# The Geomorphology of the Caves of North-West Clare, Ireland

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(Ordnance Survey of Ireland 6 in. to 1 mile, Clare, Sheets 4, 5, 8 and 9)

## INTRODUCTION

Considerable interest has been displayed at times in the caves of North-west Clare, but no general account of them has appeared for many years. The principal accounts in more recent times are by Bartlett (1936, 1937, 1938) whose 1938 account is largely repeated from Pick and Bartlett (1936). These record the exploration of some of the known caves and also some new discoveries. The principal caves explored were Faunarooska, Pollballiny, Polldubh, part of the Coolagh River Cave and Pollnagollum (Slieve Elva) and Pollnagollum (Doolin) was noted. Later this last pothole was descended and reascended rapidly when the leader landed on a dead cow (Gowing, 1938).

The next major explorations were by Coleman and Dunnington (1944) who recorded their exploration and survey of Pollnagollum (Slieve Elva) together with comments on the geomorphology of the system. This classic work stimulated the University of Bristol Spelæological Society, and parties led by Bendall and Pitts (1953) explored and surveyed the whole of the Coolagh River system adding many new passages to those already known. This work was followed up by other parties in successive years to 1955. These expeditions led to the discovery and investigation of the Cullaun series (Acke, 1953, 1954, and Jenkins, 1955), the Doolin Cave system (Robertson *et al.*, p. 159) and Gragan West Cave (Preston, p. 172). The Polldubh Cave system was investigated (Balister, p. 169) together with a number of other caves (*see* " Shorter Accounts of Caves," p. 176).

In addition to these expeditions other parties have been active in the area. The Craven Pothole Club has published an account of Poll-an-Ionian (Dickinson and Varley, 1952) and new passages in Pollelva (Holden and Holgate, 1952). The Burnley Pothole Club investigated Pollcreagh (Morris, 1954). The Royal Air Force College Society (Cranwell), Potholing Section, did considerable work in Faunarooska (private information not yet published), and also discovered new passages connected with the Pollnagollum system.

This paper deals with the area shown in *Plate* 6, *A* which contains about 21 miles of known caves. Of these this Society has surveyed about

15 miles. It is believed that no major discoveries will be made in the future in this area and so the time seems ripe for a general account of the geomorphology of the caves. This is not to say that minor discoveries will not be made and indeed they are to be expected and possible sites can be deduced from the map.

## GEOLOGY

The geology of the area is simple. There are 1,000 ft. of Carboniferous Limestone of D-S age lying unconformably upon granite, and the limestone is overlain by Carboniferous Shales. The general dip of the region is 2–3° to the south and south-west. The shale/limestone junction has minor undulations thought by Hodson (1954) to be due to pre-shale folding.

There are no important faults in the area. The joint pattern of the limestone is very simple, and, although there is some slight variation, only two main sets are present. The major one is on a bearing of 196° and the joints are often straight, continuous over long distances and often filled with calcite. The minor joint system is on a bearing of 270° but is neither so consistent in direction nor so continuous, and is rarely filled with calcite.

According to Charlesworth (1928) the topography before the Ice Age was probably very similar to that of the present day, but glacial deposition and erosion have made modifications. The whole region was at one time covered by ice. When the ice retreated the highlands to the south were uncovered first, then the Burren which includes the area of this paper. The ice then flowed in two lobes, one west to the Aran Islands and Galway Bay and the other south to Kilfenora. In a later stage minor lobes occupied individual valleys. Retreat stages have been traced by Charlesworth. Sweeting (1955) has given an account of the land forms of North-west Clare and has discussed the caves and underground drainage. A considerably larger area is described in her paper than here. An earlier account of much the same area has been given by Corbel (1952).

The resultant relief and its relationship to the geology is shown in *Plate* 6.

## FACTORS INVOLVED IN THE FORMATION OF THE CAVES

With the exception of certain isolated examples the majority of the caves consist of long passages, which may be arbitrarily grouped into series and systems. In the former are grouped a number of caves geographically and structurally related but consisting essentially of long single passages not communicating with each other, such as the Cullaun series (Acke, 1954, and Jenkins, 1955). The latter consist of a number of inter-connecting passages such as the Coolagh River Cave (Bendall and Pitts, 1953).

In both large- and small-scale features of the caves there is much room for investigation and speculation. To avoid duplication of information the factors involved in forming the caves will be considered rather than the results, except in the case of vertical features. The factors considered are shale outcrops, joints and veins, bedding planes, relative effects of solution and corrosion, and cave infillings.

## Shale Outcrops

It is clear from *Plate* 6 that many of the cave entrances lie close to, or at, the shale edge, and there is very little surface drainage on the limestone. Where a surface stream leaves the shale it almost immediately goes underground and blind valleys develop as surface denudation ceases beyond the sink hole. The shale acts as a collecting area for the water and the size of the subsequent stream affects the size of the cave. For example, on the Poulacapple ridge the watershed is close to the eastern edge of the shale and the Gragan West Cave passages, with a small catchment area above them, are in general smaller than the Cullaun series passages on the west side with a larger catchment area.

In some instances the streams disappear into the limestone within the main shale boundary, as for example St. Catharine's III, Coolagh River Cave entrance and Poldonough South entrance of the same cave. This indicates that, when thin, the shales are pervious (*see also* Acke, 1954, p. 21). It only happens close to the shale edge and inevitably gives rise to inliers of limestone in blind valleys.

The removal of shale by surface erosion will extend exposures of limestone above swallets and below risings as at Poultalloon (F 5) and St. Brendan's Well (F 4).

## Joints and Veins

The joints and calcite veins, which have the same direction, are simple, and so it is easy to see when they affect cave development. In some caves a passage follows a vein closely and it can be seen in the roof and floor. This is well seen in the Cullaun series, especially III and V. The caves only follow a joint for a limited distance and then jink, often into another joint or vein-controlled passage. The 196° set of joints is much more important than the 270° set, being the better developed. Where a cave runs across a set of joints there are often notches in the walls at the joints indicating preferential solution there. This effect is well seen in the Doolin and Polldubh caves but in the latter it is the 270° set which gives rise to the notches. The greatest effect of solution along the joints is to be seen in Ballyshanny (G 10). Often in the caves, and notably in the Doolin System, there is a tendency for the cave to become straighter as the formative stream abandons an earlier meandering course for a straight joint controlled one. On the other hand in Gragan West Cave there are some old small routes along the joints, whereas the present active route meanders.

