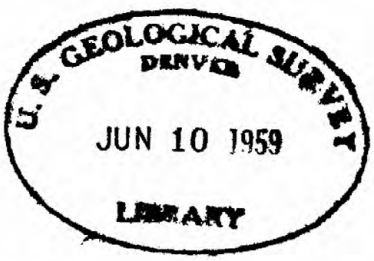
U. S. GEOLOGICAL SURVEY .
AND
U. S. NATIONAL PARK SERVICE
GLACIER OBSERVATIONS
GLACIER NATIONAL PARK
1957 AND 1958



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GEOLOGICAL SURVEY

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GRINNELL AND SPERRY GLACIERS MEASURED IN RECENT SURVEYS

A report on the results of surveys made by the Geological Survey on Grinnell and Sperry Glaciers in Glacier National Park, Montana, during 1957 and 1958, has been released to open file today according to the Department of the Interior.

Grinnell Glacier, 17 miles south of the International Boundary, is on the east slope of the Continental Divide in Hudson Bay drainage. Sperry Glacier, 25 miles south of the International Boundary, is on the west slope of the Continental Divide in the Pacific Ocean drainage.

Surveys on these two glaciers to determine annual changes have been made each year since 1949. Changes in the past two years have been more pronounced than during any previous year in which measurements have been made.

The surface elevation of Grinnell Glacier lowered 10 to 15 feet during the two-year period 1956 to 1958, whereas from 1950 to 1956 the net lowering in surface elevation was 1 to 2 feet. The setting of Grinnell Glacier is such that even though there was a pronounced lowering of surface elevation the borders and front of the glacier did not change appreciably.

The surface elevation of Sperry Glacier in its central portion lowered from 9 to 13 feet from 1956 to 1958, whereas the change from 1949 to 1956 was a net increase of from 5 to 10 feet. The entire 4,000-foot front of the glacier showed a marked recession during the two-year period.

The report contains diagrams showing the changes in surface elevation along selected profile lines together with tabular data.

Copies of "Glacier Observations, Glacier National Park, Montana," by Arthur Johnson, are available for consultation at the following Geological Survey offices: 1033 General Services Administration Bldg., Washington, D. C.; 468 Customhouse, Denver, Colorado; 724 Appraisers Bldg., San Francisco; 244 Federal Bldg., Tacoma, Washington;;and 408 Federal Bldg., Helena, Montana. Copies are also available at the following offices of the National Park Service: 307 Federal Offices Bldg., Omaha 2, Nebraska; and Glacier National Park, West Glacier, Montana.

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INTRODUCTION

This report describes and summarizes the results of the glacier investigations in Glacier National Park during the 1957 and 1958 field seasons. This report covers a two-year period as no report was issued following the 1957 season. Surveys and observations were made on the Grinnell Glacier in August and September in both years; on the Sperry Glacier in September 1957 and August 1958. The field work was carried on by personnel of the Geological Survey and the National Park Service. This report has been prepared by Arthur Johnson of the Geological Survey.

The 1957 surveys on the Grinnell Glacier, both in August and September, were made by Gordon C. Giles, engineer, with Kim McDonald and David Tillson, field assistants, all of the Geological Survey. Homer Black, park naturalist accompanied the party in September and obtained the usual series of pictures taken annually for purpose of record. Frank Stermitz, district engineer, Water Resources Division, Helena office, also accompanied the party in September to investigate the possibility of installing a gaging station in the immediate vicinity of the glacier. The 1957 surveys on the Sperry Glacier were made by Arthur Johnson, Gordon Giles, and David Tillson. Homer Black accompanied the party and obtained the usual series of annual pictures.

The surveys in August 1958 on both the Grinnell and Sperry Glaciers were made by Arthur Johnson with David Tillson and Jack Snavely as field assistants. Francis Elmore, chief park naturalist, and Homer Black, park naturalist, accompanied the party on the August trip to the Grinnell Glacier and took pictures from a number of points to duplicate pictures taken in previous years, particularly pictures in 1911. Mr. Elmore was with the party on the Sperry Glacier, and as on the Grinnell, took a number of pictures to duplicate those taken in former years as well as those taken annually for record purposes. Mr. Stermitz was on the August trip to the Grinnell Glacier and made further studies of a prospective gaging station location and made several streamflow measurements at this point.

The September 1958 surveys on the Grinnell Glacier were made by Arthur Johnson and J. B. Dugwyler, Jr., of the Geological Survey, and Homer Black of the Park Service. W. A. Blenkarn of the Helena office of the Geological Survey accompanied the party and made a measurement at the proposed gaging station site.

John Good, geologist on the Washington office staff of the National Park Service, accompanied the party during the August surveys on the Grinnell and Sperry Glaciers. The purpose in so doing was to become more familiar with the glacier investigations that have been made in Glacier National Park as well as consider what plans should be followed in the future.

