An Indicator of Water-flow in Caves

By J. C. Coleman

INTRODUCTION

Most cave-explorers must have noticed curious patterns of inter-connected hollows on rock-surfaces in caverns. They are present on walls, ceilings, and to a limited extent on floors, where free of dripstone or not obscured by fluviatile deposits.

The directional aspect of this pattern-form has been previously noted[1] and limited use has been made of the fact in some geomorphic studies of North American caves, but it appears that no application or study has been made of the pattern in caves in these islands.

As an added tool in spelæological research, especially in ascertaining the direction of water-flow in *stream-deserted* caves, the pattern is worthy of more attention than it has received so far.

I have investigated the problem in a number of Irish caves and the results of this field work, together with rules which have been worked out to ascertain from the pattern the direction of water-flow may, therefore, be of interest for future cave studies.

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PREVIOUS LITERATURE

The pattern has often been noted in descriptions of caves as " honey-comb walls ", " pitting ", " oyster-shell markings ", etc. Wright noticed the pattern (" a delicately faceted pattern ") in the lakeside caves at Killarney and attributed it and the caves to lake erosion.[10]

Davis, in his epoch-making paper on limestone caves, alludes to this and other rock-forms of solutional and erosional origin in caverns, and suggests that these forms should receive special study.[5]

The first examination of the pattern was made by Maxson in 1940.[9] This writer studied the pattern in surface-rivers, and coined the word " flute " to describe it and allied forms, and " fluting " the process. Similar types produced by wind action were also investigated, but no mention is made of " flutes " in caves. Later, Bretz[1] took up the problem for the first time with regard to caves and noted the directional aspect of the pattern and the possibilities of determining direction of water-flow in stream-deserted cave-passages. A few examples of this use are given in his paper, but no specific rules for examining the pattern are forthcoming.[1]

TERMINOLOGY

The word " flute " is not a happy choice of Maxson to describe the pattern under discussion. A flute in everyday usage is a long, continuous groove of concave cross-section (e.g., columnar fluting in architecture). The pattern is *not* a continuous grooving of rock-surfaces, but a series of interrupted concavities. At this stage it might be well to quote the excellent definition of the pattern by Bretz[1]: " small shallow asymmetrical cups, close set and even overlapping with the steep side invariably *upstream*. Or they may be described as unsymmetrical irregularly placed short ridges, in the ground plan of which continuity of crest lines is more nearly attained across the current than with it ".[1]

In view of the unsuitability of the term " flute " to define this pattern form I have proposed that " scallop " be substituted, and " scalloping " used to describe the process.*

FORMATION

The formation of scallops is a result of the movement of water in a definite direction. Turbulent flow induced by skin friction along flat rock-surfaces, the presence of obstacles to direct current flow, and sharp bends in the current bed give rise to vortical movements within the water mass. The abrasional effect of the current load caught up in these vortical movements is a major tool in the excavation of scallops.

Maxson has noted the presence of scalloping in many types of homogeneous rocks in stream—and river—beds, and has suggested that in the case of limestone the effects of solution on the rock must not be overlooked.[9] In the case of scalloping in caves, however, solution may play a major part, for interbedded materials such as chert usually remain unpocketed, standing out from scalloped limestone surfaces as bridges and ledges.[3]

The erosional and solutional effects of the vortices in initiating scallops is to a great extent stabilized once they are formed. In other words, scallops once formed have a fixation effect on vortical axes. But variations

* In a preliminary note which I published in 1945 I provisionally suggested " pockets " and " pocketing ". Since then it has become clear that confusion would arise if the 1945 terminology was adopted, as Bretz and others define pockets rightly as large, rather formless, solution hollows. Hence, in this paper, I am proposing that " scallops " and " scalloping " become generally accepted in relation to the pattern.

