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GRINNELL GLACIER, GLACIER NATIONAL PARK,
MONTANA

BY

GEORGE R. GIBSON AND JAMES L. DYSON



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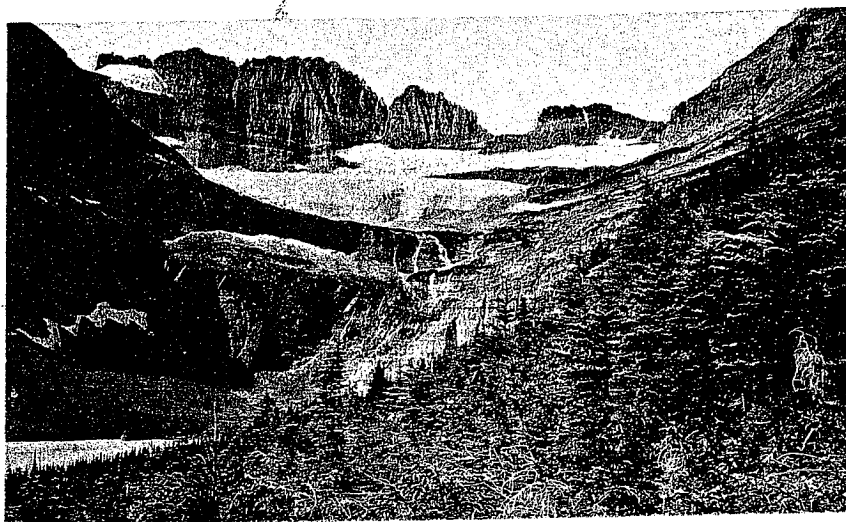


FIGURE 1. FROM THE EAST, AUGUST 1911
Photo by T. W. Stanton, U. S. Geological Survey.

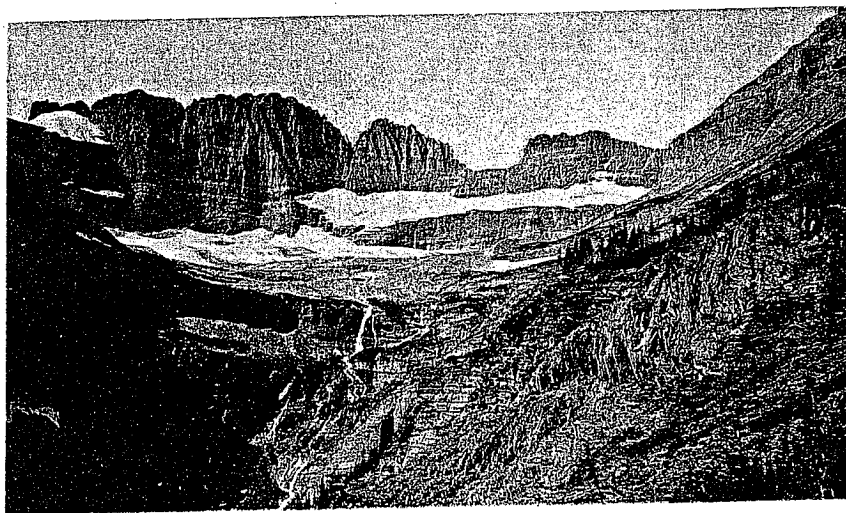


FIGURE 2. FROM THE EAST, AUGUST 29, 1935
The glacier consists of two separate ice bodies in contrast to the condition depicted in Figure 1.
The north moraine lies at the extreme right edge of the lower ice mass.

GRINNELL GLACIER

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GRINNELL GLACIER, GLACIER NATIONAL PARK, MONTANA

BY GEORGE R. GIBSON AND JAMES L. DYSON

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ABSTRACT

Stratification due to the annual accumulation of snow is well exhibited in Grinnell Glacier. Layers of snow in the narrow firn zone at the head of the glacier are wedge-shaped and have a steep initial tilt toward the glacier front. Weight of overlying layers forces the earlier-formed layers to rotate so that after travelling a relatively short distance they assume a backward dip which gradually increases until, approximately halfway between cirque wall and glacier front, a maximum of 45 degrees is attained.

Detailed study of the position of ice strata in various parts of the glacier has yielded information on the nature of the ice motion, the age of the ice, and its probable thickness.

Available records dating back to 1897 and direct observation by the authors over a 4-year period indicate that Grinnell Glacier has been reduced to about half the size it was in 1900, and that the recession during recent years has been most rapid.

INTRODUCTION

Most of the data for the preparation of this paper were secured during the mapping of Grinnell Glacier in the latter part of August 1937 and from observations made at intervals during the summer months of 1935, 1936, and 1938.