Saddle horses and pack horses for travel and transportation of equipment to and from the glaciers were furnished by the Park Service each year.

GRINNELL GLACIER

Surface changes

The two previously established profiles, designated as profile no. 1 and profile no. 2, were remeasured on August 13 and September 10, 1957, and on August 12 and September 14-15, 1958. The two sets of measurements each year, approximately one month apart, were made to obtain quantative data on the amount of ablation occurring during the latter part of the summer season.

A third profile, designated as profile no. 3, was established and first measured on September 11, 1957. The location of this profile, as shown on figure 1, is 1,400 feet southwest of and approximately parallel to profile no. 2. It was remeasured on August 13, 1958. A remeasurement of this profile was also planned for September 1958 but could not be made due to adverse weather conditions.

The results obtained from the measurement of the three profiles gives a fairly good indication of what changes are taking place in the surface elevation of the entire glacier. These results are shown graphically and in tabular form on figures 1 and 1-A and are commented on in the following paragraphs.

As a means of comparison each of these profiles was divided into segments. For profiles no. 1 and 2 the first segment in each case included the section between 100 feet and 500 feet from the initial point which is a bench mark tablet set in the ledge rock near the edge of the glacier. The succeeding segments in each case were 500 feet long. Profile no. 3 was divided into two 700-foot segments, 300 to 1000, and 1000 to 1700 feet from the reference point. In the following discussion the reference to the segments is based on the distance from the initial point.

Profile no. 1

For profile no. 1 the mean elevation of the 4 segments on September 10, 1957, varied from 3.7 feet to 7.1 feet lower than on August 30, 1956. In the first 3 segments, 100 to 1500 feet from the initial point, this decrease averaged slightly over 4 feet. The fourth segment, 1500 to 2000 feet, showed a decrease of 7.1 feet. This segment includes a depression in the profile which is due to the erosive and melting action of a stream falling on the glacier in this area.

In the 4-week period from August 13 to September 10, 1957, the lowering of the surface elevation varied from 3.3 to 5.3 feet. In this instance, the lowering in the sections between 100 and 1500 feet averaged 3.5 feet and lowering between 1500 and 2000 was again the most pronounced, 5.3 feet. A comparison of the August 30, 1956,

and September 10, 1957, profiles shows that the changes in surface elevation during the year were quite uniform along both profiles. Although not shown graphically on figure 1, the changes during the month interval in 1957 were also quite uniform.

For the period September 10, 1957, to September 14, 1958, the mean elevation of the four segments decreased in amounts varying from 8.9 feet to 10.7 feet. Over half of this change occurred during the 5-week (33 day) period, August 12 to September 14, 1958.

From 1900 to about 2100 the September 1958 profile is shown as a dotted line on figure 1 and indicated as approximate. It was estimated from the observed points on either side and the shape of the August profile. No rod points were observed in this section as, due to the configuration of the glacier, this section was out of view from the instrument set up. Time, and very unfavorable weather conditions, prevented making an additional setup that would have permitted observations in this section.

Profile no. 2

For profile no. 2, the mean elevations of the 5 segments on September 10, 1957, varied from 3.2 to 5.1 feet less than on August 30, 1956. The segment nearest the edge, 100 to 500 feet from initial point, had the greatest change, 5.1 feet. The next three segments showed an average decrease of about $3\frac{1}{2}$ feet and the final segment, 2000 to 2500 feet from initial point, showed a

decrease of 5 feet. Considering the month interval from August 13 to September 10, changes varied from 2 to 3.6 feet. Here again, the greatest change, 3.6 feet, was in the 100-500 foot segment. The difference became progressively less in proceeding toward the cirque wall with the exception of the final segment where a slight increase in the change was noted.

For the period September 10, 1957, to September 15, 1958, the mean elevation of the five segments decreased in amounts varying from 8.1 to 12.2 feet. As in the case of profile no. 1 over half of this change occurred in the 5-week (34 day) period, August 12 to September 15, 1958.

On figure 1 only the profiles for the September observations in 1957 and 1958 have been drawn. These indicate a fairly uniform difference from year to year as well as for the two-year period. Although not drawn, the August profiles in each year were roughly "parallel" to the preceding and succeeding profiles.

The measurements on profiles no. 1 and no. 2 in August and September for both 1957 and 1958 indicate a rapid change in the surface elevation at this time of year. This change is so pronounced that annual comparisons, to be realistic, should refer to the conditions at some specific date each year. The 1956 observations were made on August 30. In order to compare 1957 and 1958 with 1956 estimated values for August 30 were determined for 1957 and 1958. These values are based on the assumption that

the change between the August and September observations in each year were at a uniform rate. Although this may not be entirely true, the results so obtained should be reasonably accurate. The following tables show the observed values for August 30, 1956, and the interpolated values for the same date in 1957 and 1958 along with annual differences and differences for the two-year period.