in stream-velocity (flood periods, etc.) will cause a redistribution of vortices and ultimately rock-surfaces become covered with scallops, often overlapping ; or, in some cases of smaller scallops excavated within larger ones. The mechanics of vortical movement in water-flow is not well understood and it is very difficult to investigate the problem in the field.[7]

A number of surface streams and rivers in Ireland were examined during the present survey and only in rare cases were examples of scalloping found. On the other hand scalloping in caves was well developed in many sites. All caves do not show this effect of directional water-flow ; for example, Dunmore cave, Co. Kilkenny, does not appear to be affected by current-flow and is largely a product of ground-water solution. Also a number of caverns well advanced in the dripstone deposition stage (e.g., Carrigtwohill, Co. Cork) do not provide much opportunity for examining rock-surfaces.

In general it can be said that where scalloping is present in a cave it is far better developed there than in any open-air stream or river site. In caverns the effects of other sub-aerial weathering agents are absent and scalloping, once formed, therefore retains its sharpness and individuality to a high degree. Rarely is it found as isolated patches of scalloping on a few rock-surfaces ; the ' all-over ' scalloping, with overlapping and interconnecting of scallops, is the characteristic pattern of the cave type. In my opinion this well-developed pattern, due, as stated earlier, to re-distribution of current vortices, is in a great measure the outcome of the considerable variations in velocity and volume of underground drainage in limestone regions.

RECOGNITION OF DIRECTION

During the examination of the pattern in Irish caves, it was seen at an early stage that some simple set of rules was required to determine the direction of water-flow from the examination of a scalloped surface. Previous writers have not dwelt on this point, except to state that the " steep side of the pocket is invariably upstream ".[1] This fact holds good no matter how much overlapping or intercutting of pockets has taken place.

The ideal scallop is triangular in plan, with a slightly curved base. This base is the ' scarped ' upstream side of the scallop and a less inclined ' slip-slope ' of concave form ends in the apex of the triangle. Solution (largely in limestone) and erosion are greatest at the upstream side of a scallop due to the rotation of the vortices and if any migration of scallops occurs therefore it must be upstream. Overlapping, etc., tend to destroy the ideal scallop form, and whilst examples are frequently seen, the ground plan of scalloping is mostly of curved-sided polygonal concavities.

In *Fig.* 16, Nos. 1 and 2 are typical scallop forms from Ovens Cave, Co. Cork, and Pollnagollum Cave, Co. Clare, respectively. A horizontal

