THE HISTORY OF THE "HOODOOS" NEAR MAMMOTH HOT SPRINGS, WYOMING.

By ALLEN D. HOLE, Earlham College.

The area here referred to, known popularly as the "Hoodoos," is located in Yellowstone National Park about two miles in a southerly direction from Mammoth Hot Springs. It is crossed by the main north-south road leading southward to Norris Geyser Basin, and is therefore familiar in a general way to all who have visited the Park.*

The most striking characteristic of this area, as an observer first views it, is its exceedingly rough and apparently chaotic nature. Huge, angular blocks of stone, varying in size up to 30 or 40 feet in diameter, lie tilted at various angles, and the confused effect is heightened by the fact that the road winds about in a most irregular manner in order to find a possible path across the forbidding surface (see fig. 1). To one who remains on the road the general relations existing between the Hoodoos and the surrounding topographic features are effectually concealed; but to one who climbs to the top of Terrace Mountain, or well up on the slope of Bunsen Peak, the area appears strikingly different, partly because the details of its surface no longer obscure its general features, and partly because the relations of the area to the adjacent slopes, cliffs, and mountains can then be seen.

As seen from an elevation sufficient to permit a general view, the area called the Hoodoos appears somewhat like a relatively broad, slightly winding stream of rock fragments extending from near the base of a portion of the nearly perpendicular cliff face which forms the eastern face of Terrace Mountain in a general southeasterly direction across the road and on down the valley slope practically to the waters of Glen Creek. The particular portion of the cliff face on Terrace Mountain lying directly above this rock stream bears about north 45° east, thus facing southeastwardly. This portion of the face is, measured along its edge, about one-fourth of a mile in length, and the rock stream below has a width which is, on the average, approximately the same. The length of the area, which is here likened to a rock stream,

* The area here called the "Hoodoos" is not to be confused with another region, on the east side of the Park in the Absaroka Range of mountains which has also been called the "Hoodoos," but which is an entirely different region and different not only geographically but historically from the Hoodoos south of Mammoth Hot Springs.

Note: The account here given is based upon observations made by the author and by students under his direction, enrolled as members of classes in the Department of Geology in Earlham College. These observations were made in the summers of 1923, 1925, 1926, and 1928, as a part of a program of systematic geological field work. Acknowledgment is here made of assistance rendered to these field parties through privileges granted by Superintendent Albright, and practical interest in the work shown by rangers and other Park officials.

"Proc. Ind. Acad. Sci., vol. 38, 1928 (1929)."

measured from near the base of the cliff face on the southeastern side of Terrace Mountain to its end near Glen Creek, is about five-eighths of a mile. The average steepness of the slope of the surface of the area, measured along its length from the cliff face on Terrace Mountain to Glen Creek, is about 12°; the upper portion of the area, that is from the cliff face down to the road, is steeper than this average, being approximately 20°, while the slope below the road to Glen Creek averages less than 12°. The difference in elevation between the upper and lower ends of this rock stream is about 700 feet.

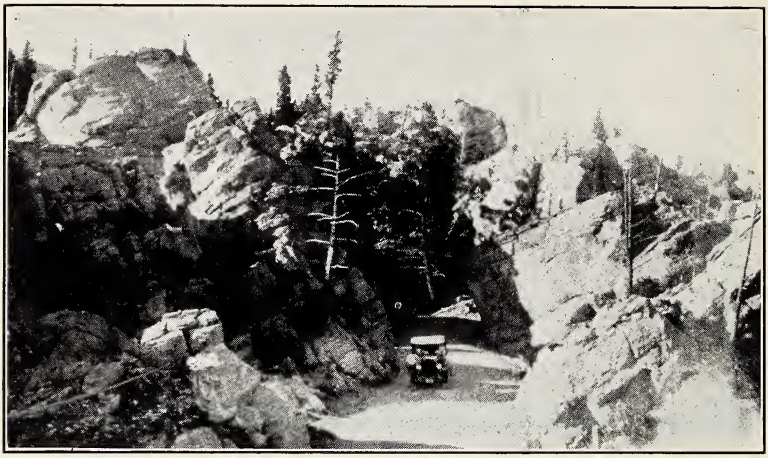

Fig. 1. View along road near Silver Gate, in the Hoodoo region; looking in a northeasterly direction. Note the stratification lines of the large blocks dipping in most cases to the left, that is, is a northwesterly direction. (Photo by Joseph Borden.)