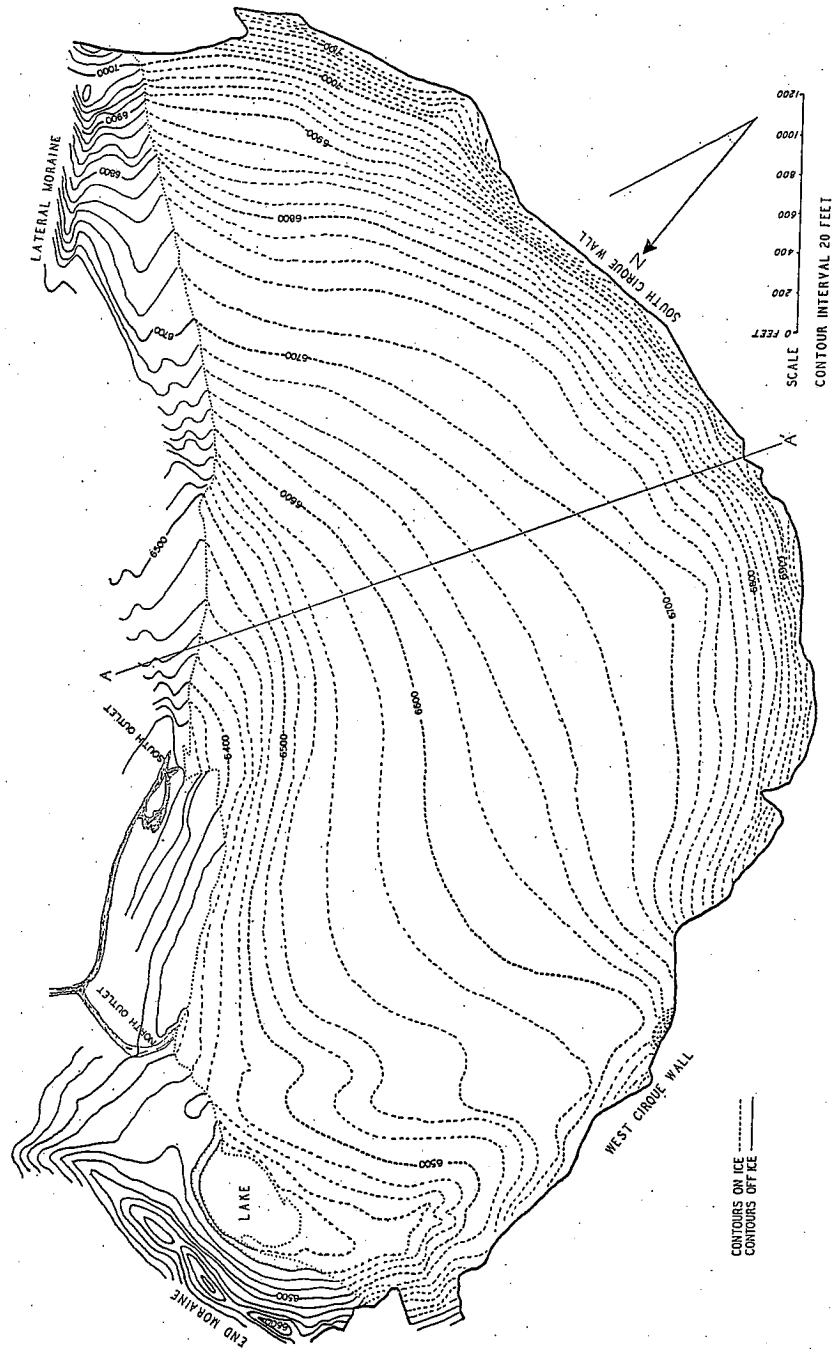


FIGURE 1.—*Topographic map of Grinnell Glacier*

Elevations based upon datum determined by aneroid. (Used with permission of The Director, National Park Service, Washington, D. C.)
For section A-A', see Figure 4.

The writers felt that a detailed study of a cirque glacier could be expected to yield interesting results. Large, rather than small, glaciers have usually been most carefully examined, and attention has been directed mainly to their broader features. Details which might provide the keys to understanding of important glacial phenomena have therefore often been neglected. Further, a small cirque glacier in an extreme state of decadence, as is the case with Grinnell, exhibits evidence of its structure and displays other glacial characteristics very clearly. Such a small cirque glacier has motion, deposits morainic material, and performs other typical glacier functions. If it is also receding, the results of these functions tend to be progressively exposed. Additional striae and moraines are being uncovered yearly, and all parts of the glacier are made accessible because of the nearly complete disappearance of snow from its surface in the late summer.

The authors wish to acknowledge their indebtedness to the National Park Service for the opportunity to carry on the work, and to Professor L. M. Gould and Professor O. D. vonEngeln for suggestions during the preparation of the manuscript.

LOCATION AND GENERAL DESCRIPTION

Grinnell Glacier, one of the larger ice masses in Glacier National Park, is situated on the east side of the Continental Divide at the head of a tributary of the Swiftcurrent Valley. Its melt water drains by way of Swiftcurrent Creek and the St. Mary, Saskatchewan, and Nelson rivers into Hudson Bay.

Grinnell is representative of most glaciers in the region in that it lies in a conspicuous steep-walled cirque, the floor of which is a shelf situated about 1300 feet above the main part of the valley which was formerly occupied by a large valley glacier. The Chief Mountain, Montana, and Glacier National Park, Montana, topographic sheets of the United States Geological Survey show Grinnell Glacier (latitude $48^{\circ} 45'$ north) as mapped in 1900. At that time and until sometime between 1911 and 1929 the glacier consisted of two parts, a very steep upper part lying on a bench in the western part of the cirque and a lower larger part—the main mass of the glacier. The upper part was connected to the lower by a narrow, much crevassed tongue of ice (Pl. 2, fig. 3). The separation of the glacier, prior to 1929, has given rise to two independent ice masses. It is the lower and larger of these that is herein considered and is referred to as Grinnell Glacier.

