ANNUAL GLACIER SURVEY REPORT

Glacier National Park, Montana

1956

United States Department of the Interior
National Park Service
in cooperation with
U. S. Geological Survey and U. S. Weather Bureau

G L A C I E R

S U R V E Y   R E P O R T

Glacier National Park

Montana

1956

INTRODUCTION
by
Harry B. Robinson, Chief Park Naturalist
Glacier National Park

This report consists of four separate parts, one on Field Measurements, by Arthur Johnson, U. S. Geological Survey; one on Weather and Climate, by R. A. Dightman, U. S. Weather Bureau; an Introduction by Harry B. Robinson, National Park Service; and a Memorandum of a Meeting at Helena, Montana, March 12, 1957, to discuss glacier research in Glacier National Park, by Walter A. Blenkarn, U. S. Geological Survey. The profile sheets, Figures 1 and 2, and the accompanying tables were prepared by the U. S. Geological Survey. The report was assembled, mimeographed, and distributed by the National Park Service, Glacier National Park.

The weather graph that has been used in previous reports has been eliminated from this report. Also, a change has been made in the method of showing comparison between the precipitation at the storage gauges and the runoff at the gauging station. The percentage relations between runoff and precipitation as shown in the 1955 report (page 6) are based on different periods, and hence are not a true comparison. For example, the precipitation for the period August 27, 1949, to July 20, 1950, is compared with the runoff for the period October 1, 1949, to September 30, 1950. Comparisons of this kind should be for corresponding periods. Hence, a new set of comparisons has been prepared for this report (see table, page 17).

The 1956 glacier measurements got under way on August 22, at Sperry Glacier. The survey party consisted of Arthur Johnson, Chief, Water and Power Branch, Conservation Division, U. S. Geological Survey; David Holmes, Student Assistant, U. S. Geological Survey; and Park Naturalists Harry Robinson and Don Robinson of Glacier National Park. The National Park Service representatives remained at Sperry only two days, making general observations and taking photographs. The U.S.G.S. members of the party, who made the instrument surveys, remained until the 25th.

The Grinnell Glacier survey began on June 27th and ended on the 31st. Messrs. Johnson and Holmes were assisted on this survey by Gordon C. Giles, also of the U. S. Geological Survey. Park Naturalist Don Robinson was with them part of the time, taking photographs from photographic points of earlier years.

THE FIELD PROGRAM

by
Arthur Johnson, Chief, Water & Power Branch,
Conservation Division, U. S. Geological Survey
Washington, D.C.

SPERRY GLACIER

The last previous trip to the Sperry Glacier was made in 1952. The results of the 1956 observations and measurements therefore cover a four-year period. The cross profile and two longitudinal profiles were remeasured, the terminus remapped, and two marked boulders first located in 1949 were relocated. A number of pictures were taken to duplicate pictures taken in 1913, 1927, and 1936.

The results of the 1956 field measurements are shown graphically on figure 2 with the corresponding results of previous years. Figure 2 also includes an outline map of the glacier on which are shown the locations of the profiles, the terminus for various years, and the position of marked rocks. A table has also been included to show the mean elevations for segments of the cross profile and the main longitudinal profile for the years for which data are available. The data for all the profile measurements that have been made to date are shown in the tables attached to figure 2.

PROFILES

Cross Profile: Reference to figure 2 shows the relationship between the 1956, 1952, and 1950 profiles and serves as a convenient basis for comparison. The 1949 profile is so nearly coincident with the 1950 profile that the differences cannot be readily shown graphically. In comparing the 1956 and 1952 profile it is found that from the left or west edge to about station 300, the two are essentially the same; from station 300 to 1500 the 1956 profile was above that of 1952 by as much as eight feet in places; from station 1500 to 2600 the two were almost coincident; and from station 2600 to the east or right edge the 1956 profile was again above that for 1952 by amounts up to seven feet.

A similar comparison of the 1956 and 1950 profiles shows that the 1956 profile was well above that for 1950 from the left or west edge to station 1700 with maximum differences up to 15 feet; from station 1700 to 2200 the 1956 and 1950 profiles as well as the 1952 profile were much the same; and from station 2200 to the right or east edge the 1956 profile was above that for 1950 with maximum differences up to 15 feet. The lowest part of the profile is at about station 1800 and it is of interest to note that for several hundred feet in this area there was no appreciable difference between the three profiles discussed.

In comparing the 1952 and 1956 results with 1950 it must be kept in mind that the observations in 1950 were made about a month later than those in 1952 and 1956. Even allowing for the ablation during that month interval it would appear that the 1956 profile would be considerably above the 1950 profile with the exception of the central portion already mentioned. Whether or not this increase in surface elevation represents the beginning of a build-up in this area of the glacier or merely a variation in the residual snowfalls from year to year is a point that can only be determined by measurements in future years.

Longitudinal Profiles: The two longitudinal profiles, for convenience in references, have been designated as No. 1 and No. 2. Their locations on the glacier are shown in figure 2.

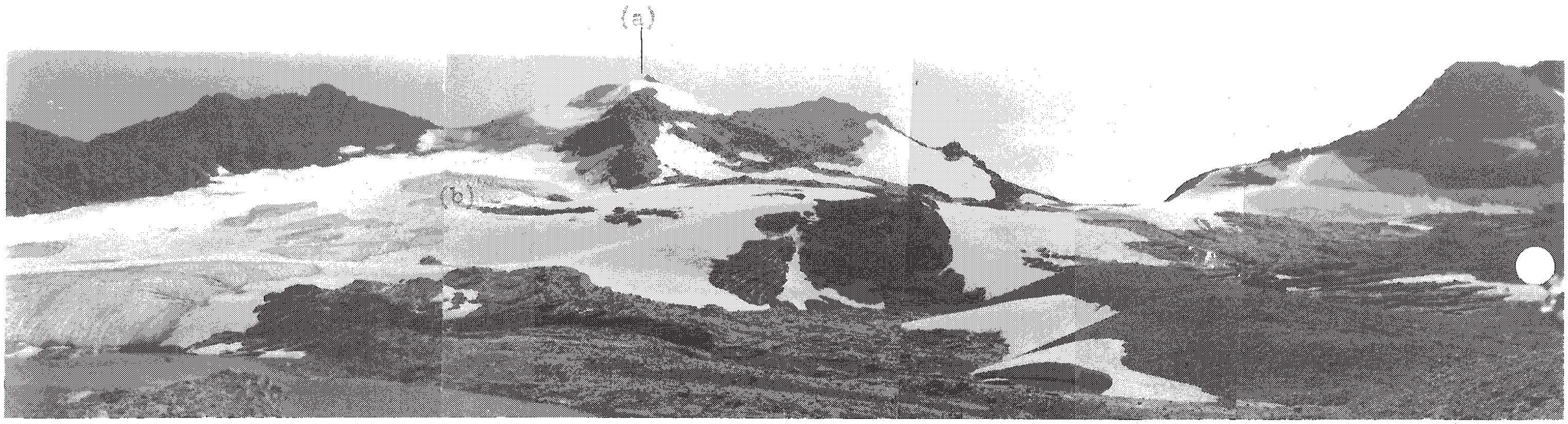
The changes that have occurred along longitudinal Profile No. 1 are readily apparent by reference to figure 2 and are interesting to note. The lower portion of the glacier has shown a continued decrease in surface elevation whereas the upper section indicates a slight increase or build-up. The point of transition is approximately 2,000 feet from the 1956 terminus of the glacier and near the point of intersection of Longitudinal Profile No. 1 and the Cross Profile. Near the terminus the 1956 surface was as much as 35 feet below the 1952 surface and as much as 40 feet below the 1950 surface. At a point about 750 feet from the 1956 terminus the 1950, 1952, and 1956 profiles intersect. The section immediately upstream therefrom shows an interesting phenomenon. The ridge paralleling the front, which has been a prominent feature of this glacier for many years, has been increasing in elevation and moving upglacier. The crest of this ridge was 16 feet higher in 1956 than in 1950 and was about 60 feet farther upglacier. The change between 1952 and 1956 was about an eight-foot increase in elevation and 30-40 foot movement upglacier. Similarly, the trough or depression on the upper side of this ridge had likewise been moving upglacier. The low part of this trough was about 100 feet farther upglacier in 1956 than it was in 1950 and about three-four feet higher in elevation. The change in the position of the low point from 1952 to 1956 was about 75 feet and the bottom of the depression in 1952 was two to three feet higher than in 1956. Continuing up the glacier the 1956 surface was definitely below that of 1952 and

1950 for the next six or seven hundred feet. From that point on the 1956 surface was above that of 1952 and 1950 by varying amounts. The maximum difference between the 1956 and 1952 surfaces was about five feet whereas the difference between the 1956 and 1950 surfaces was from 12 to 15 feet. As mentioned under the cross profile any comparison between 1956, 1952, and 1950 must take into account the difference in time of year at which the measurements were made. Allowing for this difference in time observations, the available data indicate that the upper part of the glacier, if not actually increasing in surface elevation, is at least holding its own whereas the lower portion is definitely decreasing in elevation.

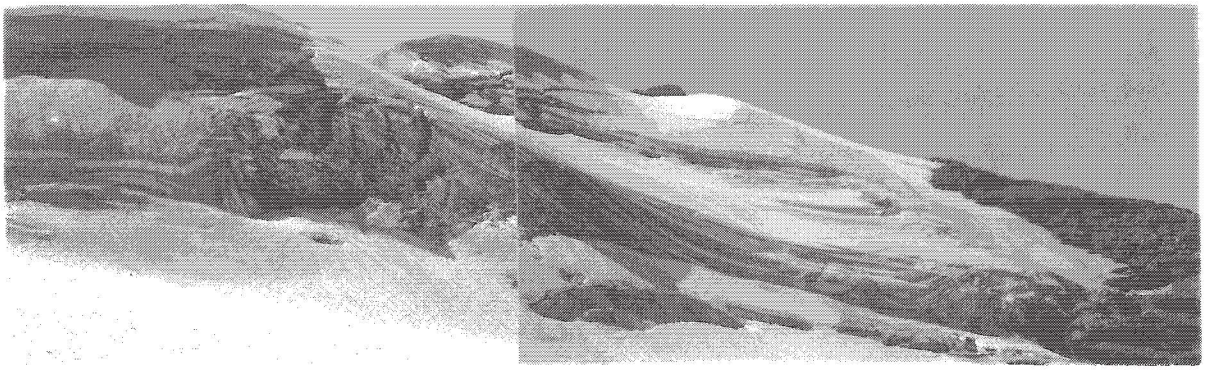
Longitudinal Profile No. 2, previously measured in 1947 and 1950, was remeasured in 1956 and the results are shown graphically on figure 2. Along this profile the ridge paralleling the front of the glacier had also moved upglacier but, unlike Longitudinal Profile No. 1, near the center of the glacier the crest of this ridge had decreased in elevation. The crest of the ridge in 1956 was practically 100 feet farther upglacier than in 1947 and about 30 feet lower. The decrease in elevation was about 15 feet since 1950. There was a corresponding change in the position of the trough on the upper side of this ridge. The 1947 and 1950 profiles extended only a short distance beyond the low part of the depression or trough. In this short distance the 1956 surface was about 30 feet lower than it was in 1947 and four or five feet higher than it was in 1950. If results for 1950 had been available they would probably not have been far different from those obtained in 1956.