DETAILED DESCRIPTION.

In addition to the general characteristics and relations enumerated above, the following details deserve attention as being more or less essential to an understanding of the history of the area, viz.:

1. When viewed from some distance the generally inclined surface of the area is seen to be characterized by more or less distinctly marked ridges which are, in general, approximately parallel to the cliff face on Terrace Mountain near which the upper end of the rock stream lies. Instead of being precisely straight, however, these ridges tend to be slightly concave in a northwesterly direction; or, stated in another way, they are slightly convex toward Glen Creek as if their central portions had moved a little farther than their ends. Furthermore, the ridges are, in general, straighter and more distinct near the cliff face than farther from it. The first ridge, the one nearest the cliff face, is well marked for a part of its course. Farther away from the cliff face, in that portion of the area in which the largest blocks of rock are found, the ridges are not perceptible except when the surface is viewed from a distant point.

2. The rock represented in the angular fragments observable on the surface of the area is chiefly travertine, precisely similar to the travertine forming almost the whole of the cliff faces on Terrace Mountain. In addition to the travertine, however, there are found scattered irregularly here and there throughout the area boulders, gravel and rock fragments of a variety of kinds, including limestones, sandstones, quartzites, and shales indistinguishable from the rocks constituting the Paleozoic formations outcropping in the Gallatin Mountains, together with a variety of igneous and metamorphic rocks, such as gneiss, schist, granite, andesite, dacite, basalt, and obsidian. These metamorphic and igneous rocks are identical in kind with outcrops in the Gallatin Mountains and other points situated in the direction from which glacial ice of the last epoch came—identical also with the kinds of rock found on top of Terrace Mountain which have been interpreted as evidence that the ice sheet (or ice sheets) of the last glacial epoch passed over Terrace Mountain from the west, southwest, and northwest into that portion of the valley of Glen Creek lying north of Bunsen Peak and east of Terrace Mountain, moving thence northeastwardly to join the glacier which moved down the valley of Gardiner River.

3. In that portion of the area in which the largest blocks of travertine are found the spaces between the blocks are especially large, the openings in some cases seeming to lead downward as if to the entrance of caverns. A number of these openings were explored, especial care being taken to make note of any signs which might be interpreted as evidence of formations characteristic of caverns, such as stalactites, stalagmites and sheet incrustations of calcite. Not only were no such formations observed, but it was also noted that the openings entered had in all cases merely the irregular shapes which result when large blocks of rock are heaped together. In general these openings extend but a short distance. One, however, which it seemed could not be entered except by use of a rope let down into it from above, was found to end abruptly in a dark, angular, enclosed space occupied by bears. Needless to say, exploration in that particular direction was promptly abandoned. Examination of these openings was prosecuted with sufficient thoroughness, however, to warrant the conclusion that not only are there now no caverns in that area due primarily to the work of solution by underground waters, but that the fragments of rock forming the surface of the area have not in general formed parts of walls of such caverns in the past.

4. In the search for data in the field which would be of significance in reading the history of the area it finally seemed clear that a test should be made to determine, if possible, whether the arrangement of the large blocks, as shown by their average direction of dip, is in reality so entirely chaotic and lacking in order as a first glance at the surface suggests. It was therefore determined to record accurately the amount and direction of dip of as nearly all blocks above 20 to 25 feet in diameter as could be examined in the time available. This plan was followed in each of four field seasons, with the result shown in Table I. The measurements listed and collected on the graphic circular diagram,

figure 2, include all measurements made by two separate groups of observers. The total number of observations made is far in excess of those here recorded, but the prevailing trend when all are taken into account is essentially the same as shown here. The smaller number, representing as it does the essential relations observable in the total, is chosen for presentation chiefly because a diagram with a larger number of lines would be more confused and therefore less clear.