The elevation of the lowest part of Grinnell Glacier in August 1937 was approximately 6300 feet as determined by aneroid, and the difference in elevation between this point and the highest part of the ice was 840 feet

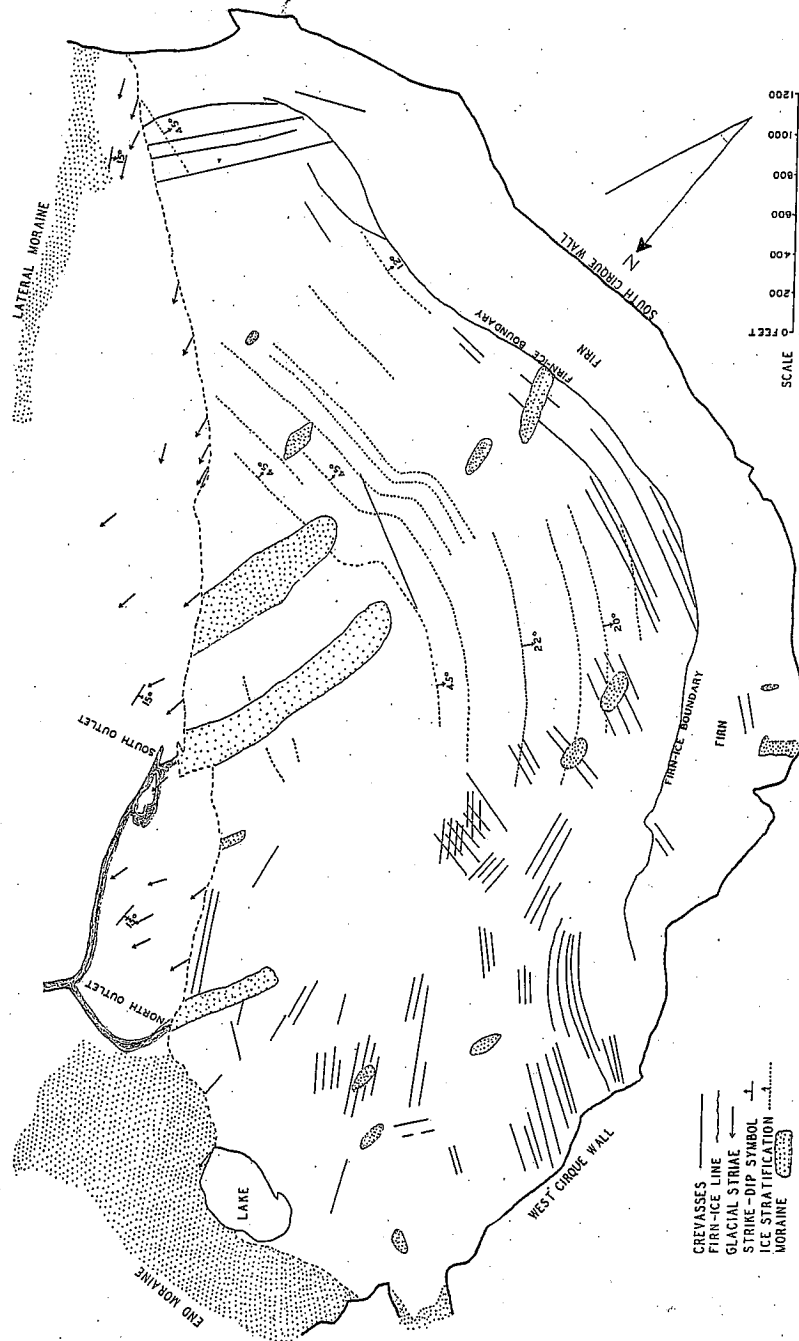


FIGURE 2.—Grinnell Glacier in August 1937

(By permission of The Director, National Park Service, Washington, D. C.)

(Fig. 1). The surface area at that time was about three-quarters of a square mile.

The longest dimension of the glacier (northwest-southeast) was 6800 feet, only slightly less than the same dimension as recorded on the U. S. Geological Survey maps. This figure gives the approximate maximum extent of the glacier from side to side. At a right angle to this direction the ice mass had a length of 3200 feet, which is considerably less than the same dimension on the United States Geological Survey maps. This value is also smaller than that recorded by Alden (1914, p. 19) from his observations in 1911 when the glacier had a length of about a mile (northeast-southwest).

On its west and south sides Grinnell Glacier is bounded by the vertical walls of the cirque. The east border of the ice for the most part is thin and rests on a smoothed and striated bedrock surface. This edge of the glacier has been retreating more rapidly than the north border of the ice. An abandoned lateral moraine roughly parallels the east edge of the glacier. This morainic embankment was separated from the ice in August 1937 by a distance varying from approximately 200 feet to a quarter of a mile. The moraine at the north side of the glacier is much higher and more conspicuous. Between the north edge of the ice and this moraine there is a small lake immediately east and west of which (Fig. 1) the ice front rests against the base of the moraine. This lake, because of the presence of snowdrifts, does not usually appear until late June. In August 1937 several conspicuous blocks of ice broken from the glacier appeared as icebergs in the lake (Pl. 2, fig. 2). At its eastern end the bottom of the lake is a grooved and striated bedrock surface.