It is often stated (e.g., Bretz, 1942, p. 734) that calcite is less soluble than limestone. In many places and most certainly in North-west Clare caves the calcite veins are evidently more soluble than the surrounding limestone. This apparent anomaly is due to the nature of the veins. A perfect crystal may well be highly resistant to solution but blemishes in crystal structure provide ready points of attack. A large single crystal may be expected to have less blemishes than a mass of minute crystals and hence it would be less prone to solution. A mass of minute crystals may have a considerable micro-porosity due to spaces between crystals, which would lead to easier penetration by liquids and therefore to easier solution.

Limestone is a polycrystalline aggregate of small crystals and therefore a cube of limestone would be more soluble than a similar cube of calcite. From this it is clear that a vein of coarse calcite should be less soluble than the surrounding limestone and that veins of calcite should stand out from the cave walls. This is not always the case and the nature of the calcite vein must be considered in more detail to explain the apparent contradiction.

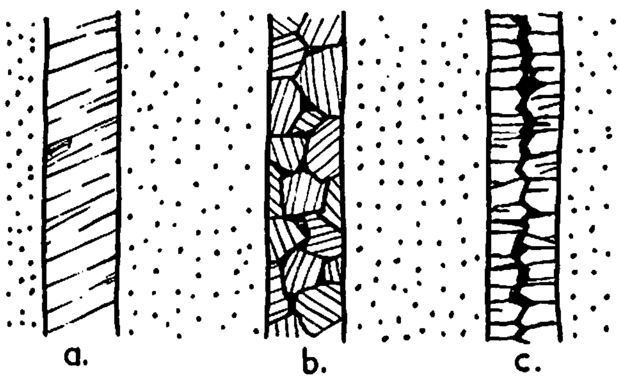


*Fig.* 21.—Diagram of calcite vein forms.

There are several varieties of vein depending on the nature of the filling. One type of vein consists of a sheet of calcite with one crystal orientation (*Fig.* 21, *a*). The many cracks transverse to the vein wall enable some solution to take place, but usually this type of vein is less soluble than the surrounding limestone. Another type (*Fig.* 21, *b*) consists of coarse poly-crystalline calcite, and the solubility of this type depends upon how well the crystals fill the vein. If they completely fill it solution will be retarded ; if there is considerable porosity due to spaces between the individual crystals solution will be enhanced. A third type occurs when there is symmetrical banding of the calcite in a fissure (*Fig.* 21, *c*). Calcite grows in from both sides and may completely fill the fissure. More often, however, there is space along the centre of the vein allowing easy penetration of water, which leads to considerable solution along the vein. This type of vein is rather common in County Clare and accounts for the marked vein control on the direction of the caves. It should be noted that in the last two cases the increased facility of solution is due to the vein structure allowing easy access of water and not to differences of crystal size. A vein may thus provide an easy route for water, which is at first concentrated upon the calcite and dissolves it. The limestone is then attacked forming a cave along the joint.

A further factor was suggested by Acke (1954, p. 21). A fissure may be lined with non-calcareous material before the calcite filling occurs, and, when the cave comes to be formed, there may be water seepage along this dirt line, and therefore solution along the interface between the calcite and the limestone.

## BEDDING PLANES

Bedding planes were important lines of early phreatic development, and the earliest vadose streams were also controlled mainly by bedding planes. Joint control has often made important modifications but many cave passages appear to be superimposed from the original meanders in the bedding plane roof. An early phase of this is seen in *Plate* 8, *A*.

There are, however, two distinct types of passage in the present stage of development. One, known as a bedding plane, is relatively wide and low; the other, known as a canyon passage, is relatively narrow and high. Which will develop from the initial stages of cave formation appears to depend on local conditions and stage of development.

In the early stages it appears that a braided stream of branching and anastomosing streamlets flowed over the bedding planes, and corresponding channels were incised. At this stage a wide bedding plane passage may be

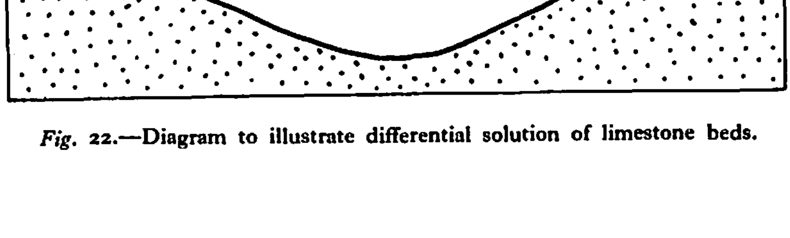

*Fig.* 22.—Diagram to illustrate differential solution of limestone beds.

present. Ultimately the drainage became better integrated, and one main meandering channel was developed, leaving a number of dry ox-bows at higher levels. When one well-definéd channel is present from a very early stage a simple T-section canyon passage may develop without any ox-bows.

In some caves there appears to be differential solution along beds, the limestone immediately above a bedding plane being less soluble than that below. This gives rise to the type of cross-section shown in *Fig.* 22. When this is developed to an extreme, thin, broad, razor-edged shelves result. In parts of Aran View Passage (Doolin Cave) this form is present and the passage is extremely dangerous as shelves collapse under the weight of an explorer. A more moderate form is seen in Gragan West Cave and in parts of other caves.

The usual roof of either canyon or bedding plane passage is a fairly flat surface with pendants, half tubes and so forth developed to a greater or less extent. In most cases there is little relief in the roof and widely spaced

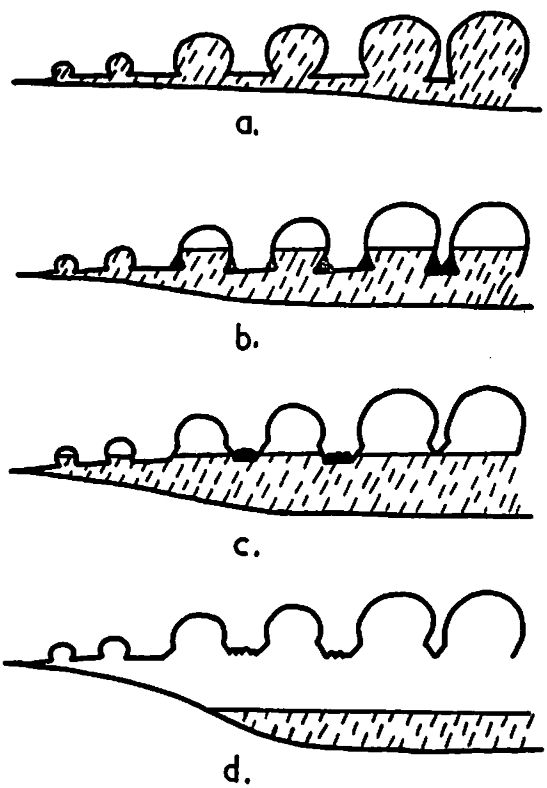


*Fig.* 23.—Mode of formation of half tubes and pendants.

