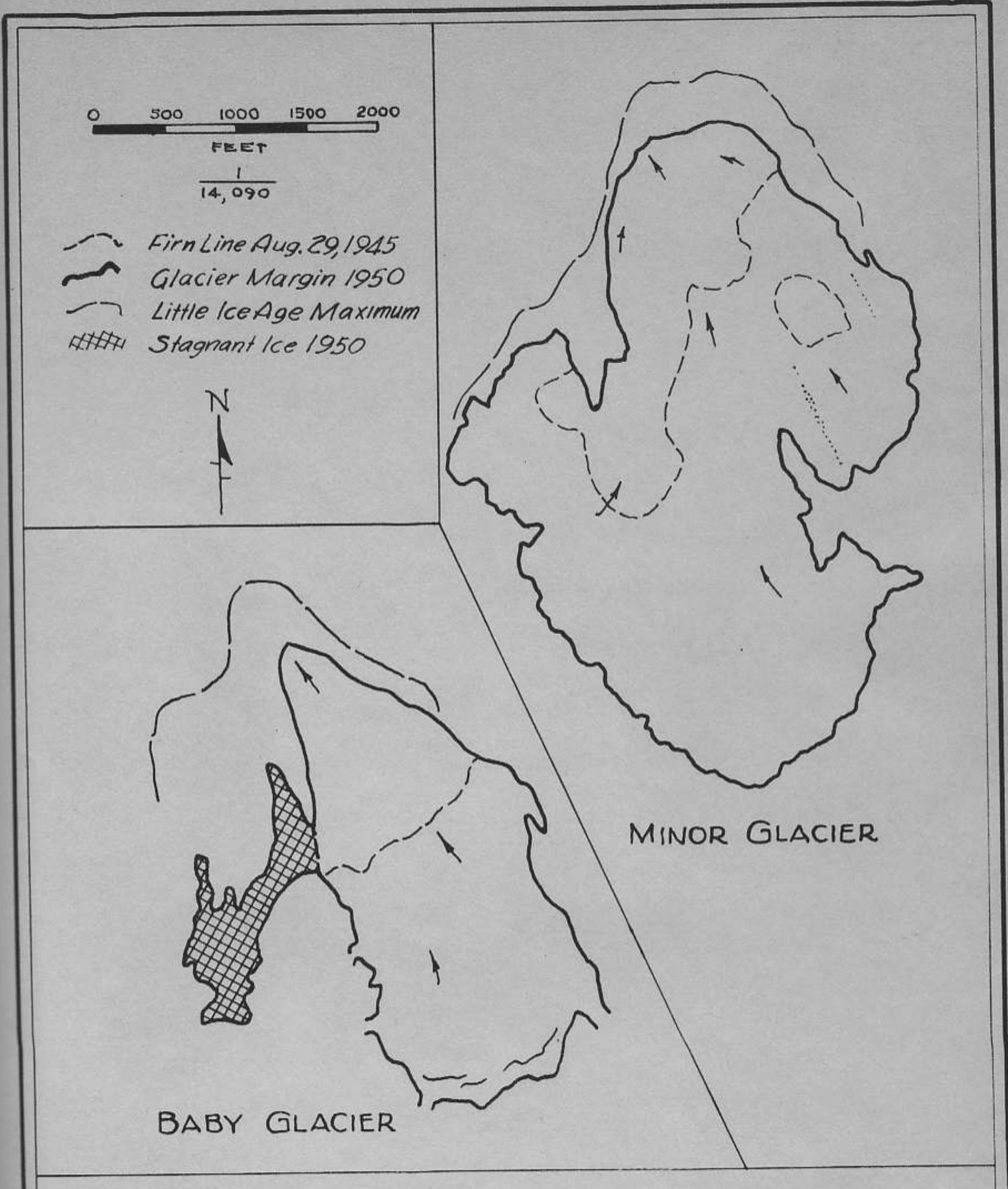

0 500 1000 1500 2000
FEET
1/14,090
Firn Line Aug. 29, 1945
Glacier Margin 1950
Little Ice Age Maximum
Stagnant Ice 1950
N
MINOR GLACIER
BABY GLACIER
MFM

FIG. 29

at about 10 degrees, although just above the snout the slope is somewhat steeper. The firn basin is elliptical in shape, with the long axis parallel to the west face of Gannett Peak.

Intricately contorted dirt bands are exposed at the snout. These are probably primary sedimentary bands that have become folded through shearing and plastic flow.

Grasshoppers

The outstanding surface feature of Minor Glacier in 1950 was the large amount of organic material littering the surface. Most of this debris was in the form of grasshopper remains, but parts of moths, dragonflies, and other insects; grasses and deciduous leaves; and a small bird and another small animal were collected. Unfortunately the collection was lost while leaving the area in September.

Most of the remains were imbricated or flattened, although some relatively whole specimens of grasshoppers were found. No remains were found completely imbedded in the ice, but several specimens were partly surrounded by ice and the bird was found next to an ice cavity that seemed to fit the contour of the bird closely. The remains occur only where old glacier ice was exposed, and none are above the firn line. The debris was not definitely traceable to a single layer in the ice.

Grasshopper remains on Wind River glaciers have been reported before. Henderson (1933, p. 365, footnote) says:

> Not only here on the Fremont Glacier but also upon Mt. Helen and Gannett Peak this party 1924 found grasshoppers in such numbers that "the air was as if infected." Mr. T. G. Koven also speaks of large areas of their rotting carcasses on the Mammoth Glacier in the Wells Creek Valley on the other side of the range. (Letter to the writer) A party which climbed Fremont Peak in 1931 reported large numbers of grasshoppers on the summit. (Pinedale Roundup, August 27, 1931)

The same author, when describing a 1936 ascent of Fremont Peak (Henderson, 1939, p. 53) mentions that, "...they discovered that the entire Fremont and Knife Point Glaciers were covered with billions of grasshopper carcasses which stank horribly."

Grasshopper remains have been reported from several other Rocky Mountain glaciers. The most famous of these is the Grasshopper Glacier in the Beartooth Mountains of Montana. A short bibliography of references to this glacier may be found in Dyson, 1950, p. 7.

The author is not able to offer a satisfactory explanation for the presence of grasshopper and other remains only on Minor Glacier. It is perhaps possible that a swarm of insects was caught in an exceptionally high wind and carried to the higher regions of the Wind River Mountains. These may have been covered with snow and preserved from further decay, later to melt out of glacier ice. They may have appeared at the surface of Fremont, Knife Point, and Mammoth Glaciers earlier than they did on Minor Glacier because of faster motion of the ice on the larger glaciers.

<u>Moraines and Recession</u>

Minor Glacier is encircled on the north and northwest by a prominent Little Ice Age moraine less than 100 feet high. Between the moraine and the snout is a small milky-green lake. The glacier has retreated about 350 feet from its maximum extent of the Little Ice Age, and the present area represents about 68 per cent of the recent maximum. No measurable retreat has been detected since 1945.

Baby Glacier

General Description

The name Baby Glacier was apparently first applied by Henderson (1933, p. 356). Richmond (1950, personal communication) suggested the name "Wells Glacier," but it is thought that the use of this term might cause confusion with Baker's (1946, p. 593) usage of the name "Wells Creek Glacier" for the larger Mammoth Glacier.

Baby Glacier is located less than 1,000 feet west of Mammoth Glacier (Fig. 2) . It is contained in a northward facing cirque at the foot of Mt. Whitecap and G-1 Peak (Figs. 15 and 30). The length of the ice mass is about 3,500 feet and the maximum width about 1,600 feet. The area of active ice is about 94 acres, and it is the tenth largest of the glaciers studied. The highest firn extends to about 12,500 feet, the snout is at about 11,700 feet, and the median altitude is estimated at 11,900 feet. The shape of the glacier (Fig. 29) and its topographic setting indicate that it should be classed as a cirque glacier.

Fig. 30

Baby Glacier, as seen from a point on the Little Ice Age moraine east of the present terminus. The peak in the center background is Mt. Whitecap. Notice the outcrop of shear surfaces, which are here nearly parallel to the border of the glacier.

The surface is rather uneven, for there are several steps of benches in the long profile (Fig. 30). No crevasses were seen with the exception of a prominent bergschrund on the apron below Mt. Whitecap. The surface of the ice is covered with considerable debris, probably derived from the cliffs at the head of the glacier. Dirt bands, probably the outcrop of shear surfaces are prominent. The glacier appears to be thin. Crevasses, normally expected where a glacier moves over an uneven bed, are absent here probably because the motion is very slow. The outlet stream contains very little rock flour.

In 1945 the firn limit was at about 11,500 feet. About 32 acres were included in the ablation zone, 34 per cent of the total area. West of the active part of Baby Glacier is a remnant of a lobe of the glacier which once covered nearly 40 acres. At the present time only about 15 acres of stagnant ice remains. This is slowly wasting away under an ever-increasing mantle of debris.

Moraines and Recession

A large fresh moraine exists around the terminus of Baby Glacier. It is generally low, but east of the present terminus it attains a height of over 100 feet.

At one time in the last hundred years or so the main part of the glacier extended over 119 acres, and it has retreated 470 feet and diminished in area by about 21 per cent since that time. The west lobe which once covered nearly 40 acres is now only 38 per cent of its former size. The recession in the last few years could not be determined because the snout was buried beneath a heavy drift of snow in 1950.

Heap Steep Glacier

Nomenclature

The author was not able to find any published name for this small glacier. The policy followed in cases such as this was to name the glacier after the mountain on which the body of ice is located. This glacier is at the foot of the northeast face of Heap Steep Peak and the north face of Sunrise Peak. It was thought that the name "Sunrise Glacier" would cause confusion with the small glacier on the southeast side of Sunrise Peak (Fig. 2, page 3). Therefore the name Heap Steep Glacier is suggested.

General Description

This glacier nestles close under the walls of the above-mentioned mountains, and is east of Dinwoody Glacier. It is so well hidden from view that Wentworth and Delo (1931, pp. 618-619) wrote:

> This small hanging cirque was not visited nor its extreme floor viewed from a distance, but enough of its side walls was seen from the spur south of North Gannett Gannett Glacier to reveal any such ice-mass as that shown on the Fremont Peak map. A few snow-banks were seen on the more sheltered slopes but there was no evidence of a true glacier here...

The length of this glacier is only 2,100 feet on the map constructed by the author (Fig. 31) and the area is only about 46 acres. It is believed to be a true glacier for the following reasons:

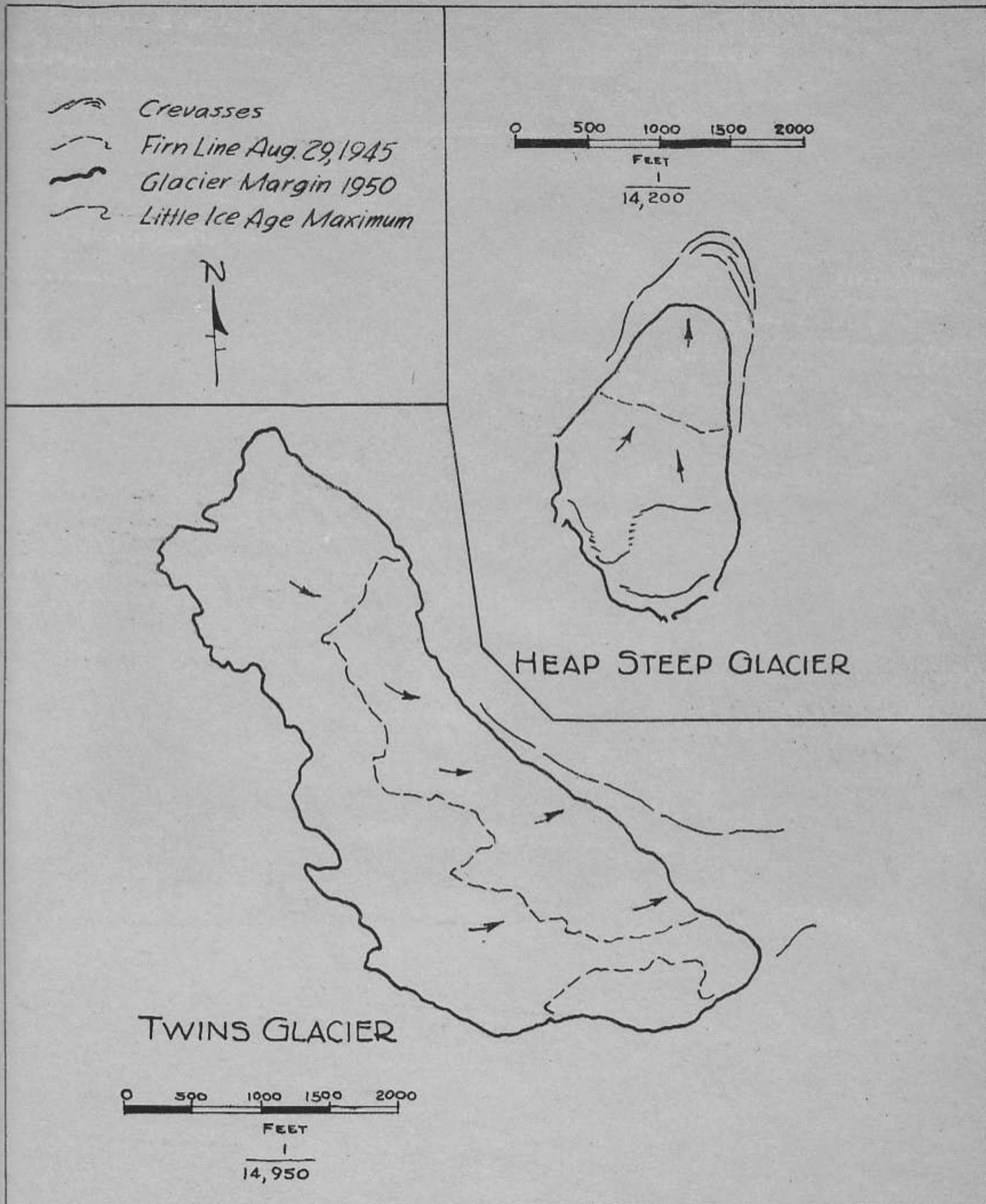

Crevasses
Firn Line Aug. 29, 1945
Glacier Margin 1950
Little Ice Age Maximum
N
0 500 1000 1500 2000
FEET
1
14,200
HEAP STEEP GLACIER
TWINS GLACIER
0 500 1000 1500 2000
FEET
1
14,950
MFM

FIG. 31

(1) a large bergschrund probably indicates considerable movement; (2) definite ablation and accumulation zones separated by a firn line exist; (3) curved shear surfaces show definite evidence of movement at the lower part of the glacier; (4) a large Little Ice Age moraine has been accumulated; and (5) the ice-contact lake at the terminus has a typical glacial milky-green color.

Firn begins at about 12,600 feet, the snout is at about 11,700 feet, and the median altitude is estimated to be 12,100 feet. The ablation area in 1945 embraced about 12 acres or 26 per cent of the total area. The firn limit at that time was about 11,900 feet. The horizontality of the firn line is striking (Fig. 32).