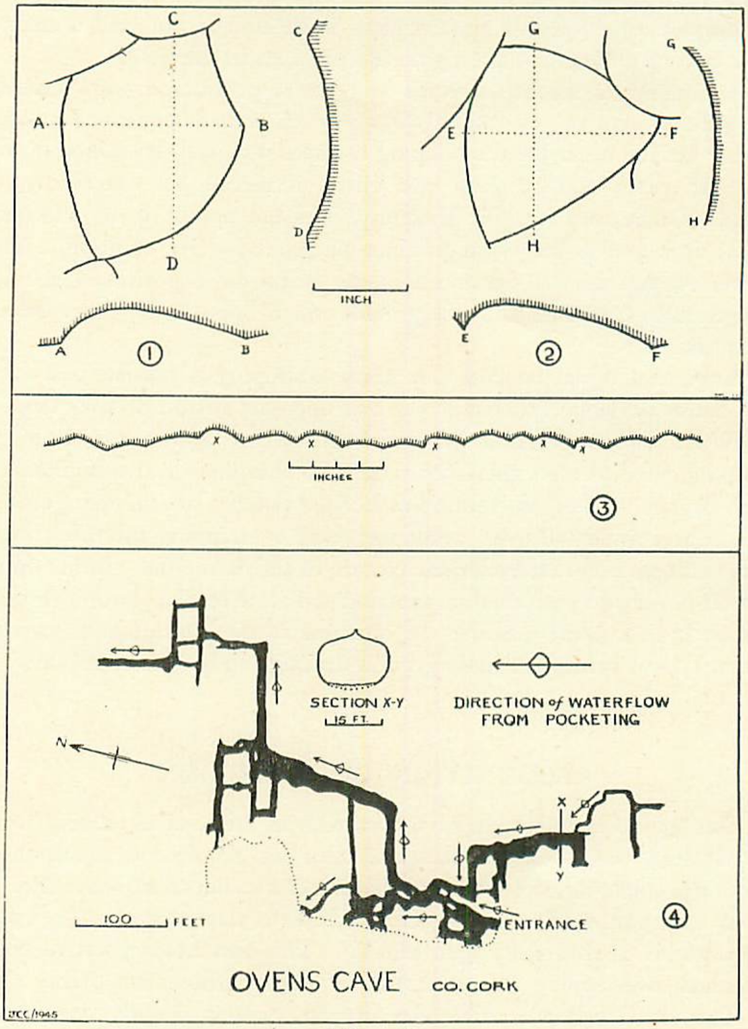
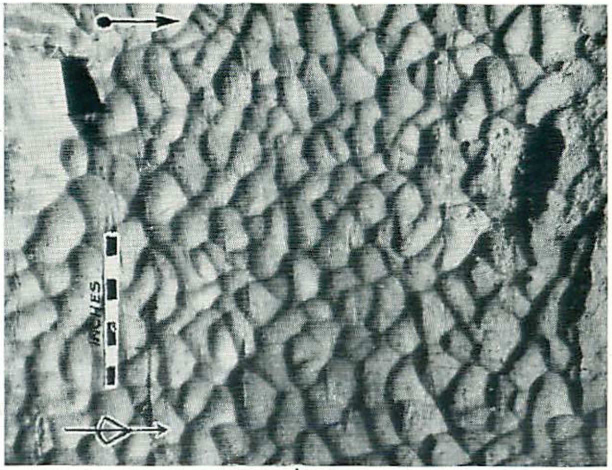


Fig. 16.

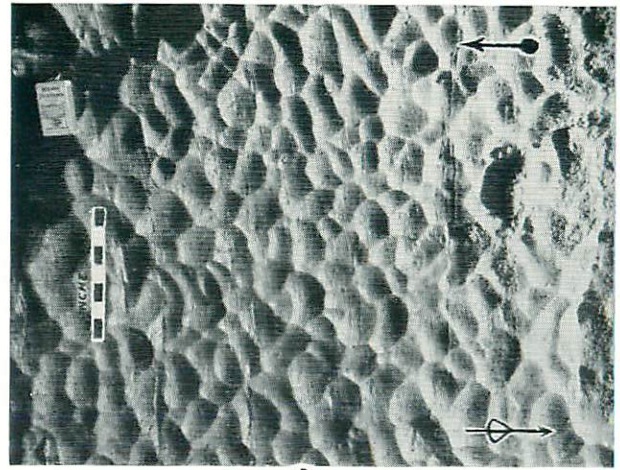
section (i.e., a section along the line of flow) in each case shows the unmistakable upstream ' scarp '. A vertical section is not essential, as in all cases it shows only a curve of no particular characteristics.* But as the direction

* Except that in scalloping on walls tilted outwards towards their base there is a tendency for the top of the vertical section curve to overhang the bottom end of the curve.

PLATE 8



A



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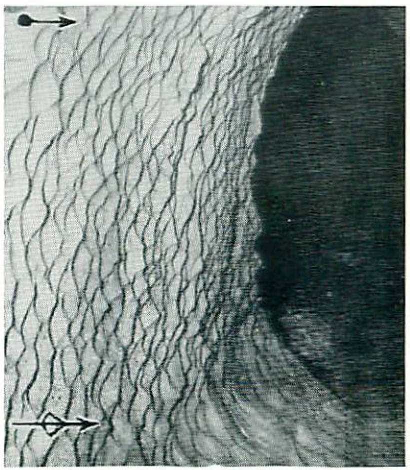