pendants project from an otherwise flat surface (*Plate* 9, *A*). In exceptional cases well developed roof features enable a sequence of development to be worked out. The stages are shown diagrammatically in *Fig*. 23, *a–d*. At first conditions are entirely phreatic and half tubes are formed above the bedding plane. The tubes are larger in the centre (*Fig*. 23, *a*). At this stage there has been little downward solution. Further downward solution or less water flow causes the larger tubes to become partially air-filled, while the smaller tubes remain water-filled (*Fig*. 23, *b*) ; in the still phreatic tubes there is still all-round solution, while in the vadose ones solution proceeds only in the lower part, which is still submerged, producing a tapering pendant. With further downward solution the water surface drops still further. The tapering pendants may already be above water but others will project beneath the surface where the tips are removed by solution leaving a flat or scalloped surface (*Fig*. 23, *c*). The small tubes on the margin become air-filled relatively quickly and so retain essentially their phreatic form. The present-day form is shown in *Fig*. 23, *d*. More complicated forms than those shown in *Fig*. 23 can occur. This course of development is unlike that postulated by Bretz (1942, p. 736).

## Relative Effects of Solution and Corrasion

The evidence of the caves indicates that solution plays a far greater part in cave formation than corrasion. Solution in the phreatic stage has already been described but in the vadose stage, too, erosion by solution is far more important than corrasion in cave formation. In the commonly occurring shelved passages (*Fig*. 22 and *Plate* 8, *A*) only solution could have picked out the bedding planes so well and it is impossible for corrasion to produce this type of feature.

Scalloping or fluting is believed by Bretz (1942, p. 731) to be due to solution. On floors, walls and occasionally on roofs scalloping is a marked feature of these caves. The asymmetry of the scallops has been used to determine the direction of water flow in caves (Bretz, 1942, p. 90) and Coleman (1949) has applied this to Irish caves. The asymmetry is extremely well marked over miles of passages, the direction of the flow is known as the streams are still flowing and the steep side of the scallops is always upstream. A crawling caver is most uncomfortably reminded of this when moving upstream. The asymmetrical scallops are of varying size but considerably smaller than the symmetrical ones formed under phreatic conditions. Both types can be seen in Faunarooska (Ollier, p. 181). Chert bands remain unscalloped as described by Bretz (1942, p. 731). In the caves of north-west Clare the chert bands are usually but a few inches thick, in discontinuous sheets parallel to the bedding. In places they form false floors, which can only be produced by solution of the underlying limestone. If corrasion were a major factor in cave formation then these chert bands would have to be eroded away before the underlying limestone could be attacked. An example of these false floors is figured by Bendall and Pitts (1954, *Plate* 29, *B*).

In a canyon passage formed by corrasion slip-off slopes develop at meanders as in a surface river, but unlike a surface river the undercut slope remains in a cave, and matches the slip-off slope (*see* Bretz, 1942, *Fig.* 9). Such slip-off slopes are rare in these caves, and instead canyon walls are more or less vertical in all parts of a meander indicating downward cutting mainly by solution. Occasional passages do show slip-off slopes.

The profile of a canyon passage is dependent upon two factors, which may act separately or jointly. One is the solubility of the rock and the other is the volume of the water. In downcutting the cave will become wider if a more soluble band is reached, or if the water volume increases. If a less soluble band is reached, or if the volume of water decreases, the cave becomes narrower. In the caves of North-west Clare the typical profile is a simple U with a T-section at roof level, but other types occur as may be seen from published surveys and photographs in these *Proceedings* and other publications.

## Base Level

Limestone is a pervious but not porous rock and the water table is the surface of water saturation. The water table is by no means a flat surface, being affected by relief and geology and fluctuating with rainfall and run off. Obviously vadose caves cannot form beneath the water table, but they may well be on the water-table surface. The rising at St. Brendan's Well (*Plate* 6, *A*, F 4) is obviously on the water table and is due to the shale/limestone surface having a greater dip than the surface topography (*Fig.* 24 *and also* Sweeting, 1955, *Fig.* 9). Regarded simply, the shale dams back the water in the limestone, and at the lowest point on the shale edge, as at St. Brendan's Well, the water will overflow as a rising. Water in the limestone near the higher parts of the shale edge will flow approximately along the edge to the lowest point rising, if the channels are large enough, which allows one to postulate the line of drainage of Cullaun II–V waters. Under flood conditions risings other than the lowest point risings may be used. A river will rise above St. Brendan's Well at various places depending on the temporary height of the water table. The water table, whether on the surface or underground, acts as the temporary base level to which vadose streams erode.

The shale margin lies at over 400 ft. above O.D. and is the main water table control for the region between Slieve Elva and Poulacapple, so the water table cannot have a very steep gradient in this area. Where a water table meets the surface there must be a rising and the Killeany rising is an example of this (*Fig.* 24). In this area the water table is never very far below

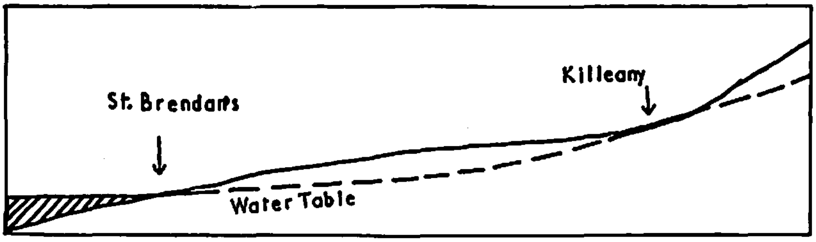


*Fig.* 24.—Diagram of risings at Killeany and St. Brendan's Well and their relation to the water table.

the surface and the caves consequently are also close to the surface and have gentle gradients.

If the limestone is not made pervious, by fissuring by solution, the water must run along the surface. The Caher river is of this type and it is postulated that the Caher has failed to develop a cave system because it has a wide catchment on limestone only, and there is no concentration of water on shale, which seems to be necessary for large cave formation in this area. The gradient of the valley, which takes a short direct route to the sea, is steep, and it seems that the rate of erosion has kept pace with the tendency for the water to go underground. Glacial drift is present in the lower part of the limestone valley of the Caher but in the upper part the river undoubtedly runs on limestone. The Rathborney river, just north of the area considered here, also flows on limestone, probably for the same reasons.

