

to insure their permanence. The extent to which streams have dissected the blocks and have been adjusted to their differentially resistant beds testifies even more emphatically to the antiquity of the process.

Two poor examples of Toreva-blocks are known to have formed in historic times. Both involve the Mancos-Mesaverde contact. One, about 250 feet long, lies back of Chimépo, Day School and dropped about 1870. It is stated to have caused a local quake and the drying up of the old walled spring. While dropping about 60 feet, with maximum rotation of 14° , it broke into several pieces, now standing at different levels. The other known recent slide is said to have occasioned a slight quake in 1927¹² at a place 43 miles north-east of Toreva, some 6 miles north of Black Mountain Store. The block, about 300 feet long, dropped 60 feet and tilted to 45° . It cracked into numerous angular fragments which, however, were not jostled.

That a more humid climate than the present would have been conducive to the production of Toreva-blocks, by moistening and lubrication of their relatively incoherent underpinings, seems evident. The effects of the Pleistocene climatic regime were certainly marked in the region discussed. The writer has observed evidence of nivation along the top of the Chuska Mountains, about 160 miles east of Toreva and 2,000 feet or so higher; and the probably Wisconsin alpine glaciation of San Francisco Peaks 115 miles to the south-west has been made familiar by the work of Robinson.¹³ That some late Pleistocene or post-Pleistocene climatic regime was responsible for the production of the majority of the Toreva-blocks seems not unlikely. A conspicuously wet climatic episode is believed¹⁴ to have occurred during the first millennium B.C. That any appreciable number of Toreva-blocks were formed at that time may be doubted, both on the grounds of the relatively short duration of that episode and of the apparent antiquity of the slides as evidenced by their stage of dissection.

¹² T. Armijo (Indian trader), oral communication.

¹³ H. H. Robinson, "The San Francisco Volcanic Field," *U. S. Geol. Surv. Prof. Paper* 76 (1913).

¹⁴ C. E. P. Brooks, *Climate through the Ages* (1928), p. 393.

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SNOWSIDE STRIATIONS

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ABSTRACT

Snow, sliding in considerable mass down steeply inclined stratification plane surfaces of limestone, has produced, with the aid of rock tools, striations identical with those due to glacial action. The boulders which caused the marks were found in place at the end of the striations.

INTRODUCTION

Striations and groovings, in practically every characteristic aspect exact replicas of those produced by glacial scour, occur on rock surfaces immediately adjacent to the fronts of small glaciers in Glacier National Park. An extraordinary feature of the development is the retention, at the end of a groove, of the rock tool which did the engraving, a fact which makes inescapable the conclusion that one boulder, in a single traverse over the course, produced the groove. On first examination the phenomenon could be accounted a perfect confirmation of orthodox inferences in regard to the processes of glacial abrasion. While such inferences may be warranted, the grooves here described are probably not due to glacial action. But they do apparently afford a striking demonstration of the facility with which processes akin to glacial action can effect such grooving. If the conditions under which it was formed were not known, a similar development encountered away from the associations present at this site would almost certainly be interpreted as of glacial origin.

DESCRIPTION OF THE SITE AND THE GROOVES

Near the eastern base of Mount Jackson in Glacier National Park the top surface of a massive bed of Siyeh limestone dipping outward $20^\circ-25^\circ$ constitutes the mountain slope over a considerable area. On this surface, superposed on older glacial striae, is a set of similar but less numerous and clearly younger markings. These consist of straight grooves which trend in the direction of dip (down the slope).

Journal of Geology, 1937, v. 45.

At the lower termination of such a groove is found a boulder which apparently is the tool that did the grooving. These boulders are limestone of the same formation as the underlying rock and range in size from small fragments several cubic inches in volume to boulders roughly 8 inches on a side. The sites where some of them were pulled from the bedrock can be identified. Others were brought down to the grooved surface from morainic deposits or from bedrock higher up the slope.

As is commonly true of glaciated rock surfaces, the one on which these boulders occur exhibits a more or less corrugated appearance due to the abundance of glacial grooves and striae present. Here these range in size from very small scratches to grooves several inches deep and up to nearly a foot in width. The entire surface, including the portion within those grooves which are certainly of glacial origin, is weathered to the extent that the rock is somewhat softened and has a uniform buff color. The fresh rock is bluish gray. The maximum thickness of the weathered shell probably does not exceed $\frac{1}{8}$ inch and for the most part measures about $\frac{1}{16}$ inch.