The ice in places is prominently crevassed and relatively free of debris except for thin morainal bands along the east border and isolated "debris islands" scattered over the surface (Fig. 2).

ICE STRATIFICATION

If the glacier is viewed from a point several hundred feet above its surface and from the east or west sides, parallel lines will be noted sweeping across the ice in a series of graceful curves more or less conforming to the configuration of the cirque wall (Pl. 3, fig. 1). They are most prominent in front of the snow-covered area which bounds the south wall of the cirque.

At places these zones or bands are about 2 to 3 inches in width and are composed of ice mixed with dust, organic material, and fine particles of rock. Because of the greater absorption of the sun's heat by this material, the bands are made more conspicuous by being depressed slightly below the surface of the ice. At other places where the ice is charged

with more debris, these zones may be several feet wide. They are from 6 to 15 feet apart on the surface and have a dip of 12 degrees to the south at the firn-ice boundary, but gradually become steeper until at some points 1100 feet from the border of the firn they attain a maximum dip of 45 degrees to the south. Thus the thickness of the ice between the zones is 4 to 6 feet. Because of minor irregularities of the ice surface these dips can be readily noted (Pl. 3, fig. 2). In crevasses the dips of these zones can be measured to depths of 40 feet below the surface. At each site examined the dip was found to be constant to that depth.

The banding of glacial ice has been often discussed in the literature, and there seems to be general agreement among observers in regard to its causes. The type of banding found on Grinnell Glacier, for the reasons cited above, is that which most authors describe as the boundary planes or zones between successive snowfalls. Agassiz (1840, p. 40) mentioned it, and Russell (1897, p. 43), in discussing the glaciers of the Sierra Nevada, called the phenomenon "dirt bands" and said that these were to be observed on nearly all the glaciers of that region. He described them as discoloring the ice in well-defined strata dipping into the glacier at a low angle with the surface. Sherzer (1907, p. 118-119) described several types of banding in the glaciers of the Canadian Rockies and attributed one type to stratification resulting from the separation plane between successive annual accumulations of snow. The stratification in Grinnell Glacier corresponds to these descriptions. Sherzer designated the surface manifestation of the stratification "dirt zones" in order to make clear the distinction between them and the "dirt bands" of Forbes, which are due to dirt accumulating in open crevasses that later close as they move toward the glacier front. Seligman (1936, p. 273) said:

"A form of stratification is particularly well seen in the firn snow region of glaciers, especially where crevasses have laid bare enormous sections. There is little doubt in the minds of modern glaciologists that these strata tally with the seasonal precipitation, although it seems probable that during the latter part of the firnification process the individual falls of snow become absorbed. When stratification is apparent in true ice this is still more certain."

The location, size, and shape of the snowfield area adds support to the interpretation that this banding on Grinnell Glacier can be attributed to seasonal falls of snow, with each season contributing a stratum. On Figure 2 the snow-ice boundary can be noted extending from the east side of the glacier westward to the point where the cirque wall turns due north. The shape of the firn field is that of a crescent slightly over a mile in length and 600 feet wide at the center. Its location is at the head of the glacier resting snugly against the cirque wall. The total area occupied by the firn field is approximately 0.06 square mile or about 8 per cent of the surface of the glacier.

Several factors govern the size and shape of the firn area. Most of the day the back portion of the glacier is protected from the sun's rays by a high vertical cliff, preserving the snow there from much melting, while the portion of the glacier not so protected loses all its winter accumulation of snow during the summer. The cirque wall lessens the velocity of the wind in its immediate vicinity also. Farther out on the ice, the wind is distinctly effective in evaporating snow, especially in summer. The prevailing west wind sweeps over the cirque basin in the winter, causing a whirlpool of air which drifts the snow back against the cirque wall, piling it to a much greater thickness there than elsewhere on the glacier. The authors studied these currents from the top of one of the cliffs above an abandoned cirque late in August. A map was snatched by the wind and carried out over the basin 2000 feet below. As the map moved toward the open end of the cirque it gradually settled and when a certain level was reached it came back toward the foot of the cirque wall and rose slightly, then settled. This type of wind action and the fact that the snow melts from the rest of the surface would be responsible for the firn field being the steepest part of the glacier with the greatest declivity next to the bergschrund. Therefore, the protection offered by the cliff at the rear of the cirque and the drifting action of the snow by the wind would account for the location, shape, and size of the firn field.

EXPLANATION OF DIP OF ICE STRATA

In observing the stratification lines, it was noted that the dip was approximately 12 degrees to the south at the firn line and gradually became steeper until about halfway to the glacier front at places it reached a maximum of 45 degrees to the south. A similar observation was made on the Victoria Glacier by Sherzer (1907, p. 38-39). He says:

"These strata all dip toward the regions of accumulation, directly beneath the front of the hanging glacier. In the lower part of the glacier this dip averages 22 degrees, ranging from 12 degrees to 26 degrees, while farther up-stream the dip is more gentle, only 5 degrees to 10 degrees, as well seen in the crevasse walls."

Why should the dip increase as the ice moves toward the front? An answer to this question might tell us something concerning the movement of ice in the vicinity of the head of the glacier.