The outstanding characteristics of Heap Steep Glacier are the perfect, regular configuration and the steepness of the surface slope. The shape of the glacier suggests that it might be well adapted for a special study, but this is precluded by the constant danger of rock-fall from the steep cliffs and the steep slope (21 degrees and more).

The surface of the glacier below the firn line is marked by three prominent features: (1) many glacial tables (these are indistinctly visible in Fig. 31); (2) a regular arrangement of dirt bands; and (3) a regular arrangement of bumps on the ice. These bumps are the result of the regular intersection at right angles of the dirt bands (shear surfaces) by superglacial stream channels. The dirt bands are very close together at the foot of the glacier

Fig. 32

Heap Steep Glacier, from the top of the bedrock knob in the center of the large cirque. Note the straight firn line, the curved dirt bands, the large bergschrund, the moraine emerging beneath the terminus, and the large, compound Little Ice Age terminal moraine. Heap Steep Peak to the right and Sunrise Peak to the left in the background.

(some were less than one inch apart), but higher six bands were counted in a distance along the surface of 25 feet. The dip of the bands was 32 degrees up-glacier at this point, and many dust wells were observed. The average size of the ice crystals near the firn line was found to be between 0.1 and 0.2 inches in diameter, and at the terminus the average size was about 0.3 inches in diameter.

Moraines and Recession

The symmetry of Heap Steep Glacier is marred at the terminus by a broad, low morainal ridge beneath the ice on the west side (Fig. 31). The material in this feature is unsorted till, and shows no evidence of having been deposited by water. This debris ridge must, therefore, be developed in the lee of a projection of the bed-rock.

The Little Ice Age terminal moraine is very prominent. It is not a single ridge, but consists of a series of concentric moraines. These may represent several advances and retreats, or at least several pauses in the recent recession. The moraine is high and apparently has an ice core.

Heap Steep Glacier has retreated nearly 500 feet from its farthest recent moraine, indicating a reduction in area of about 12 per cent. Since 1945 the glacier has retreated less than 50 feet.

Twins Glacier

General Description

This name, like many others in this report, was first suggested by Henderson (1933, p. 356). This glacier is one of a group to which the name Titcomb Glaciers has been applied.

Twins Glacier is located at the headwaters of Titcomb Creek west of the Continental Divide (Fig. 2). Winifred and Twin Peaks rise above the west side of the glacier. This ice mass is slightly over a mile wide and is about 2,200 feet long in the direction of motion. Its area is about 173 acres, and it is ninth in size of the glaciers studies. The glacier extends from about 11,200 feet to about 12,200 feet in altitude, and the median altitude is estimated to be 11,700 feet. The elongation perpendicular to the direction of motion and the topographic setting classify the glacier as a cirque glacier (Fig. 31).

No crevasses and no bergschrund were visible on the surface of this glacier in 1950. The surface was nearly completely covered with snow on September 1st (Fig. 33), but pictures taken in 1948 show considerable old ice exposed in the ablation zone. Faint dirt bands are visible in those pictures. It was not possible to study this glacier closely in 1950 or investigate the outlet stream immediately below the glacier. The stream is quite milky where it joins the main Titcomb Valley, but some of this flour may have been contributed to

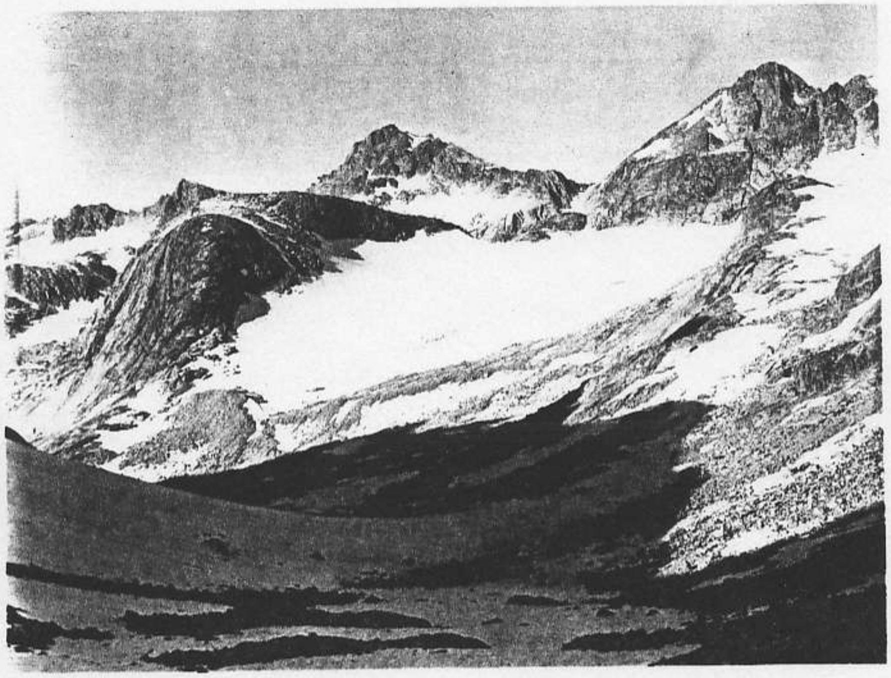


Fig. 33

Twins Glacier. Note that the surface is nearly completely covered with snow although the summer season is nearly over (photograph taken September 1, 1950). The Little Ice Age moraine is in the form of a sloping bench below the glacier, and there is no single outlet stream. The head end of the Titcomb Lakes valley appears in the foreground.

the stream from the Sphinx Glacier. In 1945 the firn limit was at about 11,500 feet in altitude and about 67 acres were included in the ablation zone (38 per cent of the total area).

Moraines and Recession

The Little Ice Age moraine at the foot of Twins Glacier is in the shape of a sloping bench rather than an encircling ridge. The surface of this bench is apparently scored with regular, straight furrows. This type of furrowed till surface has been reported by Ray (1935, pp. 310-311) and Tarr and Martin (1914, pp. 448-449, Plate CLXXX) from Alaska, and by Dyson (1950, personal communication) from Glacier National Park. Unfortunately, this moraine was not visited in the field, and the furrowed till surface was discovered only after careful study of aerial photographs.

The form of this moraine makes an estimate of the Little Ice Age extent of Twins Glacier very difficult. The recession of this glacier in recent years is negligible.

Sphinx Glacier

General Description

This name was first suggested by Henderson (1933, p. 356). The names "Wilson Glacier" and "North Titcomb Glacier" are used locally, but they have apparently not been published.

This glacier lies close under the south face of the Sphinx and Mt. Woodrow Wilson, and is on the west side of the Continental Divide. The area of Sphinx Glacier is only about 60 acres, and its greatest dimension is but 3,600 feet (Fig. 34). The glacier extends from about 12,100 feet to 12,800 feet, and the median altitude is estimated to be 12,450 feet. This glacier is elongated perpendicular to the direction of motion, and it is evidently a cirque glacier.

The surface of Sphinx Glacier slopes at a steep angle. A discontinuous bergschrund exists at the highest margin of the glacier, and a number of marginal crevasses appear along the east side. The surface of the ice below the f irn line exhibits a typical system of dirt bands. In 1945 the ablation area was only 10 acres or 16 per cent of the total area. This is even more unusual considering the moderate altitude and the southern exposure.

Moraines and Recession

Sphinx Glacier is located on such a steep slope that the extensive Little Ice Age moraine forms a cone below the glacier. The glacier has thinned and receded considerably from this moraine, but it is not possible to give an accurate estimate of the maximum recent extent of the ice. The recession since 1945 amounts to less than 50 feet.

F-3 Glacier

General Description

This glacier is not, to the best of the author's knowledge

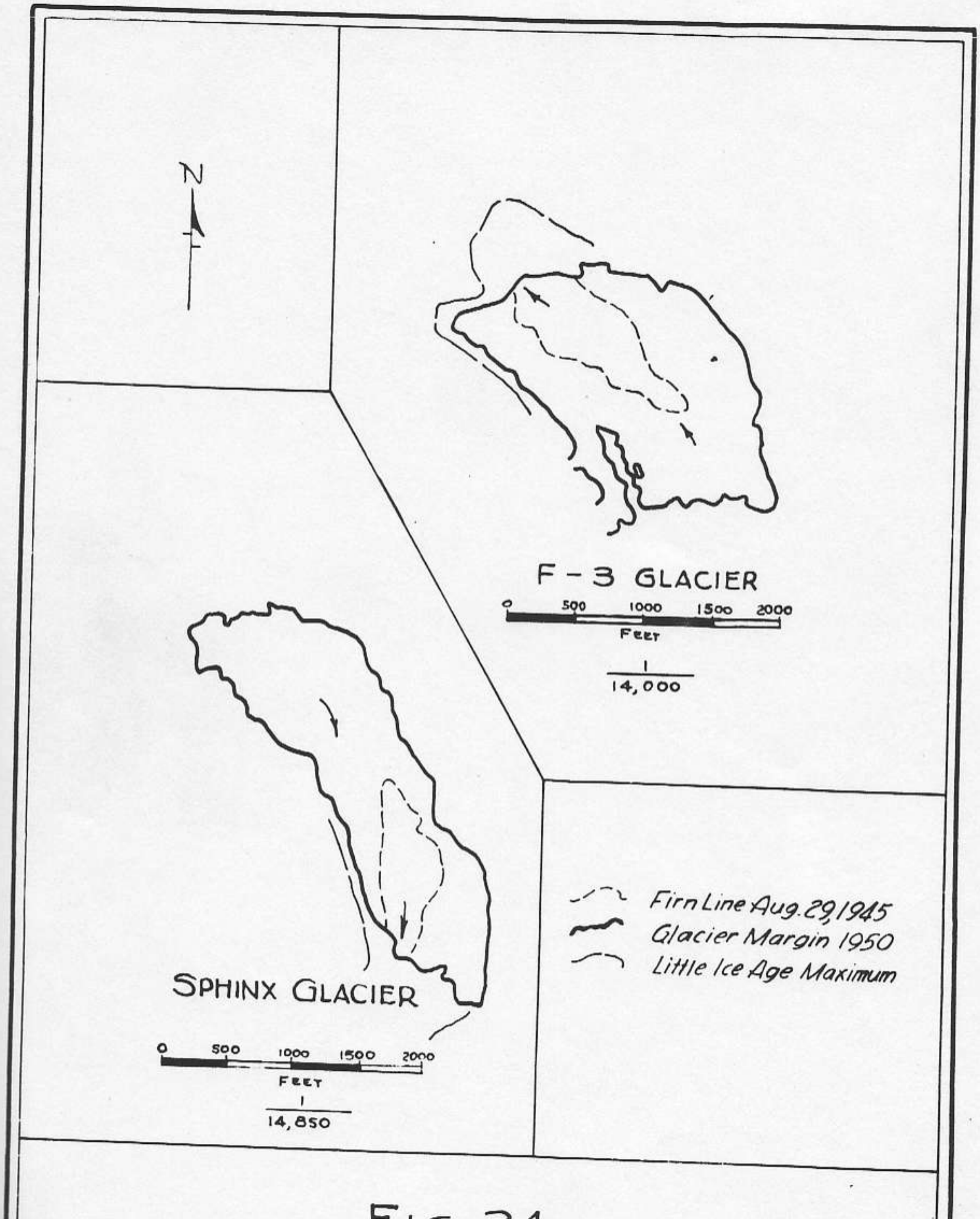

N
F - 3 GLACIER
0 500 1000 1500 2000
FEET
1
14,000
Firn Line Aug. 29, 1945
Glacier Margin 1950
Little Ice Age Maximum
SPHINX GLACIER
0 500 1000 1500 2000
FEET
1
14,850
MFM

FIG. 34

named in any publication. Richmond (1950, personal communication) suggested the term "Knife Point Glacier," but this would have conflicted with Henderson's (1933, p. 356) usage of that name to describe the larger glacier on the other side of the mountain. The author proposes the name F-3 Glacier since this small ice mass is located between Knife Point Mountain and F-3 Peak (Fig. 2, page 3).

This ice body is a small cirque glacier (Fig. 35) having an area of but 59 acres, and it is one of the smallest glaciers studied. The glacier is oval in shape (see the map in Fig. 34). The surface is uneven, and slopes from about 10 to 20 degrees. No crevasses of any sort were seen on the surface in 1950, but dirt bands arranged in the typical pattern of cirque glaciers indicates glacier movement, as does the milky-green ice contact lake at the terminus. The glacier extends from about 11,700 feet to about 12,500 feet in altitude, the median elevation is about 12,150 feet. In 1945 the ablation area enclosed about 13 acres, this is 21 per cent of the total area.

Moraines and Recession

This glacier is enclosed by a prominent Little Ice Age moraine which is nearly 200 feet high in places. The glacier has retreated about 450 feet from this moraine and the present area is only 84 per cent of the recent maximum. The vicinity of the glacier is shown in the sketch from the top of Fremont Peak by the 1878 Hayden party, but it is not possible to define the exact limits of the glacier

Fig. 35

F-3 Glacier, from near Indian Pass. The ridge in the background extends from Knife Point Mountain (off the picture to the left) to F-3 Peak (just out of view to the right). Note the high Little Ice Age moraine, and the typical pattern of dirt bands on the surface of the ice in the small ablation area.

from the nearby snowfields. The recession of the glacier in recent years is not known, except that since 1945 the terminus receded perhaps by as much as 50 feet.

Other Glaciers In and Near the Area

North of Bastion Peak

North of Gannett Glacier is a large glacier that occupies broad upland along the Continental Divide (Fig. 2, page 3). This glacier apparently extends for at least 2½ miles along the divide, and is probably one of the largest glaciers in the range. The ice is not protected by cirque walls or valley sides, but exists here because of heavy accumulation (alimented by wind drift) and relatively high altitude. At the time of the U. S. G. S. Fremont Peak quadrangle mapping (1907) this glacier was apparently continuous with Gannett Glacier at the south, and flowed into Klondike Lake on the east. At the present time it has retreated considerably. The south end of this glacier is shown in Fig. 36.

