A Glacial Pothole on the Ridge of the Green Mountains Near Fayston, Vermont

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During the summer of 1934, the occurrence of a pothole on the ridge of the Green Mountains about a third of a mile south of the summit of Burnt Rock Mountain, in the town of Fayston, was brought to the attention of the writer by Professor George V. Kidder of the University of Vermont. The pothole is situated at the base of a cliff approximately seventy-five feet west of the Long Trail. Its discovery was made by Mr. Henry Webster of Moretown, Vermont, while hunting in the vicinity. In October, 1935, the writer made a journey to the locality and made the following observations.

The elevation of the pothole as determined by an aneroid barometer is 2,820 feet above sea-level and so far as the writer is aware, it is, probably, the highest known *in situ*[1] pothole occurring in New England (Fig. 1). High elevation potholes have been reported from various localities by writers in the past. Jackson[2] gives an account of several potholes at Orange, New Hampshire, at an elevation of more than a thousand feet. Hitchcock[3] describes high elevation potholes in southeastern Vermont, in the townships of Newfane and Wardsboro, at elevations of about 2,600[4] and 1,500 feet above sea-level, respectively.

Where still intact, the Burnt Rock Mountain pothole has a diameter of four feet at the rim and, when measured from the lowest lip of the rim, tapers very gradually toward the bottom to a depth of thirty inches. A gradually widening, winding, semi-cylindrical channel extending upward from the pothole, in the face of an east-west trending, vertical cliff, suggests the direction from which the "moulin" torrent came. If this channeled, upward

[1] Potholes on Mt. Jefferson; Irving B. Crosby, Appalachia, Vol. 17, pp. 44-45 (1928-29). This article describes several potholes at an elevation of nearly 4,000 feet, but it appears that they occur in a glacial erratic and not in bedrock, to which the term *"in situ,"* above, refers.

[2] Geology of New Hampshire; C. T. Jackson, pp. 113-114 (1844).

[3] Geology of Vermont; Edward Hitchcock *et al.*, Vol. 1, p. 216 (1861).

[4] An examination of the U. S. G. S., Wilmington and Brattleboro quadrangles, has shown this figure to be much too high. The highest elevation in the town of Newfane is 1,840 feet above sea-level.

extension of the pothole be considered the remnant of a once complete structure, it would seem that its original depth must have been in the neighborhood of fifteen feet, since the height of the cliff at this point is twelve feet. This winding channel, or pothole remnant, curves upward in an east-northeasterly direction upon reaching the top of the cliff, which, in turn, is toward the ridge of the main range. The crest-line of the ridge is about forty feet higher than the present pothole. From the above observation it might be inferred that the stream which made this pothole came from a general easterly direction.

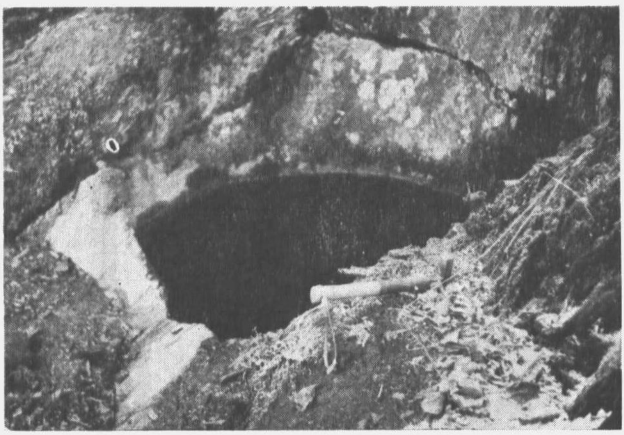

FIG. 1. THE POTHOLE ON BURNT ROCK MOUNTAIN

When first discovered the pothole was filled with soil and a few angular rock fragments derived from the cliff above. This material was removed by the discoverer who reported that it contained no rounded pebbles or boulders. Because of protection by this soil-fill, the walls of the pothole have retained their original smoothness of surface. The lower lip on the downslope side of the rim has been smoothly grooved by the overflowing waters.

The pothole has been drilled approximately along the planes of schistosity in a green, epidotic, micaceous schist, the strike and dip of the schistosity being N20E and 50NW, respectively. Intercalated with the contorted schists are thin lenses or veins of quartz. The cross-sectional plan of the pothole does not appear to have been affected by the foliated structure of the rock, for its diameter is quite constant.

About fifty feet west of the pothole, on the vertical east-west cliff, is a small polished area displaying thin glacial striae with an east-west direction and a pitch of 18° to the west, which would be down the slope (Fig. 2). A second smoothed and polished surface, with a shallow striated groove a foot in width, occurs on the same cliff higher up on the slope, about fifty feet to the east of the pothole. This glacial groove and its striations give the same directional readings as the striae previously mentioned. A shallow vertical channel in the face of the cliff at another place, leads the writer to believe that there may be more potholes buried beneath the soil at its base.

