ART. XV.—*The Formation of Natural Bridges;* by HERDMAN F. CLELAND.

UNTIL recently the text-books of Geology and Physical Geography have given the idea, whether intentionally or not, that natural bridges are universally formed by the partial caving in of a long cavern, the bridge being that portion of the roof strong enough to span the cavity.* The belief seems to be prevalent that these cavities extended for long distances, a condition comparable to that which would exist if the greater part of the roof of Mammoth Cave should fall in, leaving a small portion as a bridge. This theory is simple and logical and is one which immediately appeals to the reader, but, as will be seen from the examples cited in this paper, not only is it not of universal application but it must be exceptional rather than otherwise. The writer was led to this study by an examination of the natural bridge near North Adams, Mass. which has long been considered to be a typical example and proof of the formation from caverns.

The North Adams Natural Bridge spans Hudson Brook and has been an object of more than local interest for many years both because of its natural beauty and because of the rarity of these objects. Hudson Brook is a small stream emptying into Beaver Creek, a tributary of the Hoosick River. From the dam (shown in the sketch fig. 1) to the pre-glacial valley the brook flows through a gorge 30 to 60 feet deep and from 5 to 40 feet wide, the average width above the bridge being from 1 to 10 feet and below from 10 to 30 feet. This gorge is cut in a coarsely crystalline marble which, because of its color and texture, presents a striking appearance. The rock is Cambro-Silurian and belongs to the Stockbridge formation.

The top of the natural bridge is 44 feet above the water of the stream and the bridge itself is about 8 feet thick. The span of the bridge is less than 10 feet long and the width at present 25 feet, but at one time it probably extended a short distance farther south where it is now fallen in. It is extremely difficult to take a good photograph of the bridge because, as will be seen from the sketch, the stream turns sharply both above and below. Because of this condition it was found necessary to make a drawing, in order to give a correct idea of its appearance.

Prof. E. Hitchcock described the North Adams Natural Bridge and published a rough drawing of it in 1841.† Concerning this drawing he says, "I thought it better that a sketch

* Chamberlain and Salisbury, Geol., vol. i, pp. 145–147.

† Geology of Mass., by Edward Hitchcock, vol. i, 1841, pp. 287–288.

should be taken by one not at all accustomed to drawing, than that no memento be left of this interesting place," (there was danger at that time that the bridge might be destroyed by the quarry-men.) Hovey* in his "Celebrated American Caverns" describes this bridge but gives the locality as Adams, Mass.

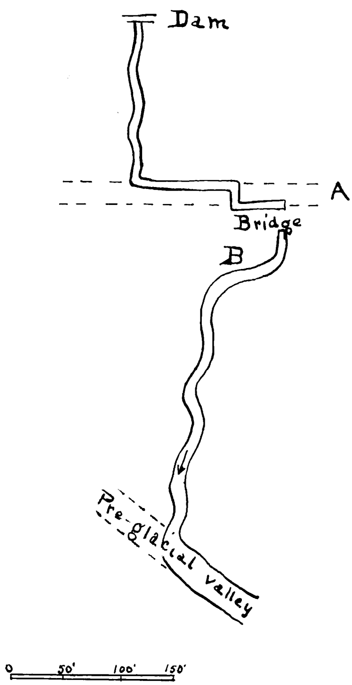

FIG. 1.—Sketch map of Hudson Brook, Mass., showing the position of the natural bridge, the joint planes A-A, and the pre-glacial valley.

The explanation of the formation of the North Adams Natural Bridge, as given by Hitchcock and accepted by Hovey, is that it is the section of the roof of a cavern, the ends of which have fallen in. In illustration of this point, Hovey states that, "the combination of cave, chasm and natural bridge, on Hudson Brook, Mass. is even a better example (than that of the Natural Bridge in Virginia) of the same thing," i. e., "that what are now open canons were once caves, the arch being merely a remnant of an ancient cave roof."

On examining the course of the stream and the rock in the vicinity of the North Adams Natural Bridge one is struck with the width of the joints, and the fact that the stream has, for a portion of its course, followed the joint planes. In the upper part of the accompanying sketch (fig. 1) the relation of the stream to the joint planes is indicated by the dotted lines A–A. The channel through which the stream flowed previous to the formation of the bridge is also well marked a few feet to the west at B. A pot-hole situated near the edge of the gorge at B is further evidence of the former position of the brook.