As shown by the table the net change from 1957 to 1958 was more than double the net change from 1956 to 1957 for both profiles. Considering the two-year period 1956 to 1958 the total ablation varied from 10.6 to 15.3 feet for profile no. 1 and 9.2 to 14.0 feet for profile no. 2.

Profile no. 1

Mean elevation, feet

Date	Distance from reference point, feet			
	100-500	500-1000	1000-1500	1500-2000
Aug. 30, 1956	6462.6	6504.4	6522.9	6515.4
Aug. 30, 1957 a/	6459.5	6502.0	6519.8	6510.4
Aug. 30, 1958 b/	6451.7	6493.8	6510.3	6500.1
Change:				
Aug. 30, 1956 - Aug. 30, 1957	-3.1	-2.4	-3.1	-5.0
Aug. 30, 1957 - Aug. 30, 1958	-7.8	-8.2	-9.5	-10.3
Total change, 2-yr. period Aug. 30, 1956 to Aug. 30, 1958	-10.9	-10.6	-12.6	-15.3

a/ Interpolated values based on observations on Aug. 13 and Sept. 10.
b/ Interpolated values based on observations on Aug. 12 and Sept. 14.

Profile no. 2

Mean elevation, feet

Date	Distance from reference point, feet				
	100-500	500-1000	1000-1500	1500-2000	2000-2500
Aug. 30, 1956	6461.7	6521.6	6563.8	6604.6	6659.9
Aug. 30, 1957 a/	6458.0	6519.2	6561.6	6601.7	6655.8
Aug. 30, 1958 b/	6449.3	6512.4	6554.2	6593.6	6645.9
Change:					
Aug. 30, 1956- Aug. 30, 1957	-3.7	-2.4	-2.2	-2.9	-4.1
Aug. 30, 1957- Aug. 30, 1958	-8.7	-6.8	-7.4	-8.1	-9.9
Total for 2-yr. period Aug. 30, 1956 - Aug. 30, 1958	-12.4	-9.2	-9.6	-11.0	-14.0

a/ Interpolated values based on observations on Aug. 13 and Sept. 10.
b/ Interpolated values based on observations on Aug. 12 and Sept. 15.

Profile no. 3

Profile no. 3 was remeasured for the first time on August 13, 1958. The results of this, compared with 1957, are shown graphically and in tabular form on figure 1-A. For comparative purposes this profile was divided into two 700-foot segments, 300 to 1000 and 1000 to 1700 feet from initial point. The mean elevation of these two segments decreased 2.9 and 3.9 feet respectively during the 11-month period, September 10, 1957 - August 13, 1958. This change was not as pronounced as along profile no. 2 during the same period. Unfortunately, it was not possible to remeasure profile no. 3 along with profiles no. 1 and no. 2 in mid-September due to adverse weather conditions. It would seem logical to assume that had such a measurement been made the change since mid-August would have been in the same order of magnitude as the change observed for profile no. 2 during the same period.

The annual measurement of the three profiles on the Grinnell Glacier in future years should give a good record of whatever changes are taking place in the surface elevation of the entire glacier.

Movement

Movement of the glacier for the 1956-57 period was determined by the relocation of 7 rocks marked and located in previous years. In 1958 two of these rocks were not found and

a third one was no longer on the glacier, due to a combination of recession of the glacier front along with possible sliding of the rock. In other words, only 4 of the 7 rocks located in 1957 were usable in determining movement for the 1957-58 period. In 1958, however, 4 points that had been marked (3 in 1957, 1 in 1956) in connection with the measurement of profiles no. 1 and no. 2 were relocated. The results of the 1957 and 1958 determinations, along with the total movement and average annual rate during the periods of observation for the several marked rocks, are shown in the table on page 10. As seen from this table the average annual rate of movement is in the order of magnitude of 35 to 40 feet per year. The higher results for rock 52-2 is inconsistent with the other values. Part of this observed movement may be due to sliding, a very likely possibility considering the shape of this rock and its location near the edge of the glacier. The position of the rocks in the various years is shown on figure 1. The direction and the annual rate of movement that has been observed is fairly consistent.

In order to have replacements for those rocks that are now nearing the edge of the glacier and give information on movement through a larger area of this glacier it would be advisable to include in the 1959 program the marking and location of about ten well selected rocks through the area about 1000 to 1500 feet from the present front or edge of the glacier.