The reservoir of the glacier is the firn field which lies against the cirque wall where the ice receives protection from the sun and wind. It is crescent-shaped, slightly over a mile in length, and about 600 feet wide. It probably is at least 40 feet thick at the cirque wall and tapers to a thin edge toward the north. Away from the firn field the ice strata range between 4 and 6 feet in thickness, thus requiring 40 to 60 feet of snow for the formation of each layer. This amount of snow seems large

in a region where the annual precipitation is approximately 30 inches. However, drifting apparently accounts for it.

Each winter a new layer of snow is added, dipping north since that is the direction of the slope. In summer, dust, particles of rock, and organic material are deposited on the surface by the wind, thus making

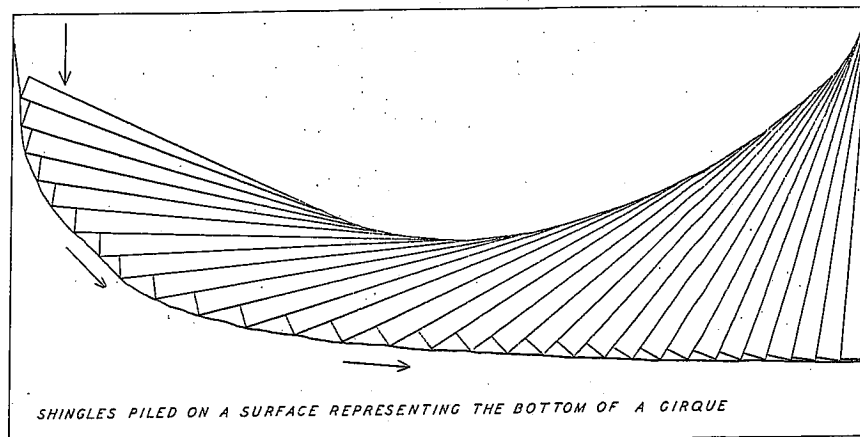


FIGURE 3.—*Diagram of shingle model*
Showing movement of ice strata in Grinnell Glacier.

a visible bounding plane between each season's accumulation. Each season's snow is compacted into a wedge-shaped mass of granular snow, thickest at the cirque wall. By its own weight and that of the later layers this wedge moves downward.

The bedrock floor upon which the glacier rests may be either a nearly horizontal surface or a distinct basin. Both these types of floors are exhibited by other cirque basins in the region. Assuming either, the ice layers as they move down the cirque wall and then over the floor would have to tip backward, and the dip of the stratification planes would become steeper with increasing distance from the cirque wall.

A model (Fig. 3) was made which illustrated this rotating movement at the rear part of Grinnell Glacier. A number of shingles were used in experimentation for the development of the model. Each shingle, because of its wedge shape, represented one season's accumulation of snow. The profile of the cirque floor was that of a vertical backwall joined to a nearly horizontal floor by an arc. If a complete basin with the floor a surface concave upward were used, approximately the same rotating results would be attained.

The shingles, with the thick end at the backwall, were placed one on top of the other and pushed downward. The curvature of the lower

part of the backwall forced the shingles to rotate, taking a higher dip backward as each shingle moved downward and forward. This type of rotation would continue until the more level surface of the cirque floor is reached and would probably be inhibited where the downward pushing of the later layers ceased and where the horizontal pushing became the more important. In the case of a basin-shaped floor the layers would rotate slightly until the lip of the basin is reached. If this model indicates the ice motion near the head of the glacier, the thin part of each wedge is removed by melting before it has travelled far and only the ice which was originally next to the cirque wall, or which composes the thick end of the wedge, reaches the glacier front. The strata starting out inclined toward the front rotate and take a backward dip while passing over the arc connecting the cirque wall and the floor.

There is other evidence that the ice probably moves in this way. Piles of rock debris are found on the ice from a short distance in front of the firn line to the ice front. The material forming these piles came from the cirque wall at some distance above the glacier, as can be noted by the scars left by rock avalanches. Because of the steepness of the firn slope they probably came to rest near the firn line and were buried by the next season's snowfall. However, they soon reappear because of melting and ride on the surface to the glacier front. Even if a pile of rock were buried in the middle of the firn it would soon reappear at the surface; this seems to be the case because some of the largest piles are near the snow-ice line.

The fact that the stratification planes have a constant dip to a depth of 40 feet, as noted in crevasses, would indicate little differential movement across the planes. Most of the movement must have been parallel to the bedding planes. In this respect the glacier moves in a more or less rigid manner with approximately the downstream half moving as a unit. Plastic flow apparently takes place in a very thin zone along the base of the glacier, as indicated by the small amount of distortion in ice strata at places along the ice front and by the sinuous courses of striae adjacent to Grinnell and other ice masses of the Park (Demorest, 1938, p. 700-725).

With the aid of a hand lens on Figure 1 of Plate 3 a count of the stratification lines was made. From the south cirque wall to a point on the east front about 300 feet east of the easternmost morainic band (Fig. 2), a distance of 1800 feet, approximately 60 stratification lines were counted. If these lines are the surface expression of boundary planes between successive seasonal accumulations of ice, the time necessary for the ice in the eastern part of the glacier to travel from the cirque wall to the ice front is approximately 60 years. Thus the average rate

of movement for the last 60 years in that part of the glacier is about 30 feet per year.

