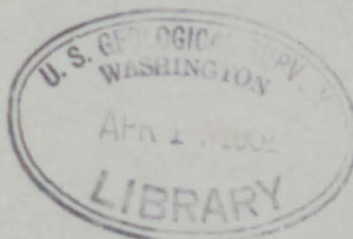


UNITED STATES
DEPARTMENT OF THE INTERIOR
✓ U.S. GEOLOGICAL SURVEY
WASHINGTON 25, D. C.

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U. S. GEOLOGICAL SURVEY
AND
U. S. NATIONAL PARK SERVICE
GLACIER OBSERVATIONS
GLACIER NATIONAL PARK, MONTANA
1961



by
Arthur Johnson, 1963 -

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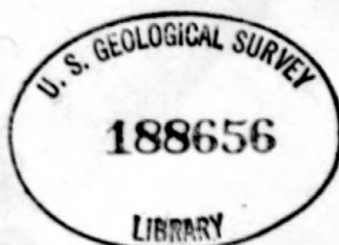
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Washington 25, D. C.

GEOLOGICAL SURVEY

For Release April 16, 1962

The Geological Survey is releasing in open files the following report.

Glacier Observations, Glacier National Park,
Montana, 1961, by Arthur Johnson.

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1961 PROGRESS REPORT

GLACIER OBSERVATIONS

GLACIER NATIONAL PARK, MONTANA

INTRODUCTION

This report records the results obtained during the 1961 season in the continuing program of glacier observations in Glacier National Park. The investigations currently in progress relate to the Grinnell and Sperry Glaciers. This program is carried on cooperatively by the Geological Survey, the National Park Service and the Weather Bureau. The program includes the determination of annual changes in the surface elevation of the glaciers by the measurement of profiles, and changes during the summer months by the establishment of and observations at ablation stakes; mapping the glacier termini in selected years to record advance or recession; determination of annual movement by the location of marked rocks; the operation of two storage-precipitation gages in the immediate vicinity of the Grinnell Glacier to record annual precipitation; the operation of two gaging stations, one just below the Grinnell Glacier during the summer months and one just below the outlet of Grinnell Lake on a year round basis; temperature data near the Grinnell Glacier and temperature and precipitation data at the Sperry Chalet near the Sperry Glacier during the summer months. The results of the work are described in the following sections.

GRINNELL GLACIER

The work on the Grinnell Glacier consisted of the placing of ablation stakes in July and their remeasurement in August; the partial measurement of one profile, the location of several previously marked

rocks, and the delineation of that portion of the lake shore bordering the glacier in mid-September. Due to adverse weather the complete measurement of the profiles, location of all of the previously marked rocks, and observations at the ablation stakes planned for mid-September could not be accomplished. In addition to the work on the glacier 25 trees which had been cored for age determinations by G. M. Baden, seasonal Ranger Naturalist, were located on the base map of the Grinnell Glacier. The location of these trees of known age will give some indication of the maximum extent of the glacier within the past two or three centuries.

Surface Changes

Profiles

Profile no. 1 (fig. 1) was measured for about 1100 feet. In this section the surface was uniformly from 6 to 8 feet lower than on September 2, 1960. As shown on figure 1 the mean difference in the section from 100 to 500 was 6.0 feet and in the section from 500 to 1000 it was 6.7 feet.

Ablation Measurements

Nine ablation stakes were set on July 17, 19 and 20 and their positions located by triangulation from a base line below the glacier. Eight of these, nos. 1-8, were set close to the same locations at which stakes were set in 1960. (See fig. 1). The location shown as no. 9 was not used in 1961 but in lieu of it a new location, designated 8-A was used.

The results of the ablation measurements in 1960 and 1961 are listed in tables no. 1 and no. 2, p 3 and 4.

Table 1.-Results of ablation measurements on Grinnell Glacier
(Ablation stakes set on July 21, 22, 1960)

Stake: no.	Depth: of hole	Depth: of snow	Decrease in surface elevation (feet)				Oct. 4, 1960 to date	
			July 21, 22 to Aug. 25	Aug. 25 to Sept. 6	Sept. 6 to Oct. 4	Total July 21, 22 to Oct. 4, 1960:	Change	indicated in 1961 Date
1	19.8	6.1	8.2	0.9	2.8	11.9		
2	19.8	14.1	10.3	1.0	2.8	14.1	4.4	Aug. 24
3	19.8	18.3	8.6	1.0	2.1	11.7	2.1	Aug. 24
4	19.8	4.6	6.9	1.1	2.8	10.8	0.0	July 19
5	16.3	5.4	7.5	1.0	2.5	11.0		
6	19.8	14.2	6.9	0.7	2.1	9.7	1.3	Aug. 24
7	18.3	0.5	7.6	1.5	2.5	11.6	1.2	July 19
8	18.7	6.4	7.9	1.0	1.3	10.2	See note	July 19
9	18.7	4.5	8.5	1.0	2.0	11.5	See note	July 19

Note:

Stake 8 was exposed 2.1 feet and leaning downglacier about 60°. This stake was exposed 3.5 feet on Oct. 4, 1960.