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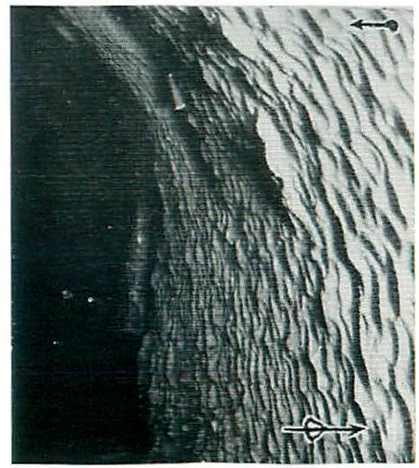

D

Scalloping in Ovens Cave,
County Cork, Ireland.

Arrows :—
direction of waterflow.

Ball-ended arrows :—
direction of lighting.

of water-movement under consideration is in or near the horizontal, it is a section on this line which provides the information as to direction of water-flow.

One method, therefore, of determining direction of flow is to draw horizontal cross-sections of scallops, which will reveal the position of the steep upstream scarp. In this connection it may be mentioned that these sections are best drawn from a number of individual scallops in various locations in the passage or chamber under examination. An extended horizontal section will not show a progressive series of scarp and slip-slopes (like that in the ideal section of current-ripples). An example of such a section is given in *Fig.* 16, No. 3, where in a length of approximately 30 in. only four (marked X) show the characteristic scallop section. This is due to the fact that in many places along such a line only the upper or lower parts of a scallop are cut across, where the ' scarp ' is not so well pronounced or has been obliterated by overlapping of scallops.

Apart from the cross-sectioning of selected individual scallops (which is a safe guide in doubtful sites) I have found that four special views based on lighting and viewpoints quickly give the information as to direction of water-flow.

. If a selected rock-surface showing scalloping is examined : (*a*) With the light pointing downstream and close to the surface, the observer stationed in front of the pattern (looking at it in plan), the effect is of dark edges with the slip-slopes brightly illuminated. *Plate* 8, *Fig.* A ; (*b*) The observer in the same position and the light now pointing upstream, the scarps are now brightly illuminated and the slip-slopes almost in darkness (*Plate* 8, *Fig.* B) ; (*c*) Standing close to the wall and pointing the light downstream and looking in the same direction, the effect is of a series of triangular ' peaks ' (*Plate* 8, *Fig.* C) ; (*d*) Looking upstream with light in the same direction, a series of more or less continuous wavy ridges is generally seen (*Plate* 8, *Fig.* D).

A general rule, therefore, could be made from (*c*), to the effect that the ' peaks, point downstream '—but this rule should not be used alone.*

A word of caution is not out of place here with regard to plan photographs of scalloped surfaces. Owing to an optical illusion at times, instead of a series of concavities, one is inclined to see the pattern as *convex* (*Plate* 8, *Figs.* A, B). This effect can be produced sometimes by revolving the photograph in front of the eyes. It is not noticeable in perspective views.

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* In the case of rock-floors, free of deposits and showing scalloping, there is a physical method of determining direction. When crawling on hands and knees on such a surface, the downstream course is comparatively easy, but moving upstream is usually a painful process.

NOTES ON SITES EXAMINED

Pollnagollum Cave, Co. Clare

This large active cave-system, which has been surveyed for $3\frac{1}{2}$ miles, shows excellent scalloping in almost all parts.[3] It occurs on wall-surfaces, on the top of meander terraces left by stream-erosion, and also on rock-floors beneath the present watercourse (where not obscured by stream deposits). The direction of water-flow from scalloping everywhere coincides with the present direction of stream-flow in the cave-system. Allied with the scalloping are other unmistakable signs of directional water-flow—meander terraces, horizontal flutings, etc.