GRINNELL GLACIER
Movement of marked rocks or points

Rock or point	Movement in feet, year or period						Average annual movement during period observed
	Year	Movement	Year	Movement	Period	Movement	
47-1 a/	1956-57	30	-	-	1947-57	370	37
47-2 b/	1956-57	35	-	-	1950-57	240	34
47-2 A	-	-	-	-	1947-53	210	35
50-1	1956-57	45	1957-58	30	1950-58	290	36
50-2	1956-57	40	1957-58	25	1950-58	270	34
52-1	1956-57	55	1957-58	35	1952-58	270	45
52-2 c/	1956-57	75	1957-58	40	1952-57	280	56
52-3	1956-57	50	1957-58	30	1952-58	250	42
Marked point along profile no. 1, 1040 feet from reference point	-	-	1957-58	35	-	-	35
Marked point along profile no. 1, 1030 feet from reference point	-	-	-	-	1956-58	70	35
Marked point along profile no. 2, 690 feet from reference point	-	-	1957-58	25	-	-	25
Marked point along profile no. 2, 1430 feet from reference point	-	-	1957-58	30	-	-	30

a/ Not found in 1958. Probably fallen into crevasse.
b/ 1958 front of glacier at about 1957 position of this rock. Not found in 1958.
c/ This rock near edge of glacier in 1957 and beyond edge of glacier in 1958.

Recession

The edge, or front, of the glacier formed by the shore of the lake (figure 1) was accurately located. The front or edge extending about 2500 feet southeast from the lake was delineated but this was based on comparatively few points. In this 2500-foot section the change since 1950 varies from practically no change to a maximum of about 150 feet. The variations in the edge of this portion of the glacier is influenced to a large extent by the irregularities in the bedrock topography and these changes are not too closely related to the changes in the glacier as a whole. The change in the lake shore since 1950 varied from 100 to 200 feet with a small section approaching 300 feet. Along with the advancing lake shore, or receding glacier front, there has been a noticeable change in the character of the shore line. Formerly, most of the lake shore was in the form of an "ice cliff" several feet in height. In 1958 most of the shore line was formed by the ice sloping to the water's edge instead of ending abruptly in a "cliff."

The above lake showed an interesting change during the latter part of August 1957. Within less than a week (exact period not known - may have been within a day or two) the elevation of this lake dropped over 8 feet. After this lake lowered about one foot there could be no more outflow through the usual outlet. With this lowering of the lake the entire runoff from the glacier was

into the drainage course or channel located about 2,000 feet southeast from the former lake outlet (see figure 1). Previously there was only a small stream flowing in this channel, the major portion of the glacier drainage being through the lake. On September 10, 1957, the original lake level was clearly discernable so an accurate determination of the change in elevation was readily obtainable. This was found to be 8.3 feet.

In 1958 the lake was still at the elevation following the lowering in 1957 and the entire runoff from the glacier was into the channel above mentioned.

The exact cause for the change in lake elevation can only be surmised. The following explanation may be applicable. As pointed out in a previous section the 1957 profile measurements indicated a pronounced lowering in the glacier surface since 1956, being lower than recorded by any of the previous measurements. The thinning of the ice sheet and the change in the edge or front bordering the lake resulted in the opening up of a channel, or channels, underneath the glacier from the lake to the drainage course southeast therefrom. Evidently some combination of the strike and dip of the bedrock made such a channel possible. Inasmuch as the drop in lake surface was concurrent with the pronounced thinning of the ice sheet and the increasing area of the lake it seems reasonable to assume that the present condition will remain until there is a change in the recent trend and the glacier surface

builds up again to where it was prior to 1957 along with the glacier advancing into the lake. The condition and behaviour of this lake should be carefully observed into future years.

Precipitation and runoff

The two storage-precipitation gages--established and maintained by the Weather Bureau and the Park Service, one near the end of the horse trail installed in 1949 (see figure 1) and the other about one-half mile southeast therefrom, were contined in operation. The results of the annual observations at these stations, along with the runoff at the gaging station at the outlet of Grinnell Lake is shown in the table on page 14. This data is presented here only as a matter of record. A discussion of the precipitation-runoff data along with other climatic data in relation to the observed changes in the glacier is being prepared for a comprehensive report on the studies of the glaciers in Glacier National Park that is being prepared for formal publication.

The gaging station at the outlet of Grinnell Lake, established in 1949 by the Helena office of the Water Resources Division has been in continuous operation since then.

Mr. Frank Stermitz, district engineer, Water Resources Division, Helena office, accompanied the party in September 1957. He made a reconnaissance of the stream draining from the glacier and found a site satisfactory for a gaging station within about a 1000 feet of the glacier. Such a station would give a record of

GRINNELL GLACIER, MONTANA
PRECIPITATION - RUNOFF COMPARISONS

Date	Number of days	Precipitation (inches) a/	Runoff (inches) b/	Precipitation (inches) c/
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 21, 1950 - July 24, 1951	369	117.5	109.8	-
July 25, 1951 - Sept. 12, 1951	50	8.7	20.6	-
Sept. 13, 1951 - July 15, 1952	307	99.6	69.8	-
July 25, 1951 - July 15, 1952	357	108.3	90.4	-
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. 1, 1953 - Aug. 5, 1954	370	138.2	107.3	-
Aug. 6, 1954 - Sept. 27, 1954	53	19.0	23.0	-
Sept. 28, 1954 - Aug. 10, 1955	317	90.2	82.2	-
Aug. 6, 1954 - Aug. 10, 1955	370	108.2	105.2	-
Aug. 11, 1955 - Aug. 7, 1956	363	100.7	98.5	152.8 d/
Aug. 8, 1956 - July 16, 1957	342	88.7	81.4	137.2
July 17, 1957 - July 17, 1958	365	78.9	94.0	115.8

a/ Measured at storage precipitation gage near end of horse trail 0.4 mile from glacier.
b/ Measured at gaging station at outlet of Grinnell Lake.
c/ Measured at storage precipitation gage about ½ mile southeast of gage described in footnote a/.
d/ August 15, 1955 to August 7, 1956.