The Polldubh–Coolagh River system is largely formed close under the shales, and the gentle cave gradients indicate a water table close to the surface as would be expected.

The Doolin system is graded to a water table, which is intimately related to the sea level, but the shale/limestone junction comes down to the sea level in this region and so the water table, lying between the shale/limestone junction and sea level, is fairly flat, and the system consists of caves of gentle gradient. The Aille river crosses the cave on the shales and is an example of a perched water table. At present the river is leaking extensively into the cave and will eventually disappear into it (Robertson *et al.*, p. 167).

Poulnagree and Faunarooska are situated at the top of steep limestone slopes where the water table must also be steep as there are no risings on the limestone slopes. The caves following the water table are also of steep gradient and have vertical pitches often of considerable height. Pollapooka is probably a cave of this type, but as it consists of only one initial vertical pitch it is not possible to be sure. (*See also* Tratman, p. 182.)

It must be stressed that in the caves, local temporary base level is more important than general base level, i.e., sea level. The local level is controlled by shale outcrops as at St. Brendan's, and by the openness of joint and bedding planes, etc., and these factors affect the sectors of the cave upstream. Changes in sea level would not affect the upper parts of caves. Vertical features are developed during a normal sequence of events, and are not evidence of general rejuvenation. If the caves were related to the erosion levels (Sweeting, 1955) then the higher ones (e.g., Pollnagollum) would presumably be older than the lower ones (e.g., Doolin), but the evidence in the caves indicates that they are contemporary.

## Cave Infilling

The caves are formed by the streams that now occupy them, as will be explained later (p. 155). The mud deposits in the caves all seem to have been left in places now more or less deserted by the streams, including the sides of bedding plane passages, and it is not considered that Bretz's (1942) phase of general infilling has occurred in these caves. Bendall and Pitts (1953, p. 240) have noted that mud deposits, which they regard as having once filled the cave, are now being removed but local changes in stream flow may deposit or remove mud without there having been any general phase of infilling.

Well-rounded shingle of flat shale pebbles occurs extensively in the broad bedding plane passages. Dripstone deposits are relatively infrequent though occasionally very fine formations occur (Dickinson and Varley, 1952). They can be extensive (Acke, 1954, p. 18). The formations consist of all the usual varieties which therefore need no further description. Helictites, especially the more complicated forms, are not absent and long bands of stumpy ones have been noted in Cullaun II (Acke, 1954, p. 16). Some stalactites observed in Cullaun V are composed of iron oxides, limonite and goethite. In the same cave some stalactites are formed of alternate layers of calcite and goethite. Often a line of stalactites follows a calcite vein or joint (*Plate* 8, *B*).

At the bottom of Polldubh hollow mud balls were found. Their diameter was about ½ in., and they were very thin and irregular walled. The surface appearance resembled butter balls.

Infilling by dripstone formations often occurs where the cave is still occupied by an active stream and does not await abandonment of a passage by a stream as stated by Davis (1930, p. 477). Sometimes they are still reached by flood waters and in the Doolin cave in particular small helictites are being formed on flood-borne grass or straw wound round stalactites. In other places re-solution is occurring, sometimes, but not always, associated with flooding. This is a general phenomenon and not one confined to the caves of North-west Clare.

## Vertical Features in the Caves

These include the following four types (*Fig.* 25, *a–d*):

1. *Simple Descent.*—In this type the stream descends rapidly to a lower level. As there is no continuing passage at the higher level the descent must have been present as long as the stream has flowed and must, in fact, have a phreatic origin. An example of this is seen in the First Vertical Feature of Cullaun I (Acke, 1954, p. 11).

2. *Descent to a Lower Passage.*—This type differs from the simple form in that the descending stream enters a continuous lower stream passage. As in the simple form there is no continuing dry passage to correspond with the high-level passage and therefore the development of both passages must have been contemporary and, as argued for the simple descent, must have been initiated at the phreatic stage. Examples of this type can be seen in the Year Passage of Cullaun II (Acke, 1954, p. 16).

3. *Descent Leaving a Dry Roof Passage.*—In this type a vadose stream finds a lower route by gradual enlargement of joints and bedding planes and eventually the entire stream takes the lower route leaving a deserted passage beyond the original point of descent. An example of this type can be seen in Cullaun V at section 17 of the survey (Jenkins, 1955, *Plate* 5).

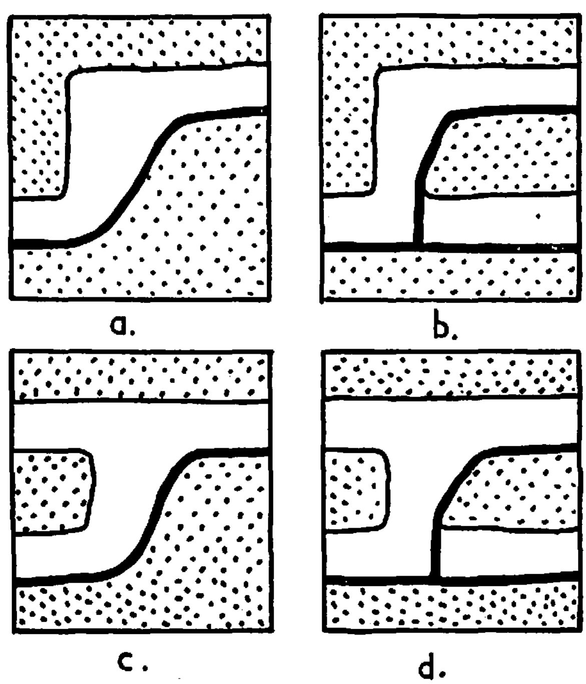


*Fig.* 25.—Diagram of forms of vertical features.

4. *Connexion of an Upper to a Lower Stream Passage leaving a Dry Upper Passage.*—In this type a higher level stream and a lower one first cross without connexions. Subsequently a connexion is developed and the continuing upper passage becomes deserted. This type is rare in Clare, but an example is the crossing of Poldonough South Passage over the Coolagh River passage (Bendall and Pitts, 1953, p. 232).

