OBSERVATIONS ON THE TETON GLACIER, GRAND TETON NATIONAL PARK, WYOMING, 1965 AND 1966

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Abstract.—Resurvey in 1966 of markers placed across the Teton Glacier near the snowline in 1963, 1964, and 1965 indicates that the average rate of ice movement near the center is probably about 28 feet per year. Previously computed and reported movement rates of 30 to nearly 35 feet per year between 1963 and 1964 are too high because of surveying errors. Transverse profiles indicate that the central part of the glacier was 2–8 feet thicker in 1966 than in 1963. Direct measurement in a glacier mill near the surveyed provle indicates that the ice is about 64 feet thick. Locally, the terminus has advanced as much as 30 feet, but most of it remains in virtually the same position as in 1963.

During the summers of 1965 and 1966, surveys on the Teton Glacier were continued to determine the amount and rate of movement, the thickness of the ice, and general regimen of the glacier. Reed (1964, 1965) has reported the results of similar surveys in the summers of 1963 and 1964 and summarized previous observations on the regimen of the glacier. R. Alan Mebane, Assistant Chief Naturalist of Grand Teton National Park, assisted in making the 1965 and 1966 surveys, as well as those in 1963 and 1964; William McKeel assisted in both the 1965 and 1966 surveys. Their able and enthusiastic assistance and the generous cooperation of many other members of the staff of Grand Teton National Park are gratefully acknowledged.

The 1965 survey was made on August 19 with an engineer's transit. Weathering during the survey was extremely bad; much of the lower part of the glacier was still covered by snow so that only one of the stakes placed in previous years was recovered. The reference mark at the north end of the profile along which the 1963 and 1964 marks were placed was also snow covered, and therefore the 1965 markers had to be placed along an arbitrary line from the reference mark on the south wall to a new reference mark on the north wall. The line of markers was placed as near as possible to the line used in the 1963 and 1964 surveys (line $Y—Y'$, fig. 1), but measurements in 1966, when both the old and new reference points on the north end of the line were visible, showed that the 1965 line was 7.5 feet too far downglacier at point 12, 1,110 feet from the south wall. The location and altitude of the 1965 markers are given in table 1.

TABLE 1.—*Location and altitude of markers placed on line across the Teton Glacier on August 19, 1965* [1]

Point	Distance from red paint mark on south wall (feet)	Altitude of snow or ice surface above arbitrary datum (feet) [2]	Depth of snow (feet)
1	35	621.5	----
2	87	624.4	1.5
3	185	629.3	.6
4	310	654.2	.9
5	410	651.1	1.5
6	510	646.5	1.6
7	610	653.9	1.5
8	710	653.3	.5
9	810	648.0	0
10	910	655.2	.1
11	1,010	656.8	.8
12	1,110	659.8	1.5
Yellow painted cross (+) on boulder in moraine	1,266	----	----

[1] All points, except 9, marked by nails 1 foot long countersunk into snow and surrounded by yellow painted rocks. Point 9 is marked by a cross (+) painted red on top of a large erratic boulder 6.5 feet above the ice surface.
[2] Arbitrary datum is approximately 9,780 feet above sea level.

The 1966 survey was made on July 25 with a plane-table and telescopic alidade. Weather conditions were ideal. Most of the central part of the glacier was free of snow, and many of the markers placed during previous surveys were found (fig. 2). A new series of stakes was placed along the transverse profile used in the 1963 and 1964 surveys (line $Y–Y'$, figs. 1 and 2); their locations and altitudes are given in table 2. In addition, the longitudinal profile of the glacier along