West of Rampart Peak

Richmond (1950, personal communication) suggested the presence of two small glaciers north of Desolation Peak and west of Rampart Peak (Fig. 2). Aerial photographs show small masses of snow or possible ice here, and at the foot of each is a small moraine or protalus rampart. To the author these have neither the size nor the

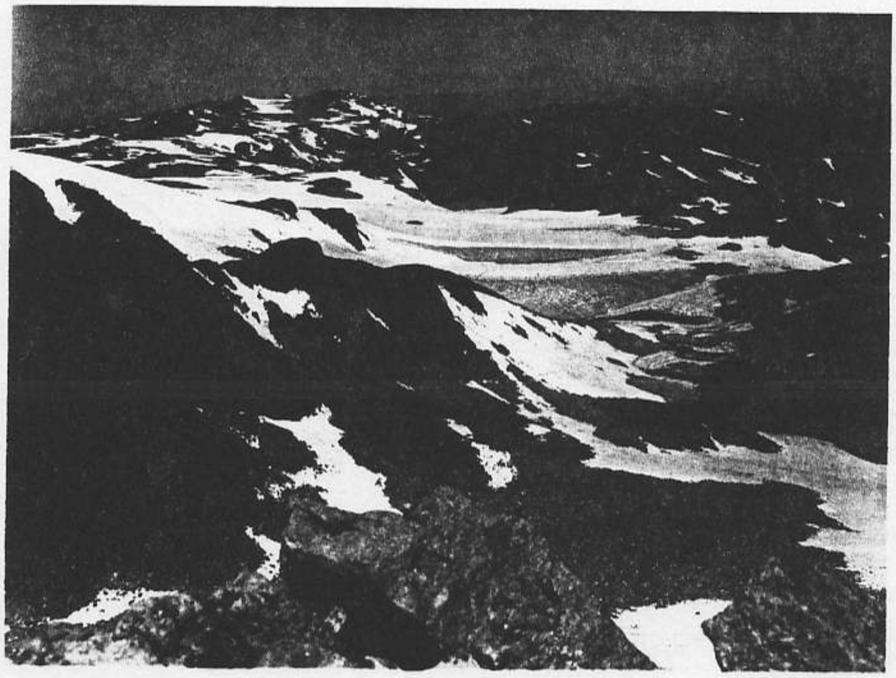


Fig. 36

South margin of unnamed glacier north of Gannett Glacier. This glacier extends for several miles north along the divide. Another glacier is barely visible in the low saddle on top of the broad high peak in the left background. Notice that the regional snow-line is just above the level of the high erosional surface shown here. This view taken from the summit of Rampart Peak, looking north.

appearance of true glaciers. It was not possible to visit these ice bodies in 1950.

Top of Horse Ridge

Two small glaciers are indicated on the top of Horse Ridge (about 3 miles east of Gannett Peak, see Fig. 2, page 3) on an unpublished map sent the author by Richmond in 1950. The author saw this area from a distance in 1950, and no true glaciers were seen. Aerial photographs show only snowfields and no well defined moraines. The stream from these patches of snow has been used as the water supply for Gannett Peak Camp, and contains no appreciable amount of rock flour. Therefore, it seems probable that no glaciers exist here. Interestingly enough, the U. S. G. S. Fremont Peak quadrangle indicates a very large glacier in this location.

East Slope of Horse Ridge

Apparently small ice masses exist in protected locations at the head of the Dry Creek drainage system. The author was not able to examine these in the field, and therefore does not know if they are real glaciers. From their appearance on the aerial photographs it is possible, if not probable, that they are glaciers.

Southeast of Sunrise Peak

Aerial photographs show what is probably a true glacier in a protected, northward facing cirque between Sunrise and Turret Peaks.

This ice mass is comparable in size and shape to Heap Steep and F-3 glaciers, and has a very large Little Ice Age moraine. It was not visited.

South and East of Knife Point Mountain

There are apparently several very small glaciers in protected locations in cirques or on north sides of ridges in this area (extreme southeast corner of Fig. 2, page 3). None of these were visited.

East of G-8 Peak

In a cirque between G-8 and Winifred Peaks (southwest portion of Fig. 2) are two small "tandem" ice masses (only the upper one is shown on the map). At the time of the recent maximum extension of ice in the Wind River Range these were probably true glaciers, and may have then coalesced. The lower ice mass is now certainly stagnant. The upper ice mass may possess some glacial characteristics, but is more likely also stagnant. The outlet stream from these bodies of ice is clear.

Stroud Glacier

This is a true glacier which exists in a cirque east and north of the mountains from Sulphur Peak to Mr. Arrowhead (southwest portion of Fig. 2). This glacier is comparable in size to Twins and Baby Glaciers, and has a definite firn line, bergschrund, dirt bands, and encircling moraine. It was seen only from a distance in 1950.

Table

SUMMARY OF CHARACTERISTICS OF

Name of Glacier	Classification	Present Area in Acres		Little Ice Age Area in Acres
Gannett	Complex	1,130	V	1,390
Dinwoody	Palmate Cirque	860	IV	950
Mammoth	Valley	900	V	1,105
Helen	Valley	305	III	388
Sacagawea	Valley	940	IV	1,030
Fremont	Tandem Cirque	600	IV	720
Knife Point	Complex	760	IV	800
Gooseneck	Cirque	87	I	147
Minor	Cirque	214	II	242
Baby	Cirque	100	I	150
Heap Steep	Cirque	46	I	56
Twins	Cirque	175	II	—3
Sphinx	Cirque	60	I	—3
F-3	Cirque	30	I	71

1. In 1963
2. Difference between median and highest elevations
3. Not known

I

INDIVIDUAL GLACIERS

Recent Area Reduction Per Cent	Ablation Area[1] Per Cent	Median Altitude Feet	Firn Basin Altitude[2] Feet
18.7	30.1	12,250	12,675
9.5	33.9	12,220	12,630
12.0	32.3	12,400	12,630
25.5	38.9	12,160	12,580
6.9	47.1	12,150	12,675
8.8	40.0	12,070	13,035
17.0	47.6	12,090	12,505
41.0	25.7	12,310	12,670
11.6	65.0	12,100	12,600
21.8	35.9	11,900	12,200
17.8	26.4	12,100	12,350
--3	38.4	11,700	11,920
--3	16.3	12,450	12,680
16.8	21.4	12,190	12,305

361 acres

REGIMEN STUDIES

Regimen investigations according to the methods used by Ahlmann (1948, pp. 15-55) were undertaken on Dinwoody Glacier. This glacier is typical of the larger glaciers studied, and probably these regimen investigations apply approximately to many other glaciers in the range for the year 1950. Unfortunately this year was abnormal, so these results can not be regarded as typical.

Accumulation

In order to measure the accumulation of snow on the surface of a glacier during a winter season it is necessary either to have a continuous record of the snowfall throughout the season or to be able to sample the depth of snow at the beginning of the ablation season. Since no meteorological records exist at high altitudes in these mountains, and as the author did not reach the glacier until after the start of the ablation season, it was not possible to obtain a direct measurement of accumulation and an indirect method was devised.

In order to check on the value of accumulation obtained from the regimen computations (this will be described later), an estimation must be made of the probable accumulation of snow over the glacier for a normal year. Snow course readings (U. S. Soil Conservation Service, 1947, a, b) indicate that the snow remaining on the flanks of the range at about 9,000 feet in altitude at the last of May is usually around 2 04 3 feet. C. L. Baker (1946, p. 593) estimated that the mean annual precipitation above 10,000 feet might be 40 to 50 inches of water, and that the belt of maximum precipitation might be as high as 13,000 feet.

Starting with this figure it is possible to estimate the order of magnitude of accumulation to be expected on the glacier during a normal winter. By estimating the greater precipitation due to higher altitude, the effect of wind drifting, and the ratio of catchment basin area to the area of the glacier; then decreasing this figure to allow for the slight amount of precipitation that falls as rain, and the snow that is retained and ablated on the cirque walls; an estimate of 60 to 80 inches of water is obtained. This is more of a guess as to the order of magnitude than an exact determination.

Ablation

Method of Measurement

Eight aluminum-painted 36 inch dowel rods ½ inch in diameter were set in the glacier at intervals from the snout to a high level to measure the surface ablation. The level of the firn or ice on these stakes was recorded as often as possible, and the stake was reset after each reading. In many cases where the stake was not set in hard ice the density of the firn was recorded. This was done by weighing an uncompacted known volume of the material on a portable spring balance. The weight of the sample container was known both empty and when full of water, so the density of the firn could be quickly determined by the relationship:

$$\text{density} = \frac{\text{wt. of can with sample} - \text{wt. of can}}{\text{wt. of can with water} - \text{wt. of can}}$$

The author did not have equipment to measure the density of glacier ice, but this ordinarily differs little from the value 0.91, and this figure was used in calculation. In all cases the raw ablation data were reduced to a water-equivalent basis.

The main difficulty with these ablation measurements was setting the stakes into glacier ice to sufficient depth. The author had only ½ inch and 5/8 inch star drills and used a hammer to drive the drills. At depths approaching 9 inches the star drills often became so tightly wedged that they could be extracted only with the greatest difficulty. Consequently stakes could not be set deeper than 9 inches in ice, and often melted out before they could be revisited. Two stakes set in firn were lost when a superglacial stream unpredictably changed its course so as to wash out the stakes.

The 8 stakes were set in a line from near the snout at an elevation of about 11,230 feet to a point east of the Sphinx at about 12,300 feet. Ablation at higher altitudes was estimated by noting the depression of the firn surface around rocks near the summit of Gannett Peak over a 3½ week period.

Losses of readings due to melting out of the stakes between readings accounted for frequent breaks in the ablation record for some of the higher stakes. The record for Stake 1, which was visited most often, is complete from July 25 to September 5 with a break of only one day. The gaps in the record for other stakes were computed on the basis of the ablation trend recorded on Stake 1 or on other stakes which had a more complete record for the period. It was therefore possible to obtain a reasonable estimate, although not a precise determination, of the surface ablation on Dinwoody Glacier for most of the ablation season. These values are plotted in Fig. 37. The graph shows that the ablation was greatest on the flat central portion of the glacier, not on the northward-sloping terminus. The total surface ablation is computed by dividing the glacier into increments of altitude (separated by contour lines), multiplying the area of each increment by the average surface ablation shown on Fig. 37, summing these products, and converting to units of cubic feet of water.

<u>Sources of Error in Ablation Measurements</u>

(1) Only surface ablation was measured. This introduces two errors: one due to ignoring internal ablation; the other due to uncertainty of the amount of melt water which is redeposited in the firn (failing to differentiate between gross and net ablation).

The internal ablation(ablation along the inner surfaces of crevass walls, tunnels, and hollows in the ice: Ahlmann, 1948, p. 26) is probably negligible on Dinwoody Glacier because of the very few crevasses and tunnels in the main part of the glacier.

The complicated phenomenon of redeposition of melt water has

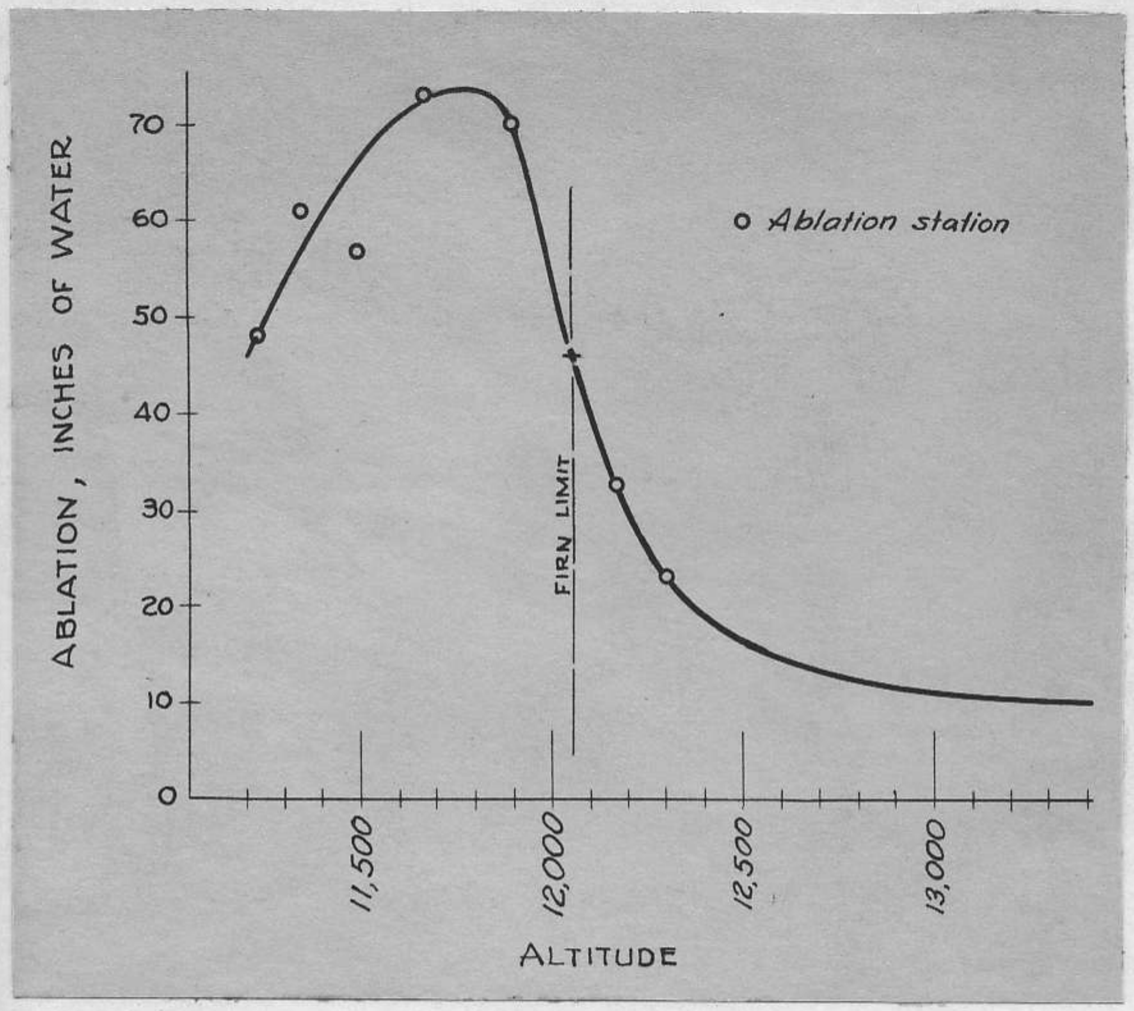


Fig. 37

Measured and computed surface ablation at different altitudes on Dinwoody Glacier for the period July 25 to September 5, 1950, expressed in inches of water.

been studied by Hughes and Seligman (1939, pp. 642-643) and Seligman (1941, pp. 306-308) at the Jungfraujoch on a glacier which is geophysically similar to Dinwoody Glacier. They state that "The increase in firn density due to the freezing of water held in the firn at the end of the summer by the slowly penetrating frost was concluded to be very small by Sverdrup..." From their own research they concluded that the density increase of the firn due to freezing of the melt water was slight compared to the density increase due to the slow settling of the firn. Ahlmann (1948, pp. 26-27) stresses the importance of the geophysical character of the glacier in respect to the quantity of melt water redeposited in the ice or firn. He mentions that on Isachsen's Plateau (West Spitsbergen) the deposit was "about 30 per cent, but in general it is certainly much less." Wallen, in his comprehensive study of the Karsa Glacier (1948, pp. 80-82)follows Schytt in showing that net ablation can be calculated from gross ablation with reasonable accuracy by using a firn density somewhat below average. In the case of the Karsa Glacier the value 0.50 gave good results.

The author had no way of computing the difference between gross and net ablation. Since Dinwoody Glacier geophysically resembles Karsa Glacier, it was decided to follow Wallen and Schytt and assume a value of firn density (0.50) less than the measured average value (0.55). This should allow a reasonable estimation of the net ablation for this glacier.

(2) Ablation is greater on convex slopes, near bedrock, near

melt water runnels, and other similar features. In order to eliminate this error the ablation stakes were carefully located to represent average slopes and smooth surfaces. One stake was purposely located for a few days 10 feet south of a large boulder, but the ablation recorded at this stake was not greater than the ablation at a similar stake located in the clear. Probably reflected radiation from the cliffs along the northeast edge of Dimwoody Glacier affects the ablation locally, but aside from this effect the error is probably negligible.