Movement: Two rocks which were marked and located in 1949 were found and relocated in 1956. These rocks each showed a movement of about 80 feet during the seven-year period and in parallel directions; and each was lowered between seven and eight feet in elevation. As seen from figure 2 these rocks are located a short distance upstream from and near the lowest part of the cross profile. The observations on these two rocks would indicate an annual movement of approximately ten feet per year. Considering the shape of the glacier it is possible that a greater rate of movement might occur about midway between these rocks and the west or left edge. It is doubtful that such movement would be at any appreciably greater rate than that which was observed. The general observation can therefore be made that the Sperry Glacier has a very slow rate of annual movement. It would be advisable to locate and mark additional rocks, or set dowels, in such position as to furnish data that would be representative of movement for the entire glacier.

Terminal Recession: The entire terminus was remapped in 1956. An exact delineation of the true terminus was not possible as in a number of places there was a cover of residual snow from the previous winter which extended as fingers varying distances down valley. The most downstream points shown for the terminus in 1956 would be considered somewhat indefinite as these are primarily snow fingers. The portions of the terminus that extend farthest upstream are actually along the edge of the ice and represent the true front in those particular areas. Near the center of the glacier the terminal recession was as much as 200 feet since 1952. Near either edge there were minor variations indicated but the general position was not far different from that in 1952. No attempt has been made to compute the average recession as was done in some of the previous reports in view of the indefiniteness of some parts of the front as shown. The information obtained however does indicate that the terminal recession is continuing and is most pronounced near the center of the glacier.



A. Upper Portion of the Sperry Glacier Basin, photographed from the terminal moraine at lower end of the melt-water lake in left foreground. The active glacier is to the left of point (a), the major portion of the terminus being to the left of the photographed area. The build-up illustrated by Photograph C on next page is located at point (b).



B.

B. Bergschrund and Neve Field of Sperry Glacier.
Photo by Park Naturalist D. H. Robinson, August 23, 1956.

C. Upper Crevassed Area of Sperry Glacier, where increased activity or build-up is indicated. (See (b), Photo A.)
Photo by Park Naturalist D. H. Robinson, August 23, 1956.

C.

GRINNELL GLACIER

The 1956 field program included the remeasurement of the two profiles which have been measured in previous years, the location of eight previously marked boulders so as to determine rate of movement, the taking of pictures with a phototheodolite for use in compiling a map by the application of terrestrial photogrammetric techniques, and the taking of pictures from a number of points to duplicate pictures taken in 1911, 1920, and 1936 to serve as bases of comparison and an approximate determination of changes that have occurred during the intervening years.

PROFILES

The two profiles designated as No. 1 and No. 2 were remeasured and for the first time each was carried across the entire glacier. The final point on Profile No. 1 was at the foot of a talus slope emanating from the cirque wall. The final point on Profile No. 2 was an estimated 70 feet from the cirque wall as the steepness of the glacier surface and the dropping of small rocks from the cliffs made it too difficult and too hazardous to reach the actual edge of the glacier.

For the current report a new illustration has been prepared, figure 1, on which have been drawn the 1956 profiles along with the 1952 profiles. The latter were included as these extend farther across the glacier than any of the other profiles prior to 1956. The statistical data on the changes in surface elevation of the glacier for segments of the two profiles have been included in tabular form on figure 1. Figure 1 also includes an outline map of the glacier on which are shown the location of the two profiles and locations of the marked rocks in the various years. The data for the profile measurements that have been made thus far are shown on the tables attached to figure 1.

Profile No. 1: As seen from figure 1, there was no significant difference between the 1956 and 1952 profiles in the first 400 feet from the initial point. Beyond this the 1956 profile was definitely lower than the 1952 profile and for the most part by about six feet. The 1950 and 1952 profiles were essentially the same. The changes that have occurred in this profile during the period of record are shown in the table of mean elevations on figure 1 and can be summarized as follows. As above stated, the 1950 and 1952 profiles were essentially the same. There was an appreciable decrease from 1952 to 1953, varying from three to six feet. Since 1953 the segment from station 100 to 500 had indicated a gradual increase with a total of slightly over two feet whereas the segments from 500 to 1000 feet and 1000 to 1500 feet have indicated a net lowering of about one foot. The reversal in slope and the depression in this profile near station 2000 are considered due to the stream that falls from the cirque wall onto the glacier near this area.

Profile No. 2: The conditions along Profile No. 2 have remained much the same during the 1950-1956 period as shown by the table of mean elevations on figure 1. The 1956 and 1952 profiles, which are shown graphically on figure 1, are essentially the same throughout with the exception of a slight increase indicated for 1956 in the first 400 feet from the initial point. The tabular data show a decrease from 1952 to 1953 of from two to three feet, a change similar to that noted for Profile No. 1. This decrease has been recovered in subsequent years and the 1956 values are practically the same as the 1952 values.

As a matter of record attention is here called to an error that has been shown in the tabular data in previous years. For 1952 the mean elevation of the segment of this profile from station 1000 to 1500 has been shown as 6358.8 feet whereas the correct value is 6363.8 feet.

General: As pointed out in the 1955 progress report, in comparing the data for the various years certain factors should be kept in mind and the recorded figures not be taken too literally. Among these should be mentioned unavoidable errors or variations in field observations, differences in the number and placement of observed points from year to year, conditions under which the observations were made, and the variations in the dates of observations. In plotting the data for individual years minor differences will be found between successive years but so far these differences have not been significant enough to indicate any general over-all change in trend. The method of showing mean elevations for segments of the profile is believed to present the best summary of the observed data.

In brief, the observed data indicate that for Profile No. 1 there has been a lowering of the surface elevation since 1952 in amounts up to as much as six feet. For Profile No. 2 the changes in the surface elevations of the glacier have been within such narrow limits that it can be considered as being essentially the same throughout the six-year period 1950-1956.

It is of interest to note that there was no essential difference between 1952 and 1956 for Profile No. 2 whereas Profile No. 1 showed a definite lowering during that period. The fact that the latter is nearest the lake, which, as will be explained later, appears to be the actual terminus, may have some significance. This may also indicate a condition similar to that observed on the Sperry Glacier, viz., that the section adjacent to the terminus is lowering whereas the upper part remains much the same. The difference exhibited by these two profiles should be carefully watched in future years. It would be advisable to establish a third profile about 1000 to 2000 feet southeast of Profile No. 2 and approximately parallel to it. The measurement of this additional profile along with the continued measurements of the two present profiles should serve to give a reliable record of what changes may be occurring over the entire glacier.

Movement: Eight previously marked rocks were located. Each showed movement approximately 35 to 40 feet per year and continuing in the same direction. This direction is generally north or slightly east of north whereas what had been previously considered the terminus or front has a northwest-southeast direction. It now appears that this is more a lateral boundary or edge rather than a terminus. The actual terminus is the southern edge of the lake now forming the northern border of the glacier. It is of interest to note that the general direction of movement indicated by the marked boulders is much the same as the direction of the two long, narrow scree areas shown on the 1950 U. S. G. S. maps.

Terminal Recession: In some of the previous years field observations included a survey of a portion of the terminus. In these observations and subsequent reports the terminus was considered as the boundary or edge of the glacier extending southeastward from the lake at the northern border of the glacier. The alignment of this boundary is approximately normal to the valley. In view of the direction of movement as shown by the observations on marked rocks it would seem more logical to consider the actual terminus as that portion of the glacier ending in the lake and what previously had been referred to as the terminus as a lateral boundary. Some of the changes in this lateral boundary may not have had the significance attached to them at the time of observation. This boundary of the glacier is controlled to some extent by the series of rock ridges and is roughly parallel to the strike of these ridges. The troughs between these ridges are five to six feet lower than the ridge crests. On several occasions it has been observed that the edge of the ice will be cantilevered over a ridge crest as much as ten to 15 feet and then a wedge of ice will break away from the main body. This wedge, after breaking away, melts more rapidly than the main ice body and a new ice front soon results and gives the impression that a considerable recession had occurred when in reality such was not the case.

If the real terminus is in the lake as suggested the changes in it from year to year are not too meaningful unless the rate of recession or advance is very pronounced in view of the variations that result from time to time due to blocks of ice breaking away from the main body. The presence of a large number of blocks of ice in the lake indicate that this is a continuing process.

The foregoing comments should be considered in relation to the results of terminal recession given in previous reports.

USE OF PHOTOTHEODOLITE

The mapping of glaciers by the use of terrestrial photogrammetry has been considered for several years. The Grinnell Glacier, in view of its accessibility and the availability of a map recently compiled by aerial photogrammetry (1950 photographs) that could serve as a basis for comparison appeared to be a favorable location to try this method. As explained in the 1955 progress report, an attempt was made that season but the necessary field work could not be completed due to adverse weather conditions. An attempt was again made in 1956 and the necessary photographs and control data were obtained. The actual map compilation will be undertaken in the near future by the Topographic Division of the Geological Survey.

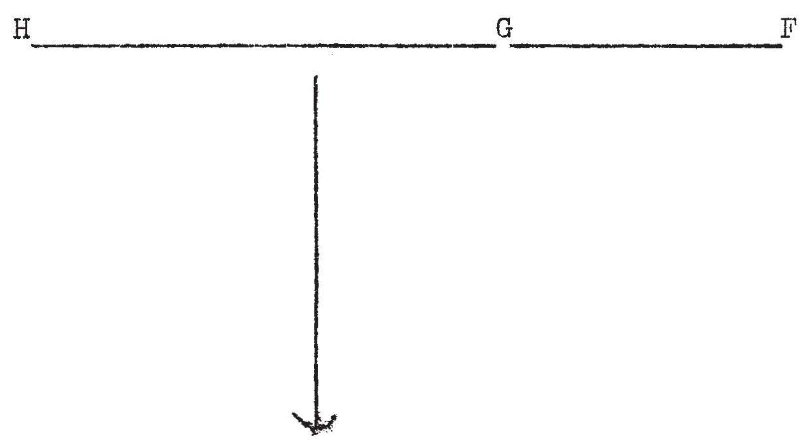
The application of terrestrial photogrammetry to the compilation of a topographic map requires stereoscopic pairs of photographs taken from one or more base lines of known length, position, and elevations of end points. The pictures are usually taken normal to the base line, and if greater coverage is required additional pictures are taken at known deviations to left or right of normal. The direction or azimuths of corresponding pairs of photographs from the ends of a base line must be parallel. The length of base lines selected is dependent on the area to be mapped and the detail desired in the map. The usual requirements are that the most distant part of the area to be mapped shall be within twenty times the length of the base line. There is a "dead space" immediately in front of the camera stations in which there is no stereoscopic coverage. This dead space extends to about five times the length of the base. For example, with a 300-foot base line the area that could be mapped would extend from

1500 feet to 6000 feet beyond the camera stations. In actual practice an effort is made to determine the horizontal and vertical positions of two or three points in each stereoscopic pair that are readily recognizable in the photograph to serve as control points in the compilation.

The equipment used was a Wild T-2 phototheodolite. The pictures taken with this instrument subtend a horizontal angle of about 43 degrees and a vertical angle of about 28 degrees.

As explained in the 1955 report, a base line for the camera stations was selected on the high morainal ridge north of the glacier. The length of this base line could not be measured with a tape due to the rugged terrain. A base line was measured in a comparatively flat area between the morainal ridge and the glacier. From this base line the length and elevation of the base line for the camera stations was determined by triangulation.

In order to obtain the required photographic coverage two base lines were required, one long and one short. In view of the terrain conditions the possible locations were limited. A plan therefore was selected using three camera stations on the same straight line as illustrated below.