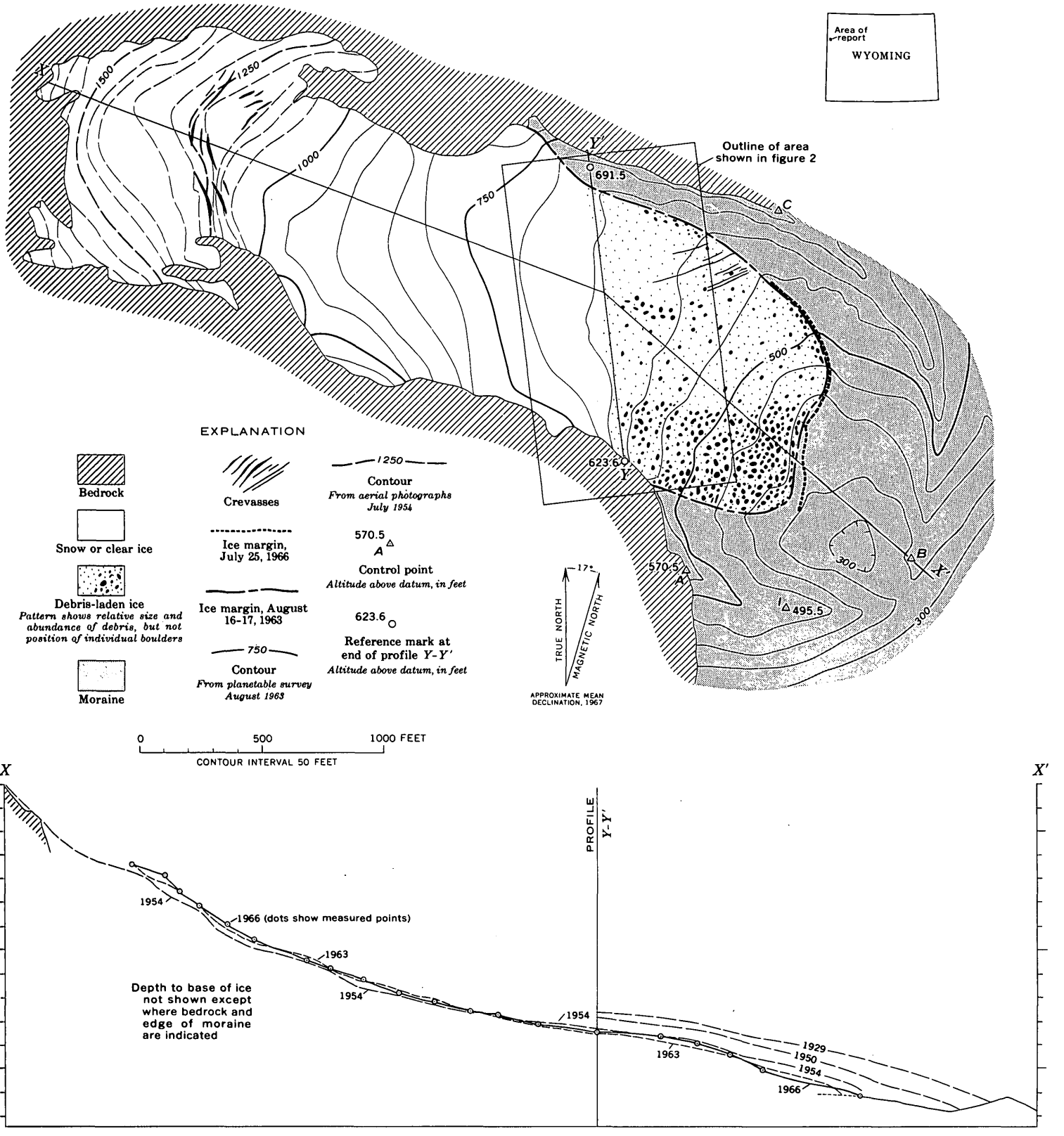

FIGURE 1.—Map and logitudinal profile of the Teton Glacier. Contours show elevation above arbitrary datum, 9,780 feet above sea level.