the runoff actually originating from the glacier. Consideration was given to the construction of a station at this site during the 1957 season. It seemed advisable, however, to forego such an installation until it could be determined if the entire flow from the glacier would continue in this channel or if the lake at the north end of the glacier would return to its former level in which case the drainage from the glacier would be in two channels. Mr. Stermitz again accompanied the party in August 1958 and studied the site further and made 3 discharge measurements at it. Mr. Blenkarn, also of the Helena office, made a measurement at this site on September 14. The results of these measurements along with the mean discharge for the day at the gaging station at the outlet of Grinnell Lake are shown below as a matter of record.

Date and time	Measurement No.	Discharge measured about 1000 feet downstream from glacier (c.f.s.)	Mean discharge this date at gaging station at outlet of Grinnell Lake (c.f.s.)
Aug. 11, 2:25-3:00 p. m.	1	47.8	40
Aug. 12, 10:50-11:30 a. m.	2	38.5	43
Aug. 12, 2:25-3:05 p. m.	3	45.8	43
Aug. 12, 3:45 p. m.	-	50 a/	43
Sept. 14, 2:35-3:05 p. m.	4	27.7	47

a/ Estimated discharge based on stage.

The further study of the proposed gaging station site in 1958, along with the measurements made there, verify its suitability. Based on the 1958 observations it seems very probable that the outflow from the glacier will continue in the present channel for several years at least. A return to the condition of the main part of the flow from the glacier draining out through the lake will probably not occur unless there is a pronounced thickening of the ice sheet and an advance of the ice front into the lake. Even if this thickening and advance should occur it is questionable if the lake would return to its former level. The channel, or channels, underneath the glacier connecting the lake with the present outlet channel being once established might conceivably remain operative even though the ice thickens and advances. In any event it seems entirely probable that a gaging station at the proposed site would record the entire flow from the glacier for several years at least. Such a record, even if only for a period of 2 or 3 years, would be extremely valuable as it could be correlated with the record at the Grinnell Lake outlet and thereby determine the proportionate amount of the runoff coming directly from the glacier. Steps should therefore be taken to establish a gaging station at the proposed site as early as possible in the 1959 season.

The monthly and annual discharge at the gaging station on Grinnell Creek below the outlet of Grinnell Lake is included on page 18 as a matter of record.

GRINNELL CREEK NEAR MANY GLACIER, MONTANA

Summary of monthly and annual discharge in c.f.s.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Mean	Inches Runoff
1949											28.2	29.8	-	-
1950	11.2	12.7	4.24	1.00	1.00	1.40	6.27	30.8	97.7	87.6	44.7	20.3	26.7	106.54
1951	31.6	12.9	8.40	2.09	2.04	1.24	13.5	47.9	58.8	71.7	35.2	27.8	26.3	104.98
1952	26.9	4.23	2.64	0.73	0.79	0.78	18.9	49.4	62.1	48.9	35.4	16.8	22.4	89.59
1953	5.66	0.96	0.87	7.44	4.91	2.52	8.19	38.3	88.5	78.2	41.8	19.4	24.8	97.16
1954	6.00	7.15	5.04	2.60	2.52	2.43	7.94	50.3	79.7	93.2	50.3	30.5	28.3	110.74
1955	17.9	11.1	4.17	2.49	0.75	0.84	4.17	21.4	93.3	76.6	37.7	17.4	24.1	94.27
1956	30.2	8.61	4.91	2.26	0.63	1.27	9.12	53.0	82.4	60.8	38.9	19.9	26.1	102.37
1957	15.3	4.01	26.2	1.72	0.76	2.36	6.40	71.5	69.0	44.3	30.3	16.4	22.2	86.87
1958	9.38	4.34	1.74	1.23	2.29	1.98	5.36	73.8	65.8	44.3	37.0	24.7	22.8	89.19

Mapping

During the 1956 season terrestrial photographs were obtained with a phototheodolite and the necessary control established for the compilation of a map of the glacier. The resulting map when compared with the measured profiles showed close agreement along profile no. 2. The agreement was not as close along profile no. 1, particularly in the section near the cirque wall but conditions for reliable contouring in this area were not satisfactory. The results of this mapping project indicated that with some changes in approach to the problem reliable maps can be made from terrestrial photographs. Where periodic resurveys are desired for comparative purposes this provides a very desirable method, as pictures can be taken from exactly the same points and in the same direction for each successive mapping. The necessary pictures can be obtained with a comparatively small amount of field effort. As an example, the pictures required for mapping the Grinnell Glacier could be obtained by a 3-man party in 1 or 2 days.