Dripstone cascades obscure scalloped surfaces in some places and rock-falls have left scars on otherwise scalloped walls. Vertical flutings beneath waterfalls also have obliterated previously scalloped surfaces as, for example, at the First Waterfall in the Main Cave.[3]

The large part which solution plays in scallop-formation in limestone is excellently shown in this cave. Fossils (especially of crinoids) often stand out uneroded from scalloped surfaces, and chert is left as bridges, ledges, and knobs protruding from the deeply scalloped limestone.*

Polldonough Cave, Co. Clare

An active linear cave engulfing the Coolagh river in a limestone inlier, 2 miles NNW of Lisdoonvarna.[3] The entrance passage-walls and part of the rock-floor show scalloping with direction of flow coinciding with present stream-flow into the cave.

Mullinahone, Co. Tipperary

A surface stream near the village sinks at the 'Rocks' through impenetrable fissures at the base of a limestone outcrop. It rises again 300 yds. to the west in a reed-filled depression.

To the right of the present stream-sink is a cave with twin entrances showing scalloped walls (on an older solutional joint—and bedding—plane anastomosis). The direction of flow is inward, i.e., in the same direction as the flow at the stream-sink. This cave probably represents an older engulfment-point of the stream and is occasionally used by it in periods of exceptional flooding.

* See, for example, the chert bridges and ledges near Pollbinn pot-hole in the Upper System ([3], *Plate XVII, Fig.* 1).

MITCHELSTOWN CAVES, CO. TIPPERARY

In 1944 a preliminary examination was made at the New Cave of the well-known Mitchelstown series and scalloping was located at a few places. Owing to lack of equipment no examination was carried out of the Old, or Desmond, Cave.

From an examination of some photographs of the Old Cave Entrance Passage it appears that a north to south flow is indicated from the pocketing seen in the photographs.

The New Cave is largely a product of ground-water (phreatic) solution, based on the joint-network and the dominant bedding-planes, dipping south. Rock-falls, in part probably helped by erosive stream-action at one period, have considerably altered the topography of the original cavern. Enlargement of chambers has been largely brought about by collapse of adjacent bedding-plane slot-passages. Th main joint passages and galleries running north and south have preserved in most places their original forms, but 'strike' passages are mostly altered by rock-collapse, as mentioned above.

The extensive rock-collapse and the fact that the cavern is now well advanced in the dripstone stage made it difficult to observe records of scalloping in the cave. Scalloping was noted in the Kingston Gallery (see plan of cave in ([8], *Plate XV*) with direction of flow north to south (magn.), along the gallery. Doubtful scalloping was noted in the Cathedral, south of the House of Lords, with a similar direction of flow. In the Victoria Cave at the eastern termination of the system, scalloping showed on the east wall with direction of previous flow north to south and curving to the west. Near Cust's Cave the walls in places had faint scalloping with direction of flow east to west, but this portion of the cave was not examined in detail owing to lack of time.

In general, therefore, it can be said that records of scalloping in the New Cave show a north-to-south flow with possible east-to-west indications in some localities. The north-south direction accords with the suggestion of the previous explorers, who thought that an engulfment of the surface run-off of the Galtees, north of the cave site, was responsible for erosive enlargement of the cavern.[8]

The present entrance to the cavern is a result of quarrying, and the old entrance (or entrances) is now obscured by glacial drift filling the valley-floor north of the cave. Through these old orifices the cave probably received its water-supply.

It may be noted also that the suggestive scalloping indicating in places a possible east-to-west flow in the cavern is contrary to the present drainage of the area. The Sheep River north of the cave entrance flows west to east.*

* The river is noted incorrectly as flowing west in ([8]).

It might be that a now buried valley carried a west-flowing drainage north of the cave, which became filled with drift and the new drainage initiated on this surface suffered a reversal in flow. Owing to the meagre information available this point cannot be laboured, but it would be interesting when a full examination is made of the two caves to see if this can be substantiated and if by using the caves any reconstruction of the probable buried valley could be carried out.