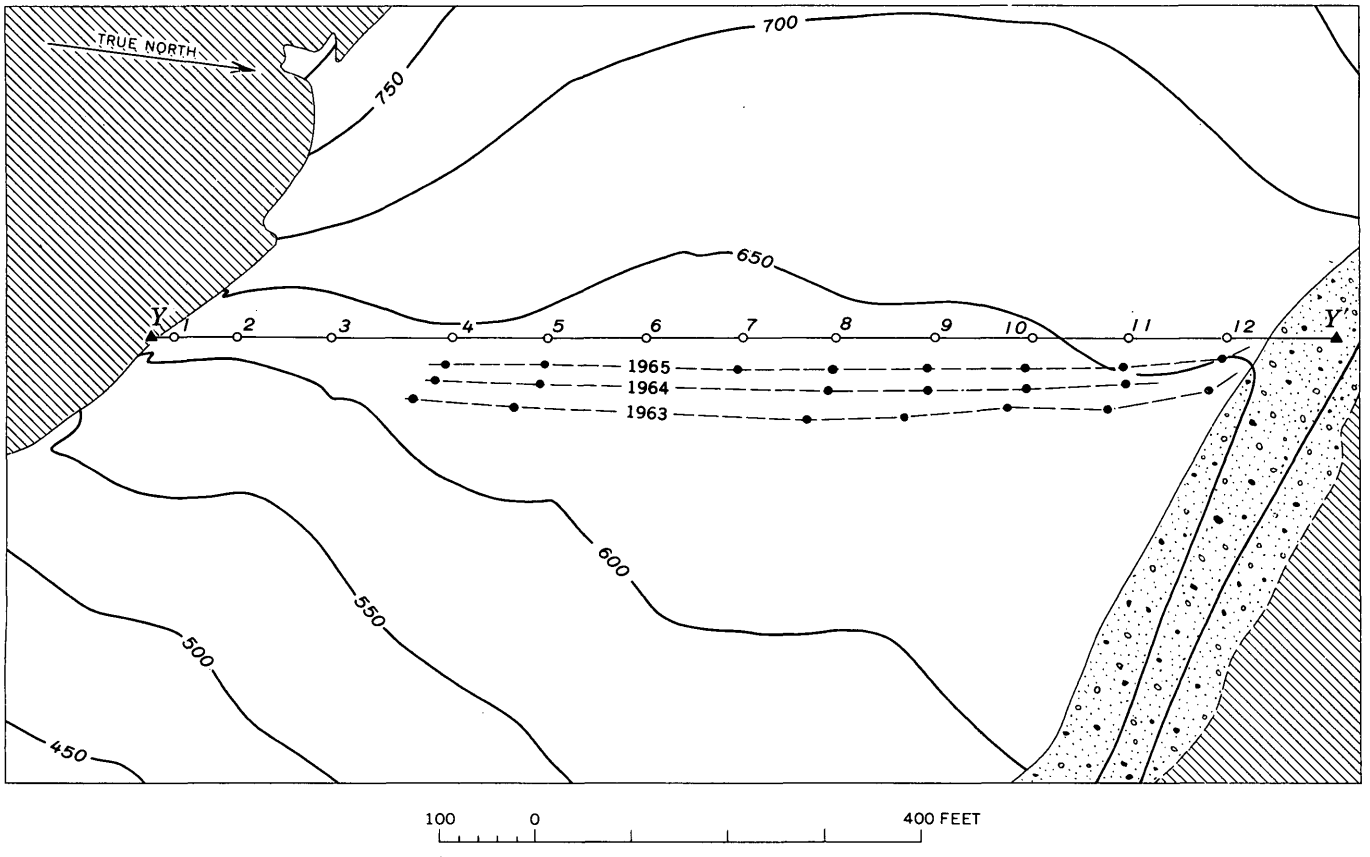

FIGURE 2.—Map showing positions of markers placed along line Y–Y' in 1966 (open circles) and positions of markers from previous years (solid circles). Dashed lines connect positions of markers originally placed along Y–Y' in 1963, 1964, and 1965. Solid triangles show position of fixed reference points marked by red paint +'s. Ruled areas are bedrock; stippled area is moraine. Contours show configuration of ice surface in 1963. Altitude of 1966 points (table 2) therefore cannot be reconciled in detail with contours shown. Contour interval is 50 feet; arbitrary datum is 9,780 feet above sea level.

line X–X' (fig. 1) was resurveyed, and the position of the terminus was redetermined.