SPERRY GLACIER

Surface changes

The cross profile and longitudinal profile no. 1 were remeasured on September 14, 15, 1957 and on August 16-17, 1958. Longitudinal profile no. 2 was remeasured on August 18, 1958. An additional profile designated as profile no. 3, was selected and

measured on August 18, 1958. The locations of these profiles are shown on figure 2. The changes observed along these profiles are described in the following paragraphs.

Cross profile

The results of the 1957 measurements, along with the results of previous measurements, are shown graphically and in tabular form on figure 2. The 1957 and 1958 profiles, along with the 1956 profiles are shown on a supplementary drawing, figure 2-A for sake of clarity. The tabular data for 1958 is included on figure 2.

The glacier surface in 1957 was below that in 1956 along the entire length of the cross profile in amounts varying from 3 to 8 feet with the exception of a small section near the right or east edge where the difference was as much as 15 feet. For comparative purposes this profile has been divided into three 1000-foot segments and the mean elevation determined for each, as well as for the total distance covered by these segments for the years of observation. As shown by the table on figure 2, the mean elevations of the 1000-foot segments from west to east were 5.4, 5.7, and 8.1 feet lower in 1957 than in 1956. The change, considering the mean for the entire 3000 feet was 6.3 feet. In comparing the results for 1957 with 1956, it must be kept in mind that the 1957 measurements were made 3 weeks later than those in 1956. If the differences observed between the mid-August and mid-September measurements on the Grinnell Glacier in

1957 and 1958 are representative of changes occurring on the Sperry Glacier, the difference between the 1956 and 1957 measurements, if made on corresponding dates, would have been 2 to 3 feet less than above indicated.

It is of interest to compare the 1957 and 1950 data as the measurements were made on essentially corresponding dates, September 14, 1957, and September 19, 1950. As shown by the table on figure 2, the mean elevation for the three 1000-foot sections was 1.6 feet higher in 1957 than in 1950. The difference in the segments from west to east were +5.7, -0.3, and +1.1 feet. There was, however, considerable variation along the profile, as indicated by the following summary.

Distance from initial point, feet	Remarks
100-250	Essentially the same.
250-750	1957 Surface above that of 1950 by as much as 14 feet.
750-950	Within 2 or 3 feet of being the same with the 1957 surface higher than in 1950.
950-1500	1957 Surface above that of 1950 by as much as 5 to 6 feet.
1500-2600	1957 Surface below that of 1950 from 4 to 5 feet through most of the section.
2600-3100	1957 Profile crosses 1950 profile at about the 2600-foot point and is above that of 1950 for the next 500 feet by as much as 6 to 7 feet.

The lowest point of the profile is about 1800 feet from the initial point on the left bank. In a 1000-foot section extending from 1600 to 2600 feet from the initial point the 1957 profile was below any previously measured. The variations noted between the 1950 and 1957 profiles are probably due in large measure to differences in snow accumulation on the glacier resulting from wind currents and drifting after the snow has fallen.

The 1958 surface was below the 1957 surface along the entire cross profile. As shown by figure 2-A, this difference was fairly uniform, varying from a minimum of 4 feet to a maximum of 8 feet. Referring to the tabular data the differences for the 1000-foot segments, from west to east, were -4.9, -5.4, and -4.8 feet. The overall mean for the 3000-foot section considered was -5.1 feet. The 1958 measurements were 4 weeks earlier than the 1957 measurements. Again referring to the Grinnell Glacier, and assuming a comparable rate of ablation, the difference between the 1957 and 1958 measurements on the Sperry Glacier if made in mid-September would have been 5 to 6 feet greater than those above mentioned. The 1956 measurements were made on August 23 and the 1958 measurements on August 16, within a week of a full two years. The differences in this two-year period for the three segments were -10.3, -11.1, and -12.9 feet or an overall mean of -11.4 feet.

The 1958 surface was lower than any previously measured along the cross profile. The change from 1957 to 1958 was the most pronounced of any annual change observed thus far. Considering corresponding dates the change in this year period would approximate 10 feet.

Longitudinal profile no. 1

Longitudinal profile no. 1 for 1957 is shown on figure 2. It is also shown on a supplementary drawing, figure 2-A, along with the 1958 and 1956 profiles for convenience and clarity. Mean elevations for 500-foot segments of the profile are shown in tabular form on figure 2.