FH served as the long base line and FG as the short base line.

Six points, well distributed over the glacier, were selected and these positions and elevations determined by triangulation for use as check or control points in the stereoscopic compilation.

The use of the phototheodolite promises to have other applications in glacier studies in addition to that of map compilation.

The study of early pictures of a glacier along with phototheodolite pictures taken at or near the same location can enable the development of a map that would show with reasonable accuracy the glacier boundaries at the time of the early pictures as well as a fairly good approximation of the topography of the glacier surface.

In cases where a complete map may not be practicable or desirable the locations and elevations of selected points for use in developing a profile or determining movement or for other purposes can be obtained by using phototheodolite pictures with a photo-alidade. In this application the same results can be obtained in the office with pictures as would be obtained by plane table triangulation in the field. In fact, by locating sufficient points contours could be sketched in a manner similar to field procedures.

GRINNELL GLACIER, MONTANA

PRECIPITATION - RUNOFF COMPARISONS

	Period	Number of days	Precipitation (inches) a/	Runoff (inches) b/
	Aug. 27, 1949 - July 20, 1950	327	125.1	87.0
	July 21, 1950 - Sept. 3, 1950	45	1.8	25.0
	Sept. 4, 1950 - July 24, 1951	324	115.7	84.8
	July 25, 1951 - Sept. 12, 1951	50	8.7	20.6
	Sept. 13, 1951 - July 15, 1952	307	99.6	69.8
	July 16, 1952 - July 31, 1953	381	106.9	101.9
	Aug. 1, 1953 - Sept. 4, 1953	35	3.4	15.1
	Sept. 5, 1953 - Aug. 5, 1954	335	134.8	92.2
	Aug. 6, 1954 - Sept. 27, 1954	53	19.0	23.0
	Sept. 28, 1954 - Aug. 10, 1955	317	89.2	82.2
c/	Aug. 11, 1955 - Aug. 7, 1956	363	100.7	99.02
d/	Aug. 15, 1955 - Aug. 7, 1956	359	152.83	97.33

a/ Measured at storage precipitation gauge near end of horse trail 0.4 mile from glacier.
b/ Measured at gauging station at outlet of Grinnell Lake.
c/ Original gauge. Was undergoing repair August 11-14, 1955; no appreciable precipitation during this period.
d/ New installation.

GRINNELL GLACIER STUDIES, A PROGRESS REPORT AS RELATED TO CLIMATE *

by
R. A. Dightman, State Climatologist,
U.S. Weather Bureau, Helena, Montana

Abstract

A description of the efforts to obtain data affecting the behavior of Grinnell Glacier, Glacier National Park, including precipitation, temperature, runoff from the glacier basin, and actual surveys of the ice body, is followed by a tabulation of some of the data so far observed. The possibility that observations to date point toward a renewal of glacier activity in the Northwest is developed, followed by a discussion of recent trends toward cooler weather in the northwestern parts of Europe and North America, and in the case of northwestern North America, wetter as well.

Introduction

In an earlier report (1) Beatty and the author covered some of the background of the program for measurements and studies of some of the glaciers in Glacier National Park. The 1952 report contained data through 1951, discussed findings from measurements, and compared observed climate trends for a 57-year period with glacier behavior and with Willett's (2) tentative forecasts. At a time when many Pacific Northwest glaciers are beginning to show definite growth, as reported by Bengtson (3), Hubley (4), Harrison (5) and others, it is appropriate to report on the first seven years of observations of precipitation and runoff in connection with measurements and observations of the behavior of Grinnell Glacier, Glacier National Park.

* Paper presented at the 148th meeting of the American Meterological Society in Asheville, North Carolina, October 30, 1956; also, published in the Monthly Weather Review, Vol. 84, No. 9, Sept. 1956

While actual measurements of Grinnell Glacier were started by the National Park Service in 1932 at about the time the rate of recession during the first half of the current century was approaching its maximum, and there are photographs of this glacier several years before the turn of the century showing roughly its extent at that time, data on precipitation and runoff for the glacier basin are available only since 1949. The history of the project covered in the earlier report (1) will not be repeated here. The present report will be confined to bringing the earlier summary up to data, to comparing observations with later climate trends, and to a discussion of the purposes of the work.

Development of Project since 1950

A Weather Bureau Standpipe Seasonal Storage Precipitation Gauge (now known as Grinnell Glacier #1), installed on August 27, 1949, about 2,000 feet NNE of the location of one of the fronts of the glacier at that time, produced its first seasonal total when the measurement made on July 20, 1950 showed a catch of 125.1 inches. The glacier, located in a cirque opening roughly to the north and northeast, has had its main terminus in recent years in a deep pool at the north end of the cirque, and glacier elevations on September 1, 1950 ran from 6,403 feet (melt pool) to around 7,300 feet at the southern (highest) end. The cirque is bounded on west and south by the Garden Wall, much of which runs between 8,000 and 9,000 feet elevations. While the glacier now flows mostly northward, old moraines indicate that at recent maximum size (around 1890), it had an eastward direction of movement at the terminus. Moraines indicate that the storage gauge is located only about 100 feet from one earlier extension of the glacier.

This storage gauge functioned well until the exceedingly heavy snows of the 1953-54 season resulted in lateral movement of the snow pack around the gauge, damaging the drain assembly, and loosening the concrete foundation. This damage was repaired during the 1955 summer season, an additional 5- ft. section was added to the gage, a larger foundation was built and the drain assembly was shielded to protect against future lateral movement of snow. (See Figs. 1 and 2). At the same time a second gage (Grinnell Glacier #2) was installed about 3,000 feet SSE of #1, the same gage height ($21\frac{1}{2}$ ft) as #1. Windshields are not used on either as experience during the first two seasons at #1 site showed that such shields could not withstand the severe winds in this area. Establishment of the second gage was expected to show important differences in precipitation, and the first seasonal measurement seemed to verify that expectation (see Table 1.). Reasons for the larger catch at the new site are probably many, and interrelated in several ways, but it is not unreasonable to observe that since the second site is nearer to the upper end of the glacier it could have been expected to be in an area of heavier precipitation. There is also some doubt as to the completeness of the #1 catch for the season.

During the 1951 and 1952 summer seasons a cotton region shelter, extreme thermometers, and a hygrothermograph were used at the #1 site and a record of daily high and low temperatures was made during those summers only (the shelter was destroyed by porcupines before the 1953 season began). Some pertinent temperature notes appear in Table 2. A continuous (throughout the year) temperature record was started by the U. S. Geological Survey in 1951 at the gaging station on Grinnell Creek about a mile from the glacier and about 1,400 feet lower than the melt pool, but little work thereon has been done so far. It is interesting to note in Table 2 the difference in average temperature between Grinnell Glacier and nearby stations for the same months. The U. S. Geological Survey has measured runoff from the glacier basin (3.4 sq. mi.) since 1949, and these data appear in Table 3. While the glacier itself currently covers only about 270 acres, its area in 1900 was 600 acres, or just about a square mile. The gaging station on Grinnell Creek could not be located nearer the glacier because of impossible winter operating conditions that exist at other sites. The runoff records are of excellent quality, and reflect in at least some degree the behavior of the glacier. In late summer, for example, the glacier furnishes the larger part of Grinnell Creek's flow.

All these data, including precipitation and temperature by the Weather Bureau, temperature and runoff by the U. S. Geological Survey, and actual surveys and measurements by the National Park Service will contribute much to our knowledge of climate and glacier relationships in the years to come - although it must be admitted that 6 or 7 years is certainly not very long in the sense of geological time. However, such data as have been accumulated so far already appear to have some significance, considering the well-documented growth of many Western North America glaciers during recent years.

Glacier Activity in Western U. S. During Recent Years

Bengtson (3), Hubley (4), and Harrison (5) have reported increased glacier activity over much of the Western U. S. during recent years. Beatty and Johnson (6), in their annual reports of Glacier National Park glacier observations and measurements, have pointed out that the rapid recession noted during the 1930 and 1940 decades has halted, and since 1950 there has been some evidence of increased activity. Spectacular growth of Coleman Glacier on Mount Baker in the Northern Cascades has been observed, and increased volume of others in this area has been reported. Activity of glaciers has increased as far south as the Central Sierras and as far east as the Northern Rockies. This change in general glacial behavior, covering at least several years over a large area, must have some climatic significance. Glaciers in a sense are integrators of climate for several years, i.e., it takes more than one year's weather to make an appreciable contribution to glacial growth or ablation.

Climate Trends in the Area Around Glacier National Park

In the earlier report (1) 10-year moving averages of average temperature and precipitation for the entire State of Montana were used to establish some short-range trends. In an effort to localize the application of these trends while bringing them up to date through 1955, several 10-year moving averages for single stations are shown in Figs. 3 and 4. Their similarity to the trends shown in (1) is apparent, and the marked agreement of the trends between stations is noteworthy. They all confirm the observation that the weather around Glacier National Park has been markedly cooler and wetter since about 1946 than during the period of rapid glacier ablation noted in the West for about 20 years after 1925.

Whether or not these observed trends are only a minor fluctuation in the larger Northern Hemisphere warming trend, touched upon by many authors, which is variously described as lasting from 100 to 200 years, we do know that there is a well-established short-range trend toward cooler weather in the Northwest. The general assumption that the warming trend continues unabated in all areas of the Northern Hemisphere (most recently by Gilbert N. Plass (7)) probably requires qualification to recognize the observed changes. The conclusion that the changes are real is supported by our knowledge of glacier behavior in the affected area for the last 10 years.

It is generally agreed that there is geological evidence that periods of glacial advance and recession on varying scales have followed each other at intervals of several hundred or thousands of years through the Pleistocene Age, and an accompanying change in climate is a corollary of that knowledge. Hans Ahlmann said in 1948 that results of excavations in southernmost Greenland seemed to him to justify the conclusion that at no time since the year 1400 had the climate been so favorable as it had been since the 1920's. However, this long trend toward warmer climate, if it has not already done so, will reverse itself eventually as such trends already have reversed themselves several times within the last few thousand years. Ahlmann (8) in 1952 pointed out that the culmination of climate improvement had been reached in many places in the 1930 or 1940 decades, and a trend to colder climate had started in Northwestern Europe. The important question, which probably will have to wait many years for an answer, is "Is the trend actually reversing itself in Northwestern Europe and in northwestern parts of the North American Continent?" The extent to which we can answer that question now seems to be that the warming trend has suffered at least a temporary interruption over sizable areas.

The periods with which we are working are extremely small on the scale of geological time. It will be many years, perhaps as many as 200 or 300, before our file of climate information will contain data for a long enough period to permit reasonably full correlation between climate and glaciation. In the meantime, it appears that our knowledge of climate history can be increased by additional studies leading to a more complete picture of glacier activity during the last thousand years or so. Ahlmann (9) said "The relations between glaciers and climate are highly complicated and still far from clear. Until we have solved the problems of the existence and variation in size of glaciers, their structure, movement, and other features, we cannot fully utilize them as the climatological registers they really are".

SUMMARY

The work done so far on Grinnell Glacier is a start toward eventual accumulation of sufficient data for studies of the relationships between glacier and climate behavior in the Glacier National Park area of the United States. The almost seven years of data accumulated so far are a very small beginning - almost insignificant when considering the many years that appear involved in most major glacial cycles. Additional work can be done, however, in dating the several terminal moraines of Grinnell to establish more of a history of the activity of that glacier than is now known and in defining the approach to building a file of climate-glacier data so that our successors a century or two in the future will have something with which to work.