FEATURES OF ICE MOTION

The direction of striae on bedrock adjacent to the ice, the trend of morainic bands on the surface of the glacier (Fig. 2), and the trend of ice stratification bands indicate that the motion of Grinnell Glacier is not from the cirque wall directly out to the ice front. Debris within and on the ice along the south cirque wall (Fig. 2) in its travel to the terminus follows a course which describes an arc convex to the west. Apparently the ice moves out from the south cirque wall and parallel to the west wall. Thus, based upon the orientation of morainic bands, striae, and ice stratification, it appears that the maximum horizontal distance ice within the glacier can move in its course from cirque wall to ice front is approximately seven-eighths of a mile. This distance then is the true length of Grinnell Glacier.

Notwithstanding its small size and apparent thinness, this glacier thus exhibits flow phenomena not unlike those of a long valley glacier which may follow a sinuous course from cirque head to terminus. Striae near the east border of the ice indicate that there was an even greater curvature in the lines of glacial motion 10 or 15 years ago, as striae, with increasing distance from the glacier, trend more toward the northeast. Ice originating in the firn zone along the south cirque wall moves in a direction somewhat west of north. After travelling a mile this ice must have been moving in a direction nearly 20 degrees east of north, about 30 degrees from its initial direction of motion.

The character of the material in the moraines themselves gives a further clue to the direction of motion of the glacier. That portion of the north moraine adjacent to the present north margin of the ice is a typical terminal moraine. In addition to much angular material, it includes numerous striated and glacially modelled boulders and much rock flour which acts as mortar binding the coarser materials of the moraine together. Thus, the inside or ice-contact slope of this accumulation is actually steeper than the angle of repose of the material. So firmly cemented is it that erosion and sliding of its surface have been negligible since withdrawal of the ice which began sometime prior to 1900. This surface of the moraine is marked by several small closely spaced ridges which run from the base of the moraine to its crest in the same direction that the former ice moved. This feature is much more pronounced on the ice-contact slopes of other moraines in the Park, particularly those adjacent to Sexton, Clements, and Sperry glaciers. On the Sperry moraine the ridges are so numerous that the inside surface of the moraine has a fluted or furrowed appearance. In addition to representing the former

direction of ice motion these small ridges indicate that the ice moved up over the inside surface of the moraine. Under these circumstances considerable material was plastered onto the surface of the moraine directly from the basal portion of the ice.

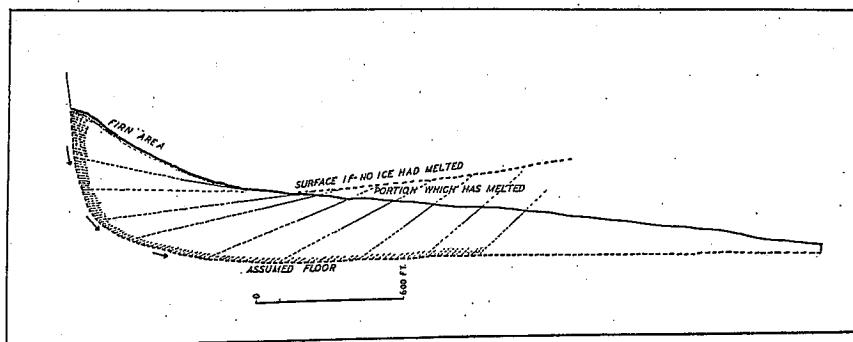


FIGURE 4.—Idealized cross section of Grinnell Glacier
Along the line A-A' on Figure 1.

The east moraine, in contrast to the north, is lateral. As material within and on the glacier was carried parallel to this moraine it is considerably smaller, in spite of the long stand of the ice against it, than the terminal moraine at the north ice front. Its contents are mainly angular blocks of rock, many of which have come to rest in the moraine after sliding across the ice surface. Striated boulders are extremely rare in this accumulation, and rock flour is not present.

Present erosional activity of Grinnell Glacier is perhaps indicated best by the milkiness of its discharged melt water. Grinnell Lake, about a mile downstream from the glacier, acts as the first settling basin for the rock flour. Despite this half-mile wide expanse of still water enough rock flour persists to the outlet to give that stream a noticeably milky appearance. It is not until the water passes through Josephine Lake and then Swiftcurrent Lake, 5 miles from the glacier, that it becomes a clear stream.

The water in the small lake at the north end of the glacier and in the north outlet (Fig. 1), which apparently drains the lake, is very milky, whereas water of the south outlet is quite clear. It appears that the source of rock flour is the north and northwest portions of the ice which drain through the north outlet. The south outlet receives melt water from the southeast section of the glacier. There probably is a high area or divide on the cirque floor under the glacier between these two drainage areas. This is indicated by the trend of the ice stratification lines. When traced from the east edge of the ice they trend in an east-

west direction. East of the center of the glacier they turn southwest for 200 feet and then resume the east-west trend. This flexure might be caused by a ridge of rock underneath the ice; in fact, a ridge of rock which lines up with the strike of this flexure can be noted passing under the ice.

The fact that the ice of the southeast portion of the glacier is too thin to do significant erosive work seems inescapable. If such is the case, ice of the northwest part may be lying in a basin such as many cirque glaciers have produced in other sections of the Lewis and Livingston ranges. This basin might give the ice the necessary thickness required for erosion and the production of rock flour.

