THE EVOLUTION OF THE CASTLETON CAVE SYSTEMS AND RELATED FEATURES, DERBYSHIRE

by

Trevor D. Ford

Presidential Address delivered February 2nd 1985

Summary

Lying beneath the topographic watershed the Castleton cave systems demonstrate a complex history of events, from mid-Carboniferous karstic erosion, Permo-Triassic vein mineralization and faulting to exhumation in late Tertiary times. Initial stages of the present karstic system utilized mineral vein cavities under deep phreatic conditions as denudation bared the limestone surface. A phreatic tube network developed and, with falling water-tables in Pleistocene times due to the incision of Hope Valley, vadose canyon cutting ensued in the main stream passages. Abandoned dry passages show speleothem growth in Ipswichian, mid-Devensian and post-glacial times. Solifluction gravels choke some early passages whilst others are filled with derived loessic clays. Although having a complex early history the Winnats Pass can be shown to be a relatively young feature, as are the dry valleys of Cavedale and Perry Dale.

Introduction

Lying at the northern end of the Carboniferous Limestone massif of Derbyshire, the Castleton area presents a complex system of caves as yet incompletely explored despite the efforts of many cavers over the years, whose drainage system is only just being unravelled by a series of dye tests, flood gauges and hydrochemical analyses. As exploration continues and hydrological studies progress our knowledge of the present day situation improves, but it is the geomorphological story on which I want to concentrate in this address: how the cave systems evolved to their present form and what the controlling factors were. As a corollary, do the caves throw any light on the evolution of the surface landscape?

Ideas on the evolutionary history of the cave systems have previously been reviewed (Ford, 1966, 1977) and the caves themselves have been described (Ford, 1977; Beck 1980, both of which contain references to much detailed literature in caving club journals). In the last ten years the possibility of dating stalagmites by uranium series methods has become available and this has necessitated a fresh look at the whole Derbyshire scene (Ford, Gascoyne and Beck, 1983) (Table 1). At the same time, concepts of the origin and development of cave systems in general have seen something of a revolution (D.C. Ford 1971; D.C. Ford and R. Ewers, 1978, Palmer, 1984) and the dating of the various climatic phases of the Pleistocene glaciations has been refined, so that a new look at some of our familiar old caves seems desirable.

Controlling Factors

A study of the evolution of cave systems anywhere must take into account a number of basic factors:

1. The age and nature of the enclosing rocks.
2. The date at which these rocks become exposed to karstic processes.
3. Structural controls on hydrological drainage patterns.
4. Climatic effects on precipitation and percolation.
5. Changes in the surface topography caused by outside factors.

Mercian Geologist, vol. 10, no. 2,
1986, pp. 91–114, 10 figs.,
plates 3–7.

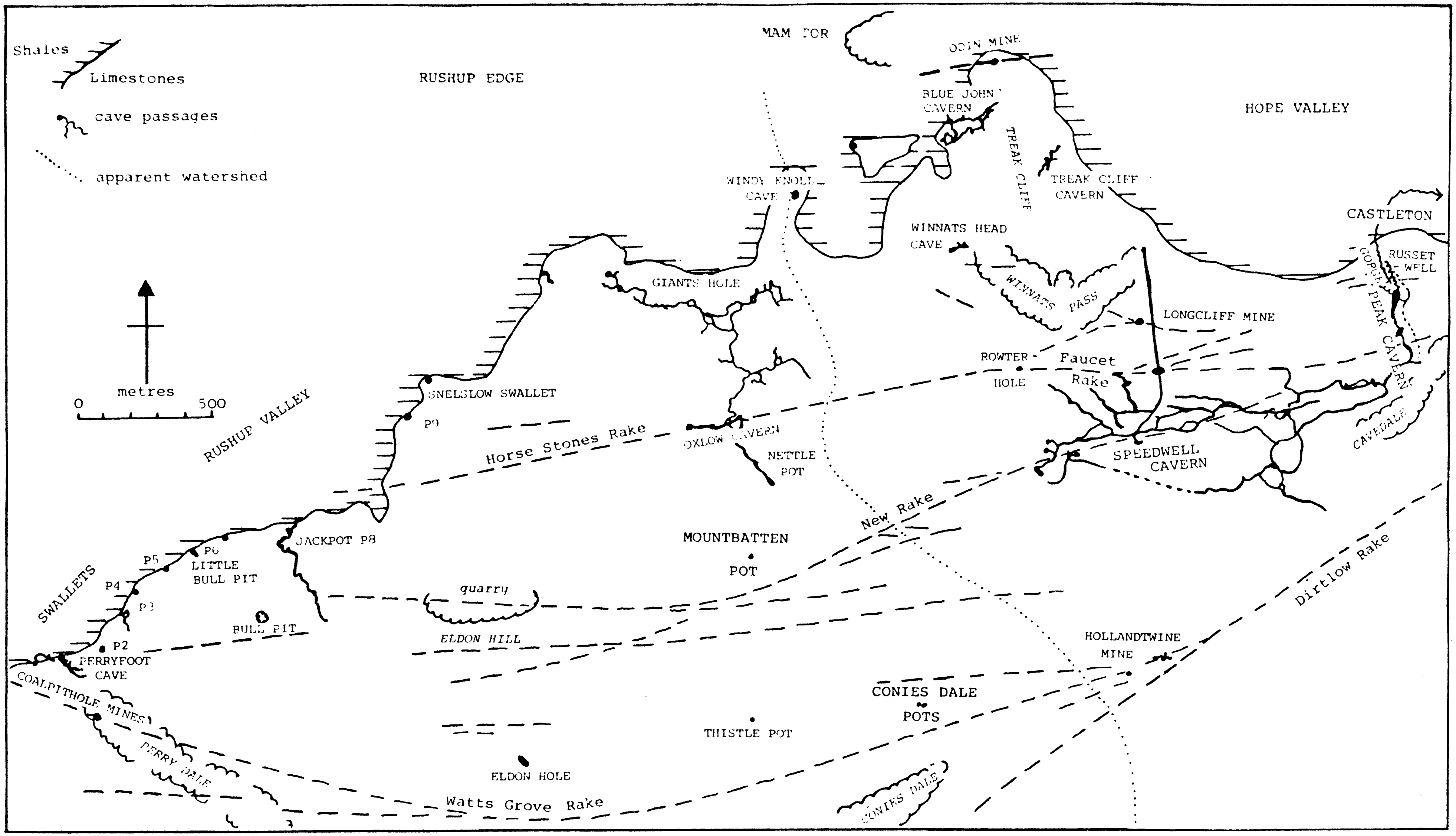


Fig. 1. Sketch map of the Castleton area showing the limestone outcrop and its boundary in relation to mineral veins and cave passages.

Some of these are easy to outline: others are not so easy. The rocks, of Lower Carboniferous age, were deposited when a deeply buried Lower Palaeozoic/Precambrian massif was transgressed by the Dinantian seas resulting in some 1600 m of carbonate sediments of which only the top 500 m or so are exposed. In effect this means that little is known of the basal parts of the karstic regime. The limestones vary greatly in lithology, being in essence a lagoonal massif filled with calcarenites bordered by marginal reef complexes. Rare thin shale partings are present. Occasional outpourings of basaltic lavas divide the lagoonal limestones but hardly penetrate the reefs; thin "wayboard" tuffs are scattered through the limestones: both provide local hydrological barriers constraining downward percolation. The limestones were covered by Upper Carboniferous clastic sediments, marine shales at first and later deltaic sandstone/shale cyclothems totalling some 2 to 3 km in thickness. They rest with pronounced unconformity, locally with basal boulder beds, on an eroded surface of the limestone (Simpson & Broadhurst, 1969), with palaeokarstic developments (Ford, 1985).

How much Permian and Mesozoic stratigraphic cover once rested on the Carboniferous is uncertain; some estimates put it at 2 km or so, but it is likely that a large part of the Upper Carboniferous cover had been eroded off before the Permian Magnesian Limestone was deposited across the South Pennine area (George, 1964). It is also somewhat uncertain how many folding phases occurred to elevate the South Pennines into their present broadly anticlinal form. There is little doubt that the uplifts were episodic, occurring in late Carboniferous to early Permian times, again in early Triassic, probably late Cretaceous, and certainly mid-Cenozoic, with final upwarping in late Cenozoic times (Walsh *et al.*, 1972). Suffice it to say here that the Carboniferous Limestone of the Castleton area was first exposed to surface karstic processes in mid-Carboniferous times but its main exposure has only been since mid-to-late Tertiary times. Most of the Brigantian Stage of the Carboniferous Limestone was eroded off the Castleton area in the mid-Carboniferous and the present cave systems are almost entirely within the Asbian Stage limestones, some 100 m in maximum thickness. The depth to the base of the limestones is unknown in the immediate area of Castleton. Subsurface processes operated in Permo-Triassic times in association with mineralization.

The structural situation resulting from the above is a gentle easterly regional dip, diversified by strongly lenticular bedding in the reef complexes on both NW and NE margins of the limestone massif, with steep outward dips. Faulting and mineralization yielded a series of more or less east-west mineral veins across the Castleton area mainly in Permo-Triassic times (Ineson & Mitchell, 1972), which have affected the hydrological systems ever since.

The changes of climate in the Pleistocene glacial-interglacial cycles undoubtedly affected the amount and kind of precipitation and the degree to which run-off could percolate into the subsurface. Concomitant with this climatic regime was the incision of the major drainage of the area, the River Derwent along the eastern margin of the limestone massif and the River Wye across it to the south of Castleton. The incision of these valleys and of their tributaries, some of the latter now being dry valleys, influenced the contemporary local base levels of underground drainage within the limestone.