It seems possible that the measurements of precipitation, runoff, and the glacier itself have been started at a turning point in the glacier's history. Whether it is a major reversal or a temporary interruption of a warming trend, only time will tell. In the meantime this cooperative project of studying Grinnell Glacier and accumulating data, participated in to date by the National Park Service, the U. S. Geological Survey, and the U. S. Weather Bureau, holds real hope for improving our ability to use glaciers as climatic indexes, and for increasing our understanding of climatic changes, of which glacier growth and ablation are only one result.

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9. Hans W. Ahlmann, op. cit. p. 5

Table 1
Record of Precipitation Measurements Adjacent to Grinnell Glacier

Season Ending (year and date)		#1, Est. 8-27-49 Seasonal Total Precipitation (in)	#2, Est. 8-15-55 Seasonal Total Precipitation (in)
1950	7/20	125.05 (11 mo.)	
1951	7/24	117.59	
1952	7/15	109.27	
1953	7/31	106.93	
1954	8/5	138.20	
1955	8/10	108.22	
1956	8/7	100.11	152.83

* *

Table 2
Grinnell Glacier (#1) Temperature Records °F.

Year	Month	Average Maximum	Average Minimum	Average	Highest	Lowest
1951	Aug.*	58.5	39.2	48.9	82	29
1952	Aug.*	64.8	43.7	54.3	79	29

* August was the only complete temperature record month in both years.

1951 temperatures observed July 25-Sept. 10 period, highest 82, lowest 26

1952 temperatures observed July 9-Sept. 16 period, highest 82, lowest 29

August Mean Temperatures at Nearby Stations Compared with Grinnell #1

Year	Grinnell #1 (el. 6,238)	Summit (el. 5,213)	Babb 6 NE (el. 4,300)	West Glacier (el. 3,154)	Polebridge (el. 3,690)
1951	48.9	53.2	55.1	60.1	57.0
1952	54.3	54.7	57.0	61.9	58.5

Table 3.
Runoff from Grinnell Glacier Basin (3.4 sq. mi.)

Water Year Ending September 30	Runoff in Inches of Precipitation	Runoff in % of Grinnell #1 Precipitation
1950	106.54	85
1951	104.98	89
1952	89.59	82
1953	97.16	91
1954	110.54	80
1955	94.29	87
1956	102.77 ∅	103 *

∅ preliminary, subject to correction.

* indicates that seasonal catch might not have been complete, due possibly to capping or icing of gage orifice. Runoff in 1956 water year was 67% of catch of 152.83 in gage #2.

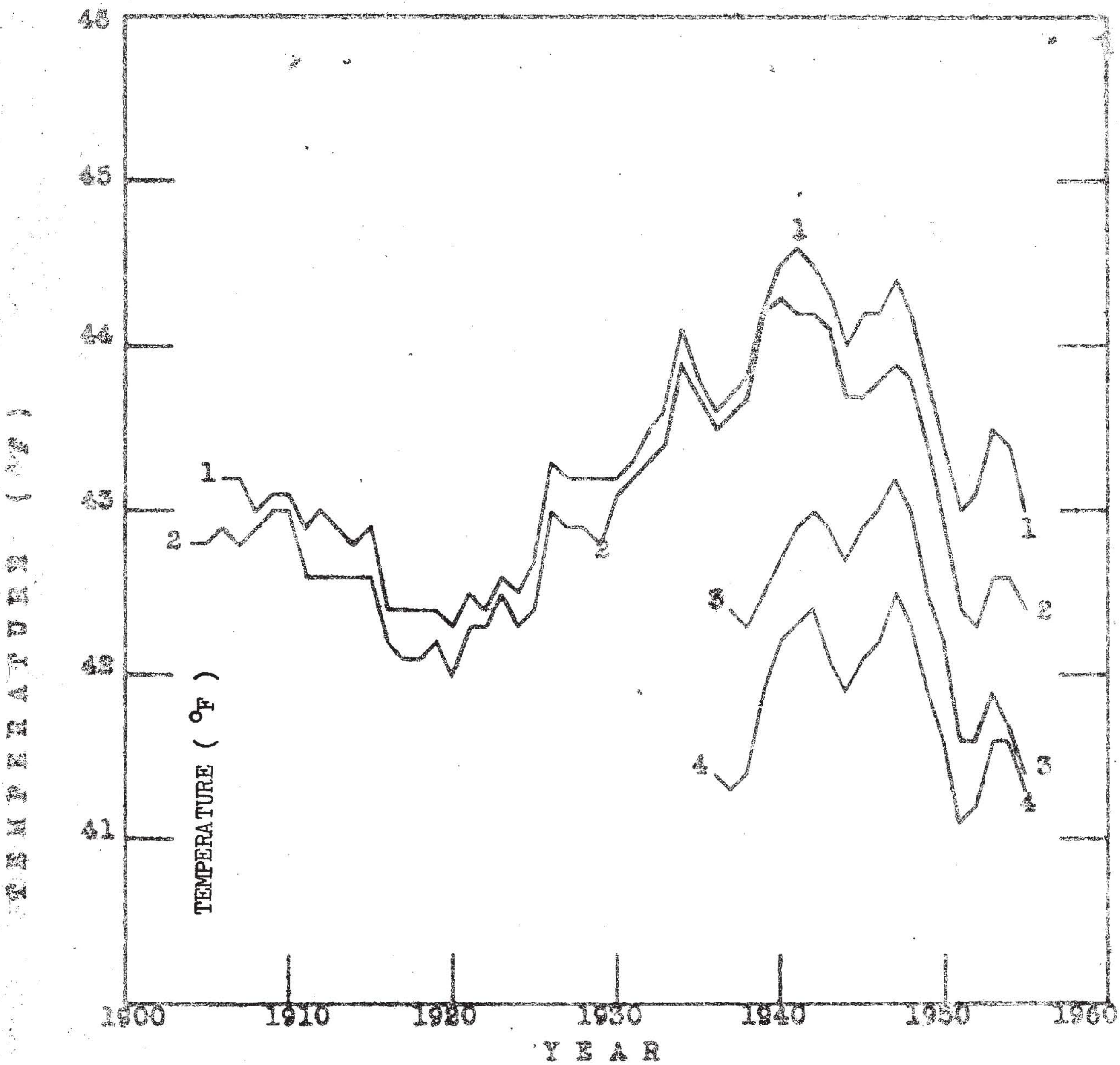

Figure 3. Ten-year moving averages of annual mean temperature, each ten year period ending with year indicated by abscissa: 1. Kalispell; 2. Areal average (weighted) for Montana; 3. West Glacier; 4. Fortine.

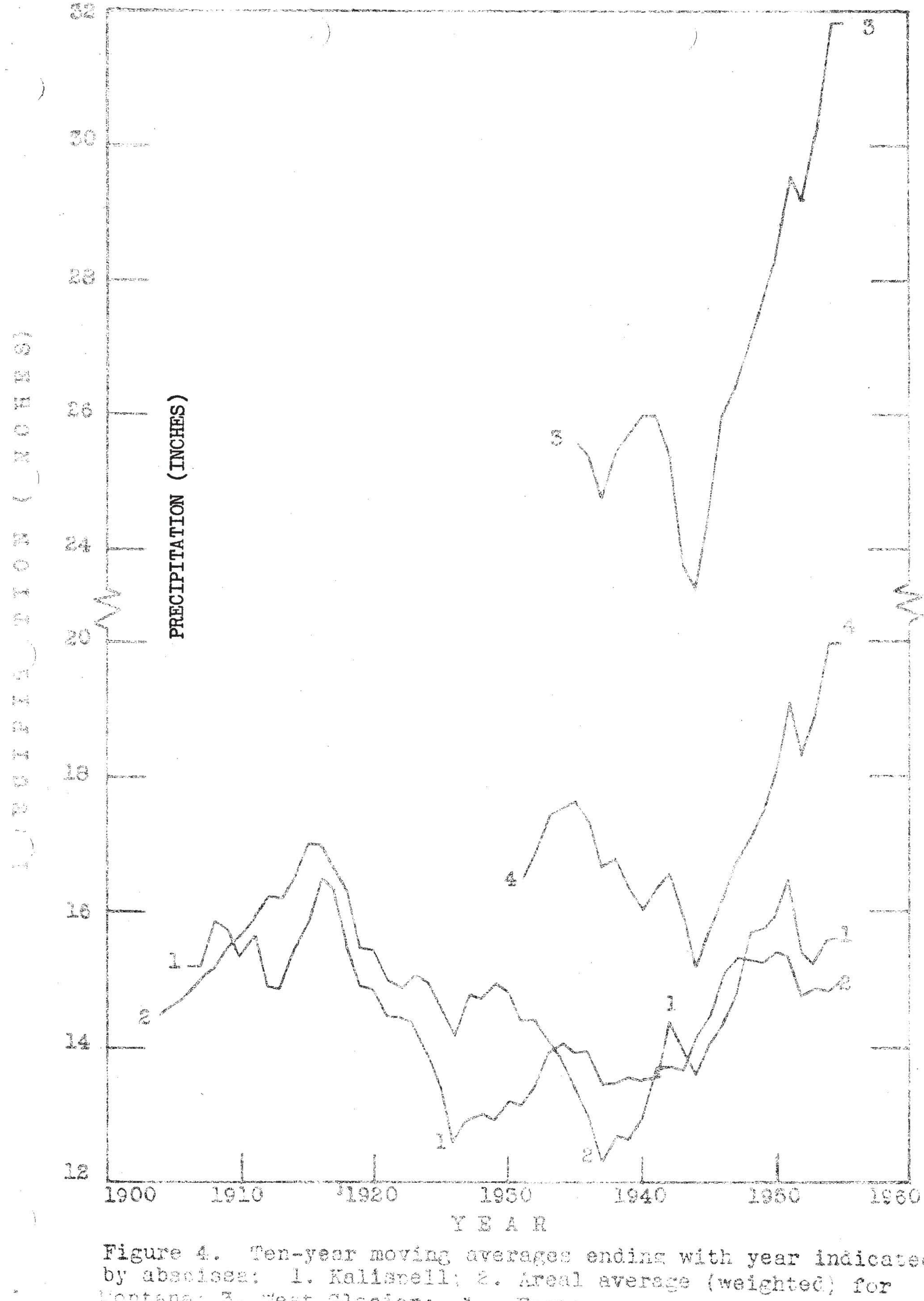

Figure 4. Ten-year moving averages ending with year indicated by abscissa: 1. Kalispell; 2. Areal average (weighted) for Montana; 3. West Glacier; 4. Fortine

Fig. 1. Grinnell Glacier Standpipe Seasonal Storage Precipitation Gage at site No. 1, showing surface of glacier (left center) in background.