The superposed striae extend parallel to the older grooves; some of them partially coincide with the courses of the older grooves. But the superposed striae appear quite fresh. Weathering has not smoothed off their edges and the surface within them is lighter in color than the adjacent limestone (Fig. 1). An identical effect is produced when the limestone is scratched with a knife point. The unweathered grooves range from a mere trace to more than an inch in width and have depths up to $\frac{1}{4}$ inch. In nearly every instance the grooves are most prominent, particularly in width, near the boulder lodged at their end. The increased width indicates that the cutting points of the boulders were blunted while functioning as the abrading tools. Examination showed such inference to be correct in the case of those at the ends of grooves which could be traced for a distance of 35 feet or more. Smaller boulders, found to be derived from the intersections of joints on the rock surface only 10 or 15 feet distant, had uniformly sharp edges. But the grooves these sharp boulders made were deeper than those made by the rounded boulders. All the superposed grooves were cut mainly in the weathered portion of the underlying limestone. However, where the courses cross joints or

irregularities in the surface the grooves extend down into the blue unaltered rock.



FIG. 1.—Several boulders on the partly weathered dip slope of Siyeh limestone at the Siksikaikwan glacier site, August 24, 1936. The largest boulder seen in the picture is roughly 8X6X6 inches. The view looks down the dip to the morainic ridge.

This area is one from which Blackfeet glacier has rather recently withdrawn. The recession of this glacier has been rapid, although

G. C. Ruhle, "Measurements on Glacier Recession in Glacier National Park. Year 1936," *Report of Park Naturalist*. Mimeographed, obtainable from National Park Service, Glacier National Park.

during the period of accurate measurements (1932-36, inclusive) its retreat has amounted to only slightly more than 10 feet annually. In view, however, of the amount of weathering which the limestone surface has undergone and the amount and kinds of vegetation on the nearby moranic deposits, it seems hardly possible that the area was ice-covered at any time during the last fifty years. It also appears that the ice which had extended thus far at an earlier date had a thickness not exceeding 50 feet. At present the west lobe of Blackfoot glacier, known as Siksikaikwan glacier,³ terminates about half a mile from this site. It rests on the surface of limestone beds dipping in the same direction and at the same angle as the surface under discussion and flows down the dip of these beds. This lobe of the glacier appears not to have developed a cirque with a floor lower than its outlet because of the steepness of the dip of the beds over which it moves. Accordingly the glacier ice does not exceed 25 feet in thickness at points approximately $\frac{1}{4}$ mile back from its front. The ice which covered the grooved limestone surface when the glacier was considerably larger than at present must have been similarly thin.

The rate of movement of Siksikaikwan glacier is 45 feet in a year according to measurements for the years 1934 and 1935 made by Dr. Ruhle.

ORIGIN OF THE GROOVES

The two possible origins of the superposed grooves are (1) glacial action and (2) snowslide action.

Glacial origin.—On the basis of the mechanics involved it would seem that a very considerable thickness of glacial ice would be required to supply enough pressure to produce striae with depths of a quarter of an inch or more in a single traverse. But the situation is such as to make the recent presence of thick glacial ice inconceivable. On the other hand, the striking similarity of the superposed grooves to striae of unquestioned glacial origin would ordinarily warrant assigning them to the same agency. Moreover, the superposed grooves extend parallel to the older ones which are undoubtedly of the U.S. Geol. Surv., Blackfoot glacier is incorrectly labeled Blackfoot glacier.

³ *Op. cit.*

glacial origin, and they are parallel to the direction of flow that a glacier covering the area would probably, though not necessarily, follow.

It is, however, exceedingly unlikely that boulders as small as those found here would have remained fifty years or more at the exact spot on which a glacier left them. During most of the period of the year (usually less than two months) that the surface on which the boulders rest is not snow-covered it is subject to the action of water from melting snow higher up the slope. The steepness of the slope leads one to infer that snowslides must be frequent, or at least that snow-masses must shift enough to have displaced the smaller stones. The smooth, steeply dipping surface forms a natural "sliding board." Accordingly the fact that the very small stones in August, 1936, were in many instances exactly in place at the lower ends of the grooves which they undoubtedly had produced makes their glacial deposition most improbable.