Applying the above factors specifically to the Castleton area, a sequence of events can be outlined as a basis for later discussion:

1. Deposition of the Lower Carboniferous limestones, with intervening lavas, thin tuffs and shale bands as aquicludes of varying significance.
2. A mid-Carboniferous phase of palaeokarst, with limited cave development in the reefs.
3. Burial by Upper Carboniferous sediments.
4. First phase of upwarping in the Late Carboniferous and early Permian.
5. Faulting and mineralization, overlapping in time with Triassic renewal of upwarping.
6. Cover by an unknown amount of Mesozoic (to early Tertiary?) sediments.
7. Very slow deep phreatic circulation probably initiated during 4,5 and 6 above and continuing into 8 and 9.
8. Main upwarping of South Pennine anticline in the Miocene (?).
9. Stripping of Mesozoic and Upper Carboniferous cover during and since the Pliocene.
10. Alternation of glaciations and interglacial phases with progressive incision of Derwent and Wye valley systems and their tributaries with resultant intermittent lowering of base level at Castleton in the Pleistocene.

Approaches

The related problems of establishing a sequence of events and dating them require the correlation of a number of different approaches:

1. The morphology of the caves themselves: do they show a sequence of developments of differing cave passages and types? Can this be related to external factors?
2. The establishment of a sequence of external events from geological evidence such as erosional events deduced from river terrace levels, glacial tills, solifluction deposits, loess sheets etc.
3. The dating of speleothems (stalagmites); these should place at least minimum dates on the evolution of some cave passages and features.
4. The dating of external events.
5. A look at the time factor: could the processes visualized have resulted in the observed cave features in the time available?

A note on Uranium series dates

Present in trace quantities in most rocks, uranium behaves very much as calcium does in a karstic environment—it is transported in solution in percolation water and is deposited in stalactites and stalagmites (= speleothems). Usually it is present as only a few parts per million in the speleothem analyses in the Castleton area and it is variable, probably owing to the presence of uraniferous nodules in the basal Edale shales as a source material. Proportions of 10 or 20 p.p.m. are not uncommon and one rare instance in Giant's Hole contained 137 p.p.m. Once in the speleothem uranium breaks down by radio-active decay, and one of the isotopes, ^{234}U, yields ^{230}Th at a fixed rate (the half life being 75,000 years). Provided there is minimal contamination by included sediment containing derived thorium, measurement of the ratio of ^{234}U/^{230}Th will give the age of the speleothem, up to a maximum of about 350,000 years owing to thorium decay. Ideally the base of the speleothem should be sampled to give the age of the start of growth and this can be checked by samples taken higher up the same stalagmite yielding younger ages. The resultant age determinations give the minimum age when the cave was above water-table and available for stalagmite growth. Also, since there is little or no percolation and thus no growth in cold periods (glacials) the spread of ages in a given area should relate to climate oscillations. Studies for Derbyshire caves in general have shown a reasonable correlation with the climatic oscillations shown by oceanic cores (Ford, Gascoyne & Beck, 1983). What the age determinations do not tell is how long a cave has been above water-table before growth started and they provide no correlation with the classic Pleistocene Stages, Hoxnian etc., as hardly any of these have provided dateable material. Reference to these stages herein is given on the uncertain conventional basis only as a help to the reader. In turn the age determinations provide no correlation with the river terraces of the Derwent (Waters & Johnson, 1958) as none of these has been dated by direct means.

Age determinations for the Castleton caves extracted from Ford, Gascoyne & Beck (1983) are given in Table 1A, and these are supplemented by determinations from Pilkington's Passage of Speedwell Cavern in Table 1B.

Table 1A

Uranium-series dates on speleothems from Castleton caves
extracted from Ford, Gascoyne & Beck (1983)

Giant's Hole	-	on solifluction fill near entrance	3.4±0.1 Ka B.P.
" "	-	flowstone near entrance	17.0±2
" "	-	flowstone near Maginn's Rift	54.0±2
" "	-	flowstone overlying last-named	48.0±1
" "	-	flowstone at Giant's Windpipe	125.0+22/−19
" "	-	stalagmite in upper series	3.6±0.2
" "	-	flowstone in upper series	2.2±0.2
Peak Cavern	-	broken flowstone in canyon	59.0±3
" "	-	eroded flowstone in canyon	59.0±3
" "	-	eroded flowstone in Victoria Gallery	51.0±2
" "	-	flowstone on mud-fill	1.1±0.1

Speedwell Cavern	– broken flowstone block in fill near Bung Hole stopes	96.0±4
	– flowstone cementing boulders at choke near Bung Hole stopes	17.0±1
Treak Cliff Cavern	– flowstone on collapsed block in Aladdin's Cave	125.0±6
	– ditto	131.0±6
	– ditto	126.0±3
Winnats Head Cave	– broken flowstone in upper series enclosing fallen stalactite	186.0±7
	– ditto flowstone	191.0+15/−13
	– broken stalactite	176.0+8/−7
	– broken stalactite in Fox Chamber	9.0±2
	– flowstone veneer in Fox Chamber	54.0±3

Table 1B

Speedwell Cavern — Pilkington's Passage
(unpublished results from D.C. Ford, McMaster University)

Pilkington's	1	48 m above Stream Cavern level	91.0±5.5
"	2	40 m " " " "	115.0±12
"	3	76 m " " " "	63.0±3
"	4	115 m " " " "	12.6±0.5

The topographic situation

The most northerly point of the Carboniferous Limestone outcrop is at the north end of Treak Cliff where the reef limestones disappear beneath the shales and sandstones of Mam Tor near Odin Mine. To the west the reef belt trends generally WSW along the Rushup Valley, with streams draining off the Millstone Grit of Rushup Edge and sinking at or close to the limestone boundary at altitudes of 310 to 370 m (Fig. 6). The underground drainage penetrates the reef belt into the lagoonal limestones with their generally gentle easterly dip, and the water resurges in Castleton either at Russet Well or outside Peak Cavern at about 195 m O.D. at the head of Hope Valley (Fig. 1). The drainage thereby crosses beneath the surface watershed between the apparent basins of the Rivers Wye and Derwent and there is little doubt that at least part of the intervening route is of deep phreatic (sub-water-table) nature following mineral vein fissures. The main mineral veins trend WSW-ENE or W-E and circulation may extend some hundreds of metres below water-table within these.

The general easterly direction of the underground drainage pattern has been known for a long time as mid-19th century mine working at Coalpithole Mine near Perryfoot discoloured the water resurging from Russet Well. In more recent years dye tests have confirmed the fact that all the swallets drain via Speedwell Cavern to Russet Well (Ford, 1966; Christopher *et al.*, 1981), with flood waters backing up in the lower part of Speedwell and overflowing into Peak Cavern (Figs. 2 and 10).

With the highest point of the limestone plateau at Eldon Hill, 470 m O.D., being 100 m or so lower than the surrounding Millstone Grit scarps there is a question of the amount of lowering by solution weathering having taken place since exhumation from beneath the Millstone Grit cover. Pitty (1968) argued for a very large part of this lowering being in Pleistocene times, but this overlooked the nature of the sub-Namurian unconformity, whereby almost all beds of Brigantian (D_2) age were stripped off before the Edale shales were deposited. The thickness of the missing Brigantian is difficult to estimate but it may well account for most of the 100 m of apparent lowering i.e. the lowering is largely a mid-Carboniferous feature.

The Millstone Grit rocks as seen at present are of course the current stage in the progressive erosion of the former cover. Understanding the evolution of the cave systems necessitates consideration of the state of affairs at former greater extents of this cover before it was stripped back. This can be done firstly by considering the