Dunmore Cave, Co. Kilkenny

This well-known cave, near Kilkenny, was examined during the present survey and no examples of scalloping were found in any part. It is largely a product of ground-water (phreatic) solution, a chambered cave of the 'Carlsbad' type of Bretz.[1] *

Muckross, Co. Kerry

The lake-side caverns in the limestone along the Muckross peninsula between the Middle and Lower lakes of Killarney show a number of small caverns of sea-coast type, excavated by wave-action along the joints and bedding-planes (illustrated in [10]). They are all more or less water-floored, depending on the level of the lake water.

The pattern occurring on the walls of these caves is essentially scalloping, but it is very small in comparison to that seen in most caves. It does not show definite direction of flow of water and is in the nature of an 'oscillation scalloping'. This is a result of the in-and-out wash of wind-driven lake-waters, and as the rock-surfaces beneath the water do not show scalloping (except very large irregular hollows) it is developed as a surface phenomenon. Such multi-directional scalloping might be found in a dry cavern near an old lake shore-line and the type should be kept in mind when definite direction of flow is not forthcoming.

Roughty River, Co. Kerry

This is not a cave site but it is described, as along the river course some examples of scalloping in Old Red Sandstone were located. Above Morley's Bridge the river has cut deeply into the sandstone, with magnificent potholes, miniature gorges, and scalloped rock-surfaces.

At one place a type of scalloping controlled by the strike is well-developed. Thin bedded sandstones dip at a high angle to the north, the

* A full report and detailed survey of the Dunmore Cave is in course of publication. A preliminary report and survey is now published in *Cave Science*, No. 7, Jan., 1949, by N. J. Dunnington.

beds varying from 1 to 2 in. in thickness. The stream has cut a series of ripple-like scallops which are elongated into roughly rectangular form by the controlling rock-strike.

Castletownroche Caves, Co. Cork

During the excavation of three small caves in the limestone gorge of the Awbeg river below Castletownroche, the excavators noted the pattern of the rock-floor beneath the basal deposits of the Foley cave as " a pattern of shallow pits which gave it an inversely mamillated appearance ".[6] I have not seen this site, but from the description it appears to be scalloping. The basal deposit above the rock-floor of the cave was a mixture of pebbles and cobbles. It would be interesting to know if any directional plotting could be done with this surface and how it would work out in regard to the limestone gorge of the Awbeg river.

Ovens Cave, Co. Cork

I have previously described this cave and reference was made to scalloping on the site, but no attempt was made to describe it in detail.[2] A re-examination of Ovens Cave in the present survey proved it to be an excellent example of a recently deserted active cave-system, with very little dripstone as yet to obscure the original rock-walls and roof.

The cave is a complex system of generally tubular cross-sectioned passages and tunnels based on joints and almost vertical bedding in the limestone (*Fig.* 16, No. 4). Excavations in various parts of the cave have shown that the floor-deposits are barren sandy gravel and cobbles of no great thickness (resting on the rock-floor), and the few recent animal remains found in the cave appear to have been introduced after the laying down of the floor-deposits.[2]

Scalloping of excellent clarity is present in almost all the passages and tunnels. It is generally small in size towards the apex of the passage-roofs and on the walls it is commonly two or three times larger. Beneath the floor-deposits the trial excavations appeared to show an absence of scalloping. This might be due to the abrasion of the water-born deposits, or on the other hand solution by water contained in the deposits might have obliterated previously formed scalloping. It is difficult to say if the scalloping was formed in the cave system before or during the introduction of the deposits.

In the southern portion of the cave, especially in the main gallery running to the Mass Rock Chamber, flooding often occurs at present in wet periods. The flood-level lines along the gallery walls coincide with a line below which the sharply cut scalloping gives place to a smoothed-off rock-surface with large irregular concavities. (*Plate* 8, *Fig*. C). It is probable that the static water of the flood periods operating over a number of years has by solutional activity obliterated the original scalloping.