(3) Settling of the firn increases the apparent ablation, while settling of the stake decreases the reading. The stakes were painted with a highly reflective paint to minimize any heating by absorbed radiation. It is thought that this error is negligible.

(4) Interpolating values of ablation to fill in gaps in the record of the higher stakes also introduces inaccuracy. The author was not able to estimate the error introduced by this rather arbitrary procedure. Probably error here does not affect the general conclusions, since the measured ablation is more of an approximation than a precise determination.

The Ablation Record

The surface ablation was found to vary greatly from day to day, and the ablation at high and low altitudes was significantly less than the ablation of the central basin (see Fig. 36). The maximum surface ablation recorded was 3.4 inches of water per day, and the average total value for the ablation in the July 25 to September 5 period was 34.8 inches. The ablation at the firn limit (about 46.0 inches of water) was obtained by interpolation since it was impossible to predict at the beginning of the season where the firn limit would be.

No study of the dependence of ablation on various meteorological conditions was made in 1950, largely because of a mercury separation in the only thermometer. The variation of ablation at Stake 1 and a brief mention of the weather are given in Table II. It is nearly impossible to draw any significant conclusions from these data.

The water-equivalent ablation was greater on ice than on snow. The difference (in the order of 30 per cent) was found to be approximately in accord with the higher albedo reflectivity of clean snow.

The Calculated Regimen

Extrapolation of the Ablation Record

Before the regimen of Dinwoody Glacier could be calculated, the ablation record had to be made complete for the entire ablation season. This was done on the basis of information on the general temperature and weather in the area as observed by the Gannett Peak Camp personnel since early in June. From this information arbitrary values of ablation were assigned to different periods of time, so that the total ablation for the season could be estimated. The following values were used in the computation:

Table II

Measured Ablation at Stake 1

Date	Average Daily Ablation (inches of firn)	Weather
J 25	1.6	hail flurries, unsettled
26	1.6	unsettled, cool
27	1.6	unsettled, cool
28	1.6	unsettled
29	1.6	unsettled
30	1.6	rain turning to snow, cold
A 1	1.6	cold, clear
2	1.6	clear
3	0.4	clear, warm
4	0.4	cloudy, light rain in A.M., storm in P.M., snow
5	0.4	storm in P.M. with hail, snow
6	2.5	warm A.M., thunderstorm P.M.
7	2.5	clear, cold
8	1.7	stormy, little precipitation
9	1.7	stormy, little precipitation
10	1.7	stormy, considerable snow
11	1.7	rain and snow
12	1.7	rain and snow, cool
13	1.7	thunderstorm
14	1.7	
15	1.7	
16	2.4	warm, scattered clouds
17	2.6	warm, scattered clouds
18	2.6	
19	2.6	warm, scattered clouds
20	2.6	clear
21	2.6	snow flurries
22	2.6	clear to cloudy
23	2.6	cold, windy
24	2.6	cold, windy, some light rain and snow
25		rain, cold, windy
26	2.2	clear, cool
27	2.2	clear

Table II (continued)

Measured Ablation at Stake 1

Date	Average Daily Ablation (inches of firn)	Weather
A 28	2.2	rain, hail, snow
29	2.2	clear, warm
30	2.2	clear, warm
31	2.2	clear, hot
S 1	2.2	cloudy, cool
2	2.2	
3	2.2	
4	2.2	
5	2.2	thunderstorms, snow pellets
6		stormy
7		rain, sleet, hail, considerable snow
8		rain below 12,000 feet, snow above
9		heavy snow above 11,500 feet; sleet, rain, snow below.
10		heavy snow at lower elevations
11		heavy snow at lower elevations

Time Period	Average Daily Ablation	Total Ablation
June 1 to June 9	0.20* of firn	1.8* of firn
June 10 to July 4	0.40	10.0
July 5 to July 24	1.02	20.4
July 25 to Sept. 5	1.62*	69.6*
Sept. 6 to Sept. 7**	2.30	4.6
	Total	106.4

* measured directly
** end of ablation season

Assuming a firn density of 0.50 (see page 102), this is equivalent to 53.2 inches of water lost during the three-month ablation season. Ablation was not extrapolated back farther than June 1 because of the abnormally late spring in the mountains. This extrapolation probably introduces considerably more error than was acquired in the measurement of ablation. However, it is thought that the estimated value of average ablation is sufficiently precise to be of value for an approximation of the regimen.

Method of Determination of Regimen

Recent careful regimen studies have shown a relation between the accumulation and ablation at the firn limit and the regimen of the glacier as a whole. Ahlmann (1948, p. 55) was apparently the first to observe that:

> The balance-sheet of the regime...bears a linear relation to the amount of accumulation and ablation at the firn limit....This indicates that the accumulation and the equally large ablation at the firn limit, expressed in millimeters of water, correspond to half the balance-sheet total of the glacier expressed in million cubic meters of water per square kilometer.

Wallen tested this idea by careful measurements over a seven year period on the Karsa Glacier. He found that the total regimen and the sum of accumulation and ablation at the firn limit differed on the average by less than 4 per cent (Wallen, 1948, p. 112).

The present writer assumed that the regimen of Dinwoody Glacier could be computed from a knowledge of accumulation and ablation at the firn limit, at least to within several per cent.

Calculation

The ablation at the firn limit (Fig. 36) was extrapolated in exactly the same manner as the average ablation. The resulting firn limit ablation is 70.3 inches of water. The total ablation plus accumulation at the firn limit is equal to two times the ablation times the area of the glacier; this figures to be 43.8×10^6 cubic feet of water or 3.57 million cubic meters per square kilometer. The total ablation is the average ablation times the area of the glacier, or 16.6×10^6 cubic feet of water. Assuming that the regimen of the whole glacier is equal to the sum of total ablation and total accumulation at the firn limit, the total accumulation becomes $(43.8 - 16.6) \times 10^6$ or 27.2×10^6 cubic feet of water. The excess of accumulation over ablation is then 10.6×10^6 cubic feet or 0.86 million cubic meters per square kilometer. These computations are given in full in Appendix B.

A check on the order of magnitude of the regimen can be made by comparing the ratio of total ablation over balance-sheet total to the percentage ablation area. If the accumulation and ablation over the different altitudes of the glacier are related in an inverse linear manner (this is often approximately true), then the two above-mentioned ratios should be equal. Since the ablation-altitude curve is not linear (Fig. 37) the greater ablation at low and middle altitudes would cause the total ablation over balance-sheet total ratio to be higher than the area ratio. This is found to be true, although the two ratios are of the same order of magnitude. The ratio of total ablation to balance-sheet total is 0.38, and the ratio of ablation area to total area is 0.34.

By working backwards from the regimen calculations the average accumulation over the glacier can be estimated. Dividing the total accumulation by the area of the glacier, the average accumulation is found to be in the neighborhood of 87 inches. This result seems rather high, but it is not inconsistent with the estimations of accumulation made earlier (page).

It must be remembered that this study of regimen was made in a very unusual year. There is ample evidence that the regimen for Dinwoody Glacier has usually been negative in the last several decades, but in 1950 it was strongly positive. According to local residents this year was characterized by the latest spring and the shortest and coolest summer for many years, perhaps for many decades. The positive regimen is explained on the basis of a short ablation season, rather than increased accumulation during the preceeding winter.

ORIGIN OF SPECIAL FEATURES

Medial Moraines

Medial moraines occur on Dinwoody, Gannett, Helen, and between Fremont and Knife Point Glaciers. The moraine separating the last two glaciers (see page) seems to be a conventional medial, resulting from the coalescence of debris from the lateral margins of the two glaciers. The moraines on the other glaciers, however, do not answer the common definition of medial moraines. They are called medial moraines in this report because they superfically resemble conventional medial moraines. The ones mentioned here, however, emerge from the ice often far away from any glacier margin (Fig. 38). On all the medials visited ice immediately underlies a coating of debris generally no more than 2 or 3 feet thick. The ice was often visible where it formed a pedestal under a large boulder (Fig. 39). These features may originate in three possible ways, as follows:

(1) They may originate in the lee of a subglacial bedrock projection. This possible explanation is suggested by two photographs of the snout of Dinwoody Glacier taken over a 20 year period. The first shows a short band of debris resembling from a distance one of the above-mentioned medial moraines. The second picture, taken after the glacier had thinned considerably at the terminus, shows a bedrock knob just above the point of emergence of the debris in the first picture. Apparently subglacial debris is lifted passing over the knob.

Fig. 38

Emergence of a medial moraine on Dinwoody Glacier. The crest of the moraine has been marked with a dotted line. This medial emerges about 2,900 feet below the nearest visible bedrock, and is continuous for about 1,600 feet. Note figure standing on near end of moraine. The lower end of this moraine is shown in Fig. 11.

Fig. 39

Surface of a medial moraine on Dinwoody Glacier. This is one of the moraines shown in Fig. 9. Note the glacier ice exposed as a pedestal supporting several of the large boulders.

and is then placed in a position higher in the glacier so that it melts out sooner.

(2) Some of the medial moraines may be largely composed of material which has accumulated in randklufts (moats) at either side of bedrock ribs projecting into the glacier. This material is covered by snow each winter, and probably will come to occupy an englacial position. This theory seems applicable to many of the medial moraines on Dinwoody Glacier (Figs. 8, 9, 38, and 39).

(3) Another possible explanation is that they consist of debris concentrated englacially at the sides of tributary ice streams by obstructed "gravity" flow (Demorest, 1943, pp. 367-369, and Sharp, 1948, pp. 184-185), and then brought to the surface in the central basin of ice by obstructed "extrusion" flow or simple rotational slipping.

Dirt Bands

Sedimentary (Primary) Bands

During the summer a considerable amount of debris is blown on to the ice surface, causing the formation of a dark layer which may be preserved under the snow of the following winter and preserved in the ice (Seligman, 1941, p. 314). If the glacier moves over an irregular bed or has a high rate of motion, these bands may become strikingly contorted in the tongue. The best display of this was in a randkluft beside a tributary ice tongue on Dinwoody Glacier (Fig. 40).

If these bands outcrop near the area of accumulation they may form parabolic arcs on the glacier surface. These were described by Washburn (1935, pp. 1879-1889) and later by Fisher (1947, pp. 137-145) who applied the name "Alaskan bands" to them. The same type of bands have been described under the name "ogives" in Europe, where their annual nature has been confirmed by pollen analysis (Godwin, 1949, pp. 325-332).

It was found difficult in the field to differentiate between these uncontorted annual bands and the outcrop of spoon-shaped surfaces of shear on the tongues of Wind River Glaciers. In some cases intersecting sets of bands are found and it is possible that one set is sedimentary and the other tectonic. In most cases where the "annual" bands were inspected closely they were found to be active shear surfaces.

Shear Bands

Shear bands are very common on the Wind River glaciers. They were studied carefully on Heap Steep Glacier, where the regular arrangement of bands suggested an explanation of the type of movement of this small glacier. A general view of this glacier is shown in Fig. 32, and a closer view of the shear bands in Fig. 41. The active surfaces are shown in detail in Fig. 42.

Gibson and Dyson (1939) discussed the rotational slipping

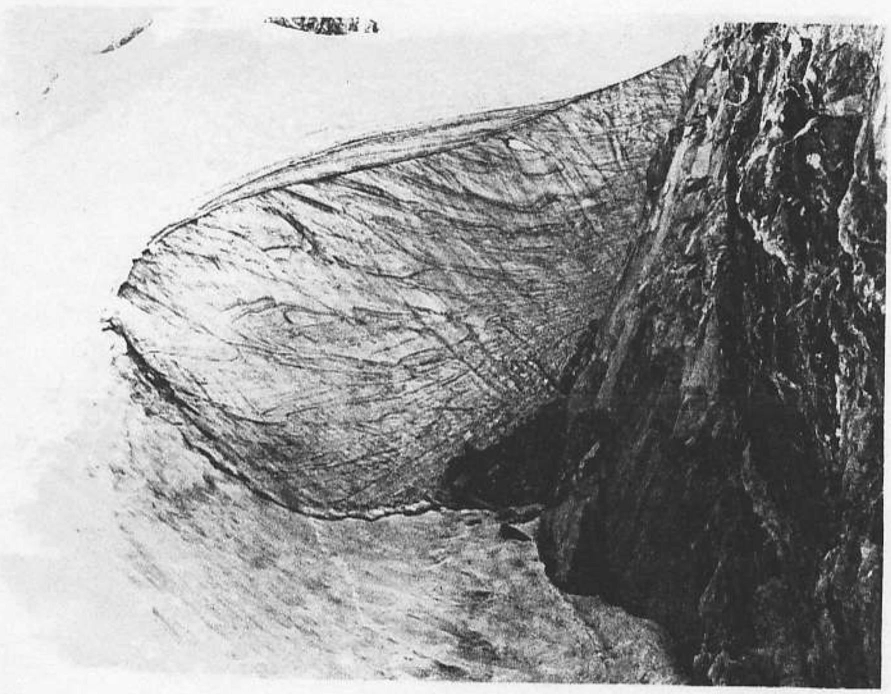


Fig. 40

Contorted dirt bands (probably annual, sedimentary bands) exposed in a randkluft beside the tributary ice tongue that descends from Mt. Woodrow Wilson to join Dinwoody Glacier. Note thrust faulting and drag folding due to obstructed 'gravity' flow and obstructed 'extrusion' flow. This moat is a bout 130 feet deep.

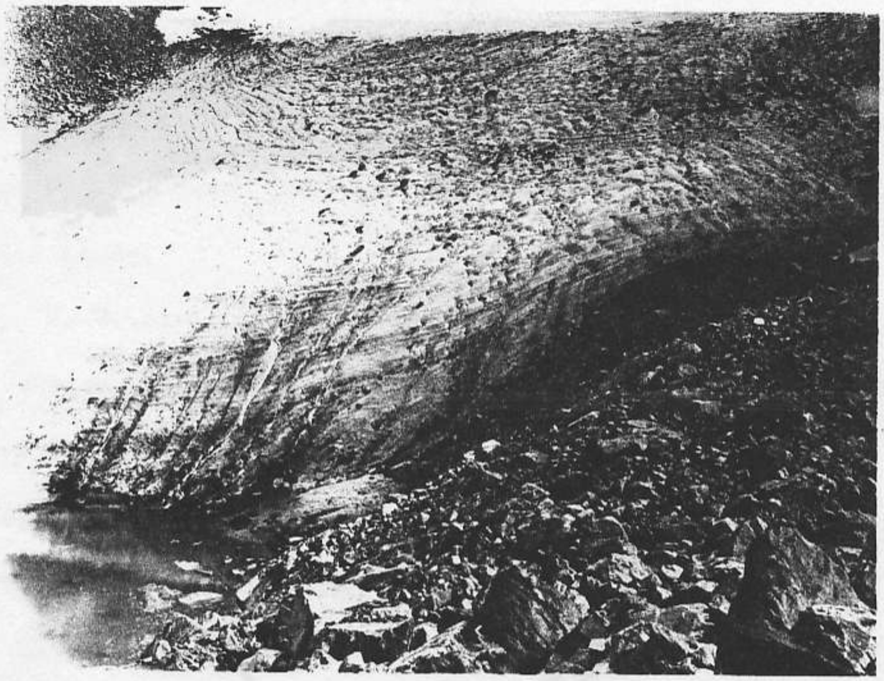


Fig. 41

Outcrop of spoon-shaped shear surfaces below the firn line on Heap Steep Glacier, a small cirque glacier. Note that the surfaces are close together at the base of the glacier, and farther apart higher. A morainal ridge emerges from beneath the ice in the right center of the photograph.