The bridge was probably formed as follows: When the stream flowed into the gorge through the ancient channel, it plunged over a fall into the pre-glacial valley. Some of the water in the joint plane nearest the present bridge seeped through an approximately horizontal crack a short distance under the present arch of the bridge. The solvent power of

* "Celebrated American Caverns," H. C. Hovey, pp. 14 and 206.

the water containing carbon dioxide (CO_2) gradually increased the size of the crack until it was still further enlarged by the erosion of the stream. The stream was finally entirely diverted from its former channel at B to its present course. The gorge from the dam to the pre-glacial valley is a succession of broken pot-holes varying in size up to 6 or 8 feet in diameter, showing

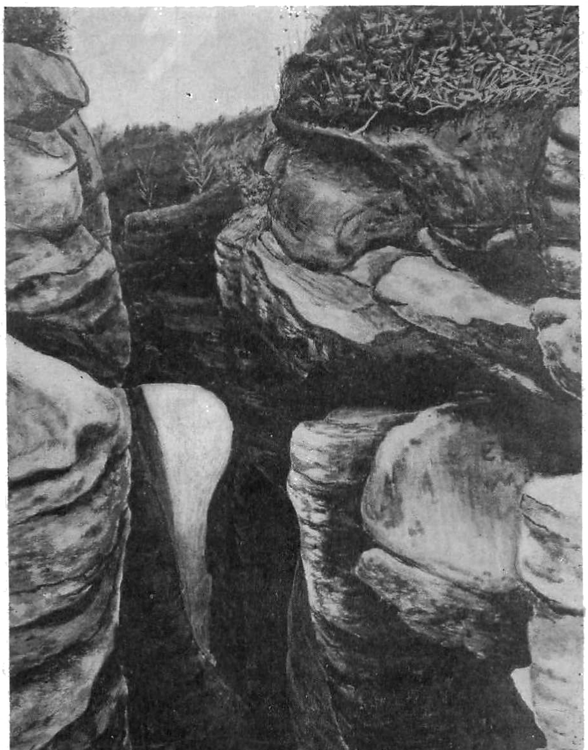

FIG. 2.—The North Adams Natural Bridge as seen from the south. Formerly the bridge probably extended nearly to the foreground of the picture.

that after the tunnel was made the gorge was largely excavated in this way. The pre-glacial valley in which the Hudson Brook flows below the gorge is broad but to some extent choked with glacial drift.

The origin of the famous Natural Bridge of Lexington, Va.,* as explained by Walcott, was similar to that of the Natural Bridge of North Adams, Mass., but is on a larger scale. Before

* National Geographic Magazine 1893, vol. v, p. 59.

the formation of the bridge the stream, which now flows under, then flowed upon the surface of what is now the arch and probably plunged over a fall a short distance below the present site of the bridge. While the stream was flowing over this fall a portion of the water was percolating through a joint plane or other crack up stream and discharging into the stream under the fall, enlarging its passage by its solvent power. In the course of time this passage became sufficiently large to contain all of the water of the stream, and the bridge resulted. It is not possible to say what the length of this underground passage was. It must have been somewhat longer than at present, but "whether one hundred feet or several hundred feet" it is not possible to determine.

The description of some wonderful natural bridges in Utah,* in a recent paper, suggests an explanation similar to that given above, except that, in the case of these bridges, the rock is said to be a sandstone (pink or gray) instead of a limestone. The most probable explanation is that, at one time, the river flowed over a fall a short distance below the lowest bridge and that, as the stream was cutting back, a portion of the water was pouring through a fissure up the stream and reappearing at the brink of the fall, dissolving out the cement of the sandstone along its course. This underground passage was gradually enlarged by the washing out of the unconsolidated sand, resulting in a tunnel of sufficient size to hold the entire volume of the stream. After this event the valley was eroded to nearly its level. This process was repeated three times with the formation of three bridges. ' When it is remembered that one of these bridges spans a canyon 335′ wide, that the lower side of the arch is 357′ above the stream and that the material of which they are constructed is sandstone, it will be seen that any explanation requiring a tunnel of great size extending for a long distance is untenable. It is, however, unsafe to do more than speculate upon the formation of these bridges, since so little is known of the rock of which they are composed.

In the Yellowstone National Park occurs a small natural bridge of rhyolite. The bridge consists of two vertical slabs of lithoidal rhyolite, parts of the contorted layers of lava flow, which stand nearly vertical in this place.† They are slightly curved and are separated by open crevices with roughened scoriaceous walls. Of the two slabs forming the ledge the eastern is two feet thick at its ends and thinner in the middle. There is a space of two feet between it and the western slab, which is four feet thick. "The span of the arch is about 30 feet and it rises about 10 feet, the top of the bridge being some

* W. W. Dyar, Cent. Mag., vol. lxviii, 1904, pp. 505–511.

† Geol. of Yellowstone Nat. Park, U. S. G. S. Mon., vol. 32, pt. II, pp. 386–7.