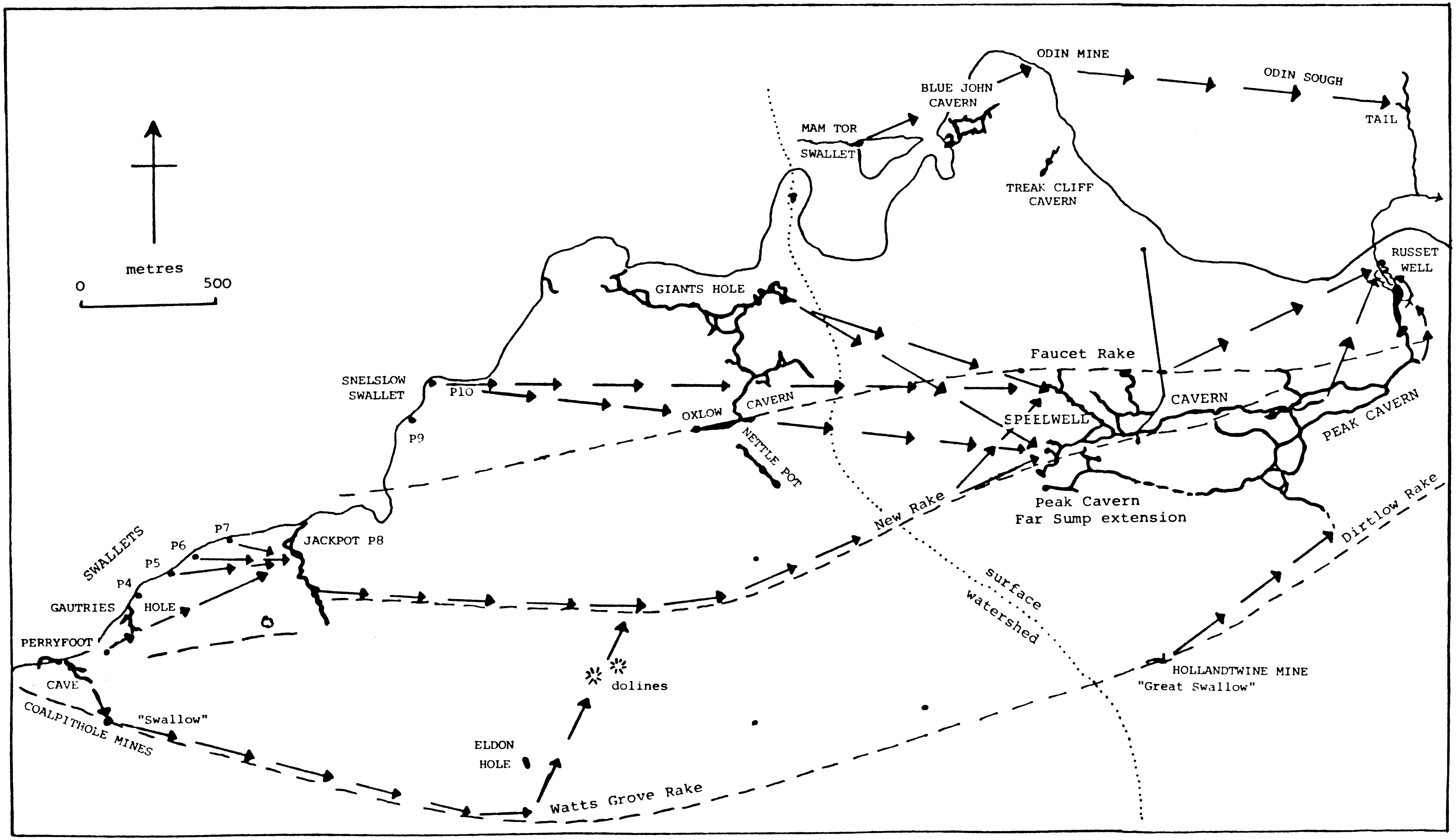


Fig. 2. Sketch map of the underground hydrology and flow routes proved by dye tests in the Castleton area.

evidence of the mid-Carboniferous unconformity and what significance it might have had in cave development, and secondly by consideration of the sub-surface effects of mineralization on early cave development. To examine these problems the caves of Treak Cliff are a useful starting point.

Treak Cliff and its caves

In the middle of the Carboniferous period, the Dinantian reef complex and the margins of the lagoonal massif limestones were uplifted and deeply eroded to provide the boulder bed flanking the fore-reef limestones and covered by shales as described by Simpson & Broadhurst (1969). Almost all Brigantian beds (perhaps as much as 100 m thick) were removed so that most of the exposed limestones around Castleton are of Asbian Age. During this period there can be little doubt that at least part of the limestone massif was subject to subaerial karstic erosion: fossil clints and grykes are in evidence at Windy Knoll and what appear to be early phreatic caves were developed at various levels within Treak Cliff itself. Late and post-Carboniferous mineralization (Ineson & Mitchell, 1972; Ford, 1969) affected these so that the original speleological and surface karst features have been partly obscured. However, the boulder-filled gryke fissures at Windy Knoll are well-known and voids between boulders lined with Blue John fluorspar in Treak Cliff Cavern are the main source of that semi-precious mineral variety (Fig. 3). Blue John is also found lining what appear to be small tube and bedding caves of general phreatic form in the Blue John Caverns and in the Old Tor mine in the Winnats Pass. However, no clear evidence has been found of ancient stream cave systems of this late Palaeozoic age.

The further development of Treak Cliff Cavern appears to have been as a swallet cave draining off a former extent of the Millstone Grit cover halfway up the face of Treak Cliff utilizing the ancient mineral cavity systems (Fig. 3). At first this fed water into a deep phreatic system in what is now the Old Series of caves near the surface and former shale cover, partly in the pre-Namurian Boulder Bed. Later the former Treak Cliff swallet fed water deeper into the fore-reef limestones to resurge at the unknown site possibly somewhere near the foot of the Winnats Pass. Falling base level permitted the incision of a vadose canyon, now abandoned and well decorated with many stalactites and stalagmites, some growing on a clay fill derived from loess (Plate 3A) whilst others are now beneath fallen blocks. Some of the latter were dated (Table 1A) as 125,000—131,000 years B.P. correlating with isotope stage 5e, probably the Ipswichian Interglacial. At present no stalagmite lying on the loessic fill has been dated so it cannot be deduced whether this is pre-Ipswichian or not.

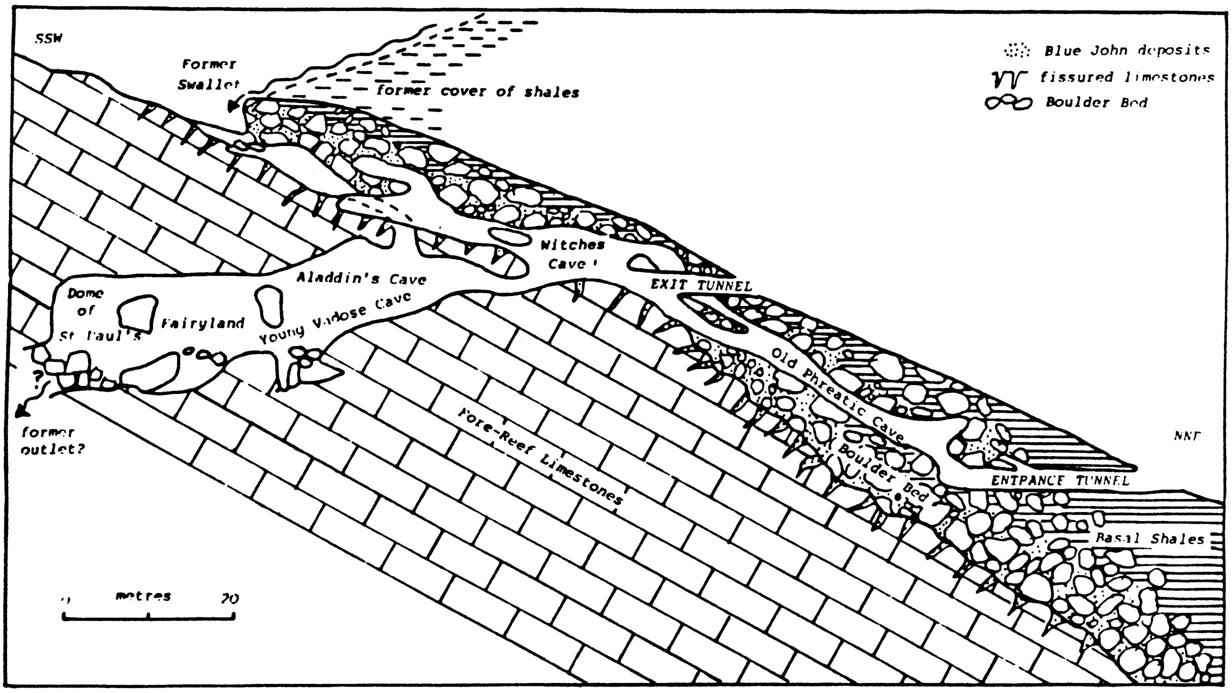


Fig. 3. Diagrammatic section through Treak Cliff Cavern showing the probable position of the former Treak Cliff swallet in relation to the former extent of the Namurian shale cover, the relationship of the cave to the pre-Namurian Boulder Bed, and Blue John fluorspar mineralization, and the later vadose cave extending into the fore-reef limestones (modified after Simpson & Broadhurst, 1969).

The Blue John Cavern is similarly a swallet-vadose cave system to a minor extent pirating a mineralized mid-Carboniferous palaeokarst, with a former input close to the present shale boundary. The large vadose canyon suggests a major input at some time, though the present catchment area hardly seems adequate, and the termination of the cave in a minute impenetrable sump provides yet another enigma.

Mineral Vein Cavities

The major mineral veins (rakes) crossing the Castleton area broadly on a WSW-ENE trend are characterized by two types of ancient cavity. The first results from the fact that mineral deposition did not always fill the space available in the fault fractures, leaving crystal-lined vugs in the centres of veins. It is reasonable to suppose that the last crystals in these were deposited by the last phase of mineralizing fluids, and that the latter must have had some degree of an integrated plumbing system to permit fluid flow to supply the minerals. Although such primary mineral-lined vugs must have been found frequently during mining few are accessible today. The mineralizing fluids also appear to have been aggressive at times and small parts of the limestone wall-rocks were dissolved, yielding pipe-caverns, later lined or filled with mineral deposits.