Stake 9 was exposed 3.3 feet and leaning downglacier about 45°. This stake was exposed 4.8 feet on Oct. 4, 1960. The glacier surface in the area of these two stakes was therefore about one foot higher on July 19, 1961 than on Oct. 4, 1960.

Table 2.-Results of ablation measurements on Grinnell Glacier.
(Ablation stakes set on July 17, 19 and 20, 1961)

Stake no. <u>a/</u>	Depth of hole (feet)	Depth of snow (feet)	Ablation, feet July 17, 19 or 20 to Aug. 24
1	16.4	<u>b/</u>	11.6
2	15.5	<u>b/</u>	11.1
3	18.8	<u>b/</u>	9.7
4	13.1	0.5	8.7
5	15.1	3.5	8.8
6	17.5	12+	8.9
7	13.1	0	8.8
8	16.4	3+	9.1
8 A	17.6	<u>b/</u>	----

a/ Stakes set in same general area as those with corresponding number set in 1960 except 8 A, which is about midway between 6 and 8 and farther back toward headwall.

b/ Transition from previous winter's snow to 1960 glacier surface not readily apparent.

The values for stakes 1 and 2 in 1961 appear questionable in view of the values at the other six locations. Some difficulty was experienced in placing the stakes at these holes and it is possible that the lowest of the three 6 foot stakes used did not actually reach the bottom of the hole and the next stake above may have been forced alongside of it instead of forcing it all the way down. A possible error of as much as a foot was noted at the time these stakes were placed. Using the values as shown, the average ablation for stakes 1-8 for the period July 17, 19, 20 to Aug. 24 was 9.6 feet. If stakes 1 and 2 are considered to be in error as much as 1 foot each this value would be reduced to 9.3 feet. The 1960 value for these same locations and essentially the same period, July 21, 22 - Aug. 25, was 8.0 feet. Considering only stakes 3-8 for each year, so as to eliminate the uncertainty of the 1961 values at 1 and 2 the mean values are 7.6 and 9.0 for 1960 and 1961 respectively. The greater ablations in 1961 is in agreement with the differences in temperature. The mean temperature at the Grinnell Glacier station in August 1961 was 61.7 and in August 1960 was 51.1, a difference of 10.6°. The August 1961 average temperature at West Glacier was 66.4° whereas the average August temperature for the 30 year period 1931-1960 was 62.0°; the corresponding values for July are 64.8 and 64.0 respectively.

It is of interest to note that 7 of the 9 ablation stakes set in 1960 were also observed in 1961, 4 in July and 3 in August. The changes since the last observation on October 4, 1960 to the date observed in 1961 are shown in table 1 p 3. It should be possible to find and observe most of the 1961 stakes soon after the glacier becomes accessible during the summer of 1962 and an effort should be made to do so. The observations

should also include their locations by triangulation so as to determine the amount of movement of the glacier since the stakes were placed. In planning the work for 1962 it would be desirable to again use a location near the no. 9 location used in 1960.

Movement

Only 4 of the previously marked rocks were relocated in 1961, viz., 50-1, 50-2, 59-1, and 59-2. As shown in figure 1 the movement was in the same direction as in previous years and from 35 to 40 feet since September 1960.

Recession

The only part of the front located in 1961 was the lake shore bordering the glacier and this is shown in figure 1. From this it is seen that the changes in the ice front from year to year are very irregular. This is due to large sections of the ice breaking away from the glacier and floating out into the lake.