The 1957 surface was below that in 1956 along the entire profile, the most pronounced difference being the lower half of the glacier. In the upper part the differences were small and in places the 1957 and 1956 profiles were almost coincident. The terminus on the profile alignment showed a recession of 70 feet from 1956 to 1957. In the 900 feet from the terminus the 1957 surface was below that for 1956 in amounts varying from 7 to 13 feet. The crest of the ridge paralleling the front of the glacier was essentially in the same location as in 1956 but 8 feet lower in elevation. The low point of the trough or depression along this ridge was 30 feet farther upglacier and 8 feet lower than in 1956. Continuing upglacier from this depression the 1957 surface was below the 1956 surface for the next 1200 to 1300 feet, in

amounts varying from 3 to 10 feet. In the remaining 600 feet of the measured profile for 1957 the surface varied from being almost coincident with 1956 surface to as much as 4 or 5 feet lower. The 1957 profile measurement ended at a large transverse crevasse, estimated as 25 feet in width and about 200 feet from the cirque wall.

The 1958 glacier surface along this profile was below that in 1957 throughout. The configuration in 1958 was essentially the same as in 1957. A maximum difference of as much as 12 feet was noted 200 to 300 feet from the terminus. The crest of the ridge, about 900 feet from the terminus, and the trough or depression on the upglacier side of it were in essentially the same position as in 1956 and 1957. The crest was about 7 feet lower than in 1957 and the trough about 4 feet lower. As shown by the table on figure 2 the differences for the 500-foot segments varied from 4.5 to 9.6 feet, the greater difference being near the terminus.

Longitudinal profile no. 2

This profile, as shown on figure 2, is located near the left edge of the glacier. It was first measured in 1947 and remeasured in 1950, 1956, and 1958. At the time of the 1947 measurement there was a prominent ridge paralleling the front of the glacier. The trough or depression upglacier from this ridge was 40 feet lower than the crest of the ridge. This ridge

decreased in elevation and prominence in successive years and by 1958 was no longer in evidence. At the position of the ridge crest in 1947 the ice surface was 70 feet lower in 1958. The front of the glacier on the profile alignment receded 140 feet in the 11-year period from 1947 to 1958. An area of bare rock just to the right (west) of the profile alignment was exposed in 1958, indicating that the ice sheet in this area is very thin. If the trend of recent years continues this exposed area will undoubtedly rapidly increase in size and the terminus in the 500-foot section from the left edge will show a pronounced recession.

Profile no. 3

As shown on figure 2, this profile originates at the same point as the cross profile and almost at a right angle to it. This location was selected so as to obtain information on changes in what appears to be a fairly active part of the glacier.

Movement

Four rocks which were first marked and located in 1949 were all relocated in 1957. Two of these had been located in 1956. In addition to the 4 marked rocks an unmarked rock which had been located in 1949 was recognized and relocated. The movement of these rocks and the decrease in elevation during the 8-year period 1949-1957 are tabulated below.

Rock No.	Movement, feet	Decrease in elevation feet
49-1	88	22
49-2	100	18
49-3	93	14
49-4	110	15
Unmarked rock	105	19

As originally located rocks 49-1 and 49-4 were approximately 300 feet apart, the latter being farthest upglacier. Rocks 49-2 and 49-3 were 30 feet apart, practically on a line between 49-1 and 49-4 and 80 to 90 feet from 49-4. The group of the 4 marked rocks are located approximately 1800 feet from the west or left edge and 1200 feet from the right or east edge of the glacier. The unmarked rock is about 700 feet from the east or right edge. The rate of movement of the 5 rocks varied from 11 to 14 feet per year during the 8-year period 1949-1957. Even allowing for some observational errors in these figures it is evident that the movement of the Sperry Glacier is at a very slow rate.

The direction of movement was essentially the same for all the 5 rocks observed. This direction is somewhat to the right of a line that would be normal to the front of the glacier. The direction of movement is undoubtedly influenced by the strike of the underlying bedrock.

The 5 rocks above mentioned were relocated in 1958. All showed essentially the same rate and direction of movement as in previous years. The 1958 elevation of these rocks was 7 to 9 feet

lower than in 1957. The 1958 position of these rocks has not been shown on figure 2.

Recession

The entire terminus was delineated in 1958 and is shown on figure 2. The position of the terminus for about 500 feet from the left (west) edge was essentially the same as in 1956. The changes along the rest of the terminus were quite variable. At several points the 1958 position was slightly forward from that in 1956. The maximum variation occurred about 700 feet from the left edge where the 1958 position had receded 600 feet from the 1956 position. There is a prominent rock ridge in this area. The ice covering it would, therefore, be thinner than the ice on either side which would explain the marked change.

While mapping the front it was noted that the large lake nearest the east edge had the typical blue-gray color of glacier water whereas the other two large lakes in front of the glacier were clear.