Although all the mineralizing effects were deep-seated, with temperatures commonly around 80–100°C, under a cover of possibly 3 km of younger strata, any speleogenetic (cave-forming) processes would have been minimal owing to the very slow movement of fluids. Once the Upper Carboniferous cover was breached by erosion at a much later date, the potential arose for hydraulic gradients to accelerate the flow through the vugs and pipes of the mineral vein system (Ford & Worley, 1977). Ideally the cover would have to be breached in two places at different altitudes, so that a hydraulic gradient could be established. Under these conditions it is likely that large solution caverns (vein-cavities) were developed by solutional enlargement of vugs and pipes. The sites of inputs and outlets are unknown but likely places for early engulfment would be on Eldon Hill and the moor to the east whilst outlets might have been in or near Peak Cavern gorge as predecessors of Russet Well and Slop Moll. Several such caverns are well-known in the Castleton area, e.g. the Bottomless Pit Cavern in Speedwell Cavern, Long Rake and Venture Mine Caverns on Bradwell Moor and Oxlow Caverns, later linked to the dry upper abandoned tube-system of Giant's Hole (Fig. 4). Oxlow and the associated Maskhill Mine Caverns show a vertical amplitude in Horse Stones Rake of around 100 m above present water table, with fill concealing any deeper extension (Plate 4A). The width rarely exceeds 5 m but the long profile shows a strong up-and-down oscillation characteristic of deep phreatic loops (Fig. 5). At the east end the east-west Oxlow system intersects (though there is no accessible connection) the NW-SE fault-guided Nettle Pot. Though obscured by collapse debris this also shows evidence of solutional development. There is little vadose modification in either cave so that the vein cavities seem to have been drained by a rapidly falling water-table. Other vein or fault-guided deep phreatic solution cavities include Eldon Hole (Plate 7B), Ghost and Maginn's Rifts (Plate 7B) and Geology Pot in Giant's Hole, Victoria Aven in Peak Cavern, the entrance shaft of Longcliff Mine. Mining records suggest the presence of others, such as "The Great Swallow" in Hollandtwine Mine and a "swallow" in Coalpithole Mine, which still feed water into the underground systems. The "Swim Hole" on an 18th century plan of Odin Mine may indicate the presence of one such cavern still beneath the shale cover. Russet Well, the outlet to most of the subterranean drainage, is in a thin mineral vein and water rises from a totally submerged vein cavity system. A feature of all such cavities is that their genesis was entirely by phreatic solution which could be at any depth below a water-table, and in fact is probably still going on beneath the present day water-table, e.g. in the canals at the bottom of Giant's Hole, and in the Main Rising of Speedwell Cavern. A critical question is when was the cover breached sufficiently to permit the establishment of this vein-cavity drainage? Other than saying that it was "early" and could have been before most of the Millstone Grit cover was stripped off there is no way of putting a date on this event. At best, in general terms, it was probably after the final upwarping of the Pennine anticline (Miocene?) and before the moulding of the present landscape by the Pleistocene glaciations, so that the initiation of vein cavity drainage can be conceived as "Pliocene or earlier".

A scatter of deep dolines on the limestone plateau suggests the presence of other vein-cavities now partly or wholly collapsed (Fig. 4). These are mostly near or on mineral veins and also lie above the drainage routes from the swallets to Castleton resurgences. Taken with the known vein-cavities these suggest a more complex, integrated, vein-controlled phreatic complex than has generally been considered hitherto.

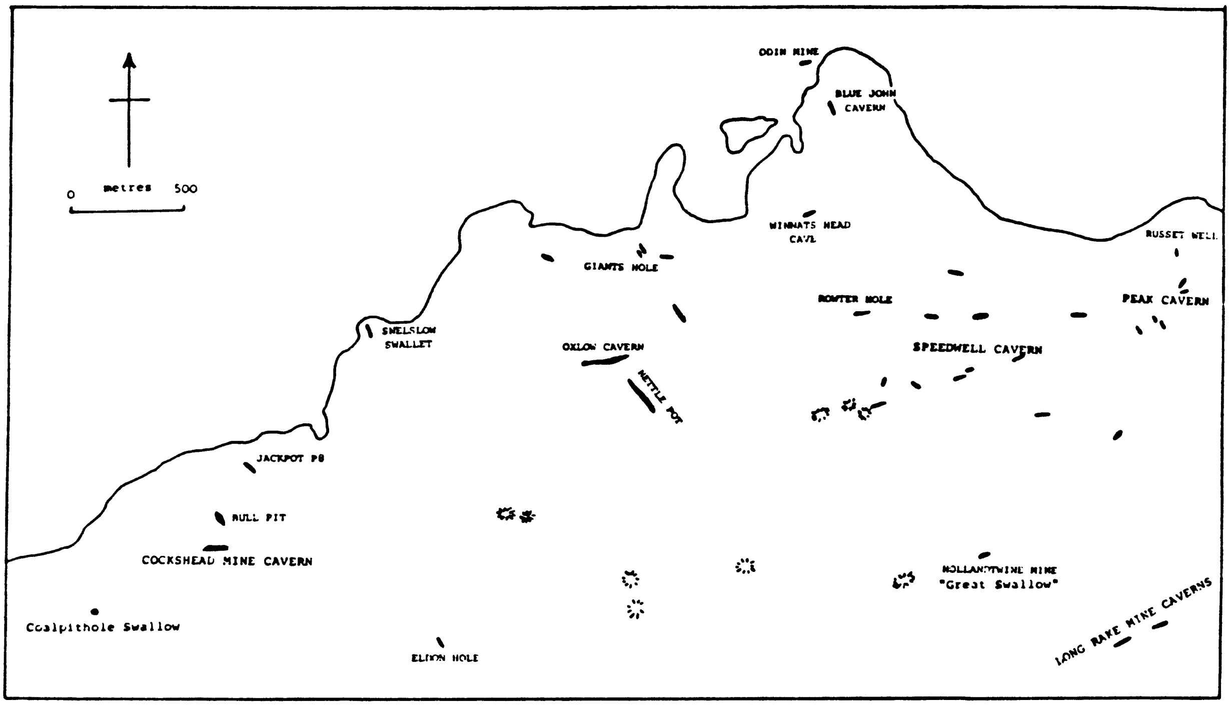


Fig. 4. Sketch map of the distribution of vein cavities, and similar caverns developed along faults and major joints, and of dolines which may overlie comparable cavities.

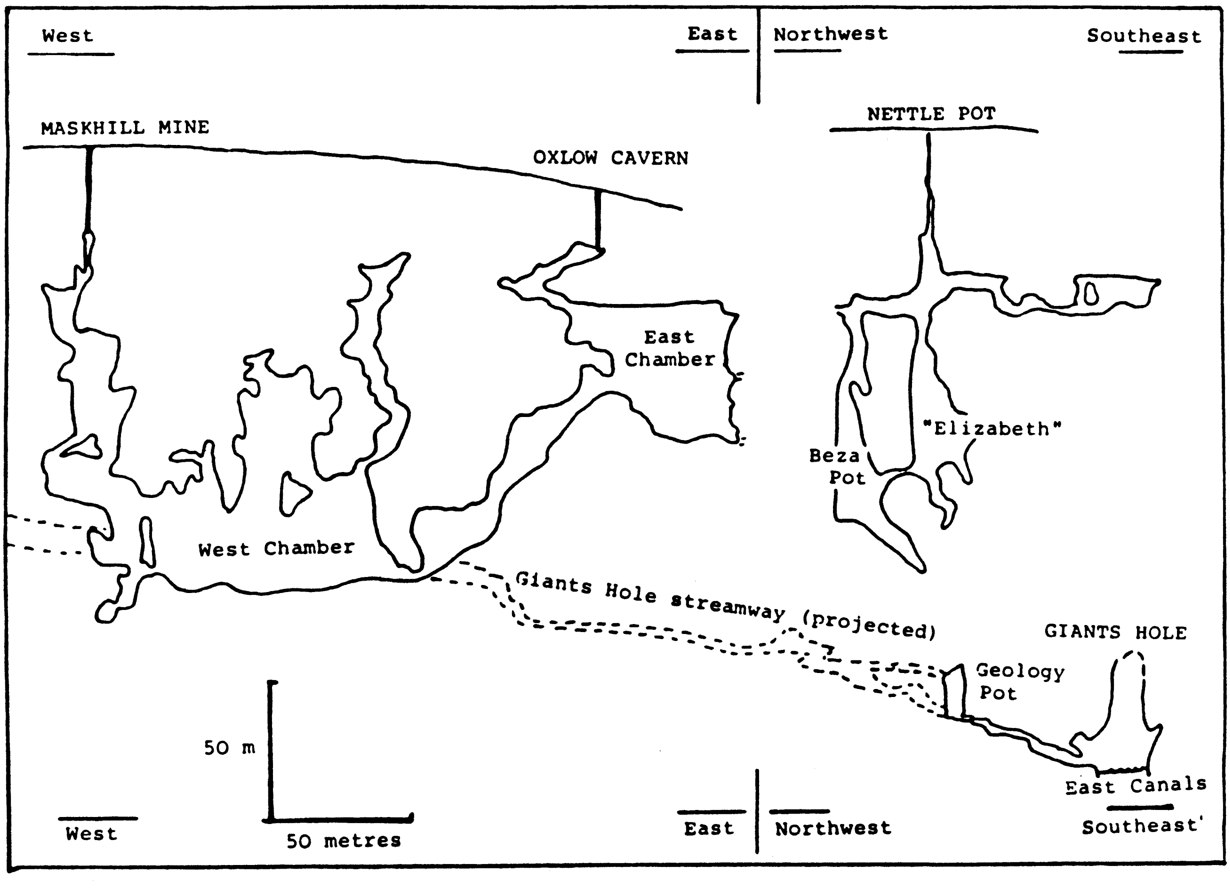


Fig. 5. Diagrammatic section along the vein cavities of Oxlow Caverns (including Maskhill Mine caverns), Nettle Pot and the East Canals on Giant's Hole. (modified from a diagram by J.S. Beck, 1980).