Fig. 42

Detail view of active shear surfaces on Heap Steep Glacier. Note that the ice above the dirt band is being actively overthrusted faster than it can be melted back. The bands here dip about 32 degrees to the right, and the glacier slopes at about 21 degrees in the opposite direction. The ice axe is 36 inches long. In the background is a high Little Ice Age moraine.

motion of the small Grinnell Glacier in Glacier National Park. They assumed that yearly accumulation was in the form of a wedge with the thick end toward the cirque wall. By stacking shingles on a cirque-shaped surface they were able to demonstrate that as successive shingles (yearly accumulations) were added the lower shingles were caused to rotate and slip, changing the dip of the inter-shingle planes (dirt bands) from a slight angle down-glacier to a steep angle up-glacier. They apparently assumed that the shear surfaces were identical with the annual bands.

W. V. Lewis has also proposed a rotational slipping hypothesis of cirque glacier motion (Lewis, 1949). This idea compares the motion of the glacier to the slipping of clay on embankments. This hypothesis seems more in accord with the observed phenomenon in the Wind Rivers than does the type of motion described by Gibson and Dyson. The author's conception of the motion of a small, steep cirque glacier, such as Heap Steep Glacier, is illustrated in Fig. 43. This type of banding is seen on the surface of Dinwoody Glacier (Fig. 8), Upper Fremont Glacier (Fig. 24), F-3 Glacier (Fig. 35), and many other cirque glaciers in the Wind River Range.

<u>Vertical Banding Parallel to the Margin</u>

This type of banding has not been mentioned by many authors. Wentworth and Delo (1931, p. 616) saw this feature on Dinwoody Glacier and reported that "The origin of these was not apparent." Godwin

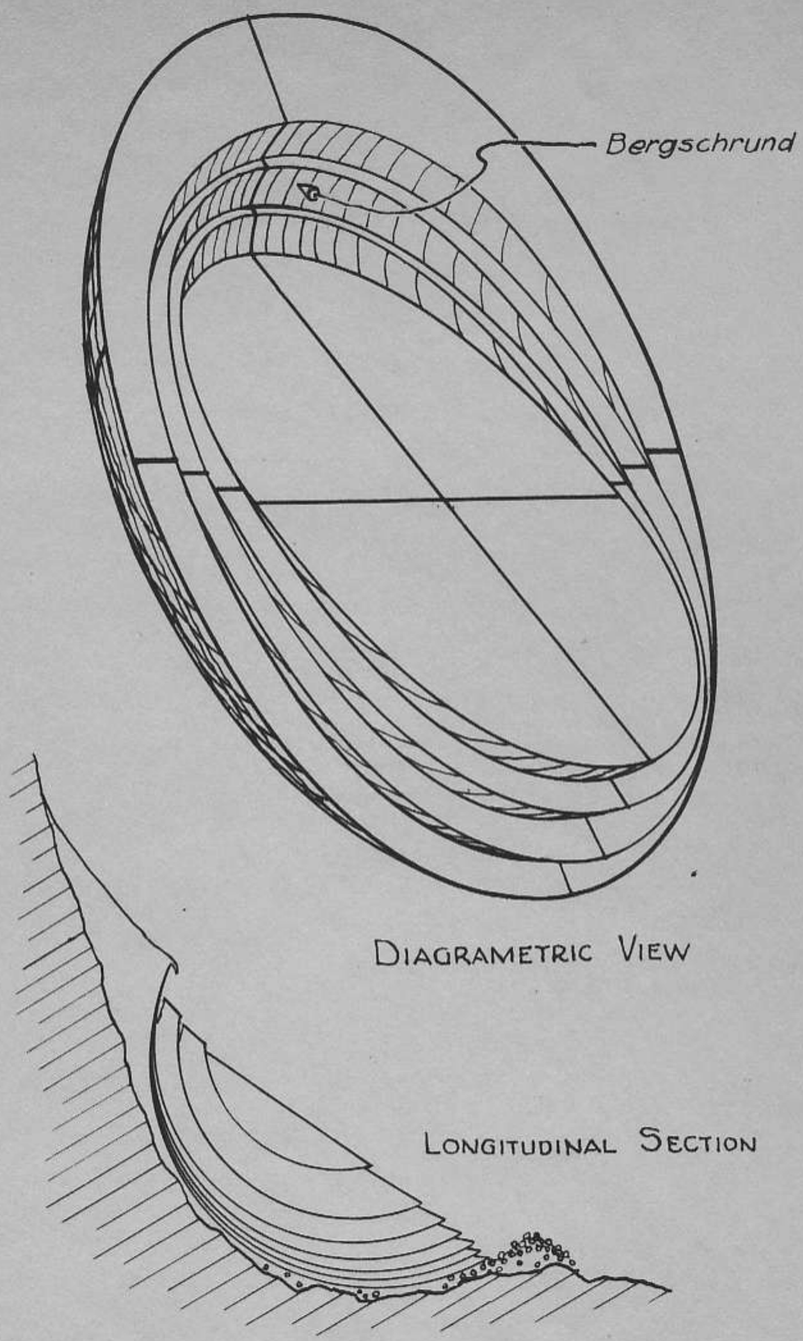


Fig. 43

Hypothetical rotational slipping movement of a small, steep cirque glacier.

(1949, pp. 328, 333) states that this type of banding is not distinctly annual. Seligman (1949, a. p. 298) mentions that these bands occur "where the rock trough of a glacier narrows." These bands were found on Dinwoody Glacier (Fig. 44) and on Mammoth Glacier (indistinctly shown in Fig. 15). The bands consisted of thin surfaces of dirty ice, and were generally vertical or nearly so. The strike was parallel to the motion of the glacier.

It is thought that these bands result from either of two processes: (1) the dragging out of normal sedimentary or tectonic bands by the shearing effect of the valley walls; or (2) a foliation induced by plastic flow under pressure near the margin, similar to the marginal schistosity found in the Cloos-Balk type of batholith.

Superglacial Debris

Very Large Boulders

Several huge boulders were seen on Dinwoody Glacier. One of these was estimated to be 60 by 40 by 25 feet according to Wentworth and Delo (1931, p. 615), see Fig. 11. These large boulders do not stand up on pedestals as do glacial tables, but are depressed as much as 10 feet beneath the surface. It is thought that this effect is caused by either melting around the base induced by reflected radiation, or by local stressing of the ice beyond the critical compressive stress.

Fig. 44

Vertical dirt bands parallel to the margin of Dinwoody Glacier. Also visible are parabolic bands probably representing spoon-shaped shear surfaces. Doublet Peak with its steep ice cascade is seen in the center background.

-- photo by C. K. Wentworth

Glacial Tables

These are common on the Wind River glaciers. Late in the season abandoned pedestals were observed, indicating that the boulders had moved from their original position (Fryxell, 1933, a, b.). Although in many cases it was apparent that the rocks were migrating south (up-glacier), nearly as many cases of travel in other directions were seen. It was not possible to use the growth of glacial table pedestals as an accurate measure of the minimum amount of ablation.

Dust Wells and Basins

Dust wells were common in all of the glaciers studied, especially in the early part of the season. Some small basins were found on Heap Steep Glacier (Fig. 45), that were identical in nearly all characteristics save size with those described by Sharp (1949) from Alaska. Wells and basins were found only in relatively clean ice.

Eskers

Description

Eskers emerge from the ice at the termini of Mammoth and Helen Glaciers. Recent eskers have been reported in the literature by only a few authors: Russell, (1892; 1897, pp. 124-125), Lewis (1949).

On the northeast edge of the terminus of Mammoth Glacier is a low, sinuous ridge of debris (Fig. 46). The ridge is about 15 feet

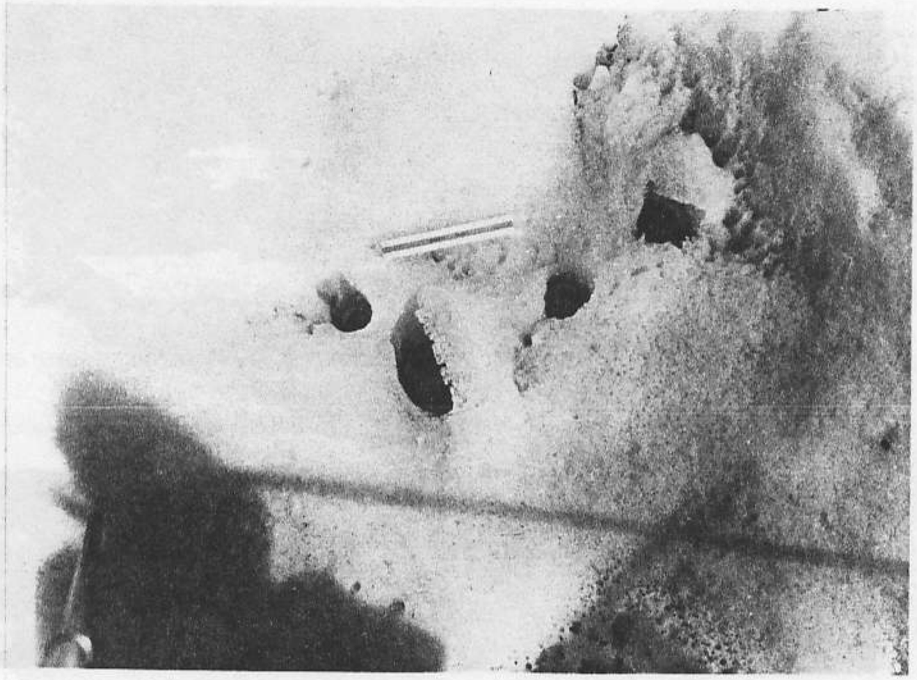


Fig. 45

Dust wells and several small dust basins on Heap Steep Glacier. The largest dust basin is 6.4 inches long and about 6 inches deep, and is half covered by a diurnal crust. Dust deposits in the bottom of the basins are only a few millimeters thick. Perforated ice in the upper right hand corner. Scale is 6 inches long.

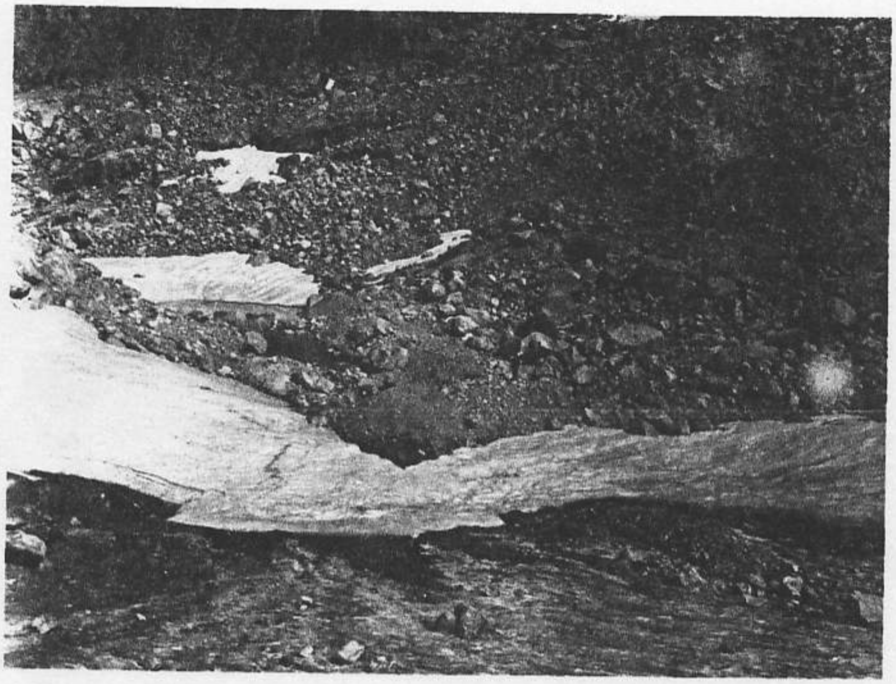


Fig. 46

Esker below terminus of Mammoth Glacier. A very recent slide from the moraine to the right has nearly obscured this feature. A small pond is seen to the left of the sinuous ridge. Note figure on near end of esker. Debris ridge in the right foreground is not connected with the esker, which disappears under the glacier in the bottom center of the view.

wide on its flat top, and is nearly 15 feet high. The sides slope at the angle of repose of the material, which is mainly sand with some flour and much coarser material. One large boulder about 10 feet in diameter was found embedded in the ridge, but this may have rolled in from the moraine slide. The material is very loose and unconsolidated, an ice axe could be thrust in 1½ feet before meeting much resistance. No sorting or bedding within the mass could be detected. The boulders were not noticeably stream rounded. No ice could be detected in the mass, at least to depths of several feet. There was no concentration of debris on the surface of the ice near the point of emergence of the esker. Standing water exists on one side of the feature.

Another set of eskers exist at the north edge of the terminus of Helen Glacier (Figs. 47 and 48). These are not parallel to the direction of ice motion, as is the esker at Mammoth Glacier, but swing around nearly perpendicular to the glacier axis. These ridges are of about the same size as the previously described one. The material here is mainly gravel, with much sand and little coarser debris. Some of the gravel pieces are definitely stream rounded. A crude sort of topset bedding was observed, but no foreset or sideset beds were detected. The outlet drainage is here impeded by a low ridge of moraine, so that a small ice-contact pond is formed. It was not possible to define exactly the point of emergence of these eskers from beneath the glacier because of snow cover, but it is near the "x"

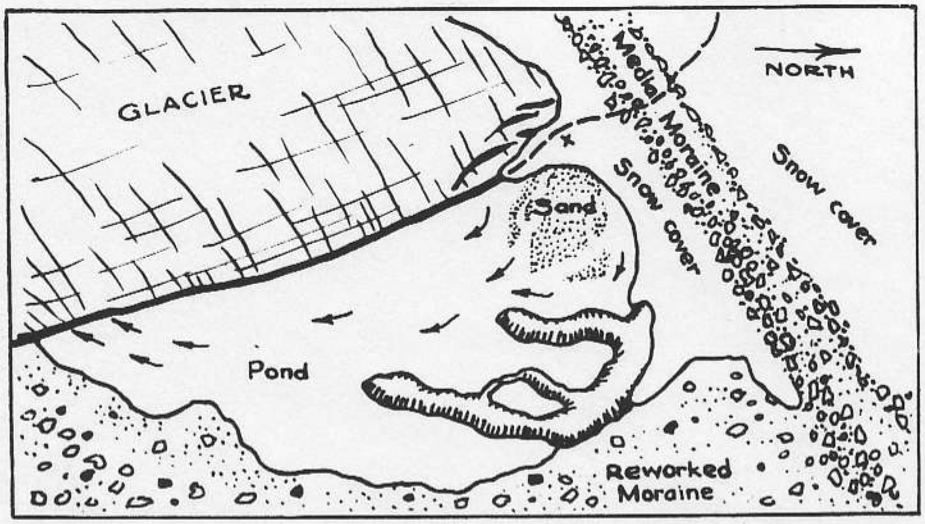


Fig. 47

Sketch map of eskers at terminus of Helen Glacier

Fig. 48

Esker at the toe of Helen Glacier

in Fig. 47, as indicated by collapse fractures in the ice.