Mapping

As a part of the 1957 investigational program on the Sperry Glacier terrestrial pictures were taken from two base lines with a phototheodolite for use in compiling a map of the glacier. Based on the experience gained in the compilation of a map of the Grinnell Glacier from terrestrial photographs it was found that the

maximum distance from the base line which would result in a satisfactory compilation should not exceed 15 times its length and the nearest area should be at least 6 times the length away. The corresponding values that had been previously considered were 20 and 4. These revised considerations for length were used in selecting base line locations. As usual, in areas of this kind, the base line locations had to be a compromise between ideal locations and locations that were readily accessible and would serve the purpose. Two base lines were selected, designated as A_1 - B_1 and A_2 - B_2 on figure 2. Base line A_1 -B_1 is located on the terminal moraine approximately 2000 feet from the present front and about opposite the east or right side of the glacier. This terminal moraine is at the north end of a long narrow lake near the east side of the glacial valley. This base line had a length of 533 feet. Two views were taken from the ends of the base line. One 15° to right of normal and one 15° to left of normal. With this deviation from normal the effective length of the base line would be reduced about 3 percent or to a value of about 518 feet. The most distant point on the glacier from this base line was approximately 6500 feet or well within the maximum ratio of 15 times the length. Using the other controlling factor of six times the length of the base line, the nearest part of the glacier that could be effectively compiled would be approximately 3000 feet away from the camera stations. This base line then allows for the compilation of the upper-half of the glacier area.

From this base line 7 supplemental control points were selected at various points on or adjacent to the glacier and their location and elevation determined by triangulation.

In order to cover the lower half of the glacier a base line was selected on the rock ridge paralleling the left or west edge of the glacier and approximately 700 feet therefrom. A 300-foot base line was selected on this ridge. Here again, two views were taken from each end of the base line. One normal to the base line and one 20° to the right of normal. The maximum distance of the area to be compiled from the phtos from this base line was approximately 4600 feet and, therefore, for all practical purposes within the limitation of 15 times the length. Except for a very small area, the maximum distance would be within 4200 feet from the base line. The near part of the glacier was only about 700 feet from the base line. In order to obtain adequate coverage for the area from the left or west edge out to approximately the mid-point of the glacier an intermediate photo point was selected at the mid-point of base line A_2 - B_2. The pictures from this mid-point could then be used with pictures from either end of the base line to obtain the desired results. The short base line would be 150 feet and would therefore allow for coverage to a maximum distance of approximately 2200 feet. The views from this base line look down into the trough or depression which roughly parallels the front of the glacier. Six supplemental

control points were selected and located from base line A_2 - B_2 by triangulation.

The pictures from base line A_2 - B_2 were affected to some extent by having to hurry the operations. These were taken in the early part of the afternoon and weather conditions then indicated an impending storm which did develop that evening. Clouds were floating by and at times it was difficult to avoid cloud shadows over certain parts of the glacier. More time might have allowed a better selection of supplemental control points. For future planning the pictures from base line A_1 - B_1 should, as far as possible, be taken within an hour on either side of noon to avoid shadows from the cliffs falling on the glacier. The pictures from base line A_2 - B_2 should be taken in the early part of the afternoon, preferably before 3 o'clock.

A map is now (December 1958) being compiled from the pictures and related data that were obtained. The experience that will be gained in compiling this map will give additional information on the best procedures and techniques to follow in the application of terrestrial photogrammetry to the mapping of glaciers.

FUTURE WORK

The measurement of profiles, terminal recession and rates of movement should be continued on an annual basis. For another year or two, at least, it would be desirable to continue the practice of making two sets of profile measurements on the Grinnell

Glacier about one month apart, one in early August and one in early September. It would also be desirable to obtain two sets of profile measurements on the Sperry Glacier to determine if the rate of ablation during the latter part of the summer is comparable to that observed on the Grinnell Glacier.

The 1957 and 1958 observations on the Grinnell Glacier emphasize the importance of making the measurements, particularly the September measurements, on as near the same date as possible each year to obtain a reliable annual comparison. In selecting a date for the September measurements two factors must be kept in mind. The ideal situation would be to make the September measurements toward the latter part of the month, near the end of the ablation period and just before the autumn snows may start to accumulate. From a practical standpoint this cannot be readily achieved. In order to take advantage of the facilities for meals and lodging at the Swiftcurrent camp ground the work must be done before September 15. Based on past experience there is frequently a period of stormy weather with some snow around mid-September. The late measurements should, therefore, be planned for around September 10, or even a few days earlier, so if a period of adverse weather is encountered it would still give an opportunity to complete the work by September 15.

The Grinnell Glacier, in view of its accessibility, could serve as a laboratory for various studies relating to glaciers.

The following are mentioned as an example. A study of the moraines and vegetation in the deglaciated area to determine the extent of the glacier at various dates. A study of the striations on the rock ledges to compare earlier and present directions of movement. A study of crevasses, their location, formation, distribution, and characteristics. A study of the ice strata in the crevasses would yield information on flow and movement within the ice body. Determination of depth or thickness of the ice by bore holes or seismic observations.