All but one of the stakes placed in previous years had melted out of the ice, but each lay with its tip within the group of painted rocks that had been placed around it, so that its position could be recovered within about 2 feet. The location of the old markers with respect to the newly placed 1966 markers was measured with a Brunton compass and steel tape. Their altitudes were measured by leveling to the 1966 marks using a hand level and stadia rod. These data are given in table 3.

The data in table 3 can be used to compute the average annual movement of the ice at each of the points where markers from previous surveys were recovered in 1966, but several adjustments are necessary. Because the 1965 markers were not placed along the same line (Y–Y') as that used in other years, an adjustment in their original positions must be made. The 1965 line was found to have been originally 7.5 feet too far downglacier at point 12, 1,110 feet from the reference mark on the south wall. The discrepancy in placement of the other 1965 points is:

Distance that 1965 point was originally off line Y–$Y' = \frac{7.5}{1{,}110} \times$ distance from south wall.

The consistency of the discrepancies in apparent directions of movement of the markers placed in the various previous years suggests that systematic errors were made in measuring the distances from the reference point at the south end of the line when the markers were originally placed. It is very unlikely that the discrepancies are due to an actual change in the direction of movement. To adjust for these measurement errors, the true movement direction at each point must be estimated. The apparent directions of movement of the 1964 and 1965 markers are reasonably consistent and indicate that these markers were more accurately placed than were those in 1963. Because the 1964 markers were originally placed on the correct line and because they represent a longer period of record, it has been assumed that the true direction of movement

at each point is that between the 1964 and 1966 markers. The assumed original positions of the 1963 and 1965 points were found graphically by projecting their 1966 positions backward along the assumed direction of movement, the 1963 markers into line Y–Y' (figs. 1, 2) and the 1965 points into the line along which they were originally placed.

TABLE 2.—*Location and altitudes of markers placed on line across the Teton Glacier on July 25, 1966* [1]

Point	Distance from red paint mark on south wall (feet)	Altitude above arbitrary datum [2] (feet)	Remarks
1	20	620.0	Head of stake flush with bare ice surface.
2	87	623.0	Head of stake 1.5 ft below snow and about 1 ft above ice.
3	185	629.7	Head of stake flush with ice surface under 1.5 ft of snow.
4	310	656.4	Head of stake flush with ice surface under 1.0 ft of snow.
5	410	651.7	Head of stake flush with ice surface under 0.5 ft of snow.
6	510	645.6	Head of stake flush with bare ice surface.
7	610	652.9	Head of stake flush with ice surface under 0.4 ft of snow.
8	710	651.7	Head of stake flush with bare ice surface.
9	810	650.5	Do.
10	910	657.5	Do.
11	1,010	662.5	Head of stake flush with ice surface under 1.7 ft of snow.
12	1,110	665.4	Head of stake flush with bare ice surface.
Edge of snow on north side of glacier	1,196	678.2	No mark.

[1] All numbered points marked by telephone-pole cleats about 1 foot long surrounded by blue painted rocks and flagged with small triangular red cloth pennants on wires about 2 feet long.
[2] Arbitrary datum is approximately 9,780 feet above sea level.

The apparent errors in placement of the 1963 and 1965 markers are given in table 4. The relatively large errors in distance from the south wall of the 1963 markers are probably largely the result of an error in the stadia reading from the reference point to the instrument station on the profile line from which all other distances were taped. Taping errors in the original surveys and errors in estimating the exact positions of stakes which had melted out of the ice probably account for the remaining discrepancies in the placement of the 1963 and 1965 markers.