40 feet above the stream." The explanation of the formation of the bridge is as follows: The stream which flows underneath

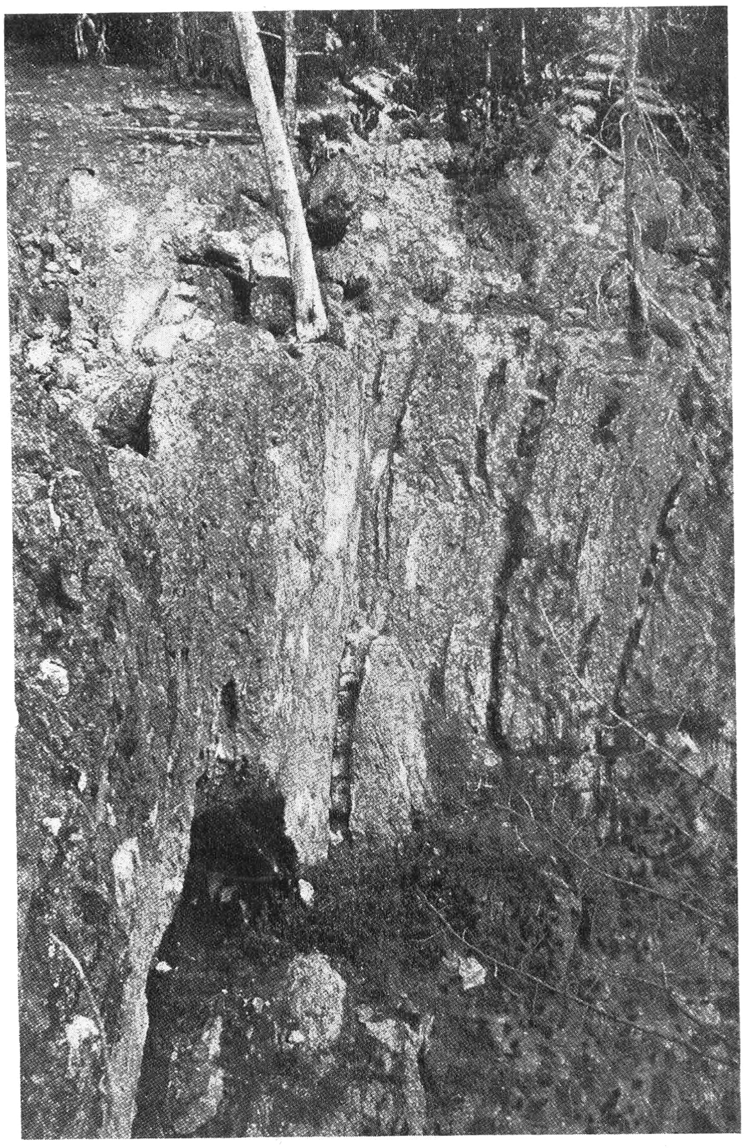

Fig. 3.—Vertical plates of rhyolite. Yellowstone Natural Bridge. (Mon. U. S. G. S. 32, pt. II, plate 49.)

the bridge has been able to excavate, owing to a former waterfall and the peculiar platy structure of the rhyolite, in which curved layers of extremely different physical texture and friability offered a favorable site for attack by frost and water.

The formation of lava bridges is usually explained as follows: The surface of a lava flow cools and hardens while the interior is still in a molten condition. As a result of this condition, if the molten rock beneath continues to flow, a tunnel will result. Such tunnels are of common occurrence on Mt. Vesuvius, the volcanoes of the western states and in other volcanic regions. From such a tunnel a bridge might be formed by the caving in of the greater part of the roof. A study of the photograph (fig. 3) showing the structure of the lava of which the Yellowstone Natural Bridge is formed shows that such an explanation is untenable in this case at least, the rock being composed of approximately vertical plates of lava of different degrees of compactness. The writer has not made a study of other lava bridges, but it seems probable that the mode of formation of the Yellowstone bridge may be exceptional for bridges of this character.

In each of the cases cited the top of the bridge was formerly a portion of the bed of the stream. If natural bridges were formed as commonly supposed, it would be unusual to find that a surface stream had once been superimposed upon the cavern for its entire length. There is, for example, seldom any relation between the surface topography of a country and the underground passages of extensive caves.

Occasionally a small natural bridge occurs near the opening of a cavern or where a spring flows from beneath a cliff. Such a bridge is the sandstone arch spanning a spring which emerges from beneath the sandstone capping of Lookout Mountain near Chattanooga, Tenn. The bridge is formed by the widening of a transverse joint, first by weathering alone and later by the combined action of weathering and erosion, thus separating the bridge from the cliff. The breadth of the span was increased largely by weathering.

The conclusion to which one is led by this study of natural bridges from different parts of the United States and composed of various kinds of rocks—marble, limestone, sandstone, and lava—is that, although bridges may be formed, and undoubtedly have occasionally been formed, by the partial falling in of the roof of a long underground tunnel, the usual mode of formation is that described above. It should, however, be said that examples exist concerning which it is difficult to say which mode of formation was the more prominent.

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