The Swallet Caves

The present day swallet caves lie along the shale/limestone boundary in the Rushup Valley, taking in allogenic drainage from the streams running south off Rushup Edge (Fig. 6). Descriptions can be found in Ford (1977) and numerous caving club publications. Few of the swallet caves can be followed for more than a hundred metres or so. All show a complex arrangement of generally small passages with their morphology controlled by an intersecting maze of bedding planes and joints. These are inclined at various angles, often contrary to the regional dip, owing to the lenticular character of the reef limestones. The surface stream channels leading to the swallets are incised some 5 or 6 metres into a solifluction sheet (Johnson, 1967) and much comparable fill can be seen in the caves themselves, indeed Giant's Hole has "old" passages completely filled with cemented solifluction gravels.

Relative chronologies for the development of the two major swallet caves have been worked out. Smith & Waltham (1973) outlined a sequence of passage developments in Jackpot (P8) whereby a series of early phreatic passages were progressively enlarged by vadose downcutting and then abandoned during falling base-level. Even so the accessible cave is only 800 m long and soon reaches a depth of 50 m in a high "rift", along a NW-SE fault. Divers have shown that the cave profile then flattens out and a further 600 m of dry passage have been reached apparently mostly along a NW-SE fault line. As yet no speleothem uranium-series dates have been obtained for this cave.

A comparable chronology has been worked out for Giant's Hole by Westlake (1967) and with some modification, is shown in Figure 7. The "old" cave again shows a complex of ramifying passages through the belt of reef limestones, with several "fossil" passages completely full of solifluction gravel suggesting former entrances near the present one (Plate 4B). Beyond the entrance series, the cave changes character. At Base Camp Chamber and the adjacent avens, there is evidence of alignment along a NW-SE fault (and evidence of a former fill of gravel), whilst below Garlands Pot striking vadose incision of the Crabwalk into the floor of one of a maze of small phreatic tubes has taken place. Westlake has suggested a sequence of morphological development of these tubes in relation to vein-cavity drainage in Oxlow Cavern which the stream no longer uses. Instead it follows the regional dip more or less ESE down an intricate meander belt (along local joints) into a group of larger joints in Maginns Rift, Geology Pot and the East Canals is some 150 m below the entrance, close to the altitude where the water re-appears in Speedwell Cavern. Westlake suggested a relative sequence of events without any fixed dates, but thanks to uranium-series dating it is now possible to say that the water-table had fallen far enough for stalagmite growth to start in the Giant's Windpipe near Ghost Rift by 125,000 years B.P., i.e. in the last interglacial (Ipswichian), and growth had started in the lower Maginn's Rift by 54,000 years B.P. (Chelford Interstadial).

Together these dates suggest that the main part of Giant's Hole was already much in its present form by the Ipswichian; tentative suggestions can be made concerning possible dates for the establishment of earlier drainage routes in now-abandoned phreatic tubes at high level, through to the North Chamber of New Oxlow Cavern. Following the development of the present drainage route, a rapidly falling water-table, perhaps controlled by the lowering of Hope Valley floor, allowed the drainage of the largely phreatic lower Giant's complex from Geology Pot to East Canals. There may have been more than one phase of fill by fluvioglacial sediments but only the last, Devensian, solifluction gravel is recognisable and the cave stream has trenched through this in late to post-glacial times, in a fashion comparable to the incision through the solifluction sheet on the surface.

A few small passages in the swallet caves are filled with sticky yellow clays and silts. It seems likely that these were derived from a former cover of loess, wind-blown dust of periglacial character, though as yet we have no evidence for the age of such material. Although loess on the limestone plateau is mostly of Devensian age (Pigott, 1962; Burek, 1977), there is no inherent reason why some should not be considerably older (Pigott 1962b).

A direct implication of the present form of the swallet caves is that the outlet end of the drainage system was within 50 m of its present altitude by the last interglacial, and thus that Hope Valley had been incised to that depth by the Ipswichian.

A second implication is that the Millstone Grit cover had been stripped back to more or less its present position before the Ipswichian, for the vadose incision by allogenic streams to have occurred. This leads to the corollary problem of what happened when the cover had not been stripped back so far? Theoretically there should be one or more earlier generations of old swallets further back up the flanks of the limestone plateau. None can be found. Some may of course be buried under solifluction deposits, loess or even boulder clay, but no evidence has come to light of an earlier generation of swallet caves, presumably taking allogenic input from a larger catchment of Millstone Grit than the present Rushup Edge. Can an explanation be offered other than

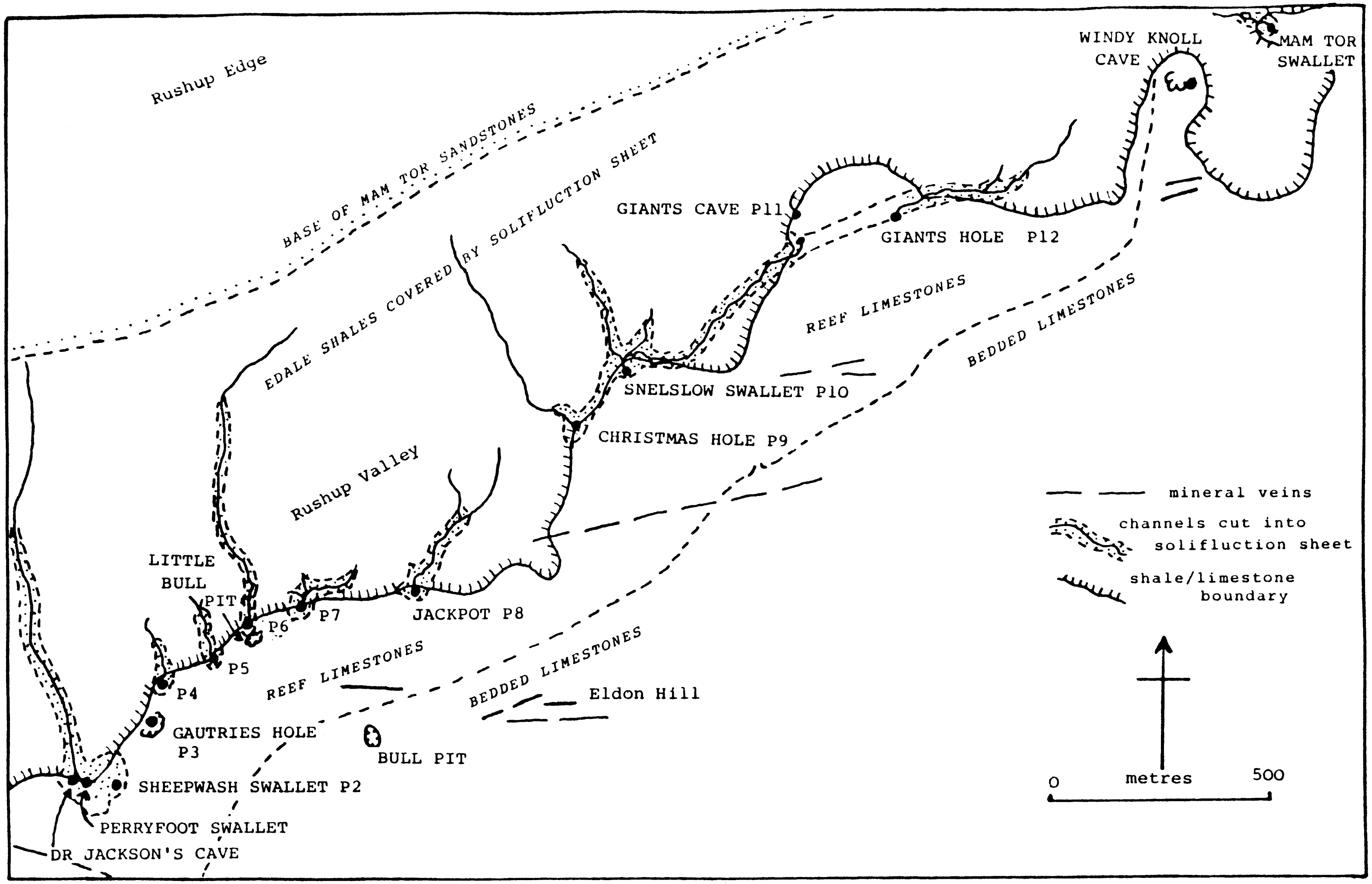


Fig. 6. Sketch map of the distribution of swallets, caves, solifluction sheet and incised channels in relation to the limestone—shale sandstone solid geology of the Rushup Valley (partly modified after Johnson, 1967).

"they are buried"? The only possibility that comes to mind is that during one of the early glaciations, Anglian or Wolstonian, the cover was stripped back very rapidly, and thus the underground drainage systems went from the breached vein-cavity stage to the present swallet stage very quickly.

The isolated Windy Knoll Cave lies exactly on the watershed between the Derwent and Wye drainage basins. It is developed close to the shale/limestone boundary and its roof is in the pre-Namurian boulder bed. The lower walls show solutional facetting characteristic of phreatic conditions but its situation suggests that a swallet once existed here. This could only have operated with a reasonable catchment where the Rushup Valley is today (Fig. 6), i.e. before the Millstone Grit shale cover had been stripped back where the present swallets are. Regrettably the cave is choked with solifluction debris a few metres inside so that no further evidence is available, but it does look as though this might have been a very early stage in the evolution of the underground drainage system.