Another, but less likely, possibility is that the glacier has receded to the extent that, with the exception of the relatively small headward portion, it no longer is an agent of corrasion; most of the rock flour in the north outlet stream is being furnished by morainic material, which does contain much finely powdered rock, adjacent to and underlying the northwest section of the glacier. This material was produced when the ice was 100 feet or more thicker than at present. Such an inference entails the conclusion that the thickness of the ice in Grinnell Glacier, with the possible exception of that in the narrow firn zone, probably does not exceed 100 feet. Such a deduction is based upon the work of Demorest (1938, p. 725) at Clements Glacier and upon observations by the authors adjacent to several glaciers similar to Grinnell in the Lewis Range, which show that ice with a thickness no greater than approximately 150 feet is quite capable of performing marked corrasion on rock surfaces of sandstone, limestone, and shale.

RECESSION OF GLACIER

Since about 1900 practically all the ice masses in Glacier National Park have been undergoing rapid recession. That there was a period prior to 1900 during which these glaciers were nourished sufficiently to maintain their size is indicated by the conspicuous, now isolated moraines which encircle the sides and fronts of all the glaciers. In some cases these moraines attain heights of nearly 200 feet. That they represent a comparatively long stand by the ice fronts is indicated by their size; in addition, as observed adjacent to the east lobe of Blackfoot Glacier, the stand was of sufficient duration to enable streams marginal to the ice to entrench themselves in bedrock transversely to the slope.

Historical records of scientific value for the glaciers of Glacier National Park do not extend back much beyond 1900, so that the only means of estimating the latest approximate date when the glaciers completely filled the areas behind the now isolated moraines, or the duration

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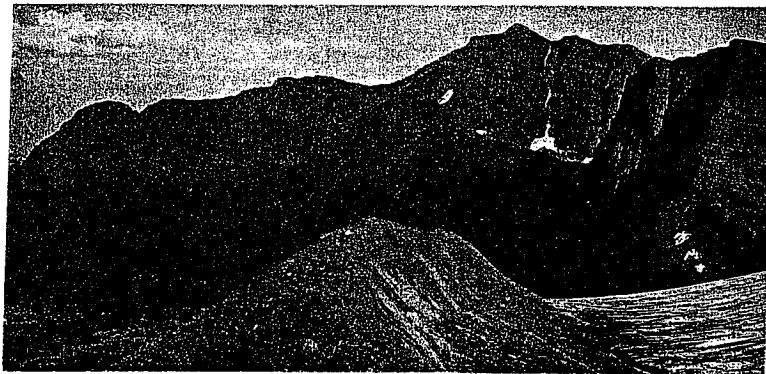


FIGURE 1. ICE RESTING AGAINST NORTH MORaine, AUGUST 1911
Photo by T. W. Stanton, U. S. Geological Survey.

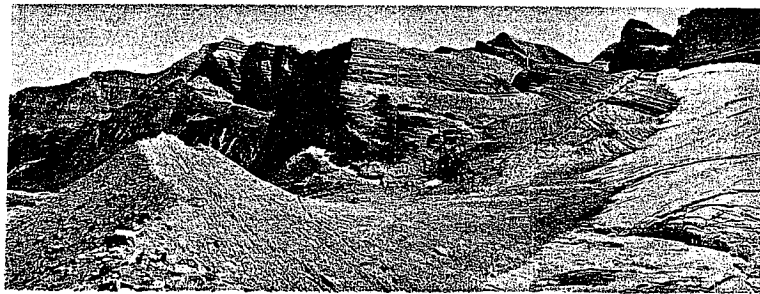


FIGURE 2. EAST FRONT OF GRINNELL GLACIER
North moraine in left foreground. Dashed line shows approximate boundary of glacier in August 1911. Photo taken August 29, 1937.



FIGURE 3. CONNECTION BETWEEN UPPER AND LOWER PARTS OF GRINNELL GLACIER IN AUGUST 1911
North moraine in foreground. Photo by T. W. Stanton, U. S. Geological Survey.

RECESSION OF GRINNELL GLACIER

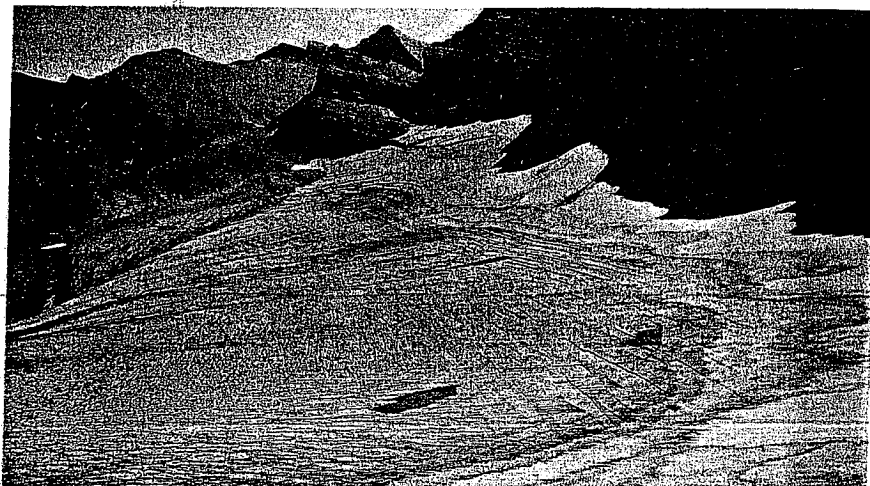


FIGURE 1. EASTERN HALF OF GRINNELL GLACIER
Showing stratification lines and firn-ice boundary.