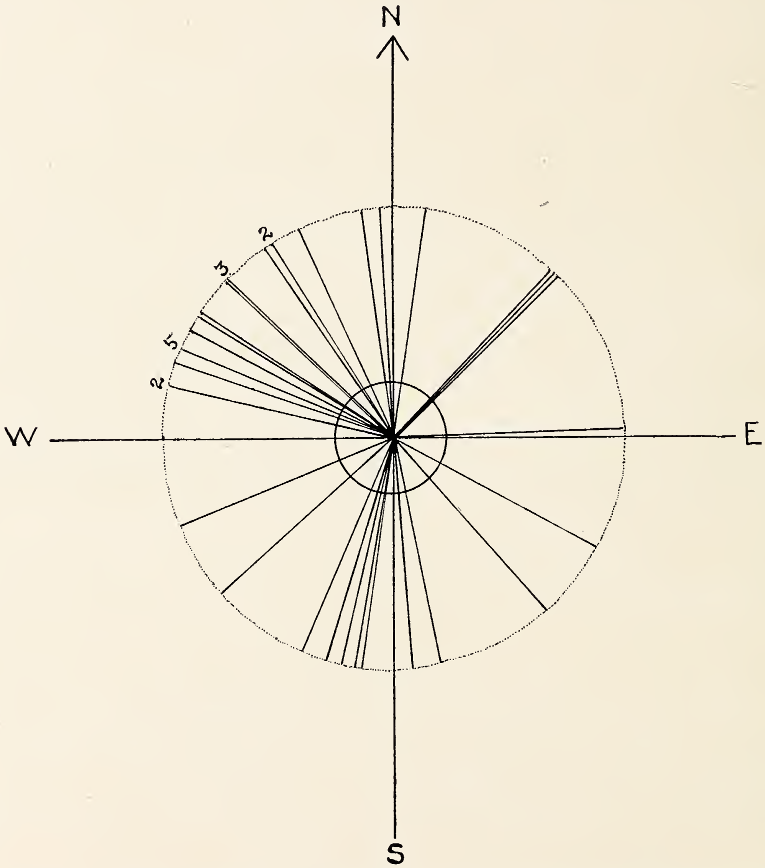

Fig. 2. Diagram showing directions of dip of the 37 blocks listed in the accompanying table. The numbers opposite certain lines in the northwest quadrant indicate the number of blocks having the same measured direction of dip; for example, the line N. 67° W. represents five separate blocks, each having the direction of dip N. 67° W. All other lines in the respective quadrants represent dips of single, separate blocks.

TABLE I. Showing measured degree of dip and direction of dip of 37 blocks 20 feet or over in diameter, selected at random.

Degree of Dip.	*Direction of Dip.*
71°	N. 44° E.
35°	N. 43° E.
43°	N. 3° W.
50°	N. 24° W.
29°	N. 46° W.
69°	N. 58° W.
47°	S. 10° W.
36°	N. 46° W.
44°	N. 34° W.
47°	N. 67° W.
41°	N. 71° W.
41°	N. 46° W.
64°	S. 4° E.
62°	N. 8° W.
33°	N. 46° E.
60°	N. 47° W.
30°	N. 67° W.
25°	N. 62° W.
30°	N. 57° W.
15°	N. 88° E.
70°	N. 8° E.
35°	N. 32° W.
20°	N. 67° W.
65°	S. 48° W.
25°	S. 12° E.
70°	N. 32° W.
65°	S. 42° E.
45°	S. 62° E.
60°	N. 77° W.
40°	N. 67° W.
30°	S. 68° W.
55°	S. 13° W.
25°	N. 77° W.
65°	S. 8° W.
40°	S. 17° W.
35°	N. 67° W.
25°	S. 23° W.

An analysis of the measurements recorded in Table I or an inspection of the diagram, Figure 2, shows that of the 37 blocks of travertine, whose dip and direction of dip are here recorded, more than 75% dip in a westerly direction; and of these 28 blocks which dip in a westerly direction 21, or 75% of the 28, dip in a northwesterly direction. In tabular form the measurements recorded may be classified as follows:

TABLE II.