## RELATIONSHIP OF THE CAVES TO SURFACE TOPOGRAPHY

*Pollballiny, Polldubh-Coolagh River System.*—These caves and their associated surface features together form a dendritic pattern (*Plate* 6, *A*). Besides the features shown there are a number of dry valleys obviously linked to this system. One dry valley runs from north of Faunarooska southwards along the limestone shelf parallel to the present shale margin and parallel to and west of Pollballiny and Polldubh North. After about a mile the valley continues, still dry, across the shale to the limestone inlier, where it is met from the north-east by the Glenaruin river near B 4.

The system is continued as the Coolagh river and the Coolagh River Cave beyond is closely matched by another dry valley system. A dry valley continues beyond the surveyed end of the cave but under flood conditions is occupied by a surface stream, and shake holes associated with the lower end of the cave become risings (Bendall and Pitts, 1953, p. 329). It seems likely that the Coolagh River Cave continues to follow the line of the surface valley.

The inlier above the Coolagh River was probably formed by normal erosion by a stream flowing on the surface of the shales gradually cutting down to the limestone. Once formed it would be modified by the stream at its upper end being engulfed at successively higher points. As the water table is high there is a rising at the lower end, which, by erosion of the shale, would extend the limestone inlier downstream (cf. St. Brendan's Well, *Plate* 6, *A* and *Fig.* 23). An additional complication in the formation of the inlier is due to some of the streams, which once flowed over the surface, going underground (e.g., Polldubh), and re-appearing at the rising. The cave system under the inlier is ill-developed as under flood conditions it cannot take all the water and an intermittent stream flows over the limestone. This inlier is unlike all the others in the area having a rising as well as a swallet.

*Pollnagollum (Slieve Elva) System.*—In this system all the caves on the east side of Slieve Elva as far south as Pollcreagh are included. Published cave descriptions include Pollnagollum (Coleman and Dunnington, 1944, and 1949), Pollelva (Coleman and Dunnington, 1949 ; Holden and Holgate,

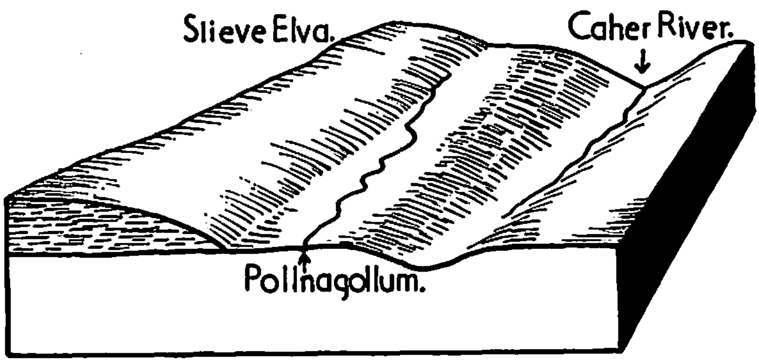


*Fig.* 26.—Block diagram of east side of Slieve Elva.

1952), and Pollcreagh (Morris, 1954). Many minor swallets feed into the system but have not been individually described.

From the available contoured maps Pollnagollum cave appears to be running in a direction obliquely across the side of the Caher river valley, but in fact there is a limestone shelf on the east side of Slieve Elva as shown diagrammatically in *Fig.* 26 and the cave is related to this shelf.

The two passages that form the uppermost parts of this cave have been shown (Coleman and Dunnington, 1944, *Fig.* 1) to commence at the shale/limestone junction and to pass under the shale to emerge at Pollbinn (E 5, 6). In the next stretch the cave takes the course shown and is matched on the surface by a dry valley system running in the same direction and which crosses Pollnagollum and Pollbeg (E 7, 8). The dry valley possibly follows the cave much further but has not been traced. South of Main Junction (E 11) (Coleman and Dunnington, 1944, *Plate* 1) the change in direction of the cave suggests joint control in the 196° direction for some distance, after which the cave reverts to its old direction. An older straighter route is indicated by a roof passage (Coleman and Dunnington, 1949, p. 273).

Upper Pollelva (Coleman and Dunnington, 1949, p. 274) does not communicate with Pollnagollum but as the survey has not been published no conclusions can be drawn. The line on *Plate* 6, *A* can only be regarded as approximate. Lower Pollelva (Holden and Holgate, 1952, p. 185) follows a course which is matched for part of the way at least by a dry surface valley, which crosses Pollelva. No connection has so far been found between Lower Pollelva and Pollnagollum.

Pollnagollum and Pollbeg are two potholes out in the limestone away from the shales and their mode of origin is not certain. The first possibility is that they were swallets, but there is no indication of a blind valley form although the potholes are large. They would be successive points of engulfment but a dry valley crosses each of them with profile unaffected. In spite of this they may have been the sites of very shortlived, small sinks which have since been greatly enlarged by other processes. Coleman and Dunnington (1944) believe that they were in fact sinks but do not discuss the factors mentioned above which are against their view. A second possibility is that they are collapses. At these pots the roofs of the cave passages are very close to the surface, which enhances the possibilities of collapses, which, though, may have been subsequently enlarged, as the main cause of their formation and location. Another factor in their formation might have been hydrostatic pressure under flood conditions in the early phases of development of the cave system when these potholes may even have served as very temporary and intermittent risings.

The pothole of Pollelva may be similarly explained.

The dry valley system must have been initiated when the underground drainage was so feebly developed that it could not cope with all the water available. Eventually the drainage went completely underground and received tributaries from streams that sink at the shale edge. Some of these sinks themselves have rudimentary dry valleys related to them.

*Cullaun Series.*—This series includes the caves described as Cullaun Zero—V (Acke, 1954; Jenkins, 1955; and Ineson, Toms and Tratman, pp. 180–181). In this region the stream pattern can be deciphered fairly well and *Plate* 6, *B* shows surface streams, dry valleys and caves. A dendritic drainage pattern is developed on a shelf similar to the one described for Pollnagollum. The streams flow south-west with modifications due to cave development and river capture. In this region the caves do not follow the old lines of the surface drainage pattern but are much more closely related to the jointing on the 196° direction. The caves therefore follow a course independent of the topography.

*Killeany–St. Brendan's Well System.*—Coleman and Dunnington (1944, p. 121) suggested that the Killeany Rising might be the point of resurgence of the Pollnagollum waters but that St. Brendan's Well was the more probable. They have also pointed out that under flood conditions the valley above St. Brendan's carries a surface stream, which rises at a progressively higher level as the degree of flooding increases and that there " is a valley of sorts " up to Killeany. The cave system is obviously imperfectly developed and cannot take all the water. Observations by this Society show that under flood conditions a surface river exists from over half a mile above Killeany right down to St. Brendan's, save for a short distance of less than half a mile, south of the Lisdoonvarna–Ballyvaghan road. Under normal conditions the water rises at Killeany only to sink again through a number of openings, of which the main one is Owenterbolea. Between this one and the Lisdoonvarna–Ballyvaghan road access to the cave water is possible at several points.