A plotting of the direction of flow from the scalloping (*Fig*. 16. No. 4) shows that the general direction of flow in the cave was from south to north, but there are numerous divergent flows. Taking into account the tubular cross-sections characteristic in the cave (e.g., Section x–y, *Fig*. 16, No. 4) it appears that the water flowed through as a pressure-fed anastomosis.

The Bride river near Ovens Cave has a south-to-north course around the site of the cave, bending in an arc to the west. The fact that the plotting of scalloping within the cave also shows a south-to-north course seems to indicate that the Bride river during the cutting of its valley, could have used the cave-system earlier in its history. Lateral swinging of the river in widening and deepening its valley has shifted the river westward from the cave—but, the probability is that the river when it was in the vicinity of the cave was partly subterranean, using the cave-passages and tunnels now deserted.

CONCLUSION

Enough has been said in the foregoing notes to outline the possibilities of determining previous water-flow direction in dry stream-deserted cave-sites. Properly used, this evidence is indisputable, and perplexity should not arise if such direction is contrary to the inclination of the passage-floor. Flow under hydrostatic pressure, especially in tubular-sectioned passages or tunnels, has often forced water up-grade, as instanced by Bretz, in the Mammoth Cave, U.S.A.[1]

Another possibility, though rather an unlikely one, is that a cave-wall might show in an upper part one direction and lower down an opposite direction of flow, indicating a complete reversal of the current. The author has not seen any example, but it might exist in some unexplored cave-sites.

Also it may appear, when a cavern is examined and the direction of flow plotted from the scalloping, that such direction is out of adjustment with the present topography and drainage of the region. For example, a stream-deserted cave drains *out of* instead of *into* an obviously river-cut gorge or valley. In such a case the cave is probably a segment of an older system, older than the present topography of the area. Such a condition would therefore be a valuable piece of evidence in any geomorphic examination of the area under consideration. To a limited extent the previous waterflow in the New Cave at Mitchelstown is opposed to the present nearby surface-drainage as already outlined above. On the other hand, the Ovens cave-system seems to have developed as an early partly subterranean stage of the Bride river, during the cutting-down of its present valley.

REFERENCES

[1] Bretz, J. H., " Vadose and Phreatic Features of Limestone Caves ", *Jour. Geol.*, 1942, Vol. L, pp. 675–811.

[2] Coleman, J. C., " The Ovens Cave, Co. Cork ", *Jour. Cork Hist. and Arch. Soc.*, 1940, Vol. XLV, pp. 47–52 ; 1944, Vol. XLIX, p. 58.

[3] Coleman, J. C., and Dunnington, N. J., " The Pollnagollum Cave, Co. Clare ", *P.R.I.A.*, 1944, Vol. LB, pp. 105–32.

[4] Coleman, J. C., " Preliminary Note on an Indicator of Water-flow in Caves ", *Geol. Mag.*, 1945, Vol. LXVII, p. 138 ; *British Caver*, 1945, Vol. XIII.

[5] Davis, W. M., " Origin of Limestone Caverns ", *Bull. Geol. Soc. America*, 1930, Vol. XLI, pp. 475–628.

[6] Gwynn, A. M., Mitchell, G. F., and Stelfox, A. W., " The Exploration of Some Caves near Castletownroche, Co. Cork ", *P.R.I.A.*, 1942, Vol. XLVIIB, p. 378.

[7] Goldstein, S., *Modern Developments in Fluid Mechanics*, 1938. Oxford.

[8] Hill, C. A., Brodrick, H., and Rule, A., " The Mitchelstown Caves, Co. Tipperary ", *P.R.I.A.*, 1909, Vol. XXVIIB, pp. 235–68.

[9] Maxson, J. H., " Fluting and Faceting of Rock Fragments ", *Jour. Geol.*, 1940, Vol. XLVIII, pp. 717–51.

[10] Wright, W. B., *The Geology of Killarney and Kenmare* : *Memoirs of the Geological Survey of Ireland*, 1927. Dublin.