	Number of Blocks.	Percentage.
Dipping westerly	28	75.67
Dipping easterly	9	24.32
Totals	37	99.99
Dipping northwesterly	21	56.75
Dipping southwesterly	7	18.91
Dipping northeasterly	5	13.51
Dipping southeasterly	4	10.81
Totals	37	99.98

SIGNIFICANCE OF DIRECTION OF DIP.

Of the various theoretically possible classifications of direction of dip of large fragments of rock lying below a parent cliff face, observation shows that only two are of practical importance, namely:

1. Situations in which the dip of strata in the rock fragments is essentially without any system; and

2. Situations in which there is a notable predominance of dip toward or approximately toward the parent cliff face.

The causes and conditions determining these two classes of situations seem to be:

1. Changes of temperature, wedge work of roots of trees, undercutting of a cliff, or some such process, in such manner and to such a degree as to cause the rock fragments to fall outward from the cliff face and to come to rest after rolling partially or entirely over. In other words, rock fragments found lying without any systematic or prevailing direction of dip are essentially talus slopes which have accumulated under conditions permitting more or less free fall outward from the cliff face. Figure 3 shows such rock fragments in size up to 30 feet in maximum diameter, lying on a slope of rock waste derived from a cliff of Ordovician limestone in the Bighorn Mountains, Wyoming. The different directions of dip represented by these large rock fragments are in general as numerous as the number of the fragments observed.

2. If, on the other hand, the method by which the large rock fragments are separated from the parent cliff face is predominantly that of failure of support, as is the case where the rock formation in question rests upon a clayey or shaly base, which is at times weakened by being more or less completely saturated with water, then the majority of the large fragments do not have opportunity to fall outward from the cliff face, but settle down and slide away at a rate determined by various factors, such as: (1) the degree of weakening due to partial or complete saturation with water of the underlying stratum, (2) steepness of the slope previously developed, (3) size of fragments of rock as determined by jointing, etc. If the migration of rock fragments from the parent cliff face follows this general method, observation shows that the blocks of rock tend to rotate on axes approximately parallel to the

Fig. 3. Large fragments of Ordovician limestone and cliff from which they were derived. Location, seven miles northeast of Hazelton, Wyoming, near east front of the Bighorn Mountains. The underlying formation here does not favor landsliding as the primary method of movement of rock fragments. (Photo by the author.)

parent cliff face so as to become tilted backward toward the cliff face as they move away by slipping and sliding on a yielding stratum or medium beneath them. This fact has long been recognized by geological observers. Russell, for example, records the results of his own observations in such cases.* Figure 4 is adapted from an illustration used by him in the article referred to, on page 487. Figure 5, reproducing a photograph of a landslide block in the San Juan Mountains in Colorado, illustrates the same fact, namely, that large blocks of rock, moving down

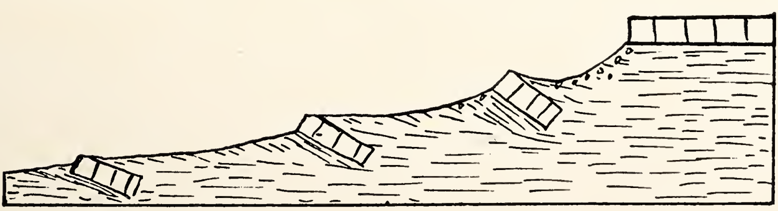

Fig. 4. Diagram, after Russell, illustrating the typical backward dip of blocks which, on breaking off, have been carried down by sliding on and with yielding material, such as water-soaked shale or clay.

* Russell, I. C., Topographic Features due to Landslides; Pop. Sci. Mo. vol. 53, pp. 480-489, August, 1898.

a slope from a parent cliff face by failure of an underlying stratum, tend to become inclined backward toward the face of the cliff from which they came.