Precipitation and Runoff

The two storage precipitation gages, established and maintained by the Weather Bureau and the National Park Service, one in 1949 and one in 1955, were continued in operation. The gaging station at the outlet of Grinnell Lake, established in 1949 was continued in operation. The results of the observations at the precipitation gages, along with the runoff at the outlet of Grinnell Lake for the corresponding periods are shown in table 3, p 7. As seen from the table the runoff at the Grinnell Lake outlet from July 22, 1960 to August 8, 1961 was 106.1 inches whereas the measured precipitation at gage no. 1 was 98.3 inches. In only one other year, 1958, during the period of record, was the total

Table 3.-Precipitation and runoff data in vicinity of Grinnell Glacier

Period	Number of days	Precipitation(inches)		Percent:Runoff B/A	Runoff (inches) c/
		A Gage No. 1 a/	B Gage No. 2 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 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	109.2	-		105.2
Aug. 11, 1955-Aug. 7, 1956	363	100.7	152.8 d/	152	98.5
Aug. 8, 1956-July 16, 1957	342	88.7	137.2	155	81.4
July 17, 1957-July 17, 1958	365	78.9	115.8	147	84.0
July 18, 1958-Aug. 4, 1959	383	111.6	184.6	165	108.8
Aug. 5, 1959-July 21, 1960	352	107.7	166.6	155	91.6
July 22, 1960-Aug. 8, 1961	383	98.3	131.8	134	106.1

a/ Measured at storage precipitation gage near end of horse trail 0.4 mile from glacier.

b/ Measured at storage precipitation gage about $\frac{1}{2}$ mile southeast of gage described in footnote a/

c/ Measured at gaging station at outlet of Grinnell Lake.

d/ August 15, 1955 to August 7, 1956.

runoff greater than the measured precipitation at gage no. 1. This, however, is readily explained by the fact that during July and August the precipitation would be least whereas the temperatures would be the highest for the year with a resulting high rate of melting and runoff. The average temperature at the station near the Grinnell Glacier was 61.7° in August 1961 and 51.1° in August 1960, a difference of 10.6° . The July record at this station is not complete. At West Glacier, the average temperature for July 1961 was 64.8° and for July 1960 it was 66.1° or 1.3° less than in 1960. The 30 year average for July at West Glacier is 64.0° , indicating that July 1961 was somewhat above average.

It is of interest to note the difference in the results obtained at the two storage precipitation gages. The two gages are 2100 feet apart. In elevation gage no. 2 is only 113 feet lower than no. 1. The results at gage no. 2 have been consistently above those at no. 1, varying from 134 to 165 percent, averaging 151 percent. The pronounced difference in catch at these two gages is probably due to differences in wind patterns which in turn are influenced by the rugged mountain topography.

The gaging station immediately below the glacier, see figure 1, was first visited on July 12, 1961 and placed in operation for the season. The recorder had continued in operation until November 28, 1960 at which time the flow was determined to be 0.2 c.f.s. When the station was first visited on July 12 it was found that it had been submerged, presumably resulting from a snow and ice jam sometime during June. In view of the topography at the site this was a rather unusual occurrence and could only have resulted from, as already indicated, some peculiar snow and ice jam.

The results obtained to date at this station are shown in table 4, p. 10 and compared with the record for the corresponding months at the gaging station below the outlet of Grinnell Lake. As shown by this table, the relation between the runoff at the glacier to that below the outlet of Grinnell Lake varied from a minimum of 34% in November 1960 to a maximum of 96% in August 1961. The latter is in keeping with the higher than average temperature for August 1961.

Table 4.-Runoff Comparisons, Grinnell Creek
at Grinnell Glacier and Grinnell Creek
near Many Glacier (Just below outlet
of Grinnell Lake)

	Grinnell Creek at Grinnell Glacier		Grinnell Creek near Many Glacier		Percent A/B
Month	Runoff		Runoff		
	Acre - feet A	Inches	Acre - feet B	Inches	
July 1959	2460	41.93	4310	23.27	57
August	1700	28.98	2260	12.21	75
September	1230	20.97	2280	12.29	54
October 1959	662	11.29	1500	8.09	44
July 1960	2770	47.30	4180	22.57	66
August	1700	28.98	2080	11.23	82
September	975	16.62	1190	6.44	82
October	351	5.98	599	3.24	59
November 1960	115	1.96	336	1.81	34
July 1961	2570	43.88	3500	18.90	73
August	2260	38.51	2360	12.75	96
September 1961	666	11.35	944	5.10	71
Drainage Areas					
	Square miles	Acres	Square miles	Acres	
	1.1	704	3.47	2221	