Origin

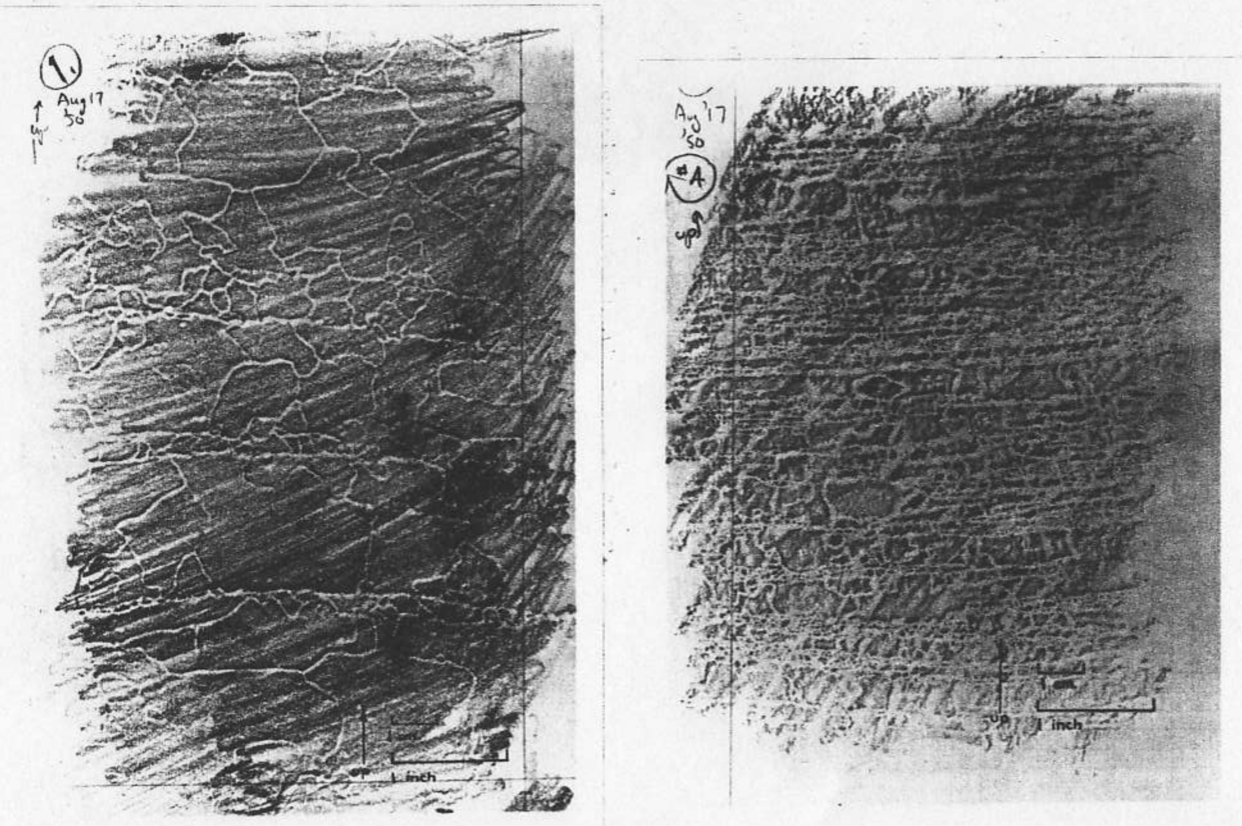
The origin of these eskers is not too clear. They are certainly stream deposits, for: (1) they are much better sorted than the nearby till; (2) some of the pieces are noticeably rounded; and (3) crude bedding is locally present. In each case these features have been formed where the subglacial drainage was impeded or blocked, forming a pond. In the opinion of the author these eskers were formed by deposition in subglacial stream channels due to the loss of velocity of streams when entering a subglacial pond. This process is assumed to take place in the "zone of fracture" (Tarr and Martin, 1914, p. 184) at the terminal margin of the glacier.

Subglacial Features

At the snout of Gannett Glacier are some ice caves formed where the glacier passes around a low rock nunatak (Fig. 5). It was possible to crawl back for over 100 feet and observe several subglacial phenomena, such as crystal structure, flow of glacier over rock, and some curious extruded ice shapes.

Crystal Size

Most of the crystals in this location average about 1.5 cm. in diameter, and the largest detected by crystal rubbing (see Fig. 49a)



(a) (b)

Fig. 49

Rubbings of ice crystals in basal terminal ice of Gannett Glacier. X 0.6

was about 3.8 cm. in diameter. These sizes agree in order of magnitude with those that Seligman (1949, a, p. 257) found at the snouts of Alpine glaciers, and are somewhat smaller than those found by Ahlmann and Droessler (1949) at the termini of active glaciers in the Kebnekajse District in Sweden. If the snout of Gannett Glacier was stagnant or very sluggish the crystals would be expected to be much larger, since crystal growth is a function of time.

<u>Shear Planes</u>

Shear planes exist throughout the whole area that was studied at the snout of Gannett Glacier. These planes are horizontal and spaced at irregular intervals. In some places the shear planes contain many small crystals, evidently a result of crushing and the formation of a "crystal breccia" (Fig. 49b). The shear planes appear to pass through some of the large crystals in Fig. 49a. (see Seligman, 1950, p. 381.

<u>Character of Basal Ice</u>

In these ice caves it was possible to observe the ice in contact with its bed. This type of investigation has been described before only by Carol (1947), who was able to reach a depth of 50 meters below the surface of the glacier. The author was able at one point to get to a depth of about 100 feet below the surface.

The basal ice was heavily charged with fine debris. The undersurface of the ice where it had pulled away from rock was coated with a thin paste of rock flour and water. Some small pebbles were found in the ice, and there were also several cavities which had probably once contained larger rocks. The ice itself is very dark in color, and the transition between clean and basal ice was abrupt, see Figs. 50 and 51. This abrupt discontinuity is apparently due to shearing, which juxtaposes clean and dirty ice. The top surface of these shear planes could be traced back into the clean ice for several feet, and the planes were remarkably flat.

Form of the Ice

At this depth beneath the glacier the ice is generally quite rigid, and fractures easily. However, a small excess of pressure causes the yield point of the ice to be exceeded, and the ice then is deformed plastically. Consequently, when ice is forced against a rock obstruction it molds itself to the contour of the rock. After passing over the rock, however, the pressure is released and the ice resumes its brittle character. Therefore the contour of the rock obstruction is molded onto the ice as a series of long flutings, see Fig. 52.

Another unexplained phenomenon was discovered here. In some places the ice was squeezed out from the side of an obstruction, causing it to be formed into a long rod like toothpaste squeezed from a tube (Fig. 53), or else a mass of peculiar contorted, twisted

Fig. 50

Abrupt contact of dirty basal (bottom) and clean ice exposed in a vertical crevasse near the terminus of Gannett Glacier.

-- photo by C. F. Darling

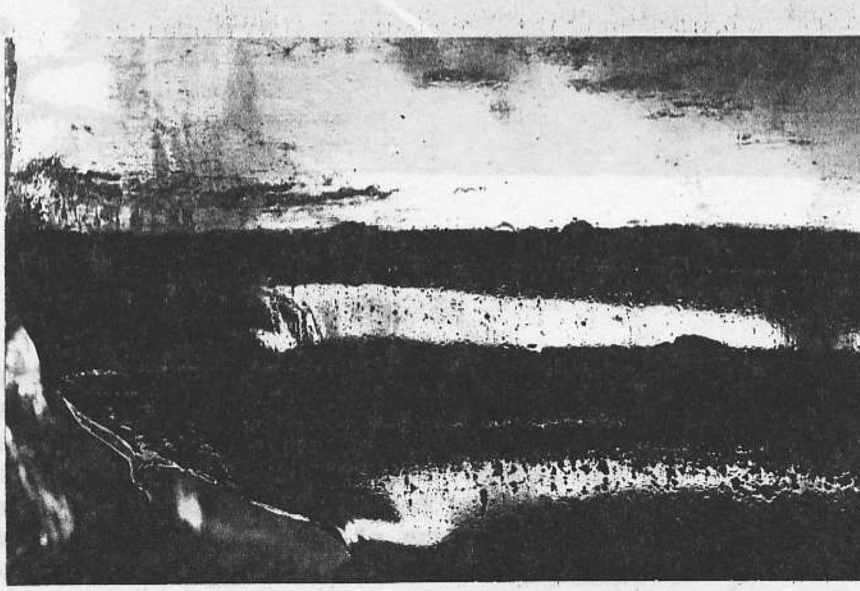


Fig. 51

Detail view of dirty-clean ice contact shown in Fig. 48. The two dirty shear planes are 2 inches apart.

Fig. 52

Photograph taken about 50 feet under the surface of Gannett Glacier near a nunatak. Note the long flutings impressed on the basal ice which here forms the ceiling. Bedrock is not easily visible in the picture due to a coating of dirt, water, and ice formed from frozen water. In the left center, just behind the figure, is a shapeless mass of extruded ice which is separate from the main mass of ice above. Intricately branched and twinned (?) ice crystals were found in a deep pool near the right edge of the picture (see Schneider, 1948).

Fig. 53

Peculiar rod of "extruded" ice in an ice cave beneath Gannett Glacier. Note how the bedrock (light colored material in the foreground) has impressed its contour on the main part of the ice as series of long flutings, passing from right to left. The "extruded" rod, however, originates slightly to the left of center and moves directly toward the camera (at about 60 degrees to the main glacier motion) then bends around to move with the rest of the ice.

shapes (center of Fig. 52). This ice is completely separated from the main mass of the glacier. The author has as yet no satisfactory explanation of this, but it may be possible that the local increase of velocity of ice at a bedrock projection is sufficient to make this ice "shoot" out independently of the rest of the mass. Unfortunately no crystal rubbings could be made of this ice.

INFERENCES ON THE VARIATIONS OF THESE GLACIERS

Are These Glaciers Remnants of the Greater Pleistocene Glaciers?

Evidence from Scandanavia and elsewhere indicates that the climate 4,000 to 6,000 years ago was warmer and drier than it is now. This period is termed the "Climatic Optimum" by Scandanavians (Flint, 1947, pp. 487-499) and the "Post-Wisconsin xerothermic interval" by Sharp (1951, p. 104). Matthes (1942, a, pp. 377-380), working largely on the basis of plant remains and buried forests, stated that the regional snow-line in western United States was 1,000 to 1,500 feet higher during this warm period than it is now. The problem, then, is to determine whether the Wind River glaciers could have survived this rise in the regional snow-line. If they were able to last through this period they probably have been in continuous existence for over 11,000 years, and are therefore "ancient." Matthes (1942, a, p. 383) suggested that this might have been true:

> Now the glaciers of the Wind River Range all lie in cirques, and, as the majority of them are situated on the east side of the divide, there is little doubt that they are all alimented in large measure by westerly winds. At least three of them, among which are the three glaciers on Gannett Peak, head at altitudes between 12,500 and 13,000 feet. It may reasonably be presumed, therefore, that these persisted throughout the "climatic optimum," when the regional snow-line rose to about 15,000 feet.

The Present Regional Snow-line

Matthes (1942, a, p. 383), probably from a study of the

Fremont Peak quadrangle, guessed that the regional snow-line in the Wind Rivers in 1942 was at about 14,000 feet. This snow-line is defined as the lower margin of the zone "in which under a given set of climatic snow conditions snow accumulates in excess of wastage and forms glacier-ice in all parts of the land save those from which the snow is removed periodically either by avalanches or by wind-action." (Matthes, 1942, a, p. 379) The summit of Gannett Peak is a sloping platform which except for a few years around 1940, is normally covered with a thick accumulation of snow and neve. Hard ice probably exists beneath the surface coating of snow, as judged by some pictures taken in 1941. This accumulation is not protected from the sun in any way, and is probably subject to considerable wind corrasion. The other summits in the Wind Rivers that rise above 13,600 feet are sharp spires or ridges, and could not carry snowfields. On the other hand, a flat upland northeast of Gannett Peak (elevation about 13,100 feet) are covered with only occasional snow patches. Therefore it seems probable that the regional snow-line in the Wind River Mountains is now 13,600--13,700 feet in altitude.

Rise in Regional Snow-line During the Climatic Optimum

There is no direct evidence in the area studied of the position of the regional snow-line during the warm period. Matthes has estimated a rise of 1,000 to 1,500 feet in the Cascades and the Sierra Nevada. Flint(1947, p. 218) has noted that the difference between the

Pleistocene snow-lines and the present snow-lines is greatest in regions which now have heavy precipitation. The present rainfall in the Wind Rivers is, say, about 50 inches, whereas at Mt. Rainier it is around 100 inches. From this it can be presumed that the rise in the snow-line on the inland mountains during the Climatic Optimum was not as great as the rise on the coastal mountains. Therefore, Matthes' figure of 1,000 feet is probably closer to the true value than 1,500 feet. However, to be on the safe side a rise of 1,500 feet is assumed. If glaciers could exist with this high snow-line, then they were probably there during the Climatic Optimum.

Present Relation of Glaciers to the Snow-line

Assuming that the centers of the accumulation basins for the present glaciers is half way between their median altitude and their highest altitude, the larger glaciers (Gannett, Dinwoody, Mammoth, Helen, Sacagawea, Fremont, and Knife Point) head at altitudes of between 460 and 1,120 feet below the present regional snow-line of 13,700 feet. The smaller glaciers head from 1,050 to 1,750 feet below the snow-line, and some of the lesser glacierets head as far as 1,900 feet below. Matthes (1942, a, p. 380) has suggested that small cirque glaciers can head at elevations as low as 2,000 or 3,000 feet below the regional snow-line in exceptional cases.

Conclusions

By inspection of a topographic map it is seen that none of the Wind River glaciers was large during the Climatic Optimum, for there are no accumulation basins within 460 to 1,120 feet of the presumed maximum regional snow-line of 15,200 feet. However, it is possible that glaciers of the smaller size (heading between 1,050 and 1,750 feet below the snow-line) could have existed at that time, and certainly some small glacierets existed at high altitudes in protected locations. By a study of the topographic setting and altitude of the present glaciers it is possible to predict where glaciers might exist in equilibrium with any given regional snow-line. Fig. 56 (a) shows the glaciers that would be consistent with a snow-line of 15,200 feet. This is the maximum expectable snow-line during the Climatic Optimum on the basis of Matthes' work. Therefore, it seems rather certain that at least small masses of ice at the head of the Gannett, Dinwoody, Helen, Fremont, and possibly the Mammoth and Sacagawea cirques have existed continuously since the last great Pleistocene glaciation. It is even more certain that many of the lesser Wind River glaciers, such as Baby and Twins, are products of a new ice age.