Average annual movement rates computed from the adjusted original positions of the various markers are given in table 5. These rates of movement are somewhat less than those previously reported (Reed, 1965) because of the errors in the original positions of the 1963 markers, but they confirm the general pattern of movement described in previous papers. The differences between the average movement rates for the various points in table 5 are probably due to discrepancies in the surveys rather than to real changes in the rate of movement in the ice. Detection of changes in the rate of ice movement from year to year would require both more precise surveys and a more satisfactory method of placing the marker stakes.

The only marker stake recovered during the 1966 survey that had not melted free of the ice was the pipe placed at point 5 in 1964. The altitude of the bottom of the stake in 1964 was 642.2 feet (Reed, 1965,

TABLE 3.—*Positions of markers placed in 1963, 1964, and 1965 with respect to new markers placed July 25, 1966, on the Teton Glacier*

Point	1965 markers			1964 markers			1963 markers		
	Direction	Distance (feet)	Altitude difference (feet)	Direction	Distance (feet)	Altitude difference (feet)	Direction	Distance (feet)	Altitude difference (feet)
[1] 1									
[1] 2									
[1] 3									
4	S. 75° E.	28.0	−6.9	S. 69° E.	45.7	−11.5	S. 59° E.	75.0	[2] −13.9
5	S. 80° E.	29.0	−5.8	S. 80° E.	49.5	−9.6	S. 65° E.	82.3	−13.5
[1] 6									
[3] 7	S. 82° E.	32.8	−2.1						
8	S. 81° E.	32.2	−3.6	S. 82° E.	55.0	−5.3	S. 72° E.	89.0	−5.7
9	S. 82° E.	31.5	[4] −4.6	S. 84° E.	55.5	−7.7	S. 72° E.	89.3	−11.7
10	S. 80° E.	32.0	−6.6	S. 84° E.	53.0	−9.8	S. 72° E.	87.8	−14.0
11	S. 82° E.	31.5	−5.9	S. 87° E.	49.2	−8.2	S. 74° E.	78.0	−12.4
[5] 12	S. 82° E.	21.5	−4.4				S. 73° E.	57.0	−9.6

[1] Markers not recovered.
[2] Difference in altitude refers to ice surface. Mark on an erratic boulder was 5.0 ft above ice surface in 1963 and 6.5 ft above surface in 1966. Mark is control point E of 1963 survey.
[3] 1964 and 1963 markers not recovered.
[4] Difference in altitude refers to ice surface. Mark on top of erratic boulder was 6.5 ft above ice surface in 1965 and 11.0 ft above surface in 1966.
[5] 1964 marker not recovered.

TABLE 4.—*Apparent errors in placement of 1963 and 1965 markers on the Teton Glacier*

Point	1963 marker, error in distance from south wall (feet)	1965 marker	
		Error in distance from south wall (feet)	Distance downglacier from Y–Y′ (feet)
4	−14.7	+2.2	2.2
5	−22.5	−0.9	2.2
7	(1)	[2]−1.3	4.2
8	−15.7	−1.8	4.9
9	−18.9	−2.3	5.6
10	−18.7	−3.8	6.2
11	−17.2	−3.8	6.8
12	−16.0	[3]−3.8	7.5

[1] Not determined.
[2] Assumed to be average of errors at points 5 and 8.
[3] Assumed to be equal to error at point 11.

TABLE 5.—*Average movement rates of the Teton Glacier*

Point	Average movement rates, in feet per year, for the period—			
	Aug. 17, 1963, to Sept. 21, 1964 (1.08 years) [1]	Aug. 8, 1965, to July 25, 1966 (0.94 year) [2]	Sept. 21, 1964, to July 25, 1966 (1.85 years) [2]	Aug. 17, 1963, to July 25, 1966 (2.94 years) [2]
4	30.2	28.6	24.7	22.7
5	32.5	27.6	26.7	24.7
7	34.1	29.4	([3])	([3])
8	33.9	28.6	29.7	28.4
9	34.2	27.1	30.0	28.2
10	34.8	26.8	28.6	27.7
11	29.0	25.2	26.6	24.8
12	24.8	14.1	----------	17.8

[1] Computed from data from previous surveys (Reed, 1965, table 1).
[2] Computed from data from the 1966 survey.
[3] Marker not recovered.

table 2); in 1966 its altitude was 641.4 feet, only 0.8 foot below its original position. Thus, the inclination of the flow line in the direction of movement was only −1°, appreciably less than the −11° slope of the ice surface in 1966. At this point, at least, relative motion of the ice is upward toward the surface, as would generally be expected in the ablation zone of a glacier.