SPERRY GLACIER

Surface Changes

Profiles

The cross profile and the longitudinal profiles nos. 1, 2 and 3 (fig. 3) were measured on September 13 and 14. The 1961 profiles are shown with those for 1950 and 1957 on figure 2 as the measurements in those years were also in mid-September. Considering the cross profile the 1957 surface was at or above that for 1950 from the left or west side to 1500 feet from the initial point and below the 1950 surface for the next 1100 feet. In the 600 foot section from the east or right side the 1957 surface was above that for 1950. With the exception of a 300 foot section near the west side the 1961 surface was below that for 1950 until a point about 500 feet from the east side was reached beyond which the 1961 and 1950 surfaces were much the same. A numerical comparison of the elevations in 1000 foot sections for the three years considered is shown below:

Cross Profile

Date	Distance from initial point, feet			
	100-1100	1100-2100	2100-3100	100-3100
Sept. 19, 1950	7597.9	7534.5	7594.3	7575.5
Sept. 14, 1957	7601.6	7534.2	7505.4	7577.1
Sept. 14, 1961	7596.0	7525.0	7587.8	7569.6

Longitudinal profile no. 1 shows a continuous and marked lowering of the glacier surface below an altitude of about 7550. The terminus on the profile alignment receded over 500 feet from 1950 to 1961. At the location of the 1961 terminus the ice was over 90 feet thick in 1950 and about 50 feet in 1957. The ridge and trough upglacier has continued to move upglacier. The crest of this ridge in 1961 was about 200 feet

upglacier from the 1950 position. Above the 7600 foot elevation the 1961 surface was below that in 1957 but above that in 1950.

Longitudinal profile no. 2 is shown on figure 2 for the years in which measured. This profile was also measured in 1958 and was much the same then as in 1961. The ridge that was so prominent in 1947 is barely discernible in 1961. The terminus at the profile alignment shows a recession of 370 feet from 1947 to 1961. At the location of the 1961 terminus the ice was 60 feet thick in 1947.

Longitudinal profile no. 3 (fig. 2) has shown no significant change since first measured in 1958. The mean elevations for the section between 300 and 1000 feet from the initial point for the three years in which measured are as follows, along with distance to the edge of the glacier:

Date	Mean elevation 300-1000	Distance to edge of glacier
August 18, 1958	7822.7	219
August 18, 1959	7826.6	236
September 14, 1961	7826.2	219

Considering the results of the ablation measurements, discussed in the following section, the mean elevation in mid-August would have been about 2 feet higher.

Ablation Measurements

Seven ablation stakes were set on July 24 at locations shown on figure 3, and measurements made at them on August 21 and September 14. The results of these measurements are shown in table 5, p. 13. Ice was exposed at the locations selected for stakes 1, 2 and 3 whereas the

Table 5.-Results of ablation measurements on Sperry Glacier
(Ablation stakes set July 24, 1961)

Stake no.	Depth of hole	Depth of snow	Ablation, feet		
			July 24 to Aug. 21	Aug. 21 to Sept. 14	July 24 to Sept. 14
1	13.1	--	8.0	2.1	10.1
2	13.1	0	5.8	1.8	7.6
3	13.1	0	5.8	1.8	7.6
4	13.1	3.3	6.9	2.0	8.9
5	16.4	a/	7.0	2.2	9.2
6	16.4	a/	7.5	3.3	10.8
7	9.9	4.8	7.4	--	--

a/ Transition from snow to 1960 glacier surface not readily apparent.

others were all in snow. The lowering of the surface during the July 24-August 21 period varied from 5.8 to 8.0 feet, the average of all values being 6.9 feet. Stake no. 7 was not found in September. The surface lowering at stakes 1-6 during the August 21-September 14 period varied from 1.8 to 3.3 feet, averaging 2.2 feet. Similarly, the total lowering during the July 24-September 14 period varied from 7.6 to 10.8 feet, averaging 9.0 feet.

Movement

Three previously marked rocks and one unmarked rock were relocated. These four rocks were first located in 1949. During the 12 year period the 4 rocks showed a total movement varying from 145 to 170 feet or 12 to 14 feet per year. (See fig. 3). Relocation of ablation stakes 1, 2 and 3 in 1962 will determine if there is a greater rate of movement at the higher elevations on the glacier.

Recession

The entire front or terminus of the glacier was delineated on September 15. As shown on figure 3 the 1961 terminus was very irregular as compared with 1950. In places it was as much as 600 to 700 feet back from the 1950 position. Three narrow ice tongues in 1961 were actually forward from the 1950 position. The most pronounced change was just to the right of the center of the glacier. The irregularity of the front in 1961 is probably due to the thinness of the ice sheet and irregularity in the underlying bedrock topography. Following the system used in some of the previous reports the changes in the ice front are tabulated below:

Recession of terminus, of central half-mile section

Period	Recession (feet)	Total recession since 1938 (feet)	Average annual recession (feet)
1938-1945	351	351	50
1945-1950	177	528	35
1950-1956	85	613	14
1956-1961	196	809	39

The foregoing table shows a continual recession of the terminus. It is of interest to note that during the same period there was little noticeable change in the front or edge of the Grinnell Glacier except in the part bordering the lake. This varies from year to year and a slight recession may be indicated but not nearly pronounced as in the case of the Sperry Glacier.