Fluorescein tests by this Society have shown that Killeany is a multiple rising. It can be divided into a west portion and an east portion. The west portion is shown in Coleman and Dunnington (1944, *Plate* 3, *Fig.* 4). This is the outlet for all the Pollnagollum waters including all streams that run into it beyond the explored portion, such as Pollelva, to as far south as Pollcreagh. There is also a subsidiary rising on the west side not affected by the above tests and presumably this is the water from Pollcahercloggaun East. The many openings of the eastern portion are the outlets for Cullaun I and presumably Cullaun Zero waters. The waters of the east and west portions do not mix until after they have become surface streams.

The combined waters run to St. Brendan's and rise mainly in the pool under the east shale cliff but also in other places. The water from Pollcahercloggaun West rises at St. Brendan's mainly under the west side, though the differentiation of the parts of the rising is not nearly so well marked as at Killeany. It may be inferred that the waters from the other swallets as far west as Poultalloon from Cahercloggaun West will also run to St. Brendan's.

Coleman and Dunnington (1944, p. 121) have suggested that the waters rising at Killeany are the surplus waters that cannot be carried by an ill-developed cave system between Killeany and St. Brendan's. In 1955 this Society was able to observe St. Brendan's under extremely low water conditions. A mere trickle was emerging there, and the same apparent volume was rising at Killeany and sinking at Owenterbolea. Killeany is thus a complete rising and there can be no ill-developed cave system between Killeany and Owenterbolea but only between Owenterbolea and St. Brendan's where the cave passages cannot be explored but it is believed that they are closely related to the surface features as shown in *Plate* 6, *A*. (*See also Fig.* 24.)

Waters unaccounted for are Cullaun II, III and IV/V. It seems highly probable that these rise at St. Brendan's as the plotted ends of the caves are too far south for the waters to rise at Killeany, though they may join the system between Owenterbolea and St. Brendan's. The plotted sump ends of Cullaun V are close to the shale edge, where, by analogy with St. Brendan's, the water table will be high. There is no resurgence in this case probably because the water has found an easy route to St. Brendan's (*Fig.* 24) just north of the gently descending shale edge.

*Gragan West Cave.*—A detailed account of this cave is given by Preston (p. 172). A limestone shelf is present east of the shales as on Slieve Elva, but in this instance slopes towards the shales so that rivers do not run across the shelf. A number of traces of dry valleys have been found on the shelf but no pattern can be discerned. The water tends to run under the shales, but the structure causes the water table to be close to the shale edge, and so the caves run roughly parallel to the shale edge, and flow south. Joint control is evident in some stretches. Tributary valleys are plentiful and have a whole series of successive small swallets and the waters join the main cave underground. Very few tributaries are large enough to be explored and there is no large entrance to the cave. All the passages of the cave are small, which is due to the very limited catchment area, for most of the Poulacapple shale outlier is drained to the west.

*Doolin System.*—An account of this system is given by Robertson *et al.* (p. 159). A dry valley system runs to Fisherstreet with branches from Aran View and the St. Catharine's/Doolin Road Sink area and this was once occupied by an active river system. The upper reaches on the shale are still active streams, but the waters now sink on the limestone to form the Doolin System. The lines of cave drainage do not closely follow the lines of dry valleys, but there can be little doubt that the two are genetically related. The main cave does not follow the line of the main dry valley but goes under the shale. The Aran View tributary, which for much of its length follows a dry surface valley, eventually goes under the main surface dry valley.

The explanation of the change of route seems to be as follows. Once underground the stream is not affected by surface features, but is controlled by the water table, which is itself in this area controlled by the shale edge. The situation is similar in principle to that at the shale edge east of St. Brendan's Well. The Doolin main cave is analogous to the postulated line of drainage from the Cullaun series II–V to St. Brendan's Well. Thus the system has shifted south of the dry valleys towards the water table, which is now south of the shale edge. The Aille River leaves the shales and flows over the limestone for some distance, indicating a perched water table, but leaks extensively into the vadose cave passages.

*Faunarooska and Poulnagree.*—It has already been explained in the section on Base Level (p. 145) that these two caves are largely related to the water table and are not related to the surface valleys. (*See also* Lloyd, p. 183, and Ollier, p. 181.)

*Pollapooka.*—This is an interruption in a dry valley, but its form bears some suggestion that it was once an active swallet (Tratman, p. 182).

*Poulawillin.*—In the region of Poulawillin are several streams running northerly off the shales into swallets but only at Poulawillin itself is an explorable cave developed (Balister, p. 179). There is insufficient length of passable cave to permit any conclusion being drawn as to its relationship to the surface. The underground drainage of the swallets west of Poulawillin is unknown but the streams from the swallets near the plotted end of Cullaun V (Jenkins, 1955) presumably enter this cave and follow its drainage.

*Ballymahoney.*—The surface relief of this region is complex and not easy to explain. There is not enough explorable cave to warrant drawing conclusions as to its relationship to the topography. It does seem that the cave is too small for its catchment area and it appears to be running straight under the shale-covered hill to the south. The cave is further described by Watkins (p. 179). In view of the relationship noted elsewhere of water table, shale edge and cave direction (p. 145) it seems likely that the waters will flow easterly towards Noughaval.

*Ballyshanny.*—The entrance to this cave is in a limestone inlier fed by active streams on the shale and the development of the swallet is explained by Lloyd (p. 176). The development of the explorable part is related to the jointing and not to the surface topography.

*Ballygonnaun.*—This is an active swallet with a dry valley beyond to the west. The explorable part of the cave runs eastwards, a direction contrary to the surface drainage. The cave is described by Lloyd (p. 176).

*Noughaval Swallets.*—This series of valleys and swallets is in a comparable position to Gragan West Cave, but no cave system has as yet been entered. It seems likely that there is a system running along or close to the shale edge as at Gragan West Cave flowing to the region of surface water to the south. This area may repay further investigation. (*See also* Tratman, p. 179.)

*Poll-an-Ionian.*—This cave was discovered and described by the Craven Pothole Club (Dickinson and Varley, 1952). The published account and picture indicate that the cave is similar to others already described and from the survey appears to be largely joint controlled.