FIG. 2. GLACIAL STRIAE ON VERTICAL CLIFF

It has long been an accepted fact that potholes have their origin in moving water laden with sufficient sediment to serve as grinding tools. This moving water may be wave action or a stream current. Waves striking against a cliffed headland may be so directed by the contour of the rocks as to acquire a swirling motion; when, with the aid of rock tools, a pothole is gradually worn in the bedrock. Since the force which gives the grinding sediments a rotary motion is not applied from above, but rather from the side at a very low angle, the depth of the pothole must necessarily be exceedingly shallow. It is generally saucer-shaped with circular groundplan. Along marine coasts most effective work is accomplished during high tide by both the powerful advancing waves and the strong receding undertow. Coastal potholes are occasional occurrences in the rocky portions of a shoreline. An excellent example of this type of pothole was seen by the author several years ago, at the base of the famous Cliff Walk at Newport, Rhode Island, not far from Easton's Beach. At the time of its discovery this depression contained several well-rounded boulders.

The great majority of potholes, however, are the result of a stream current falling over a precipice. They may be divided into two groups, the subaerially and subglacially eroded. Subaerial potholes are common in rapids and below waterfalls of rivers and streams, and since this paper describes a pothole belonging to the latter group, a discussion of the ordinary stream-worn pothole will not be included. The mechanics involved in the production of potholes connected with both groups, is the same; namely, a current of water plunging from an abrupt elevation, either at a high angle or vertically. They differ, however, in their topographic locations with respect to existing stream courses, the potholes of glacio-fluvial origin showing no relationship to present stream courses.

That the pothole in question has a glacio-fluvial origin is seen in its topographic position relative to elevation and remoteness from existing streams. Additional evidence is apparent in the glacial striae in close proximity to the pothole, already described.

Upham[1] describes the moulin hypothesis in the following way: . . . . "the German and Scandinavian term, giants' kettles, may be restricted to the class of holes, bored in the bed-rock beneath glaciers or an ice-sheet by torrents of water falling through deep moulins. The name 'moulin' coming from the French and meaning a mill, is applied to a vertical tunnel, melted at first by the waters of the surface trickling into some very narrow crevasse that has just begun to open, until, after enlargement by this dissolving action, it receives sometimes a large stream . . . . pouring . . . . down a cylindric shaft to the rock floor under the ice."

The hypothesis quoted above considers superglacial streams flowing from the surface of the glacial ice into crevasses and drilling a hole in the bedrock immediately at the bottom. In his article Upham[2] refers to Mr. T. T. Bouvé and Professor George H. Stone as pointing out . . . . "that the subglacial waters, after falling down the crevasses and moulin shafts, would flow rapidly away upon the surface of the bedrock, and then might sweep past the mouths

[1] Giants' Kettles Eroded by Moulin Torrents; Warren Upham, Bul. Geol. Soc. Am., Vol. 12, pp. 27-28 (1900-01).
[2] *Loc. cit.*, p. 28.

of the potholes during the process of their erosion, supplying all the current needed for their further deepening by the whirl thus given to the water and stones at the bottom." This citation assumes further deepening of "moulin" potholes by subglacial streams flowing past them over the bedrock beneath the glacier.

Concerning the position of "moulin" with respect to its pothole, Upham[1] states: "For the largest and deepest of the giants' kettles, however, to be here noted as discovered in many localities of glaciated countries, I can not doubt that the pothole was cut down exactly at the foot of a great and very deep moulin by its powerful descending torrent." While this supposition is readily conceivable, it is also possible for subglacial streams to be the direct agents of pothole erosion independent of a "moulin" shaft. Where a subglacial stream falls over a rock cliff, a pothole may be formed in the rock at its base, and which may extend upward as a cylindrical boring whose circumference consists of the wall of the cliff on one side and the contacting ice on the other. Upham[2] explains the origin of some of the potholes and channeled cliff faces at Taylor's Falls in Interstate Park, similarly, to wit: "For the explanation of their erosion I can only suggest that here, as in places of moulin torrent action in Massachusetts and New York, effective erosion nearly as in a pothole of the largest size took place on a mural surface, with only ice, as we must suppose, to form the other side of the moulin. It is quite sure that they were worn as half-holes instead of having undergone demolition and removal of the wanting part. On a smaller scale such mural segments of cylindric water-wearing are seen in other places within this little area."

Barker[3] describes a similar occurrence on Towner Hill, where "At the foot of the cliff is the remnant of a still larger pothole that now forms a shallow niche in the face of the cliff." In his description of its origin Barker[4] presents the hypothesis . . . . "that it was bored in solid rock, and that, subsequently, the greater portion of it had been eroded away."