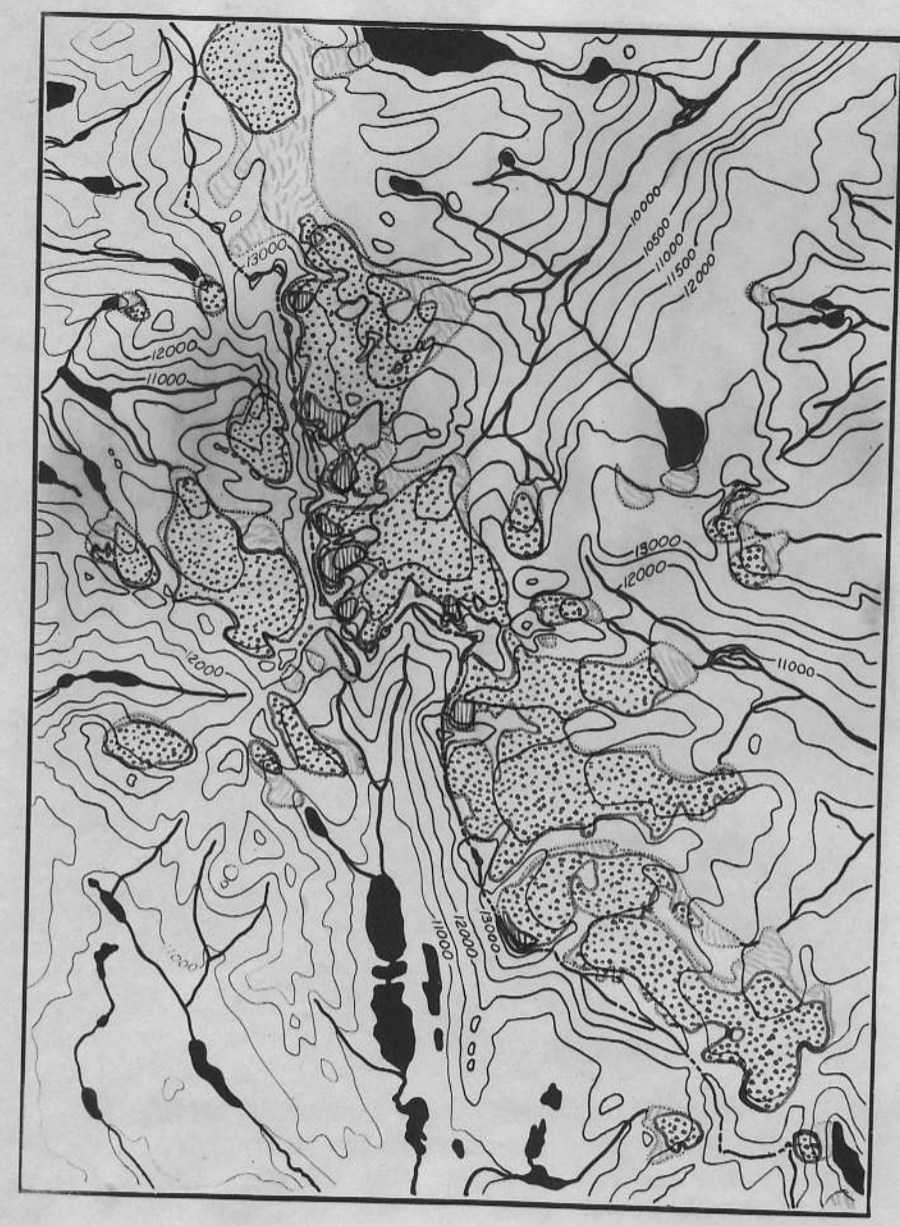
The Little Ice Age

The prominent moraines which are found beyond the termini of all of the glaciers studied indicate rather conclusively that these glaciers have been considerably larger and thicker within the last century or so. The moraines date back to a time probably shortly before the Hayden Survey (1878). Probably this maximum advance was roughly contemporaneous with the peak in Europe, Alaska, and the Sierra Nevada (Matthes, 1942, b, pp. 190-215) - about the middle of the nineteenth century. Since that time the glaciers have receded, shrinking in area about 13 per cent on the average. A map of the maximum extent of the glaciers during the Little Ice Age (inferred from a study of the moraines) is shown in Fig. 56 (b), and a map of the glaciers in 1950 is shown for comparison in Fig. 56 (c).

<u>Correlation of Recession with Glacier Characteristics</u>

Some of the Wind River glaciers have been reduced in area as much as 41 per cent but others have remained within less than 7 per cent of the maximum size (see Table I, page 96). It might be expected that a correlation exists between those glaciers which now have the most negative regimens and those glaciers which have retreated the most. A graph (Fig. 57) was plotted of the per cent recession versus the per cent ablation area (1945) for twelve of the glaciers studied. It can be seen from this that little or no correlation exists; that is, the glaciers which have retreated the most are not necessarily the ones that today show the most negative regimens.

An inverse correlation between the size of the glaciers and their per cent reduction in area does exist (Fig. 58). That is, the smaller glaciers have been percentagewise reduced in size more



(a) Glaciers of the Climatic Optimum, assuming a regional snow-line at 15,200 feet in altitude.

(c) Extent of glacier ice in 1950.

(b) Maximum extent of ice during the "Little Ice Age".

Fig. 54

Map modified from the U. S. G. S. Fremont Peak quadrangle, contour interval 500 feet, scale about 1:110,000 or 0.6" ≃ 1 mile

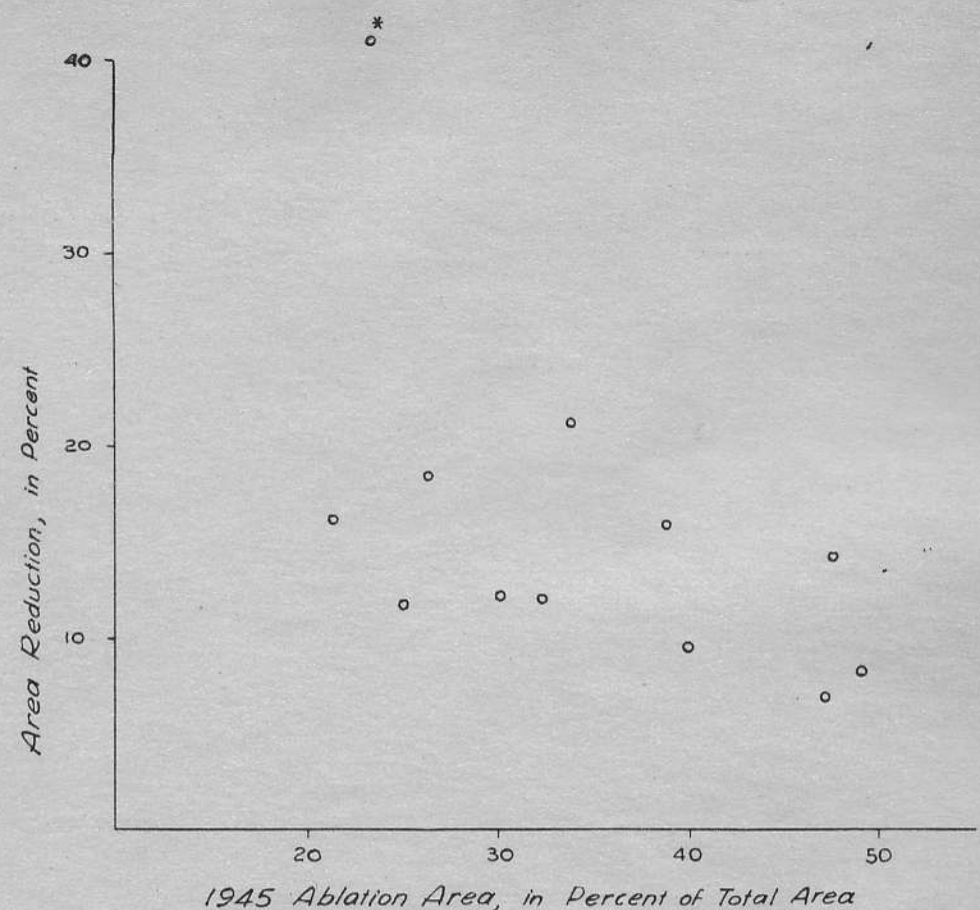


Fig. 55

Graph of recent area reduction (in per cent since the maximum Little Ice Age extent) plotted against 1945 per cent ablation area, for 12 Wind River glaciers. Note the absence of a relationship between these two factors.

* Gooseneck Glacier, an abnormal case (see page 71)

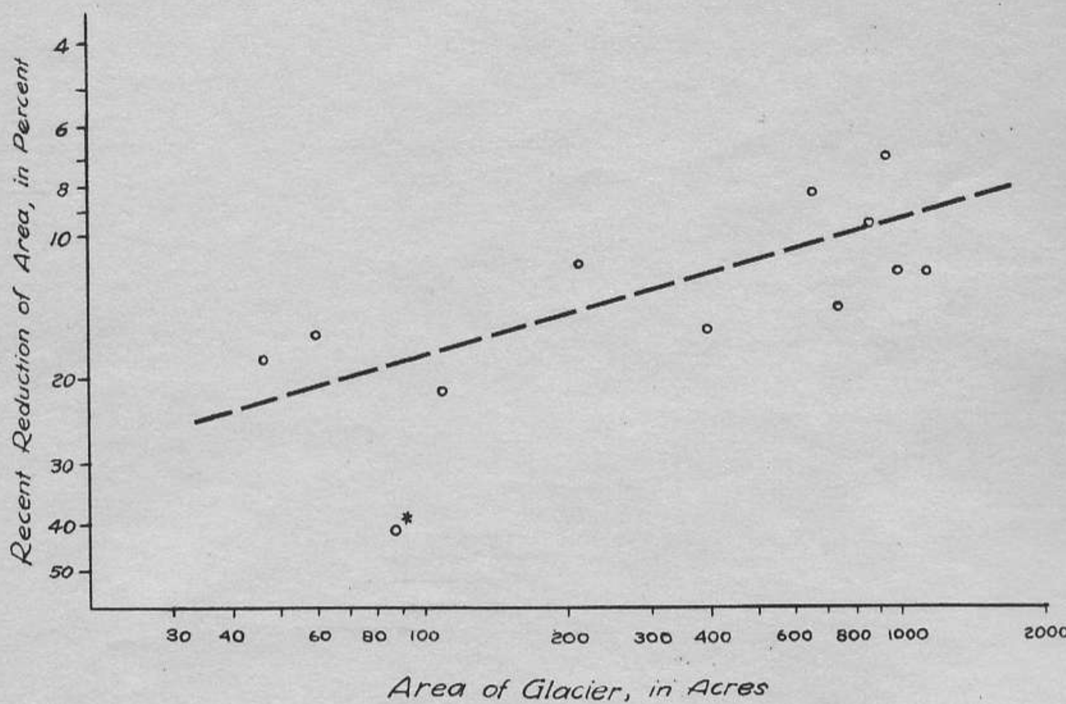


Fig. 58

Correlation between size of glacier (1950 area) and recent reduction in area (per cent reduction since the maximum extent during the Little Ice Age) for 12 Wind River glaciers.

* Gooseneck Glacier, an abnormal case: see page 71

than have the larger ones.

A study was also made to determine whether there was a relation between the present per cent ablation area and the median altitude. When these two characteristics are plotted on a graph (Fig. 59) it is seen that the correlation is very rough for the large valley and compound cirque glaciers (circles), but there is a distinct relation between these characteristics for the small cirque glaciers (triangles). In both of these cases, the per cent ablation area is approximately inversely proportional to the median altitude.

Recession in the Last Twenty Years

Recession measurements have been compiled only on Gannett, Dinwoody, and Gooseneck Glaciers. Although far from complete and not precise in many instances, the data do seem to indicate a trend. When correlated with recession measurements from three other glaciers which have a rather complete record, it is seen that the climatic trend in the Wind Rivers also was apparent in Glacier National Park (Fig. 60). This compilation shows an ever-increasing amount of recession through the 1930 to 1940 decade, climaxing around 1940. Since then the recession has been substantially less.

Possible Future Trend

The decreasing recession rate of the Wind River glaciers may

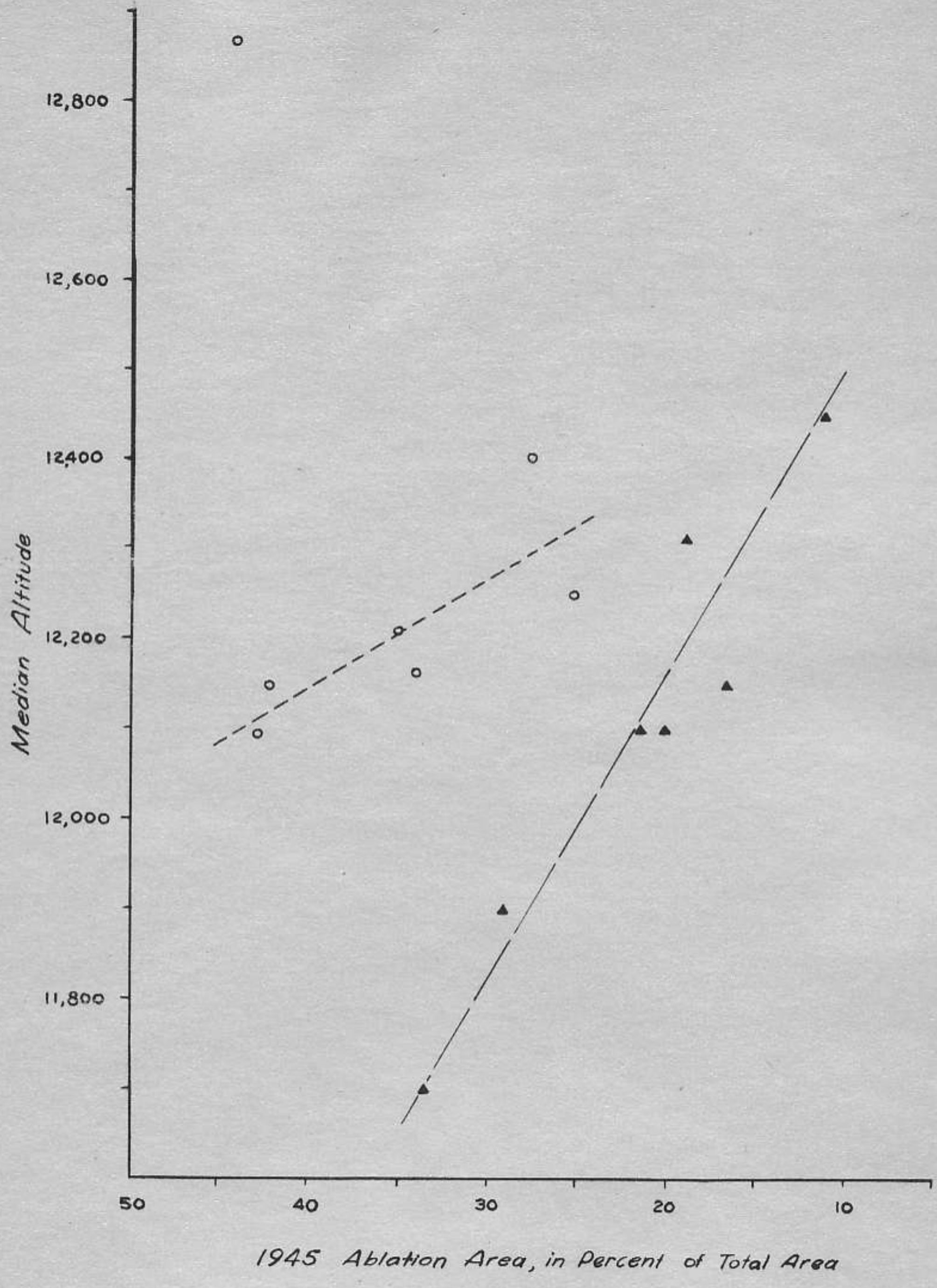


Fig. 59

Relationship between the 1945 per cent ablation area and the median altitude for 7 large glaciers (open circles) and 7 small cirque glaciers (solid traingles) in the Wind River Range.