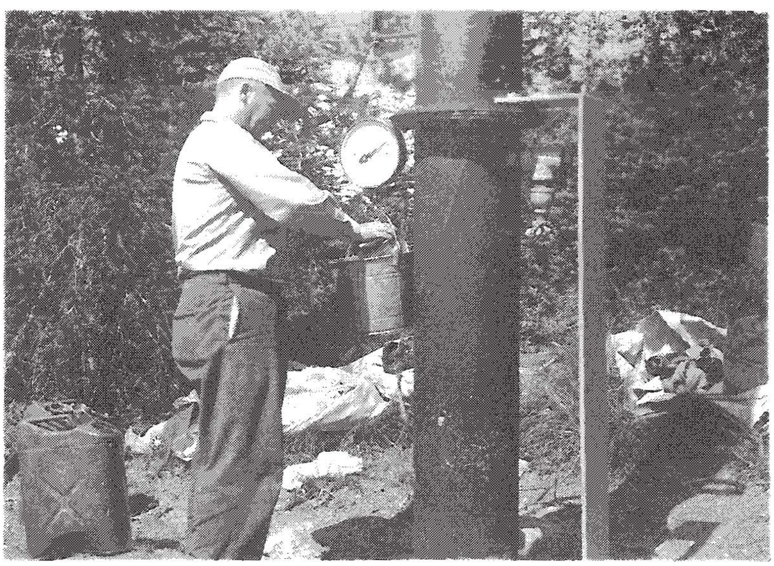

Fig. 2. Closeup of Storage Gage, site No. 1, showing drain assembly and shield.

MEMORANDUM OF MEETING
on
GLACIER RESEARCH IN GLACIER NATIONAL PARK
Helena, Montana March 12, 1957

In attendance --

Harry B. Robinson
Chief Park Naturalist
Glacier National Park
West Glacier, Montana

T. Homer Black
Assistant Park Naturalist
Glacier National Park
West Glacier, Montana

R. A. Dightman
State Climatologist
U. S. Weather Bureau
Helena, Montana

Arthur Johnson
Chief, Water and Power Branch
Conservation Division
U. S. Geological Survey
Washington, D. C.

Mark F. Meier
Project Hydrologist
General Hydrology Branch
Tacoma, Washington (Coordinator for glacier research in the United States during International Geophysical Year).

Frank Stermitz
District Engineer
U. S. Geological Survey
Helena, Montana

C. S. Heidel
Staff Engineer
U. S. Geological Survey
Helena, Montana

W. A. Blenkarn
Hydraulic Engineer
U. S. Geological Survey
Helena, Montana

Agenda

1. A review of what has been done and purpose behind each of these projects.

11. Definition of our long range objectives.

111. Discussion how best we can work toward these objectives.

1a. Johnson -- Gave a brief resume of the part taken by the Geological Survey in glacier measurements in Glacier National Park. He explained that the initial interest of the Geological Survey resulted from a discussion with Mr. G. L. Parker, then Chief Hydraulic Engineer, Mr. Heidel and himself while at a meeting in Spokane during the summer of 1944. Mr. Heidel mentioned that he understood that the Park Service was making some observations and measurements on glaciers within Glacier National Park but was not familiar with the details. Mr. Parker suggested that it would be desirable for the Geological Survey to cooperate with the National Park Service in securing records of glaciers in Glacier National Park in a manner similar to that in operation in Mt. Rainier National Park. He further suggested that the matter be discussed with the Park Service personnel in Glacier National Park. Accordingly, Mr. Tuttle and Mr. Heidel, on their return trip from Spokane to Helena, called at Glacier Park Headquarters on August 2, 1944. As a result of this call and resulting correspondence, arrangements were made for Mr. Johnson to accompany Mr. Beatty, the Park Naturalist, on the annual trip to the glaciers under observation during the early part of September. Mr. Beatty had been transferred to Glacier National Park that same summer so this was to be his first trip. Trips were made to the Sperry, Jackson, and Grinnell Glaciers on September 4, 5, and 6, respectively. Mr. Heidel joined the party on the trip to the Sperry

Glacier. An attempt was made to get to the Agassiz Glacier on September 8 but due to unfamiliarity with the route of access it was not possible to reach it. At the Sperry, Jackson and Grinnell Glaciers, several linear measurements were made from previously marked points to the ice front and a number of pictures were taken. In 1945 the fronts of the Sperry and Grinnell Glaciers were mapped with a plane table and several points were marked in the area downstream from the glacier which could be conveniently occupied in subsequent years for remapping the ice fronts. This plan has proved to be a very desirable method of recording changes in the termini. Profiles along definite lines have been measured on the Sperry Glacier in 1949, 1950, 1952 and 1956; and on the Grinnell Glacier in 1950, 1952 and annually since then. Some data on movement have been obtained on each glacier.

Dr. J. L. Dyson, who was then employed as a Ranger-Naturalist, made plane table maps of the Grinnell, Sperry and Jackson Glaciers in 1937, 1938 and 1939 respectively. Unfortunately, no permanent reference marks were established at the time of these surveys so a definite correlation between them and subsequent surveys has not been possible. Dr. Dyson also did some additional mapping on the Grinnell and Sperry Glaciers in 1946.

Aerial photographs of a number of glaciers were taken in 1950 and 1952 by the Forest Service from Missoula, on a repay basis. A map from the 1950 photographs was compiled by the Forest Service for the Jackson Glacier. Maps based on the 1950 photographs were compiled and published by the Geological Survey for the Grinnell and Sperry Glaciers.

The possibility of applying terrestrial photogrammetric techniques for recording and measuring glacier changes is now being considered. Photographs were obtained with a phototheodolite of the Grinnell Glacier in 1956. Arrangements are under way for the compilation of a map from these pictures. If this method proves to be practicable, it offers many applications in the recording of glacier changes.

A collection of old photographs of a number of glaciers in Glacier National Park are available for study. Some of these were taken in the 1880's. Some of the photographs taken since about 1900 hold promise of being usable in the mapping of the glacier boundaries through the application of terrestrial photogrammetric techniques.

The purpose of the work, at least at its inception, was primarily documentary with the thought that eventually this data would be useful in the study of glacier changes and climatic variations.

1b. Robinson -- The principal interest of the National Park Service in glacier research is interpretative. Accurate data is desired for historical purposes and for giving information to park visitors.

Grinnell Glacier is the most accessible of all the park glaciers and consequently is of the most interest. An average of 55 persons per day visited this glacier during the 1956 park season.

The Park Service is interested in continuation of the investigation and has requested that $1000 per year be used for glacier research in connection with its "Mission 66" program.

1c. Stermitz -- The gaging station below Grinnell Glacier was suggested by Johnson and Heidel. The station was installed on Grinnell Creek below Grinnell Lake in 1949. Continuous records of good quality have been obtained thereafter. This station is closer to a glacier than any other in the United States. Continuous air temperature records have been obtained at the gage site since July 25, 1951.

Summer precipitation measurements with a tipping bucket rain gage were started in 1956. In general this work has been financed by research funds of the Geological Survey.

Snow surveys have been made in the Swiftcurrent Creek basin (of which Grinnell Creek is a tributary) since 1922. These have been made by the Geological Survey in cooperation with the Water Resources Branch, Department of Northern Affairs and National Resources, Canada. The snow survey results have been used to predict the summer flow of Swiftcurrent Creek to aid in the operation of the St. Mary and Milk River irrigation projects in Canada and United States.

Gaging of the runoff immediately below the glacier was considered too difficult to be practical. It was decided to investigate further in 1957 to see if there actually is any possibility of directly gaging this flow.

Heidel commented that his interest in the glacial research was prompted by a desire to learn whether or not the recession of glaciers may eventually cause any effect on average stream flow. This is of importance in connection with the Milk River project in Montana and several large irrigation developments in Canada.

<u>1d. Dightman</u> -- In the summer of 1949 A. H. Tuttle, District Engineer, U. S. Geological Survey, Helena, Montana and Heidel called on Dightman and explained how the glaciers were being measured in Glacier Park. The Weather Bureau then became interested in the project and installed a precipitation storage gage near Grinnell Glacier in August 1949. Measurements by dip stick have been made at intervals since 1949 and the total yearly precipitation catch has been measured between the annual recharging dates. The gage has usually been recharged in late July or early August.

Hygro-thermograph records were obtained at a site near the precipitation gage in the summers of 1951 and 1952.

The drain valve on the precipitation storage gage was damaged by heavy snow load in 1953 and enough leakage occurred so that it was necessary to estimate the catch by a method described by Dightman as the "Salt density method".

Several of the other difficulties experienced in obtaining precipitation and hygro-thermograph records under the severe weather conditions that occur in this area were described by Dightman. He also explained in detail how the precipitation storage gage is drained and recharged. A second precipitation storage gage was installed southeast of the first one, some what nearer the glacier, in 1955.

The 1955-56 catch at this one was about 50% more than at the No. 1 gage. Neither of the two gages are shielded at present because the Weather-Bureau type shield installed on the original gage was badly damaged.

The Weather Bureau is interested in this work from two points of view, i.e.:

1. Glaciers as climatic indicators,
2. Climate of high altitude basins.

<u>II. Meier</u> -- Proposed a statement of the long range objectives of the various agencies. The objectives were concurred in and are given below:

A. To obtain information about the glaciers that will be of general interest to visitors in the National Park.
B. To obtain sufficient information so the present state of health of the glaciers is precisely known.

C. To obtain data so the behavior of the glaciers can be determined in the light of climatic trends.

D. To continue observations and obtain any necessary additional data so that an analysis can be made of the climate and hydrology of the truly alpine basin above the Grinnell Creek gaging station.

111. Discussion of the objectives outlined above followed:

Under 11a. Robinson said that Park visitors are most interested in the depth, area and movement of the glaciers. A frequent question is the depth of crevasses.

Meier said that crevasses may occur as deep as 165 feet and could be much deeper though depths of over 100 feet are relatively rare. Depth of a crevasse is determined by speed of extension of the ice. Deep crevasses occur only where the flow is very rapid.

It is vital to know more about glacial movement. Determination of the velocity of movement along with other data will permit computation of the ice thickness within reasonable limits of accuracy, about 20 percent.

The ice depth can be obtained by seismic methods but because of transportation difficulties this would probably prove to be quite expensive.

Under 11b. -- We should know the regimen of the glaciers.

To obtain this for Grinnell Glacier it was suggested that at least one more profile of the surface of the glacier be obtained near the east side. This will make a total of three profiles all of which should be extended to the rock wall of the cirque.

C. To obtain data so the behavior of the glaciers can be determined in the light of climatic trends.

D. To continue observations and obtain any necessary additional data so that an analysis can be made of the climate and hydrology of the truly alpine basin above the Grinnell Creek gaging station.

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Under llb. -- We should know the regimen of the glaciers.

To obtain this for Grinnell Glacier it was suggested that at least one more profile of the surface of the glacier be obtained near the east side. This will make a total of three profiles all of which should be extended to the rock wall of the cirque.

The dimensions of the glacier's surface may be more accurately and rapidly obtained by use of the phototheodolite if it proves to be satisfactory. Johnson said funds can probably be obtained for continuation of yearly measurements of at least Grinnell Glacier.

Velocity-ablation dowels set on the lower 2/3 of the glacier can produce a fair answer as to the regimen of Grinnell Glacier. A minimum of 8 stakes along profile lines were suggested. Wooden dowels about $1\frac{1}{4}$ inches in diameter (same as drill size) about 10 feet long should be satisfactory.

Meier suggested that each year at the time of the Grinnell survey the elevation and location of these dowels as well as the amount that each one projects above the ice surface be measured. Also that a map be obtained of the firn line and that the regimen of the firn be obtained by an annual snow survey of the firn along at least two of the profiles. Soundings with a small rod at other points would also be desirable.

Information as to the rate of ablation might be obtained by an ablado-graph. It was decided that use of this instrument would not be tried on Grinnell Glacier at present.

Discussion followed as to the expense and means of accomplishing these suggestions. It was decided that we would try to obtain the information suggested by Meier.