The writer is inclined to the opinion that the Fayston pothole, herein described, was bored in the solid rock and that the missing portion was later eroded away. In support of this opinion the east-west trending glacial striae previously mentioned in this paper, are evidence of glacial erosion. The plane of the face of the cliff containing these striations, if extended to meet the eroded

[1] *Loc. cit.*, pp. 28-29.
[2] *Loc. cit.*, p. 32.
[3] Glacial Pot-holes at Crown Point, New York; E. E. Barker, Jour. Geol., Vol. 21, p. 463 (1913).
[4] *Loc. cit.*, p. 463.

pothole, would cut its circumference. According to this observation it would appear that the pothole was not only glacially made, but, probably, also glacially eroded.

Further, it might be supposed that the smooth water-worn channel in the cliff above the present pothole, was the result of ordinary current channeling on the surface of the rock by a subglacial stream. But when the depth of the existing pothole at the base of the cliff is compared with the diametral depth of the upward-trending channel, and, along with this the vertical attitude of the cliff is taken into consideration, it is difficult to understand this origin for the pothole. That is, with the force of the current directed mainly downward from this twelve-foot vertical cliff, a greater depth for the still extant pothole might be expected when its proportions are contrasted with those of the channel. This channel, then, appears to have been at some time in the past a part of a complete pothole, the product of eddying currents.

Further observations at this locality tend to show that this pothole was probably not formed by a straight fall of water, but, rather, by a subglacial stream flowing from the general direction of the ridge not far away. This belief is based on the observed fact that, in its upper portion, the pothole remnant curves toward the ridge. Thus, it can be seen that the fall of water, in this case, was not introduced directly from above, as is assumed in the general "moulin" hypothesis which has been quoted above from Upham.

The "moulin" hypothesis presents a difficulty when one attempts to conceive a "moulin" remaining long enough in one place to allow a well-formed, single pothole to be bored in the bedrock. Alexander[1] refers to this difficulty, and in commenting upon potholes . . . . "as reforming in the same manner and at the same spot often enough to account for the work accomplished," he says farther on that it . . . . "rather strains the theory of probability." Upham whose work preceded Alexander's by about thirty years, advanced the theory that "moulin" formation occurs before the ice motion has acquired a definite current to move the crevasse, "moulin," and waterfall away from the spot where they were first formed. He goes on to say that when the ice was given motion because of its increased thickness and consequent pressure, pothole-making ceased. Manning[2] cites a theory of Agassiz, that a crevasse does not move forward with the advancing ice sheet because it is made by the physical features of the underlying surface.

[1] Pothole Erosion; H. S. Alexander, Jour. Geol., Vol. 40, pp. 310-11 (1932).
[2] Glacial Pot-holes in Maine; P. C. Manning, Proceedings Portland Soc. Nat. Hist., Vol. 2, pp. 185-200 (1901).

and although the glacial mass moves forward, the crevasse remains near or at the place of origin, at least for a sufficiently long time.

In view of the objectionable features associated with the "moulin" hypothesis presented above, the writer suggests that the importance of subglacial streams be given more consideration in an analysis of pothole erosion; at any rate, in those cases in which the potholes are located at the bottom of cliffs, of which there are many. However, the writer's concept does not account for potholes otherwise located. In this connection Gilbert[1] has written, "After the water of the moulin has reached the rock bed it must escape along some course beneath the ice. In flowing away it may accomplish erosion of the ordinary type, and the sculpture resulting from stream erosion may therefore be associated with moulin sculpture." It seems reasonable to suppose that the elevated pothole under discussion was formed by a subglacial stream flowing through an ice tunnel and plunging over the precipice, below which the pothole lies. The conditions best suited for subglacial stream action prevail in the marginal area of the glacial ice where ablation is marked. Here the melt-water enters a crevasse, at the bottom of which the subglacial stream has its beginning.

Alexander[2] has found that many of the high elevation potholes .... "are associated with cols through which mighty streams may have flowed from temporary glacial lakes. Such are often bounded by rock ridges on the southern side and where the water overflowed the ridge rapids would form and the conditions for the erosion of eddy holes would exist." The pothole described in this paper is situated in a col and may well have had an origin similar to that pictured in the above quotation but, owing to the nature of the topography and the great difference in elevation between the pothole and adjoining valleys, a rock ridge dam on the south side to impound lake waters, would seem unlikely. In explaining the possible origin of this pothole the writer finds himself in accord with Alexander's hypothesis of a stream crossing the divide in the col, but would postulate a more or less shallow temporary lake, filling a depression in the westward-sloping ice surface on the east side of the ridge, spilling over the ridge, and flowing upon the very uneven surface of the western slope in a series of rapids and waterfalls. In this explanation emphasis is placed on the assumption that the ridge was exposed by the melting of the ice during the waning stages of the Glacial Period.

[1] Moulin Work Under Glaciers; G. K. Gilbert, Bul. Geol. Soc. Am., Vol. XVII, p. 319 (1906).

[2] *Loc. cit.*, pp. 311-12.