CLIMATIC DATA

The weather station established at the Sperry Chalet in 1960 was operated during the period that the Chalet was open. The results obtained, along with corresponding values for West Glacier and Grinnell Glacier are shown in table 6, p. 16. As seen from this table the mean August temperature for 1961 at the Sperry Chalet and Grinnell Glacier were 10.6° and 10.2° higher respectively than the August 1960 values. At West Glacier the August 1961 mean temperature was 8.5° higher than in August 1960. The precipitation for the July-August period was appreciably greater in 1961 than in 1960 at both the West Glacier and Sperry Chalet stations.

Table 6.-Temperature and precipitation data,
July and August, 1960 and 1961

	Temperatures, °F		
	West Glacier	Sperry Chalet	Grinnell Glacier
Mean:			
July 1960	66.1	62.7	--
Aug. 1960	57.9	50.7	51.1
July 1961	64.8	58.0	--
Aug. 1961	66.4	61.9	61.7
Maximum:			
July 1960	93	84	--
Aug. 1960	87	76	81
July 1961	89	75	--
Aug. 1961	96	90	89
Mean Maximum:			
July 1960	84.4	73.0	--
Aug. 1960	70.2	57.6	59.3
July 1961	81.1	67.8	--
Aug. 1961	84.6	71.8	73.6
Minimum:			
July 1960	40	39	--
Aug. 1960	34	30	31
July 1961	35	37	--
Aug. 1961	39	30	33
Mean Minimum:			
July 1960	47.8	52.3	--
Aug. 1960	45.5	43.7	42.8
July 1961	48.5	48.2	--
Aug. 1961	48.1	51.9	49.8
Precipitation, inches:			
July 1960	0.00	0.15	--
Aug. 1960	2.75	3.82	--
July 1961	2.20	3.27	--
Aug. 1961	1.76	3.30	--

Period	Recession (feet)	Total recession since 1938 (feet)	Average annual recession (feet)
1938-1945	351	351	50
1945-1950	177	528	35
1950-1956	85	613	14
1956-1961	196	809	39

Recession of terminus of central half-mile section

The foregoing table shows a continual recession of the terminus. It is of interest to note that during the same period there was little noticeable change in the front or edge of the Grinnell Glacier except in the part bordering the lake. This varies from year to year and a slight recession may be indicated but not nearly pronounced as in the case of the Berry Glacier.

CLIMATIC DATA

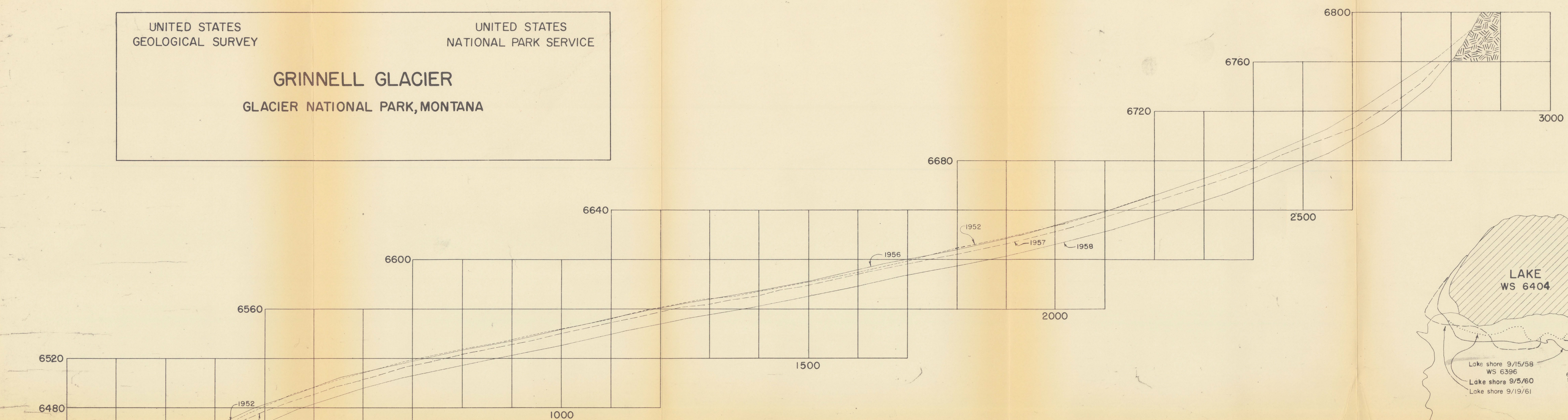
The weather station established at the Berry Glacier in 1950 was operated during the period time the Grinnell was open. The results obtained, along with corresponding values for West Glacier and Grinnell Glacier are shown in table 6, p. 10. As seen from this table the mean August temperature for 1961 at the Berry Glacier and Grinnell Glacier was 10.6° and 10.2° higher respectively than the August 1950 values. At West Glacier the August 1961 mean temperature was 8.7° higher than in August 1950. The precipitation for the July-August period was slightly greater in 1961 than in 1950 at both the West Glacier and Berry Glacier stations.