The inference that the steep outward dip of the formations promotes snowsliding and, incidentally, accounts also for the failure of the Blackfoot glacier to excavate a cirque basin (Fig. 2) is supported by the observations of Flickiger⁴ who asserts that such surfaces are the only type of structure which can inhibit glacial erosion and promote the sliding of glacial ice masses. Flickiger (p. 19) cites an ice avalanche of the Alets glacier of the Bernese Oberland on September 11, 1895. A portion of the glacier resting on a stratification plane inclined 30° broke loose and plunged down to the Spital Meadow along the Gemmi path. The exposed rock surface, Flickiger says, did not have characteristic glacier modeling. On page 47 he returns to this topic as follows:

Analysis of the glacial action at the Alets and Rosenhau glaciers makes it evident that flowing ice has minimum adhesive and erosive effectiveness when moving over the stratification plane surfaces of steeply inclined formations. If it does excavate a cirque basin in such a structure the process is one of ripping out plate after plate of the dipping beds.

The fresh appearance of the superposed grooves is further evidence against a glacial origin. The Siyeh limestone weathers so

⁴ Otto Flickiger, "Glaziale Felsformen," *Petermanns Mitteilungen, Ergänzungsheft*, No. 218 (1934), pp. 19 and 47.

rapidly that fresh surfaces would become discolored in a comparatively few years. But the smallest of these scratches appears as fresh as though it had just been made.

Snowslide origin.—As previously stated, the superposed grooves have been cut mainly in the partly weathered portion of the rock

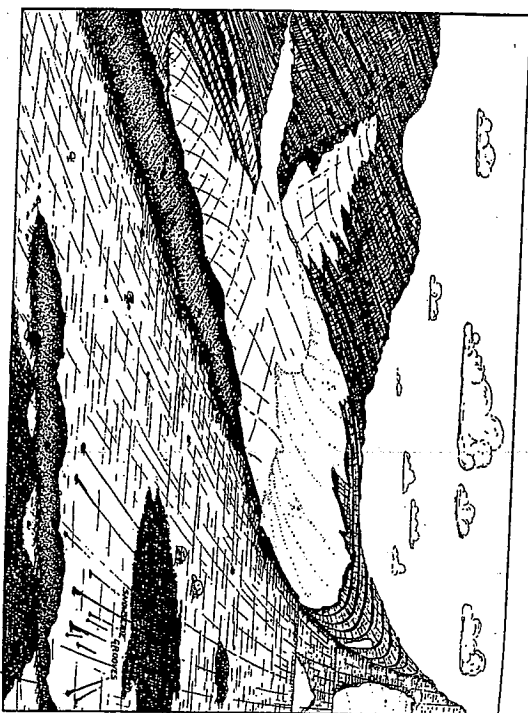


Fig. 2.—Idealized sketch showing relation of glacier, moraines, and snowslide grooves to the dip-slope surface. The grooves of most of the boulders can be traced upslope a distance of about 40 feet to the point where the rock surface meets vegetation-covered material beyond which bedrock again appears and continues unbroken, except for scattered thin patches of loose material, to the main mass of Mount Jackson where the dip, and thus the slope, appreciably steepen. The latter place is the site of snow accumulations which feed the slides.

surface. Less pressure would therefore be required to produce them than on fresh rock. Although parallel to the older grooves of undoubted glacial origin, both sets trend down the slope, a direction which snowslides would necessarily follow. Glacial striations examined adjacent to the ice-fronts of Blackfeet, Sperry, Sexton, and other glaciers on surfaces which the ice is known to have covered not longer than five years ago do not appear so fresh as the superposed grooves at the Siksikaikwan site. The recent glacial striations are

distinct but the surfaces within them do not have the "scratched" appearance which makes the others seem so perfectly fresh.