### Summary of Relationship of Caves to Surface Features

A general hypothesis of the geomorphic development of the caves and related surface features may be given. The topography at the earliest starting point was broadly similar to that of the present day. Knockauns Mountain, Slieve Elva and Poulacapple were in existence as shale-capped hills bordered by limestone platforms, the Mid-Carboniferous peneplain of Sweeting (1955), and which are parts of the shale-limestone junction from which the overlying shales have been removed. None of the platforms were level surfaces but each had a slight slope, which had a profound effect on the later development as it governed the direction of the surface streams on the shelf. Some streams on the north-west side of Knockauns Mountain and Slieve Elva drained direct to the sea. Streams between these two mountains flowed south as the Polldubh–Coolagh River. Streams from the east side of Slieve Elva flowed south-east over the limestone platform and those on the west side of Poulacapple flowed south-west over a similar platform. On the east side of Poulacapple the platform slopes towards the shale edge, causing the streams to run along the shale outcrop. A river ran from Aran View and the St. Catharine's area to the sea at Fisherstreet.

Underground drainage developed and the cave systems followed the lines of surface drainage except where factors of jointing, bedding and water table caused the modifications listed in the descriptions of the individual caves.

According to Bretz (1942, p. 208) caves whose history has been entirely vadose are extremely rare. Davis (1930, pp. 560–561) asked for branch work ground plans as evidence for the vadose origin of horizontal cave systems. He found but few and all were modifications of older network plans. Bretz, working in the field, came to the same conclusion as did Davis from his search of the literature. Most of the caves discussed in this paper are precisely the kind that Davis sought. Not only do they have a branching ground plan but the plan is so closely related to the pattern of old surface drainage that there can be no doubt that one is developed from the other. The caves show further evidence that their history is almost entirely vadose and their phreatic beginning no more than is necessary and inevitable before vadose action can occur. Caves of this type may be rare but there can now be no doubt that they do exist.

## THEORIES OF CAVE FORMATION

Various writers have propounded theories of cave formation. It is not necessary to review these here but a theory applicable to the caves of North-west Clare will be stated. It is stressed that the theory may not be applicable to caves in other areas, even in Ireland.

The form of the caves indicates in most parts a formation in two stages: first the formation of bedding plane passages and then downcutting to form meandering canyon passages into the floor of the bedding plane. The first stage must have been phreatic and there is evidence in the roof of the caves of this. An example of anastomosing channels formed in the roof is seen in *Plate* 8, *A*. There is no evidence in the caves that phreatic action did more than this. Downcutting is obviously the work of vadose streams as phreatic action would produce all-round solution. It is believed that the phreatic phase was short and was followed by a vadose stage during which most of the passages were formed and are still being formed.

Beyond the present sumps, if they are the final ones, phreatic conditions must prevail, and when these dry out the cave should show phreatic features. It is surprising that such features are not found more often near present sumps, and only in Faunarooska are fairly certain phreatic passages present (Ollier, p. 181). It is believed that these two stages are the normal sequence of events of a simple progressive process. It is not necessary to invoke changes in base level as postulated by Coleman and Dunnington (1944) and Sweeting (1955) or climate to account for cave development.

The normal sequence of events is as follows. A stream flows across the limestone surface; under it phreatic action proceeds. Bedding planes and joints are enlarged by solution beneath the stream by the stream's own waters. As development proceeds more and more of the water is underground. Eventually all the water flows beneath the surface as a vadose stream. This programme may be regarded as normal for nearly all horizontal limestone as Acke (1954, p. 22) has suggested. In the main the caves are now occupied by the streams that made them and abandoned passages are the exception. The evidence discussed (p. 144) clearly indicates that the vadose streams performed their work by solution and not by corrasion as has been suggested by various other writers.

The cave passage form, the manner in which canyon passages so often enlarge with each tributary, the closeness of the caves to the surface and the scarcity of abandoned passages are all clearly juvenile features. In fact all the caves appear to be post-glacial in origin. This conclusion is supported by the fact that the small dry valleys, associated with, and older than, the caves, are not modified by ice action and contain no glacial fill. There is no filling within the caves and potholes that could not have been brought in during development in post-glacial times.

If these conclusions are correct then the caves are younger and the rate of solution faster than is generally supposed, but, however remarkable the implications may be, the theory proposed is the simplest that fits the known facts. The problem of rate of solution, particularly under peri-glacial conditions, is one that requires much further study, which is outside the scope of this paper.

It is necessary to define more clearly what is meant by the post-glacial period. According to Charlesworth (1929) the area of North-west Clare lies within the margin of the Newer Drift. This is regarded as being formed during the second maximum of the last glaciation, which is correlated with Würm II of the Alps. The caves must, therefore, post-date this period but would start to form as soon as the ice had retreated in the interstadial before the last re-advance of the ice. This was not of sufficient extent to re-glaciate the area.

There are two outstanding difficulties of this theory. If the pre-glacial topography was similar to the present day there seems no reason why the caves should not have been formed then. Secondly, in the area immediately to the east Sweeting (1955) has deduced that the caves and other solutional features are pre-glacial.

The conclusions reached as to the mode and period of formation of these caves are very similar to those more tentatively stated by Acke (1954, pp. 21–22). Many general theories of cave formation have been propounded but none of them, save the *Invasion Theory of Cave Formation* of Malott

(1937), approximates to the views here expressed. The theory given in this paper is not meant to be a general theory, and no claim is made that it is applicable to any other area.

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## REFERENCES

Abbreviations used :—

*C.P.C.* : *Journal of the Craven Pothole Club.*
U.B.S.S. : University of Bristol Spelæological Society.
*Y.R.C.* : *Yorkshire Ramblers' Club Journal.*

ACKE, P. R., 1953, " New Discoveries in Ireland : Interim Report ", *Proc.* U.B.S.S., Vol. 6, No. 3, 246.

— — 1954, " The Cullaun Series of Caves ", *Proc.* U.B.S.S., Vol. 7, No. 1, 7–12.

BARTLETT, P. N., 1936, " County Clare—A Brief Diary ", *Y.R.C.*, Vol. 6, 329.

— — 1937, " Discoveries in County Clare, Ireland ", *Caves and Caving*, Vol. 1, 38–40.

— — 1938, " Three Easters in Ireland ", *Y.R.C.*, Vol. 7, 35–42.

BENDALL, R. A., and PITTS, J. K., 1953, " The Coolagh River Cave ", *Proc.* U.B.S.S., Vol. 6, No. 3, 228–245.