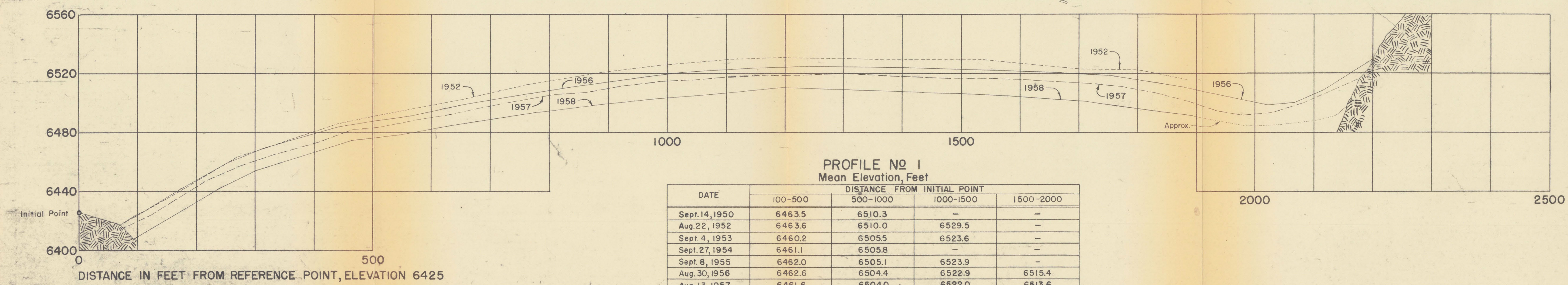
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GRINNELL GLACIER
GLACIER NATIONAL PARK, MONTANA