Robinson inquired as to literature which might be available on glacier behavior. Meier stated most good literature was foreign and no translations are available, but "Physics of the Earth-IX Hydrology, Chapter V by O. E. Meinzer" provides the best information in

English on this subject. Meier said he would furnish a copy of abbreviated instructions on determination of glacier regimen to all agencies in attendance.

Under 11c. -- It was generally agreed among those present that Grinnell Glacier is so inaccessible in April and May that it will, for the present at least, not be practical to attempt to obtain data on the glacier near the end of the snow accumulation period.

It was decided that it would be worthwhile to obtain a summer temperature record near the No. 1 precipitation storage gage. Dightman said another hygro-thermograph installation will be recommended for as early as possible in 1957.

Meier suggested that di-stick readings be obtained at the precipitation storage gages as early in the summer as possible, also at the time of the glacier survey and as late in the summer as possible. Dightman said that he would recommend that the Weather Bureau install stronger shields on the gages either this year or next.

It was decided to investigate means of measuring annual precipitation near Granite Park Chalet and at a lower elevation, near the Grinnell Creek gaging station. The latter would supplement the summer precipitation data now being collected at this site.

Although the data collection now in progress and suggested for early installation is inadequate to interpret glacier behavior in the light of climatic trends, continuation is considered justified in view of more detailed work that might be undertaken in the future.

Under 11d. -- Present observations and additional data will be obtained where possible with the goal of eventually being able to analyze the climate and hydrology of the alpine basin. Because of the expense and amount of data required, it is not known when this goal will be reached.

Summary

1. Program as it stands is of great value, and fulfills worthwhile purpose.
2. Projects that are underway should be continued in essentially the same pattern.
3. A few additions to these projects would allow more definite conclusions about some aspects of the program.

   For Grinnell Glacier these are:

   a. Installation and measurement of velocity-ablation stakes.

   b. Map of firn limit and regimen determinations.

   c. An additional stadia profile.

   d. Summer temperature records at the glacier.

   e. Measure of summer precipitation at the glacier.

/s/ Walter A. Blenkarn
Secretary, ad hoc

SPERRY AND GRINNELL GLACIER PROFILES

SPERRY GLACIER
Longitudinal Profile No. 1

Aug. 30, 1949		Sept. 19, 1950		Aug. 19, 1952		Aug. 24, 1956	
Distance from initial point (feet)	Elevation (feet)	Distance from initial point (feet)	Elevation (feet)	Distance from initial point (feet)	Elevation (feet)	Distance from initial point (feet)	Elevation (feet)
Upglacier from initial point							
		838	7734.6				
		777	7709.6				
		724	7687.4			1183	7900.9
		647	7660.5	863	7751.1	1096	7864.7
		583	7637 8	761	7711.8	981	7812.2
		514	7618.0	682	7681.2	855	7754.2
557	7627.5	432	7601.1	591	7649.8	732	7703.8
491	7611.0	364	7589.4	491	7620.5	611	7662.2
398	7593.8	292	7578.1	393	7600.3	519	7632.9
306	7579.4	218	7566.4	293	7583.6	391	7601.4
209	7563.9	136	7552.0	190	7566.0	246	7576.9
108	7545.8	59	7538.0	93	7548.2	150	7558.6
0 a/	7526.8	0 a/	7526.8	0 a/	7530.6	0 a/	7528.5
Downglacier from initial point							
99	7509.7	94	7510.1	0	7530.6	98	7507.9
202	7495.6	192	7496.1	110	7510.3	255	7484.5
305	7483.3	286	7485.0	213	7495.9	358	7473.4
415	7474.1	365	7477.1	320	7483.1	467	7460.9
519	7466.5	449	7468.5	424	7472.6	546	7453.5
741	7440.1	518	7460.4	535	7460.9	610	7446.3
843	7446.9	597	7452.4	684	7449.3	658	7456.8
939	7445.7	711	7443.1	784	7456.2	750	7464.3
1033	7437.8	757	7445.5	882	7451.7	904	7451.8
1111	7427.0	808	7447.7	987	7440.2	1011	7433.4
		873	7446.5	1093	7426.1	1152	7402.4
		923	7443.6	1180	7410.3	1209	7388.8
		988	7438.1	1267	7399.6	1313	7363.0
		1051	7430.2	1361	7376.6	1425	7334.8
		1116	7421.6	1450	7358.6	1510	7313.4
		1180	7411.5	1540	7338.8	1594	7290.1
		1253	7398.9	1629	7317.6	1682	7271.0
		1331	7385.1	1713	7296.8	1764	7256.5
		1408	7371.0	1805	7273.0		
		1483	7357.0				
		1550	7343.1				
		1622	7326.9				
		1712	7306.0				
		1788	7288.5				
		1873	7267.8				
		1934	7252.6				

a/ Initial point is intersection of longitudinal and cross profile and 1967 feet from initial point for cross profile. See Fig. 2.

SPERRY GLACIER

Longitudinal Profile No. 2

August 26, 1947		September 20, 1950		August 25, 1956	
Distance from initial point (feet)	Elevation (feet)	Distance from initial point (feet)	Elevation (feet)	Distance from initial point (feet)	Elevation (feet)
0 a/	7375.0	0	7375.0	0 a/	7375.0
210 b/	7361.7	305 b/	7360.1	290 b/	7360.2
270	7373.3	345	7366.5	380	7370.1
353	7402.8	385	7377.8	465	7383.6
427	7428.8	435	7394.3	575	7404.0
437	7431.6	502	7412.6	669	7419.4
509	7447.1	560	7426.0	760 c/	7400.0
554	7451.7	629	7434.7	851	7431.1
620	7425.2	661	7417.4	912	7458.2
659	7416.1	696	7404.3	971	7490.6
689	7412.9	732	7400.0	1039	7520.8
767	7428.7	769	7402.3	1092	7545.5
839	7457.5	813	7412.5	1196	7588.0
		854	7427.4		

a/ Initial point is painted reference mark on rock ridge near left edge of glacier. Elevation assumed from study of 1938 map by J. L. Dyson. See Fig. 2.

b/ Front of glacier.

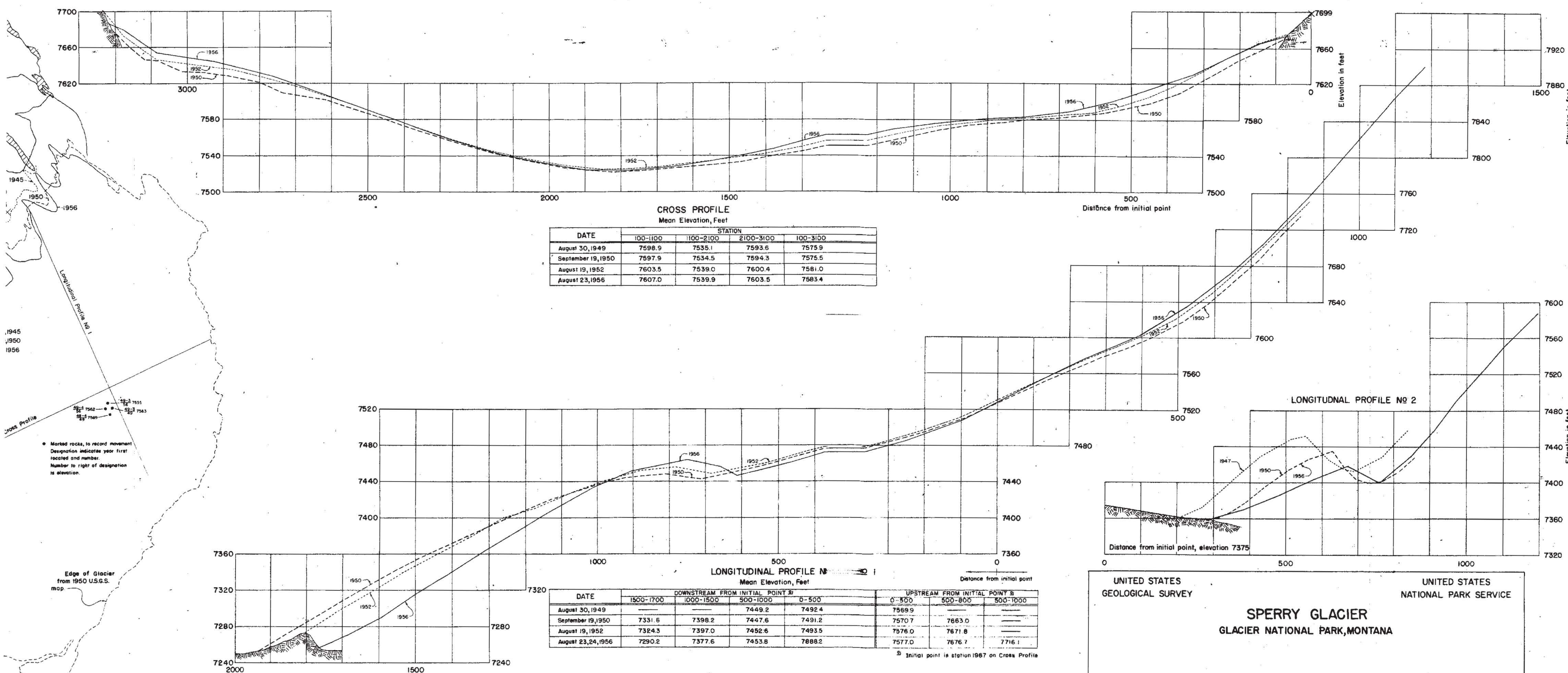
c/ Estimated.

SPERRY GLACIER
Cross Profile

August 30, 1949		Sept. 19, 1950		August 19, 1952		August 23, 1956	
Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)
0	7699.3	0	7699.3	0	7699.3	0	7699.3
93 b/	7665.2	87	7667.6	71	7675.6	73	7673.7
170	7651.5	147	7657.4	151	7665.2	145	7664.9
288	7622.6	204	7645.6	237	7649.1	237	7649.3
435	7600.6	276	7630.3	306	7633.8	332	7630.6
550	7590.2	367	7610.0	381	7618.1	466	7612.0
707	7585.6	455	7598.4	453	7605.7	564	7599.7
885	7579.7	577	7588.0	525	7596.5	674	7589.0
1034	7569.6	717	7582.4	606	7588.4	796	7583.5
1138	7560.0	788	7580.3	672	7585.8	891	7581.6
1238	7551.5	869	7577.1	763	7583.0	976	7579.1
1342	7542.9	949	7573.5	839	7581.6	1061	7575.3
1437	7536.0	1034	7567.7	938	7577.3	1156	7569.7
1532	7530.8	1123	7560.5	1033	7572.8	1276	7559.0
1637	7526.9	1217	7552.4	1127	7565.9	1381	7547.7
1732	7524.4	1297	7545.3	1217	7558.4	1466	7540.5
1857	7522.4	1376	7539.5	1311	7549.5	1561	7533.5
1967 c/	7526.8	1466	7533.3	1411	7542.0	1661	7527.9
2052	7533.2	1571	7528.9	1505	7536.8	1771	7523.7
2136	7540.4	1661	7525.9	1605	7531.8	1899	7524.6
2235	7551.9	1756	7523.1	1703	7527.8	1967 c/	7528.5
2332	7563.0	1826	7522.3	1770	7526.3	2021	7532.4
2422	7574.6	1893	7523.5	1865	7526.2	2126	7541.0
2501	7585.6	1967 c/	7526.7	1967 c/	7530.6	2230	7552.4
2594	7596.8	2051	7533.6	2062	7537.3	2330	7505.9
2683	7607.3	2151	7542.5	2169	7547.1	2455	7584.3
2767	7616.0	2244	7552.6	2268	7558.5	2632	7610.0
2861	7624.8	2328	7563.4	2372	7572.3	2764	7628.0
2956	7632.3	2402	7573.3	2470	7586.0	2932	7645.1
3106	7625.0	2480	7583.7	2568	7600.2	3216	7686.3
3192	7665.1	2549	7593.1	2684	7615.7		
3219	7682.4	2618	7601.6	2783	7626.5		
		2737	7610.4	2875	7635.0		
		2801	7620.8	2976	7641.3		
		2885	7628.2	3085	7646.8		
		2952	7631.6	3178	7672.5		
		3015	7633.3	3234 d/	7702.5		
		3082	7635.4				
		3119	7646.1				
		3162	7659.6				
		3212 d/	7679.4				

a/ Initial point on left bank. See Fig. 2.
b/ Left edge of glacier.
c/ Initial point for longitudinal profile No. 1.
d/ Right edge of glacier.