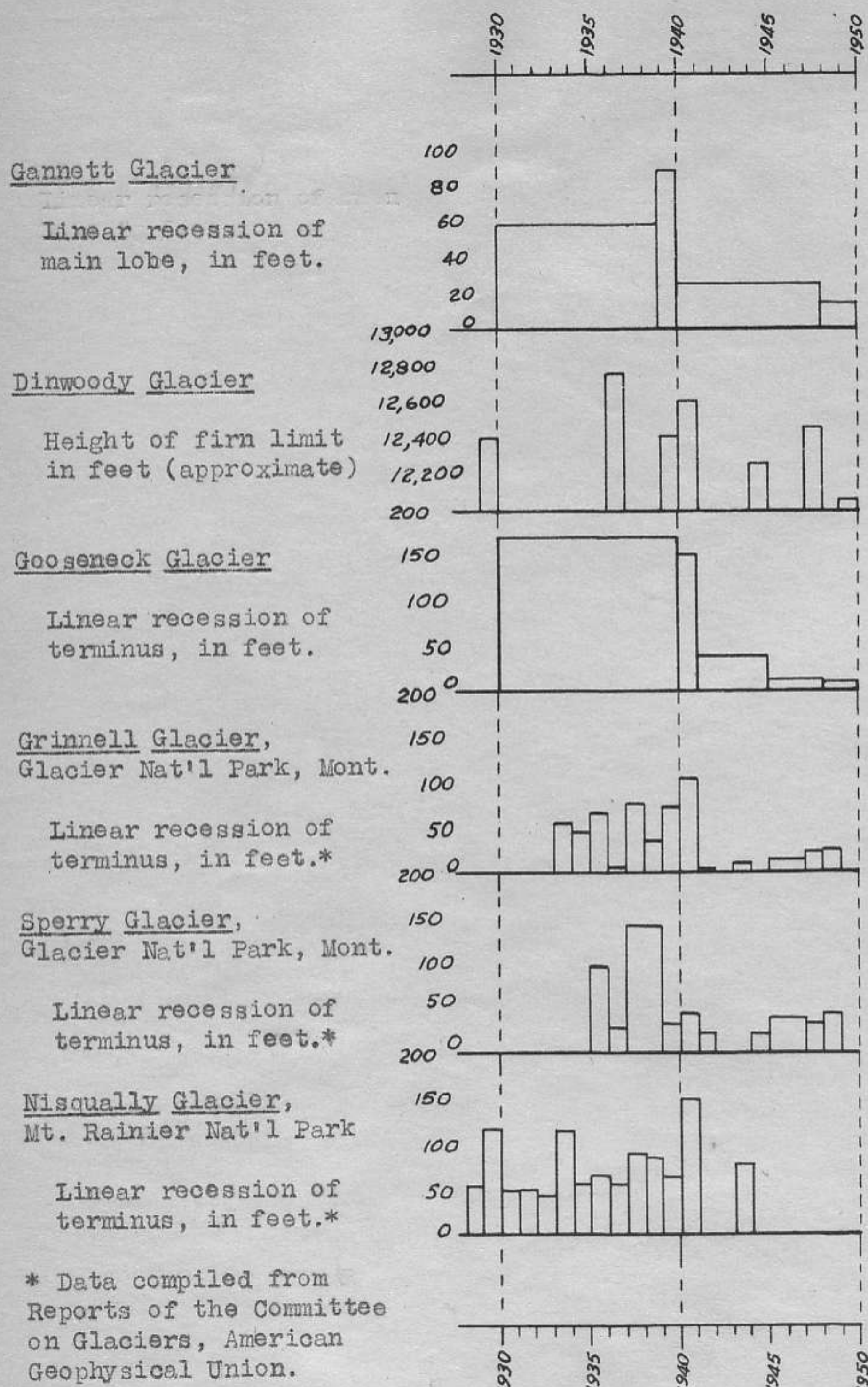


Fig. 60

Comparison of recession data for 3 Wind River glaciers and 3 glaciers in other regions of western United States.

indicate that these glaciers are coming into hydrologic equilibrium. There is actual evidence of thickening of high altitude snow fields in recent years, particularly at the summit of Gannett Peak. However, this may be due to a general rise in the zone of maximum accumulation, and may not herald a general advance of the glaciers. A definite increase in the amount of crevassing on Dinwoody Glacier has been noted in recent years. This, likewise, does not necessarily mean glacier expansion, but may be due to other factors. However, there is a strong probability that if present conditions continue, the recession of the Wind River glaciers will become generally less, and may in some cases cease altogether.

APPENDIX A

Computations for Individual Glaciers

GANNETT GLACIER

Highest elevation is about 13,100
Lowest elevation is about 11,100
2,000 Altitude interval is 200 feet

Interval	Elevation	Area units*	Per cent	
1	11,100-11,300	19	2.1	
2	11,300-11,500	38	4.2	
3	11,500-11,700	58	6.5	
4	11,700-11,900	90	10.0	
5	11,900-12,100	104	11.6	
6	12,100-12,300	111	12.4	median alt. 12,250
7	12,300-12,500	116	12.9	
8	12,500-12,700	134	14.9	
9	12,700-12,900	152	16.9	
10	12,900-13,100	76	8.5	
			100.0	

Firn basin: $\frac{1}{2}(13,100-12,250) + 12,250 = 12,675$ feet in altitude

	Total	Ablation	Maximum	% of abl.	% reduction
Area units*	898	270	1100		
Acres	1130	339	1390	30.1	18.7
Sq. miles	1.77	0.53	2.17		

* Area units refers to units of calibration of the polar planimeter used to measure the areas.

DINWOODY GLACIER

Highest elevation: 13,200
Lowest elevation: 11,200
2,000 Altitude interval is 200 feet

Interval	Elevation	Area units	Per cent
1	11,200-11,400	11	1.6
2	11,400-11,600	26	3.8
3	11,600-11,800	58	8.6
4	11,800-12,000	106	15.6
5	12,000-12,200	82	12.2
6	12,200-12,400	101	14.9 median elev. 12,210
7	12,400-12,600	121	17.8
8	12,600-12,800	95	14.0
9	12,800-13,000	53	7.8
10	13,000-13,200	25	3.7
			100.0

Firn basin: $\frac{1}{2}(13{,}200-12{,}210)+12{,}210 = 12{,}650$

	Total	Ablation	Maximum	% of abl.	% reduction
Area units	678	230	749		
Acres	860	292	950	33.9	9.5
Sq. miles	1.34	0.46	1.48		

MAMMOTH GLACIER

Highest elevation: 12,900
Lowest elevation: 11,300
1,600 altitude interval is 160 feet

Interval	Elevation	Area units	Per cent	
1	11,300-11,460	12	1.5	
2	11,460-11,620	25	3.2	
3	11,620-11,780	47	6.0	
4	11,780-11,940	64	8.1	
5	11,940-12,100	94	11.9	
6	12,100-12,260	106	13.4	
7	12,260-12,420	121	15.3	median elev. 12,400
8	12,420-12,580	158	20.0	
9	12,580-12,740	126	16.0	
10	12,740-12,900	36	4.6	
			100.0	

Firn basin: $\frac{1}{2}(12{,}900-12{,}400)+12{,}400 = 12{,}650$

	Total	1945 abl.	1950 abl.	Maximum	% of '45 abl.	% red.
Area units	789	255	153	898		
Acres	990	320	192	1125	32.3	12.0
Sq. miles	1.55	0.50	0.30	1.76		

HELEN GLACIER

Highest elevation: 13,000
Lowest elevation: 11,500
1,500 altitude interval is 150 feet

Interval	Elevation	Area units, main glacier	Area units, glacieret	Per cent of main glacier
1	11,500-11,650	18	5	6.7
2	11,650-11,800	18	15	6.7
3	11,800-11,950	19	7	7.1
4	11,950-12,100	35		13.1
5	12,100-12,250	48		18.0*
6	12,250-12,400	57		21.4
7	12,400-12,550	33		12.4
8	12,550-12,700	17		6.4
9	12,700-12,850	14		5.2
10	12,850-13,000	8		3.0
		267	27	100.0

* median elevation 12,160

Firn basin: $\frac{1}{2}(13,000-12,160)+12,160 = 12,580$

	Total	Ablation	Maximum	% of abl.	% reduction
Area units	294	114	395		
Acres	393	153	528	38.9	25.5
Sq. miles	0.61	0.24	0.83		

SACAGAWEA GLACIER

Highest elevation: 13,200
Lowest elevation: 11,700
1,500 altitude interval is 150 feet

Interval	Elevation	Area units, main glacier	Area units, glacierets		Per cent of main glacier
1	11,700-11,850	5	51		1.1
2	11,850-12,000	53	42		12.1
3	12,000-12,150	81	20		18.6
4	12,150-12,300	64	15		14.6*
5	12,300-12,450	61	4	28	13.9
6	12,450-12,600	53		43	12.1
7	12,600-12,750	50			11.4
8	12,750-12,900	40			9.2
9	12,900-13,050	19			4.3
10	13,050-13,200	12			2.7
		438	132	71	100.0

* median elevation 12,150

Firn basin: $\frac{1}{2}(13{,}200-12{,}150)+12{,}150 = 12{,}675$

	Total	Ablation	Maximum	% of abl.	% reduction
Area units	680	320	730		
Acres	940	443	1010	47.1	6.9
Sq. miles	1.47	0.69	1.58		

FREMONT GLACIER

Highest elevation: 13,600
Lowest elevation: 12,200
1,400 altitude interval is 140 feet

Interval	Elevation	Area Units	Per cent, Lower Fremont	Per cent, Upper Fremont
1	12,200-12,340	5	0.9	
2	12,340-12,480	15	2.7	
3	12,480-12,620	65	11.9	
4	12,620-12,760	112	20.5	
5	12,760-12,900	36	5.0	1.6
6	12,900-13,040	96	2.2	15.4
7	13,040-13,180	105		19.2
8	13,180-13,320	62		11.4
9	13,320-13,460	32		5.9
10	13,460-13,600	18		3.3
			43.2	56.8

Median elevation is 12,870

Firn Basin: $\frac{1}{2}(13,600-12,870) + 12,870 = 13,235$

	Total	Ablation	Maximum	% of abl.	% reduction
Upper:					
Area units	314	95	343		
Acres	376	114	410	30.2	8.5
Lower:					
Area units	237	175	257		
Acres	284	209	308	73.8	7.8
Combined:					
Area units	551	270	600		
Acres	659	323	718	49.0	8.2
Sq. miles	1.03	0.51	1.12		

KNIFE POINT GLACIER

Highest elevation is 12,960
Lowest elevation is 11,360
1,600 altitude interval is 160 feet

Interval	Elevation	Area units, South	Area units, North	Area units, Total	Area units, South	Area units, North	Area units, Total
1	11,360-11,520	18	4	22	2.9	0.6	3.5
2	11,520-11,680	23	4	27	3.7	0.6	4.4
3	11,680-11,840	40	9	49	6.5	1.5	7.9
4	11,840-12,000	58	9	67	9.4	1.5	10.8
5	12,000-12,160	67	11	78	10.8	1.8	12.6
6	12,160-12,320	53	22	75	8.6	3.6	12.1
7	12,320-12,480	18	48	66	2.9	7.7	10.7
8	12,480-12,640	29	69	98	4.7	11.1	15.8
9	12,640-12,800	4	83	87	0.6	13.4	14.1
10	12,800-12,960		50	50		8.1	8.1
				619			100.0

Median altitude: 12,090

Firn basin: $\frac{1}{2}(12,960-12,090)+12,090 = 12,525$

	Total	Ablation	Maximum	% of abl.	% reduction
Area units	618	294	745		
Acres	740	352	892	47.6	17.0
Sq. miles	1.16	0.55	1.39		

GOOSENECK GLACIER

Highest elevation: 13,000
Lowest elevation: 11,700
1,300 altitude interval is 130 feet.

Interval	Elevation	Area units	Per cent	
1	11,700-11,830	7	1.9	
2	11,830-11,960	29	8.0	
3	11,960-12,090	33	9.2	
4	12,090-12,220	44	12.3	
5	12,220-12,350	59	16.3	median elev. 12,310
6	12,350-12,480	50	13.9	
7	12,480-12,610	41	11.4	
8	12,610-12,740	45	12.4	
9	12,740-12,870	29	8.0	
10	12,870-13,000	24	6.6	
			100.0	

Firn basin: $\frac{1}{2}(13{,}000-12{,}310)+12{,}310 = 12{,}670$

	Total	Ablation	Maximum	% of abl.	% reduction
Area units	361	86	611		
Acres	86.9	20.7	147	23.7	41
Sq. miles	0.14	0.03	0.23		

APPENDIX B

Regimen Calculations

Computation of Average Ablation

Altitude increment	Area units	inches ablation	product
11,200-11,400	11	52	570
11,400-11,600	26	66	1170
11,600-11,800	58	73	4230
11,800-12,000	106	69	7320
12,000-12,200	82	45	3690
12,200-12,400	101	23	2320
12,400-12,600	121	17	2160
12,600 and above	173	13	2250
	678		23610

$\frac{23610}{678} = 34.8$ inches (average ablation over whole area)

Regimen Computations

Extrapolated average ablation: 53.2 in. water

Extrapolated firn limit ablation: $46.0 \times 53.2/34.8 = 70.3$ in.

Total area of glacier: $1.34 \times 5280^2 = 3.74 \times 10^6$ ft.^{2}

Total regimen: $1/12(2 \times 70.3 \times 3.74 \times 10^6) = 43.8 \times 10^6$ ft.^{3}

Total ablation: $53.2 \times 1/12 \times 3.74 \times 10^6) = 16.6 \times 10^6$ ft.^{3}

Total accumulation: $(43.8 - 16.6) \times 10^6 = 27.2 \times 10^6$ ft.^{3}

Average accumulation: $\frac{27.2 \times 10^6 \times 12}{3.74 \times 10^6} = 87.2$ in.

Excess of accumulation over ablation: $(27.2 - 16.6) \times 10^6 =$ 10.6×10^6 ft.^{3}

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