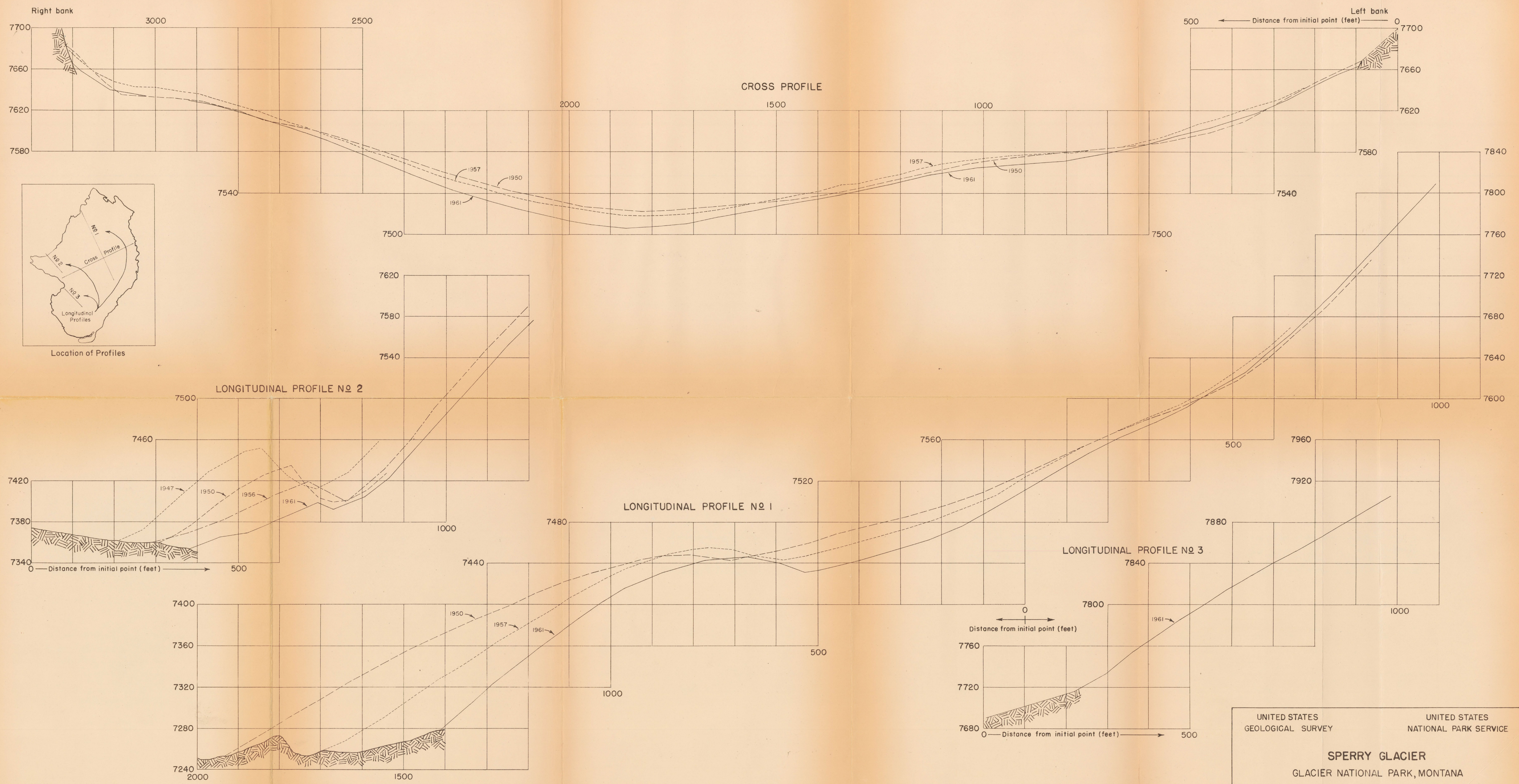
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	100-500	500-1000	1000-1500	1500-2000	2000-2500
Sept. 14, 1950	6460.1	6523.3	6564.8	—	—
Aug. 22, 1952	6460.3	6522.6	6563.8	6604.8	—
Sept. 4, 1953	6458.4	6519.5	—	—	—
Sept. 27, 1954	6459.5	6522.0	6564.4	—	—
Sept. 6, 1955	6460.6	6521.8	6563.9	—	—
Aug. 30, 1956	6461.7	6521.6	6563.8	6604.6	6659.9
Aug. 13, 1957	6460.2	6521.3	6563.2	6602.9	6657.2
Sept. 10, 1957	6456.6	6517.9	6560.6	6600.9	6654.9
Aug. 12, 1958	6452.5	6515.2	6557.1	6596.4	6649.6
Sept. 15, 1958	6446.4	6509.8	6551.6	6591.2	6642.7
Aug. 14, 1959	6453.0	6516.2	6558.6	6598.4	6651.6
Sept. 12, 1959	6449.9	6513.6	6555.7	6597.1	6649.5
Sept. 3, 4, 6, 1960	6449.9	6514.1	6555.5	6594.7	6646.7