FIGURE 2



CROSS PROFILE

Mean Elevation, Feet

DATE	STATION			
	100-1100	1100-2100	2100-3100	100-3100
August 30, 1949	7598.9	7535.1	7593.6	7575.9
September 19, 1950	7597.9	7534.5	7594.3	7575.5
August 19, 1952	7603.5	7539.0	7600.4	7581.0
August 23, 1956	7607.0	7539.9	7603.5	7583.4

LONGITUDINAL PROFILE Nº 1

Mean Elevation, Feet

DATE	DOWNSTREAM FROM INITIAL POINT [a]				UPSTREAM FROM INITIAL POINT [a]		
	1500-1700	1000-1500	500-1000	0-500	0-500	500-800	500-1000
August 30, 1949	—	—	7449.2	7492.4	7569.9	—	—
September 19, 1950	7331.6	7398.2	7447.6	7491.2	7570.7	7663.0	—
August 19, 1952	7324.3	7397.0	7452.6	7493.5	7576.0	7671.8	—
August 23, 24, 1956	7290.2	7377.6	7453.8	7888.2	7577.0	7676.7	7716.1

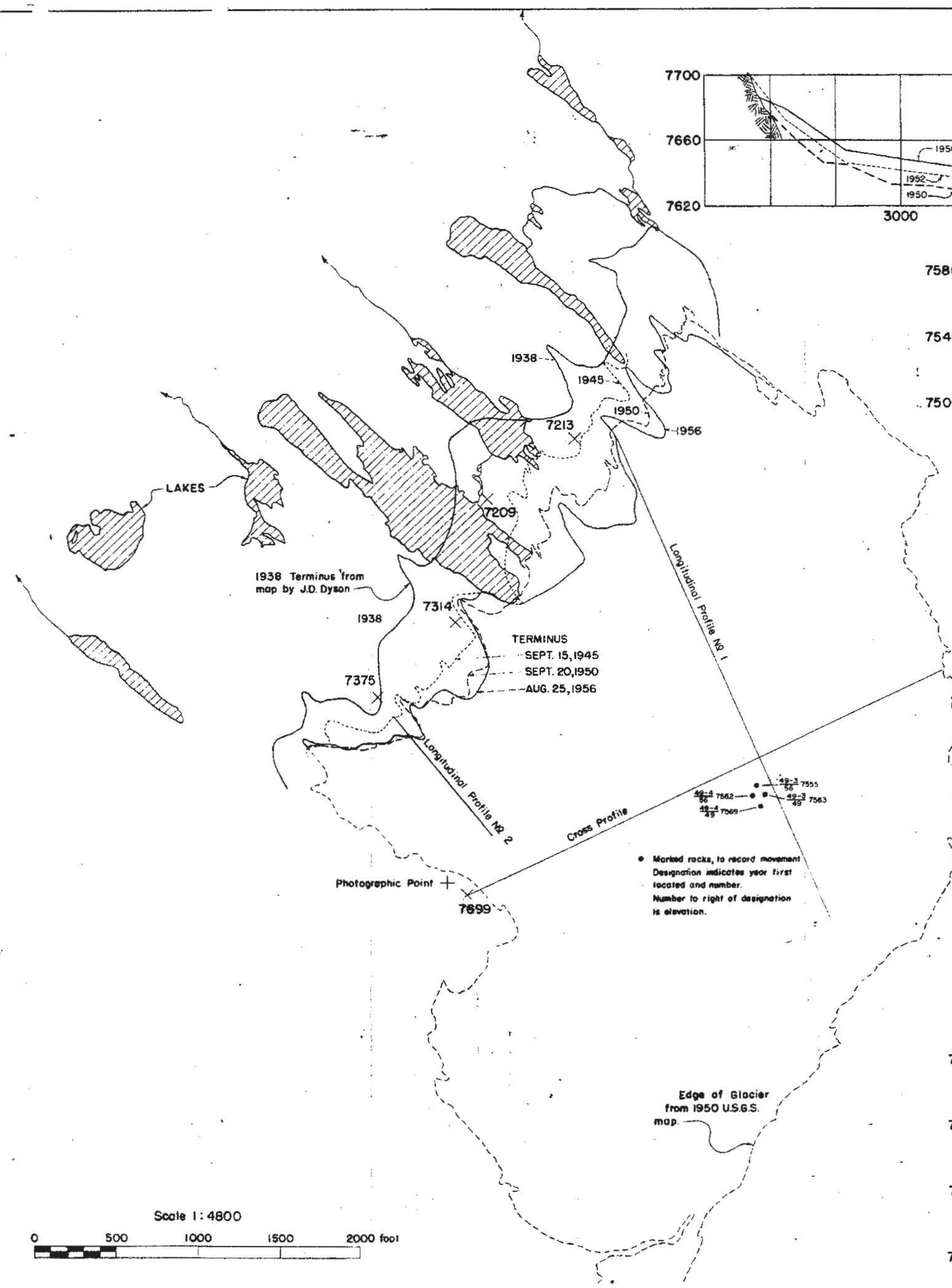
[a] Initial point is station 1967 on Cross Profile

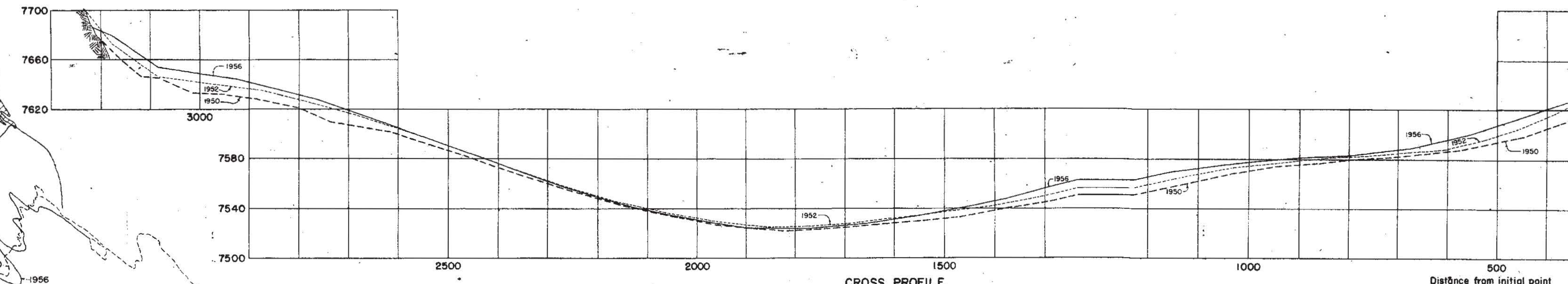
UNITED STATES GEOLOGICAL SURVEY

UNITED STATES NATIONAL PARK SERVICE

SPERRY GLACIER

GLACIER NATIONAL PARK, MONTANA

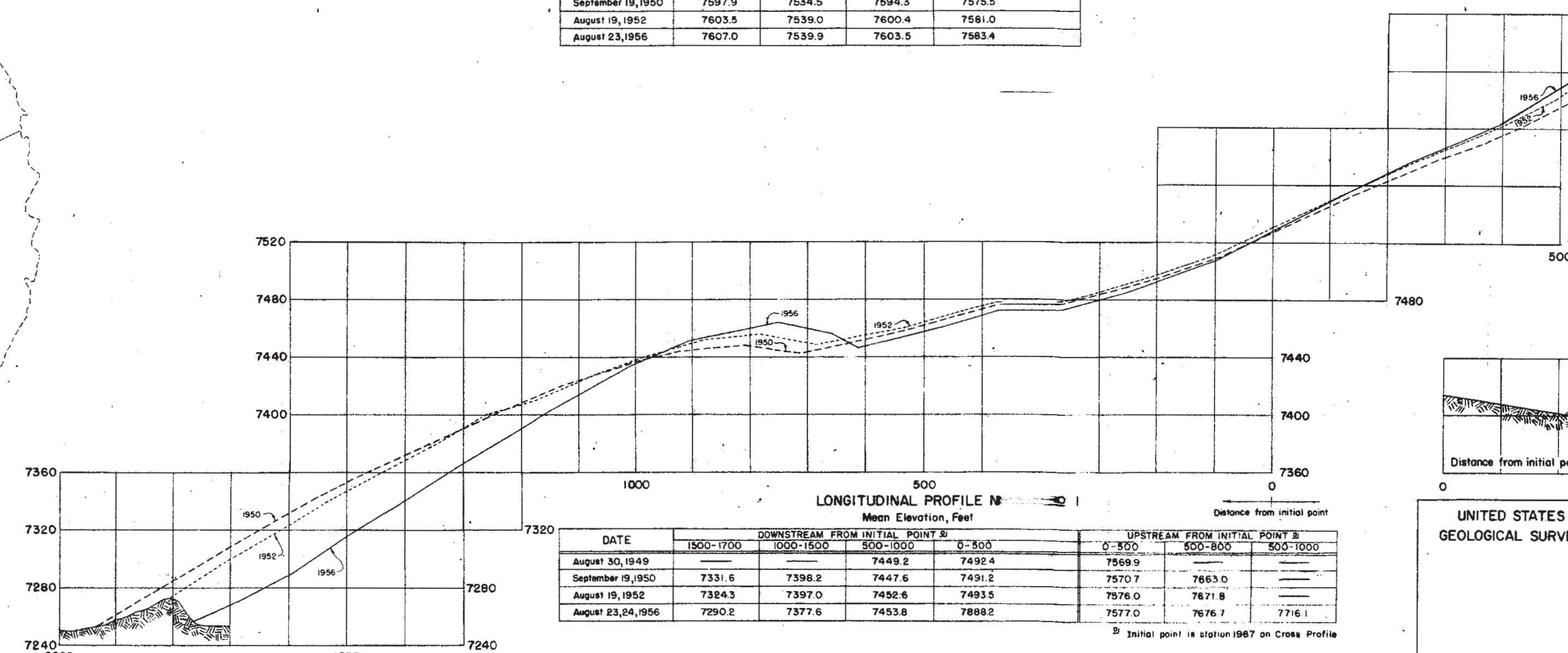




CROSS PROFILE

Mean Elevation, Feet

DATE	STATION			
	100-1100	1100-2100	2100-3100	100-3100
August 30, 1949	7598.9	7535.1	7593.6	7575.9
September 19, 1950	7597.9	7534.5	7594.3	7575.5
August 19, 1952	7603.5	7539.0	7600.4	7581.0
August 23, 1956	7607.0	7539.9	7603.5	7583.4