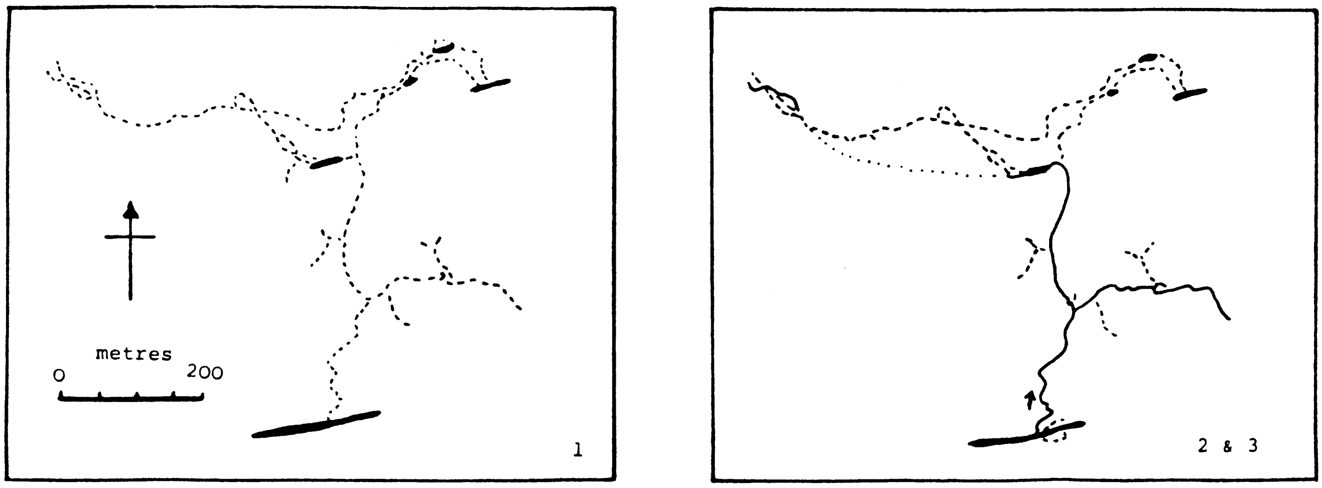
Winnats Head Cave may also have acted as an early, pre-Winnats Pass, swallet but again too little is known of its extent to provide much evidence.

A number of high-level abandoned phreatic tube passages link the Giant's Hole system with the vein-cavities of Oxlow Caverns, and others by-pass the Giant's Hole streamway. Beck (1980) has suggested that these may have developed at a time of high base level in pre-Hoxnian times. They appear to have been fed from sinks at or close to the present swallets so that there is an implication of a stage of development when the Millstone Grit cover had been stripped back in the Rushup valley but when Hope Valley was nowhere near as deep as at present. There is a hint of phreatic tube development at more than one level, but whether this represents phases of falling base levels or whether it is simply a matter of picking out favourable shale partings is unknown.

Peak Cavern

With its vast entrance, the largest in Britain, Peak Cavern looks as though it ought to be the natural outlet for all the subterranean drainage of Castleton, but it is not at present. Under normal flow conditions its stream is a minor one largely composed of percolation water from the limestone plateau around and west of Cavedale. The entrance and outer passages show changes of morphology as one passes through the reef belt, but from the Devil's Staircase onwards the cave is in bedded lagoonal limestones and the greater part of the system follows a single bedding plane with a shale parting some 14 m above that in the Speedwell Cavern. Indeed the two cave systems lie closely parallel, with one series of Peak passages actually crossing above Speedwell's Lower Bung Hole series (Fig. 8). Although there is very restricted cavers' access between the two cave systems, flood waters back up in Speedwell and overflow into Peak (Fig. 10). Speedwell Cavern now carries the bulk of the allogenic drainage. In Peak Cavern strong joints, possibly minor faults, generally trending NW-SE, have resulted in impressive caverns such as Victoria Aven, but they are crossed with little deviation by the stream cave. A network of phreatic tubes in the bedding plane is still partly filled with clays and silts derived from loess. The stream has excavated an impressive vadose canyon through much of its length. At the downstream end (immediately upstream of Buxton Water Sump) the form of a phreatic tube is maintained (Plate 3B) with a beautifully symmetrical tube some 6 m in diameter, but upstream a long profile develops where a vadose trench has been cut into the floor of the tube by some 15 m in places (Plate 5A). The tributary Upper Gallery, above Surprise View, is a similar tube with but a 2 m deep narrow slot in the floor. Further up the main stream on Boulder Rift a mass of collapsed boulders has created a dam, holding back Far Sump. Recently dived by Martyn Farr, this 400 m long submerged section is but a continuation of the great vadose trench partly filled with sediment behind the dam. The trench continues into Far Peak Cavern, some 500 m of vadose cave still awaiting full exploration, though the old 18th century lead miners had been in before (Farr, 1981, 1982).

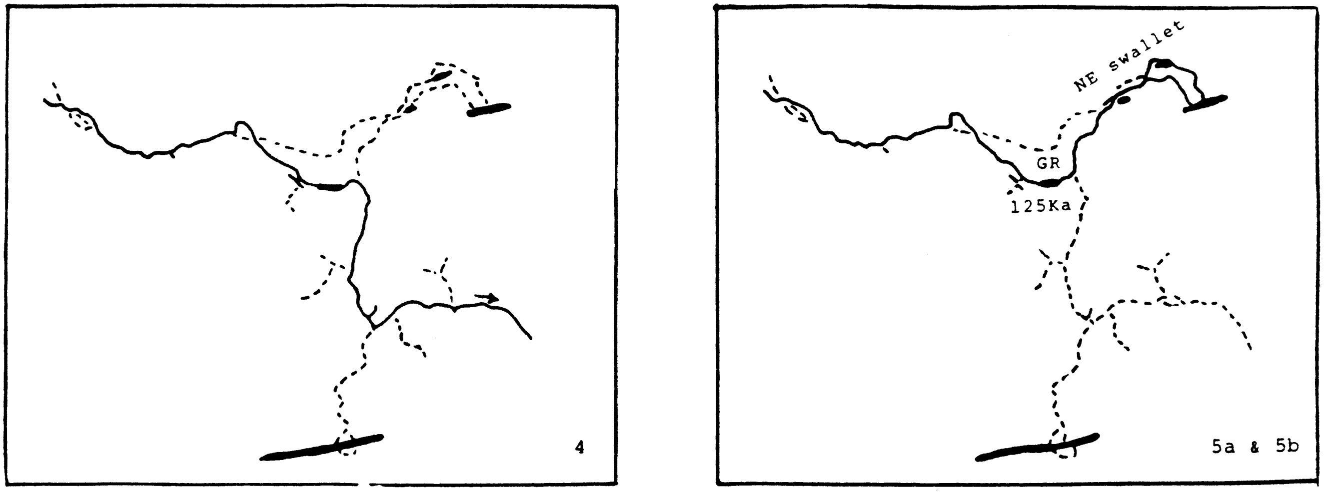
Without going into a full description of the intricacies of Peak Cavern's 5 km of passages, some of the main morphological features may be summarized thus. A network of bedding-controlled phreatic tubes, mostly filled with inwashed loessic clays and silts, is largely beneath the "umbrella" of the Cavedale Lava, so that there is little percolation input in the accessible cave. The chemistry of the waters indicates percolation origins so they must be further west, where the lava thins out. Only in flood conditions does swallet water reach the system, and even then it is not clear how (Chrisopher *et al.*, 1981). Avens rise above the phreatic network by as much as 100 metres, but little has been found of old high level abandoned passages—a feature which correlates with the lack of an early generation of swallets. One part of the tube system was enlarged preferentially and yielded the roof tube of the main streamway, as well as the Upper Gallery. Invasion by the Speedwell stream via mineral veins doubtless supplied an extra input of aggressive water (still active under flood conditions) within the phreatic network. The last stage of erosion was the incision of the vadose trench. This is large enough to suggest that far more water flowed through the Peak Cavern drainage than can be accounted for by percolation alone. One can only surmise that there has been a major change in the drainage pattern below the swallets since then, with Speedwell Cavern taking the bulk of the water today (Fig. 8).



1. Pliocene to early Pleistocene- vein, fault and joint cavities opened by deep phreatic solution.

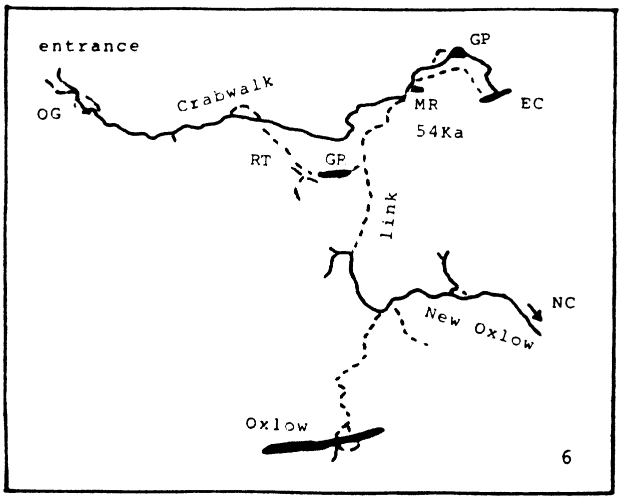
2. pre-Anglian? First swallet enters by upper levels of old Giants Hole and flows via choked tube to near Ghost Rift, then through the link to sink near North Chamber of New Oxlow Caverns.

3. Anglian glaciation? all passages filled with fluvioglacial sediments.



4a. Hoxnian. drainage of Stage 2 re-established and then diverted along the roof tube of the Crabwalk through the link to sink near North Chamber, in New Oxlow Caverns.
4b. Wolstonian glaciation. Entrance passages again filled with fluvioglacial sediment, little run-off owing to frozen ground at glacial maximum.