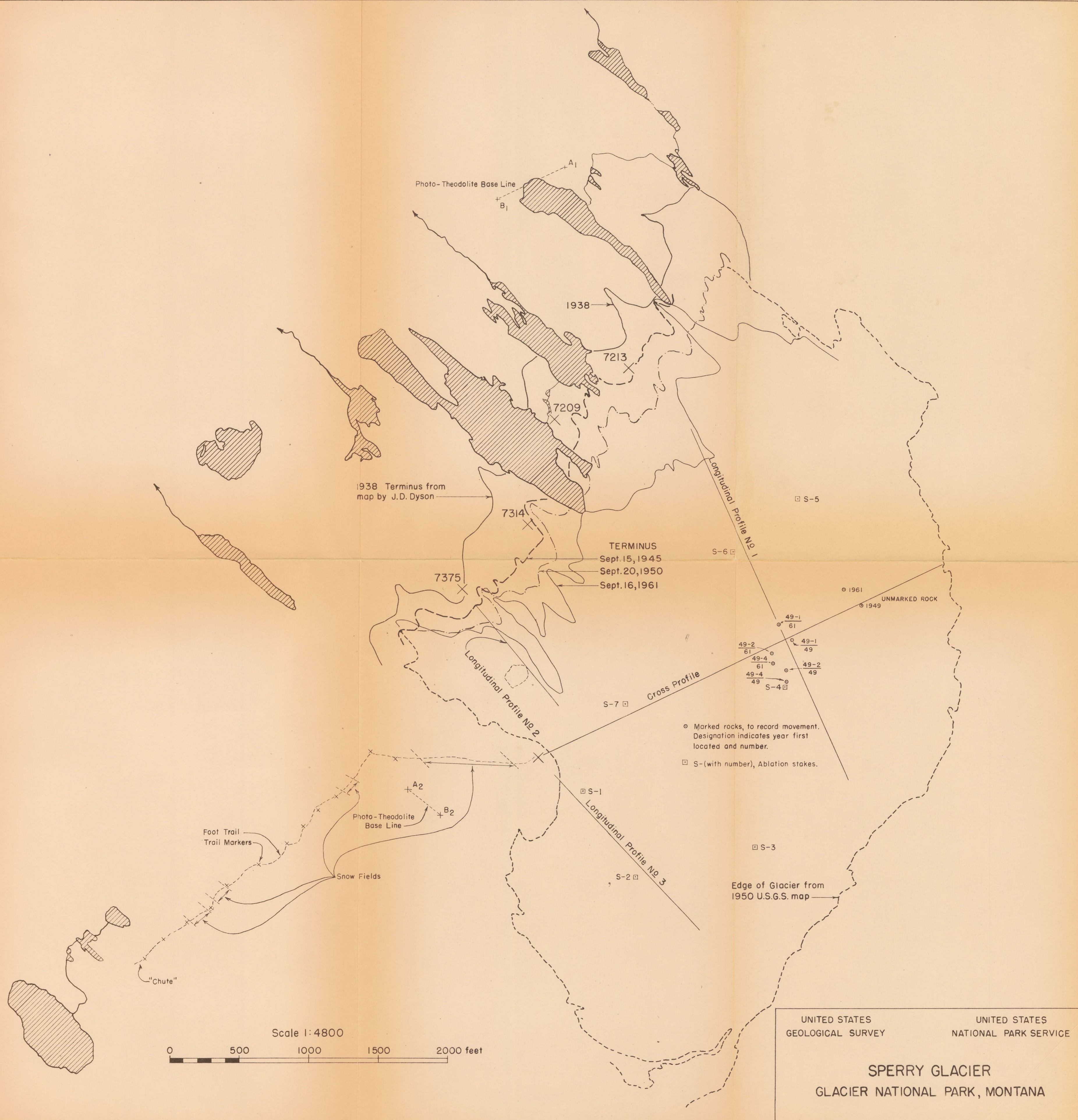


DATE	DISTANCE FROM INITIAL POINT			
	100-500	500-1000	1000-1500	1500-2000
Sept. 14, 1950	6463.5	6510.3	—	—
Aug. 22, 1952	6463.6	6510.0	6529.5	—
Sept. 4, 1953	6460.2	6505.5	6523.6	—
Sept. 27, 1954	6461.1	6505.8	—	—
Sept. 8, 1955	6462.0	6505.1	6523.9	—
Aug. 30, 1956	6462.6	6504.4	6522.9	6515.4
Aug. 13, 1957	6461.6	6504.0	6522.0	6513.6
Sept. 10, 1957	6458.1	6500.7	6518.3	6508.3
Aug. 12, 1958	6454.8	6497.0	6513.2	6503.2
Sept. 14, 1958	6449.2	6491.1	6507.8	6497.6
Aug. 14, 1959	6454.9	6498.3	6514.4	6501.9
Sept. 12, 1959	6452.2	6495.7	6512.2	6500.3
Sept. 2, 1960	6453.0	6495.9	6511.1	6502.3
Sept. 19, 1961	6447.0	6489.2	—	—



SCALE 1:4800 or 1 inch=400 feet





PAMPHLET BINDERS

This is No. 1528

also carried in stock in the following sizes

	HIGH	WIDE	THICKNESS		HIGH	WIDE	THICKNESS
	inches	inches	$\frac{1}{2}$ inch		inches	inches	$\frac{1}{2}$ inch
1523	9	7	"	1529	12	10	"
1524	10	7	"	1530	12	9 $\frac{1}{2}$	"
1525	9	6	"	1531	13	10	"
1526	9 $\frac{1}{2}$	7 $\frac{1}{4}$	"	1532	14	11	"
1527	10 $\frac{1}{2}$	7 $\frac{3}{4}$	"	1533	16	12	"
1528	11	8	"				

Other sizes made to order.

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