FIGURE 2. LOOKING NORTHWEST FROM CENTER OF GLACIER
Showing dip of contact planes between ice strata. Photo taken August 30, 1937.

GRINNELL GLACIER

of this stage, may be obtained only from examination of the moraines themselves and from studies of the recent rate of recession. It seems certain, however, that 50 years ago these glaciers had the maximum size allowed by the position of the moraines which surround them today. That all glaciers of the area were affected in the same manner is indicated by the fact that isolated moraines occur around all the glaciers. They are particularly striking at Sperry, Blackfoot, Swiftcurrent, Sexton, Harrison, Clements, and others. Recession of all glaciers since beginning of withdrawal from the moraines has been more or less uniform, although a few which lie in well-protected sites have exhibited noticeably less rapid shrinkage than others.

Photographs¹ taken by E. R. Shepard in August 1897 show Grinnell Glacier resting high against the sides of the moraine which is now isolated. Comparison with photographs (Pl. 2, fig. 1; Pl. 1, fig. 1) by Stanton in August 1911 indicates that the glacier, although somewhat smaller in size, had not undergone an appreciable amount of recession during the previous 14 years.

According to Alden (1914, p. 19), in 1911 the morainal embankment closely bordering the east and north margins of the ice reached heights of 100 feet. The north moraine is the higher of the two, and in August 1937 its crest in places was nearly 200 feet above the surface of the ice (Fig. 1). Alden's statement and comparison of 1937 photographs (Pl. 2, fig. 2) with pictures taken in 1911 (Pl. 2, fig. 1) indicate that the surface of the glacier at the northern terminus has been lowered approximately 80 feet since 1911, thus exposing the lower part of the moraine against which the ice front rested in 1911. This shrinkage of the glacier caused the crest of the moraine to be about 80 feet higher above the ice than when Alden examined it in 1911.

The apparent increase in the rate of recession since 1911 is in part due to the fact that as the ice becomes thinner, particularly at its border, smaller amounts of surface lowering will cause greater recession of the edge of the glacier. A lowering of the ice surface by 80 feet since 1911 along the north margin of the glacier has resulted in only a small amount of recession of the edge of the ice because of its relatively great thickness. Thus the northern edge is not now far removed from the positions it had in 1897 and 1911, whereas the east border of the glacier, which in the past has been much thinner than the north, has shown a large amount of recession. In spite of its greater thickness in the past, the northern edge of the ice has been lowered until it is now very thin. Thus continued wastage of the ice will probably cause a very rapid withdrawal of the

¹ These photographs are now in the possession of Mr. A. L. Sperry of Owatonna, Minnesota.

north front which will, quite probably, correspond to the rate of recession of the east border.

A similar condition has apparently been attained by Agassiz Glacier which is the largest single ice mass in the Park. As reported by Ruhle (1937, p. 298), Park Naturalist of Glacier National Park, ablation prior to 1935 had reduced the ice tongue to a thin sheet, thus probably accounting for the unusually large amount of recession (465 feet) during the 12 months immediately preceding September 1936.

It is reasonable to believe that the west lobe of Blackfoot Glacier, which has likewise been reduced to a very thin tongue (Dyson, 1937, p. 552), will show an increased average yearly rate of recession in the future, provided climatic conditions of the past 10 years continue.

Since 1932 the yearly amount of recession of Grinnell Glacier has been measured each fall by the Park Naturalist. The site used for this work is the short ice tongue at the south outflow stream (Fig. 1) near the middle of the east front of the glacier. The retreat of this part of the ice margin is indicative of the distance of withdrawal all along the east front. During the 4-year period, 1934 to 1937 inclusive, this ice tongue receded a total distance of 165 feet or a mean yearly average of 41.2 feet.

If the ice front remained stationary for a period of years, piles of debris would be formed along the margin of the glacier at the ends of the morainic bands which are so conspicuous along the east border of the glacier (Fig. 2). However, as morainic material is no more abundant on the bedrock surface adjacent to the east edge of the ice than it is on nearby portions of the glacier, the yearly amount of recession (approximately 41 feet in recent years) since the glacier retreated from the east moraine has been as great as, or greater than, the distance the ice moves each year in the frontal part of the glacier. This phenomenon does not apply to the north margin of the ice as there the glacier rests upon a comparatively thick morainic deposit.

From August 26 to August 30, 1920, Alden (1923, p. 268) found by crude measurements that the maximum movement of the ice near the northeast margin (approximately the center of the glacier front) was slightly in excess of an inch per day. If this rate is maintained throughout the entire year the amount of movement would be approximately 35 to 40 feet. This rate corresponds rather closely with the figure derived by the authors from a count of the seasonal bands. However, comparison of the two figures indicates that the rate of motion is somewhat less in winter than in summer. These values, although not accurate, have some significance because two entirely different methods have yielded nearly identical results. They also substantiate the conclusion that the yearly

recession of the glacier front is slightly greater than the distance the ice in that part of the glacier moves each year.

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