LONGITUDINAL PROFILE No 1

Mean Elevation, Feet

DATE	DOWNSTREAM FROM INITIAL POINT [a]				UPSTREAM FROM INITIAL POINT [a]		
	1500-1700	1000-1500	500-1000	0-500	0-500	500-800	500-1000
August 30, 1949	——	——	7449.2	7492.4	7569.9	——	——
September 19, 1950	7331.6	7398.2	7447.6	7491.2	7570.7	7663.0	——
August 19, 1952	7324.3	7397.0	7452.6	7493.5	7576.0	7671.8	——
August 23, 24, 1956	7290.2	7377.6	7453.8	7888.2	7577.0	7676.7	7716.1

[a] Initial point is station 1967 on Cross Profile

UNITED STATES
GEOLOGICAL SURVEY

GRINNELL GLACIER
Profile No. 1

September 14, 1950		August 22, 1952		September 4, 1953	
Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)
0	6425.0	0	6425.0	0	6425.0
47	6416.8	67	6416.7	38	6418.2
122	6428.6	165	6438.8	74	6419.2
194	6444.0	265	6462.7	141	6430.0
251	6457.8	336	6472.6	201	6445.1
295	6467.4	439	6485.4	281	6461.5
368	6477.6	500	6490.8	423	6479.7
456	6487.7	648	6501.9	476	6485.2
551	6495.0	751	6511.3	561	6490.9
616	6500.5	872	6519.5	660	6498.9
685	6506.3	977	6525.0	761	6507.4
740	6510.5	1102	6529.7	864	6515.1
848	6518.5	1194	6530.9	959	6519.3
958	6524.1	1307	6530.0	1019	6522.1
1013	6525.5	1357	6529.3	1150	6525.3
		1412	6529.5	1243	6525.1
		1537	6529.5	1348	6523.5
		1692	6523.0	1432	6522.2
		1802	6522.1	1552	6519.3
		1882	6515.7	1674	6517.8
				1787	6514.1
				1878	6508.6
				1912	6504.1

a/ Initial point is reference point, elevation 6425. See Fig. 1.

GRINNELL GLACIER
Profile No. 1

September 27, 1954		September 8, 1955		August 30, 1956	
Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)
0	6425.0	0	6425.0	0	6425.0
37	6419.8	73	6416.8	70	6417.6
64	6420.3	140	6431.9	105	6425.2
141	6429.8	212	6449.7	165	6439.9
201	6444.8	280	6463.8	249	6458.2
266	6460.4	339	6472.0	316	6469.6
433	6482.7	403	6479.3	387	6477.4
511	6488.9	553	6490.9	446	6483.7
651	6498.2	662	6499.4	561	6490.8
773	6504.4	761	6506.6	650	6498.2
926	6518.3	865	6513.5	750	6505.5
1080	6524.1	940	6518.1	844	6511.4
		1050	6522.4	959	6517.4
		1183	6524.8	1028	6520.2
		1283	6524.6	1153	6523.5
		1380	6524.4	1273	6524.2
		1480	6523.9	1413	6523.4
		1595	6522.8	1543	6522.0
		1680	6521.6	1648	6520.5
		1780*	6521.6	1753	6518.6
				1878	6510.5
				2023	6498.0
				2113	6508.4
				2188	6526.4

* Estimated.
a/ Initial point is reference point, elevation 6425. See Fig. 1.

GRINNELL GLACIER
Profile No. 2

September 14, 1950		August 22, 1952		September 4, 1953	
Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)
0	6425.0	0	6425.0	0	6425.0
70	6417.4	90	6416.5	63	6418.4
185	6434.7	176	6434.1	96	6419.8
277	6455.7	289	6459.3	144	6425.3
359	6473.6	363	6475.0	255	6450.4
422	6485.4	454	6491.0	346	6470.0
490	6496.8	553	6503.9	472	6490.5
558	6506.2	685	6517.6	556	6501.2
622	6512.1	784	6526.5	671	6513.2
727	6521.9	882	6533.5	800	6525.2
811	6529.5	910	6535.7	948	6536.7
920	6537.8	972	6541.6	1046	6545.9
1014	6546.2	1081	6550.6	1142	6553.7
1133	6555.8	1180	6559.5	1251	6562.8
1242	6565.0	1280	6567.5	1360	6570.6
1357	6573.0	1347	6570.2		
1481	6581.6	1379	6572.9		
1644	6595.2	1457	6578.6		
1783	6610.6	1571	6596.5		
		1690	6597.9		
		1784	6607.7		
		1923	6619.2		
		2022	6629.3		
		2120	6641.3		
		2199	6652.4		

a/ Initial point is reference point, elevation 6425. See Fig. 1.

GRINNELL GLACIER
Profile No. 2

September 27, 1954		September 6, 1955		August 30, 1956	
Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)	Distance from initial point a/ (feet)	Elevation (feet)
0	6425.0	0	6425.0	0	6425.0
60	6419.6	86	6415.6	84	6415.8
67	6420.0	154	6428.7	147	6429.3
187	6433.4	214	6443.3	223	6446.9
264	6451.1	291	6460.8	295	6464.0
362	6474.9	357	6475.7	378	6478.9
515	6499.7	441	6488.2	431	6487.4
632	6512.0	544	6501.8	569	6505.2
751	6522.9	643	6513.1	656	6513.4
884	6534.0	784	6525.4	802	6527.6
985	6542.1	921	6536.1	901	6534.8
1102	6552.9	1109	6553.2	1005	6544.2
1218	6562.6	1293	6567.7	1120	6554.6
1318	6570.2	1566	6587.8	1248	6564.4
1447	6579.1			1350	6571.1
1565	6588.8			1432	6577.0
				1532	6585.6
				1651	6596.6
				1770	6605.6
				1874	6614.8
				1958	6622.7
				2121	6641.9
				2273	6662.0
				2377	6676.3
				2465	6690.8
				2548	6705.5
				2629	6724.9
				2772	6763.2

a/ Initial point is reference point, elevation 6425. See Fig. 1.

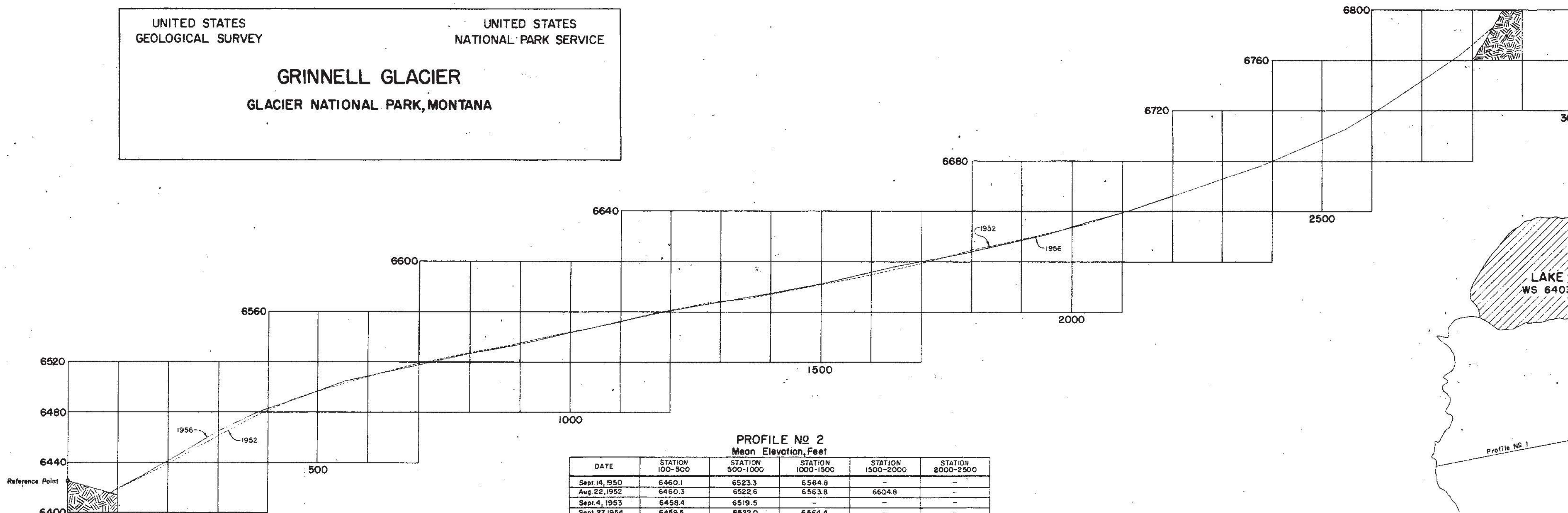
15398

UNITED STATES
GEOLOGICAL SURVEY

UNITED STATES
NATIONAL PARK SERVICE

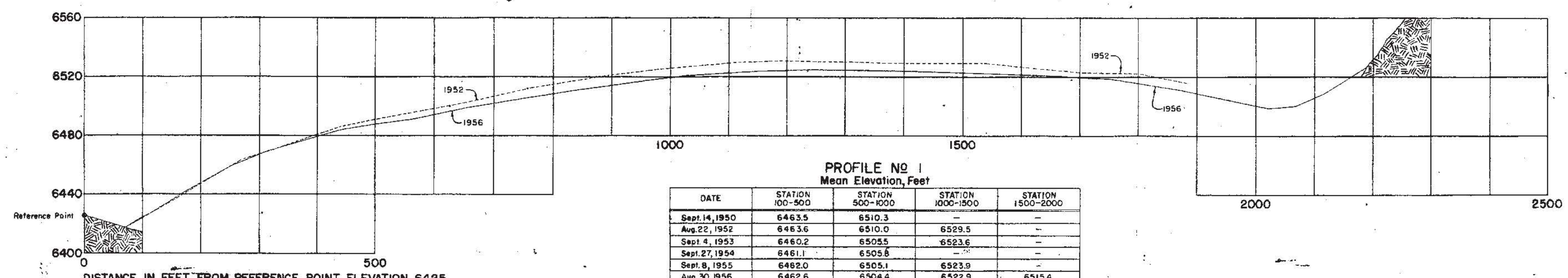
GRINNELL GLACIER

GLACIER NATIONAL PARK, MONTANA



PROFILE No 2
Mean Elevation, Feet

DATE	STATION 100-500	STATION 500-1000	STATION 1000-1500	STATION 1500-2000	STATION 2000-2500
Sept. 14, 1950	6460.1	6523.3	6564.8	–	–
Aug. 22, 1952	6460.3	6522.6	6563.8	6604.8	–
Sept. 4, 1953	6458.4	6519.5	–	–	–
Sept. 27, 1954	6459.5	6522.0	6564.4	–	–
Sept. 6, 1955	6460.6	6521.8	6563.9	–	–
Aug. 30, 1956	6461.7	6521.6	6563.8	6604.6	6659.9



PROFILE No 1
Mean Elevation, Feet

DATE	STATION 100-500	STATION 500-1000	STATION 1000-1500	STATION 1500-2000
Sept. 14, 1950	6463.5	6510.3	–	–
Aug. 22, 1952	6463.6	6510.0	6529.5	–
Sept. 4, 1953	6460.2	6505.5	6523.6	–
Sept. 27, 1954	6461.1	6505.8	–	–
Sept. 8, 1955	6462.0	6505.1	6523.9	–
Aug. 30, 1956	6462.6	6504.4	6522.9	6515.4