The longitudinal profile of the glacier in 1966 along with line *X–X′* (fig. 1) was determined by stadia and Beaman arc readings from point 8. The profile is little changed from that in 1963. The apparent increase in thickness of the ice in the upper part of the profile may be due to a surveying error but is probably real. Differences between the 1966 and 1963 profiles in the central reach of the glacier are close to the limits of accuracy of the surveys and are probably not significant. The thinning of the ice close to the terminus is apparently real.

More precise transverse profiles along line *Y–Y′* (figs. 1 and 2) are shown in figure 3. They indicate that the glacier was generally 2–8 feet thick along the line of profile in 1966 than in 1963. Part of the increase in thickness may reflect the fact that the 1966 survey was made much earlier in the ablation season than the previous surveys, but the consistency between the 1965 and 1966 profiles suggests that the thickening is not entirely a seasonal effect.

The northern part of the terminus of the glacier was in virtually the same position in 1966 as in 1963 (fig. 1), but a slight advance (locally as much as 30 feet) of the southern part of the terminus was detected. Whether this advance indicates an end of the long-term retreat of the terminus or is merely a minor oscillation remains to be seen.

A vertical glacier mill, or moulin, 10 feet in diameter and about 200 feet downglacier from point 6 of the 1966 survey, afforded an unusually good opportunity for directly measuring the minimum thickness of the glacier. A heavy stone on the end of a steel tape lowered down the opening encountered rock at a depth of 64 feet. The rock may be an erratic embedded in the ice, but it seems more likely that the mill extended all the way to the floor of the glacier. If so, the ice thickness measured is in rather close accord with the thickness of about 50 feet previously compiled (Reed, 1965) from changes in slope and elevation of the ice surface at this part of the glacier.

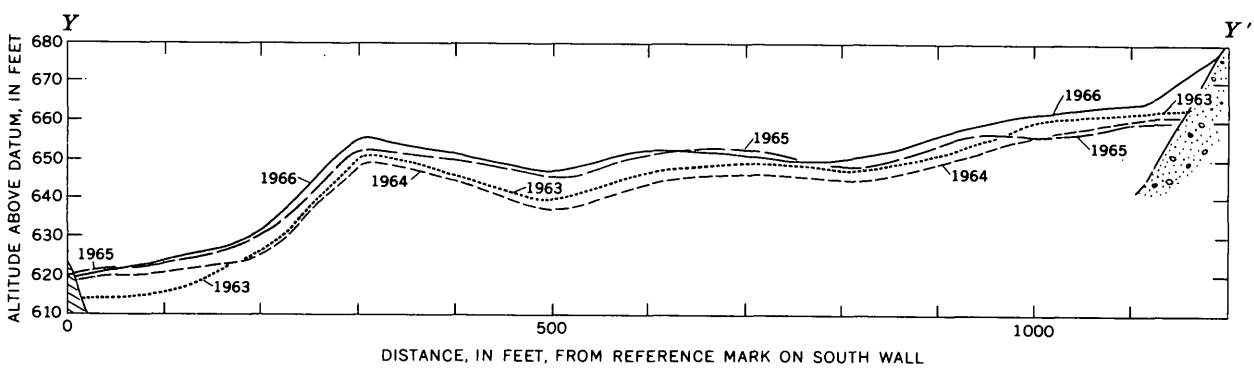

FIGURE 3.—Transverse profiles across the Teton Glacier along line *Y–Y′* (fig. 1). Arbitrary datum is 9,780 feet above sea level. Ruled area, bedrock; stippled area, moraine.

REFERENCES

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