At Sperry glacier a similar but less impressive development of the same phenomenon was noted. In front of this glacier one side of a trough or small valley down which the ice had once moved is covered with glacial grooves and striae. At right angles to them other scratches or faint grooves appear. At the lower ends of the secondary striations boulders, the tools which produced the scratches, are present as in the case of the Blackfeet glacier site. However, these Sperry glacier striae were only found near the bottom of the glacial trough and in all cases are short, the longest probably being not more than 20 feet in length. But even these small and favorably located striae may not confidently be ascribed to glacial action because the rock surface on which they occur has been free of an ice cover for at least ten years according to people who have been in the region that length of time, and the slope on which the boulders rest is steeper than that on which the grooves occur at Blackfeet glacier. Furthermore, the Sperry secondary striae also extend down-slope in the direction that snow would slide; and this direction is at right angles to the trend of the numerous larger glacial grooves which indicate the direction of the former ice movement. The surface here is argillite of the Grinnell formation and its hardness is greater than that of the Siyeh limestone, which may account for the comparatively slight development of the Sperry scratches.

At the Blackfeet site the sparseness, and hence the wide spacing, of the grooves indicates that they were made in a very brief period. Glaciated rock surfaces are usually ice-polished or else almost entirely covered with grooves and striae. As ice moves continuously across an area, silt, sand, and rock fragments are pushed over it unceasingly until polishing or such complete striation results. Here however, a very few boulders were employed (Fig. 3), a circumstance which indicates that a single snowslide in action perhaps only a few minutes or even only a few seconds was responsible.

Immediately beyond, down-slope from the grooved surface, a tightly compacted, vegetation-covered morainic deposit forms a low ridge (Fig. 2). This moraine is possibly 15 feet high and extends transversely to the slope, hence also to the trend of the grooves.

This ridge would serve as a partial check to the motion of a snow-slide from farther up the slope. On encountering the side of this

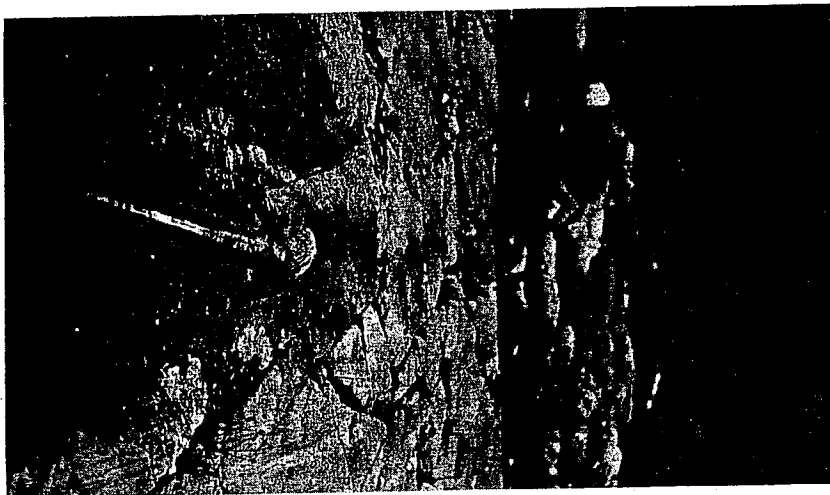


FIG. 3.—View looking down the dip at the same site as Figure 1, August 24, 1936. The boulder in the picture is the largest of all those seen. It is roughly 8 inches on a side, and its groove, at places $\frac{1}{2}$ inch or more deep, can be traced for 50 feet to the upper border of the immediate rock surface.

moraine the bottom masses of the sliding snow would have their motion abruptly checked. Such braking action might momentarily increase the pressure developed at the bottom of the snow mass and so explain the presence of more and larger grooves near the moraine

than on surfaces higher up the slope. Further, such retardation of the basal part would account for the presence of boulders so delicately lodged on a steep (25°) slope.

SUMMARY

The literature on striations and avalanches apparently contains no record of a development such as that described above.

The evidence presented indicates that the grooves in question owe their origin to a recent snowslide; one which probably occurred in the winter previous to August, 1936, when they were observed. It seems that there is no essential difference in the striations produced by the scouring erosion of both snowslides and glaciers. There is, however, a profound difference in the rapidity of the action. As those boulders which moved the greatest distance are less angular, it appears that rock-tools imbedded in the base of the snowslide are, as glacier pebbles seem also to be, subjected to rotation during transportation. Probably the velocity of motions is the factor which makes a swiftly moving snowslide capable of producing, in a second or two, striations and grooves that a thick glacier would require a much longer time to engrave by its cumbersome flow.

¹O. D. von Engel, "Flood Erosion," *Preliminary List of Titles and Abstracts of Papers, Geol. Soc. Amer.* (1935), p. 36.