BRETZ, J. H., 1942, " Vadose and Phreatic Features of Limestone Caverns ", *Journ. of Geol.*, Vol. 50, No. 2, 675–811.

CHARLESWORTH, J. K., 1928, " The Glacial Retreat from Central and Southern Ireland ", *Quart. Journ. Geol. Soc. London*, Vol. 84, 293.

— — 1929, " The South Wales End-Moraine ", *Quart. Journ. Geol. Soc. London*, Vol. 85, 335.

COLEMAN, J. C., 1946, " An Indicator of Water-flow in Caves ", *Proc.* U.B.S.S., Vol. 6, No. 1, 57–67.

COLEMAN, J. C., and DUNNINGTON, J. J., 1944, " The Pollnagollum Cave, Co. Clare ", *Proc. Roy. Irish Acad.*, Vol. 50 B, 105–132.

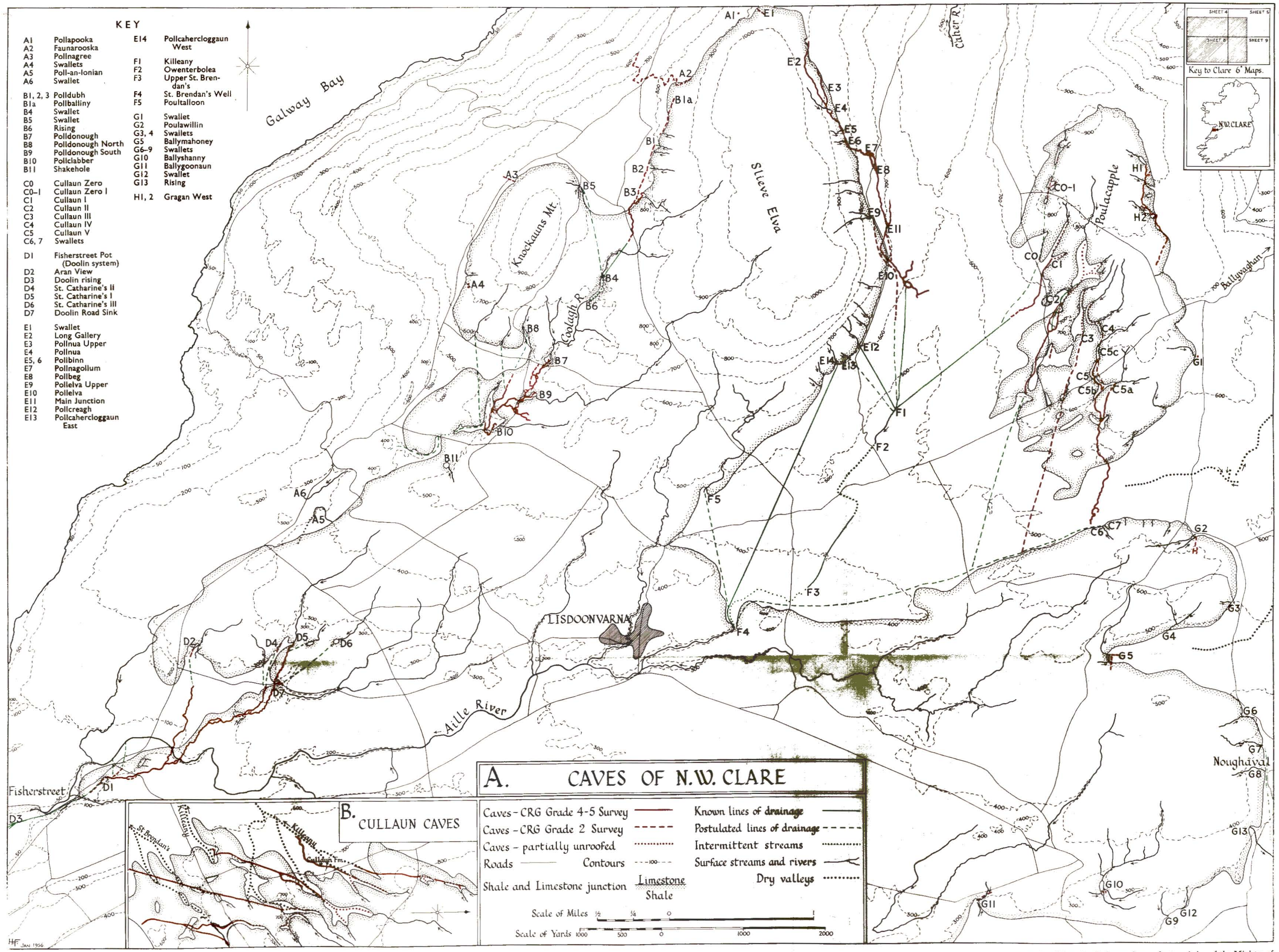
— — 1949, " Further Explorations Pollnagollum Cave, Co. Clare ", *Irish Nat. J.*, 273–274.

CORBEL, J., 1952, " Une Region Karstique d'Irelande : le Burren ", *Rev. de Géog. de Lyon*, Vol. 27, 21–33.

DAVIS, W. M., 1930, " Origin of Limestone Caverns ", *Bull. Geol. Soc. Amer.*, Vol. 41, 474–628.

DICKINSON, J. M., and VARLEY, B., 1952, " Poll-an-Ionian ", *C.P.C.*, Vol. 1, No. 4, 184.

GOWING, G. S., 1938, " Ireland Revisited. Caves in North and South ", *Y.R.C.*, Vol. 7, 43.
HODSON, F., 1954, " The Beds above the Carboniferous Limestone in North-west Clare ", *Quart. Journ. Geol. Soc. London*, Vol. 109, 259–283.
HOLDEN, B., and HOLGATE, H., 1952, " Pollelva ", *C.P.C.*, Vol. 1, No. 4, 185.
JENKINS, H. M., 1955, " Cullaun IV and V, Co. Clare, Ireland ", *Proc.* U.B.S.S., Vol. 7, No. 2, 105–109.
MALOTT, C. A., 1937, " The Invasion Theory of Cavern Development ", *Proc. Geol. Soc. Amer.*, 323 (Abstr.).
MORRIS, R., 1954, Burnley Caving Club Irish Meet. Newsletter, 2nd July.
PICK, S. J., and BARTLETT, P. N., 1936, " Cave Exploration in Ireland ", *Irish Nat. J.*, 64–68.
SWEETING, M. M., 1955, " The Landforms of North-West County Clare, Ireland ", *Trans. Inst. Brit. Geog.*, Publication No. 21.

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