5a. Late Wolstonian to Ipswichian - blocked passages cleared. Drainage via Giants NE swallet to East Canals. Maginn's and Ghost Rifts drained. Link dry. Present entrance established. Rapid downcutting in Crabwalk. Lower Complex drained. Flowstone in Ghost Rift 125000 years old.
5b. Early Devensian - solifluction gravels fill entrance passages; some loessic clay in high level tubes. Flowstone 54000 years old in Maginn's Rift.



OG-Old Giants; MR-Maginn's Rift, GR- Ghost Rift
NC-North Chamber; GP-Geology Pot; RT - roof tube

6. Mid-Late Devensian - solifluction fill partly removed. Further incision of Crabwalk. Minor inlet from branch of link to New Oxlow. Another lower minor inlet in bottom of Oxlow Cavern.

Fig. 7. Diagram of the possible sequence of phases of development of the Giant's Hole — Oxlow Caverns system (modified after Westlake, 1967).

Stalactites are few and far between in Peak Cavern, but samples from fallen blocks in the streamway, below deposits on the shoulder of the vadose trench and from corroded flowstone in the Upper Gallery, have yielded dates of 51,000, 59,000 and 73,000 years B.P., broadly the Chelford interstadial. Together they indicate that the phreatic network had been drained to within 20 metres or so of present resurgence level by then, and that most of the vadose incision had already taken place.

The entrance to Peak Cavern and its gorge outside present some problems. The Vestibule slices through lenticular reef limestones, with high narrow avens extending up master joints above, but again with no high level side passages. The gorge outside cuts through the fore-reef limestone and is graded to the present valley floor. The present stream has abandoned the main cave for its last 500 m and flows to one side in an immature bedding tube to resurge in the gorge just outside the entrance (Plate 6A). The establishment of the initial phreatic cave can only have taken place when the valley floor was much higher than at present and it seems likely that the major outlet for the underground drainage was in the form of a vauclusian spring, rising from the present entrance up through a vertical flooded pothole to the valley floor. Its lip has been cut away by the stream adjusting to falling valley floor levels, in turn reflecting the migration upstream of knick points and the development of river terraces in the Derwent Valley, as discussed later. Doubtless the removal of this lip was assisted by the upwelling of phreatic water through mineral vein cavities at what are now seen as Russet Well and its overflow spring, Slop Moll (Fig. 8).

Assigning dates for the development of phreatic drainage via Peak Cavern with its vauclusian spring, and for the conversion to something approaching the present vadose conditions is difficult, though Ford, Gascoyne & Beck's (1983) interpretation of Waters & Johnson's (1958) terrace sequence suggested that the formation of the Hathersage terrace was a critical factor at least in the conversion. A Hoxnian interglacial date can be suggested. Beck (1980) has noted that the lower ends of canyon-type incision in both Peak and Speedwell Caverns is apparently graded to the projected Hathersage terrace (Fig. 9). Subsequent incision to the slightly lower level of the Hope Terrace, possibly in Ipswichian times, has been responsible for draining the greater part of the large phreatic tube in Peak Cavern, and equivalent bedding tube in Speedwell Cavern, though any terrace development in the valley is masked by the solifluction sheet.

Whilst the Devensian glaciers did not reach Castleton, the cold phase yielded a cover of loess, with some washed down to fill (or re-fill?) the phreatic tube network. In the gorge there can be little doubt that much frost-shattering took place and the gorge was partly filled with scree damming up water in the cavern, leading to para-phreatic solution enlarging some parts. Post-glacial outflow, particularly in flood conditions, has cut through the fill, re-exposed the resurgence and left the deposits in the vestibule into which the rope-walk terraces were cut. A detailed profile through these could be very informative but none is available as yet. A temporary dam in the Inner Streamway near Lake Passage resulted in a local sediment fill with current bedding indicating flow upstream. Preliminary palaeomagnetic results suggest a date of 5,000 B.C. for this fill stage (Noel, in prep.). The dam of collapsed boulders in Boulder Rift has created Far Sump and diverted the normal flow drainage into an adjacent bedding plane now discharging water from a 5 cm high slot in the clay-filled tubes above Squaw's Junction. This and input from Ink Sump in Lake Passage now provide most of the stream in Peak Cavern: the latter gets its water from vein cavities in Dirtlow Rake or a branch thereof at present being investigated by divers.

One final comment on Peak Cavern: a phreatic tube in the roof above Boulder Rift heads off towards Dirtlow Rake and Pindale, but it is completely choked with sediment after 100 m or so. Could it be that the phreatic drainage once discharged through an unknown resurgence in Pindale?

Speedwell Cavern

The history of the intersection of the extensive natural stream caverns by late 18th century lead miners has been told elsewhere (Rieuwerts and Ford, 1985) and need only be summarized here. A canal tunnel driven south from the foot of the Winnats Pass to intersect several E-W mineral veins first encountered the Bottomless Pit Cavern, some 430 m south of the entrance. This is a large vein-cavity extending some 50 m upwards and 16 m downwards. Clearly of phreatic solution origin, it developed by enlargement from vugs in the calcite-rich Faucet Rake, but this requires both an input opening and an outlet. The input opening is buried under collapse debris and the outlet is beneath the "lake" in the bottom of the Bottomless Pit. This takes overflow water from the canals but the outlet is constricted and flood water soon backs up. An interesting point is that the present water level is some 13 m above the altitude of the final resurgence at Russet Well, so that there must be a vadose stream cave somewhere between, as yet unentered by cavers. The Bottomless Pit Cavern may thus be typical of a fairly early stage in the phreatic enlargement of a primary vein cavity, now partly drained by falling water-tables.

Beyond the Bottomless Pit Cavern, the Far Canal swings more to the southwest and intersects the steam caves in the controlling bedding plane some 14 m below that of Peak Cavern (Fig. 8). Upstream from the

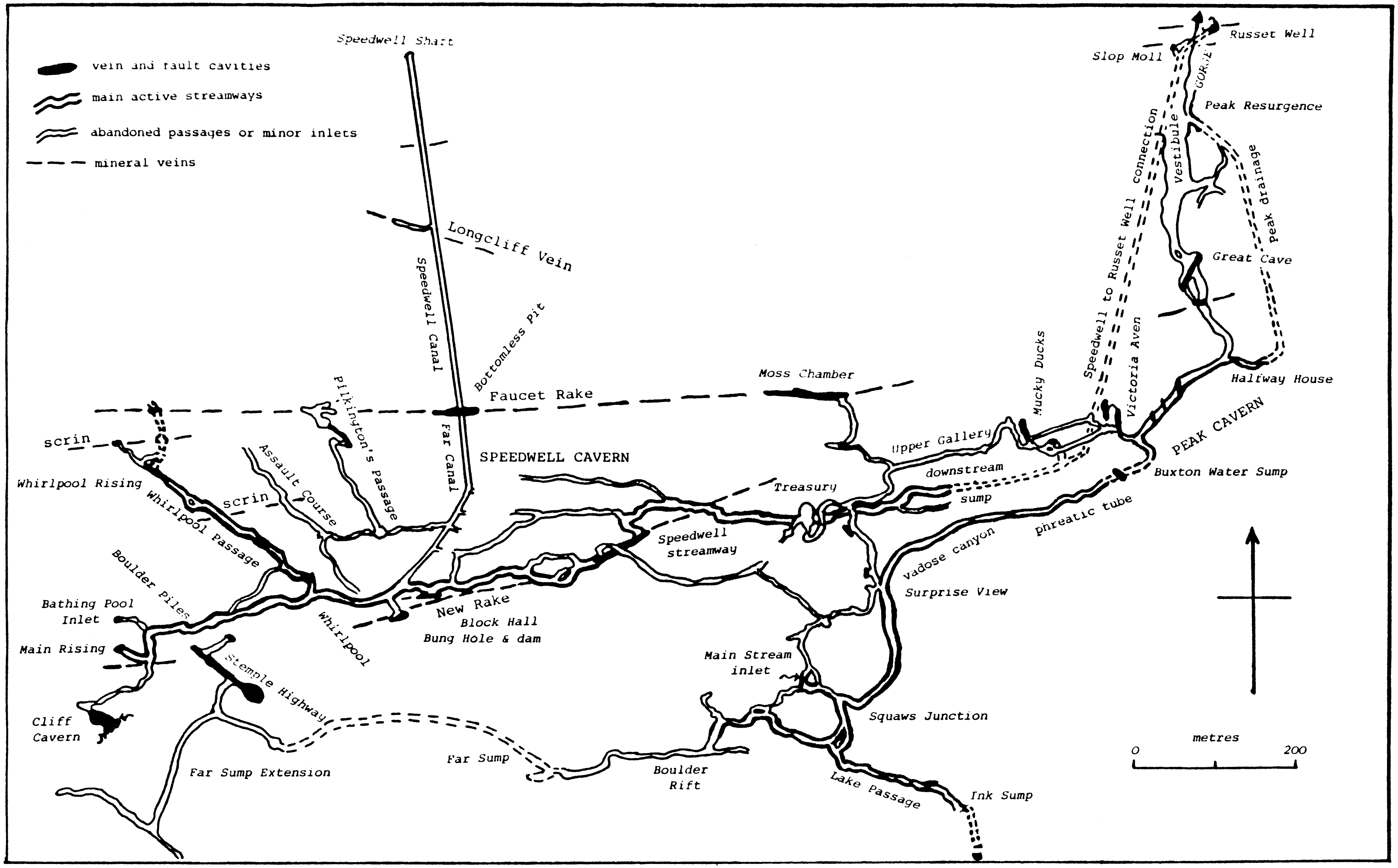


Fig. 8. Sketch plan of the cave passages of the Speedwell and Peak Cavern systems (modified after a compilation by J.S. Beck, 1980).