With the establishment of the fact that the number of large blocks having a pronounced dip toward the cliff face on Terrace Mountain is proportionately large, and with the principles in mind which have just been explained, the conclusion follows that this area known as the Hoodoos owes its origin primarily to the breaking off of large fragments of travertine from a succession of cliff faces similar to that now forming the eastern side of Terrace Mountain, and the transportation of most of these blocks toward Glen Creek by the process of landsliding.

Fig. 5. A landslide block of Potosi rhyolite, situated two and one-half miles south of east from Trout Lake, Telluride Quadrangle, Colorado. View looking north from a distance of one-half mile. Note dip back toward steep ridge, 1000 feet higher, from which this tilted block came by slumping or sliding. (Photo by the author.)

HISTORY OF THE REGION.

The principal events recorded in the region under consideration are included in these three series, viz.:

1. The formation of the travertine which now makes up the upper portion of Terrace Mountain.

2. The glacial action which has been responsible for the transportation to this area of the boulders, gravel, and other material from the Gallatin Mountains and other points to the west, southwest, and northwest of Terrace Mountain.

3. The partial disintegration of the mass of travertine, the remnant of which now forms the top of Terrace Mountain, and the distribution of a considerable proportion of the rock fragments thus derived over the eastward and southeastward-facing slope of the valley of Glen Creek.

Not only are the chief events recorded in this region included in the three series named above, but the order in which these three series of events occurred must have been, in the main, the order which has just been stated. The principal reasons for interpreting these events as occurring in this order are the following:

1. The glacial boulders, gravel, etc., found now on the top of Terrace Mountain prove that the travertine forming that mountain was deposited before the last period of glaciation in that region.

2. The huge, angular blocks of travertine forming the characteristic feature of the Hoodoo area, together with the many small angular blocks which in many places accompany them prove that the glaciers passed over Terrace Mountain before the present Hoodoos were in existence.

3. The occasional glacial boulders, gravel, etc., found today scattered here and there among the blocks of travertine forming the area known as the Hoodoos, indicate that both the travertine blocks and the glacial material which lie together in the Hoodoos were derived from an eastward extension of Terrace Mountain which has disintegrated since the disappearance of the last of the recent glaciers. The present Hoodoos are made up, therefore, of the products of such a disintegration.

SOME FURTHER QUESTIONS.

Although the general outline of the history of the area known as the Hoodoos is thus clearly established, some questions which are in the nature of detail, yet of interest and importance historically, cannot as yet be answered with certainty. The most outstanding of these questions are:

1. Of what is the yielding stratum composed upon which the disintegrated travertine forming the Hoodoos has moved by sliding and slipping to its present position?

2. How far to the eastward from the present cliff face on Terrace Mountain did the mass of travertine originally extend?

3. Is the presence of true morainal topography to the northward and northeastward of the Hoodoos due in part, possibly chiefly, to a difference in the character of the geological formation which lies a short distance below the surface there? May it be due in part to a reduction, in that section of the valley, of the amount of travertine available for disintegration?

SUMMARY.

The area known as the Hoodoos, situated about two miles south of Mammoth Hot Springs, in Yellowstone National Park, Wyoming, while marked by the presence of numerous large angular blocks of travertine lying in apparent confusion, is found to possess certain definite characteristics which, when they are considered in rela-

tion to each other, afford proof of the cooperative action of a series of geological agencies which have been responsible for the result seen in this area today. Chief among these characteristics are the following:

1. The stream-like character of the area as a whole extending from the perpendicular cliff face on Terrace Mountain eastwardly and southeastwardly to Glen Creek.

2. The presence on the surface of this stream-like area of a series of more or less clearly marked ridges extending, in general, approximately parallel to the cliff face on Terrace Mountain.

3. The fact, determined by careful measurement, that the predominant direction of dip of the stratification planes of the large rock fragments is backward at a notable angle toward the west and northwest, that is, toward the parent cliff face from which the blocks of rock came.

The conclusion from these facts and from the general field relations involved is that the area known as the Hoodoos has resulted from the transportation of loosened blocks of travertine from their original location as an extension of the mass of travertine forming the upper portion of Terrace Mountain, chiefly by the process known as landsliding.