Whirlpool junction the main stream passage is a classic phreatic tube in the roof with a vadose trench up to 6 m deep (Plate 5B). An aven developed through pipe vein cavities once linked upwards with Far Peak Cavern in 18th century miners' days (Rieuwerts and Ford, 1985) but it is now blocked with large boulders. The upstream end, to the west, is something of a surprise — turning a corner the roof suddenly comes down to the water level, and the floor drops into a flooded pothole. Developed in a minor mineralized joint this has been dived to a depth of 30 m and continues as a large submerged vein-cavity system, as yet unexplored. This Main Rising (Plate 6B) is the main outlet for the streams draining off Rushup Edge into the swallet caves (Fig. 2).

Nearby two branch passages both lead along tubes with minor vadose trenches into vein or fault cavities. Cliff Cavern rises spectacularly in joint intersections for at least 50 m, whilst the Bathing Pool is flooded and has been dived to 16 m. Both discharge only minor streams. The passage to Cliff Cavern intersects two old phreatic tubes completely full of laminated (varved?) silts and clays (Plate 7A) in one case resting on old flowstone. Palaeomagnetic data here may give a date on the fill, which must post-date the flowstone and this in turn must post-date draining the passage.

The main Speedwell tributary is the Whirlpool Passage, some 350 m long. Again, it is a classic phreatic tube with vadose trench, rarely more than 2 m high, partly developed along pipe-vein cavities up to 2 m in diameter. The stream rises from a flooded pothole and an underwater extension has been followed for some 200 m at only a few metres depth, with avens rising into vein or fault cavities. This is also fed with water from the swallets, particularly Giant's Hole, and in medium to high flood levels resurges with an intermittent action of pulses every few minutes. Though the Whirlpool Rising is 8 m higher than Main Rising both receive water from the same sources by an as yet unknown course. Studies of the variations of flow from both over the years suggest that flood waters can move sandbanks around and block one or other system as a result of flooding in the inaccessible passages.

Downstream of the Bung Hole (and Miners' Dam), the stream flows in a continuation of the phreatic tube plus vadose trench, by-passing a vein cavity, the 30 m high Block Hall, and traversing Rift Cavern along part of New Rake. Vadose trenching in the further reaches is less well developed, at times being only a series of swirl holes in the stream floor. Beyond the Treasury Connection, the last 150 m before the Downstream Sump is simply a wide phreatic tube along the controlling bedding plane. Like the streamway in Peak Cavern, there has been no vadose incision beneath a point some 16 m above final sump level. The water flows directly to both Russet Well and Slop Moll, being joined by Bottomless Pit water en route. Russett Well is on the east side of Peak Cavern gorge whilst the Speedwell Cavern is to the west so that the drainage passes under Peakshole Water in a U-tube fashion via vein cavities, Russet Well having been explored to a depth of 30 m by divers (Fig. 10).

In flood conditions water backs up in the Bung Hole series and rises through the Treasury Connection to overflow into Upper Gallery in Peak Cavern, thence discharging via the Peak Cavern stream to the Peak resurgence.

The miners evidently broke into caverns above their Bung Hole workings though the route is now blocked with fallen debris. Amongst it a sample from a large block of stalagmite yielded a uranium-series date of 96,000 years B.P., i.e. early Devensian, or late Ipswichian.

A significant part of Speedwell Cavern is Pilkington's Cavern. Discovered during sinking a shaft on Faucet Rake some 200 m south of the Winnats Pass, (Pilkington 1789) and only recently re-entered (owing to the shaft having been filled in; Shaw, 1983a and b), a series of natural vein cavity-type caverns led downwards via five vertical pitches to a long narrow winding tube plus trench passage, apparently in the same bedding plane as that which controlled Peak Cavern. A further vertical drop of 14 m entered a series of small tube-plus-trench passages tributary to the main Speedwell stream way. The significance of this tributary system of passages is that water must have gone underground under phreatic conditions to feed a bedding plane and tube system and associated vein cavities at an early stage, before water tables had fallen to anywhere near their present level. Subsequently there was sufficient input for small vadose trenches to develop. But as the input point for these was only 200 m south of the gorge of the Winnats Pass, it is difficult to conceive of the Pass being in existence when water was being engulfed into Pilkington's Cavern. This has implications for the stages in stripping back the Millstone Grit cover, and for the development of the Winnats Pass which will be discussed later.

The Speedwell Cavern's stream caves thus provide evidence for the early phreatic development of vein cavities, later utilization of a controlling bedding plane, a silt-and-clay fill stage and vadose trenching gradually draining the vein cavities. As there are few speleothems, few dates are available, except in Pilkington's Cavern, where dates of 63,000; 91,000 and 115,000 B.P. indicate stalagmite growth in Ipswichian, early and mid-Devensian times.

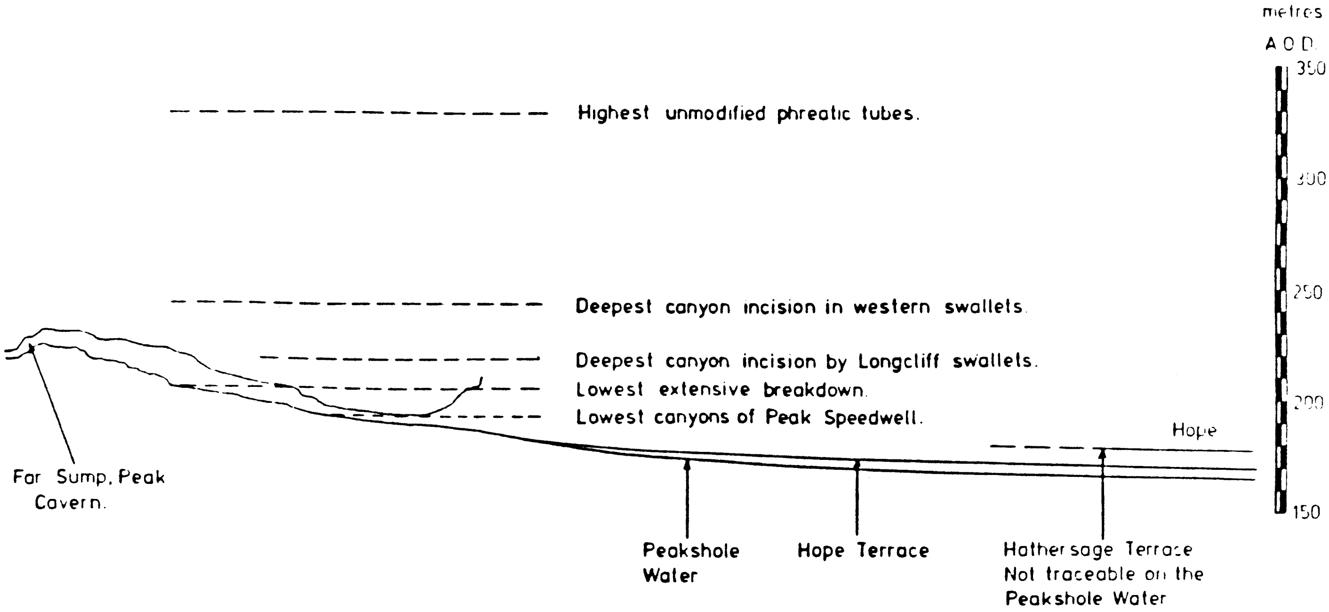


Fig. 9. Diagrammatic profiles of the Peak Cavern (and Speedwell) stream passages to show their possible relationships to the Hathersage and Hope terraces (reproduced from J.S. Beck, 1980, with permission).

Surface Features

No detailed geomorphological or morphochronological study of the Castleton area has yet been published, so that only a review of some important observations can be attempted here, with emphasis on those bearing on the evolution of the caves.

The Rushup Valley is floored with a solifluction sheet of gravels, sands and silts washed off Rushup Edge (Fig. 6). At its maximum this sheet covered the sites of the present swallet caves (Johnson 1967), and with the ground being frozen under periglacial conditions drainage must have been by a surface stream. The only possible outlet is the now dry valley system of Perry Dale. With its continuations of Dam Dale, Hay Dale and Monks Dale, this drained to the Wye Valley at Millers Dale, and the thalweg is largely graded to the present level of the River Wye though with interruptions due to the present of igneous rocks. In turn the River Wye near Bakewell has been incised some 50 metres below a terrace (the Hathersage Terrace according to Waters & Johnson, 1958) covered with several metres of boulder clay, generally thought to be of Wolstonian Age. The implication here is that the Perry Dale dry valley system has been incised to its present depth since the Wolstonian glaciation (Warwick 1964), and that the incision could have been as much as 50 m below a Hoxnian valley floor. The question arises: has there been enough run-off in late Wolstonian deglaciation, the Ipswichian interglacial and the periglacial effects of the Devensian to account for this amount of incision? And does this fit with the preceding analysis of the caves' morphology? Or, could the incision have been started in earlier Pleistocene phases and simply been rejuvenated in Wolstonian to Devensian times? Was it a dry valley, as today, in each of the interglacials?

The dry valley of Conies Dale is a tributary of Perry Dale and must be taken into account as well. Its "fresh" appearance suggests that it could have been incised or trimmed from previous incision in the same way as Perry Dale. But on the plateau above Conies Dale, there is a loessic soil cover of a metre or so of yellowish silty clay, seen in temporary excavations in the Portway "Gravel" Spar pits (SK 128 811) and in on an old lead mine working close to the summit of Eldon Hill. The age of this loessic clay is uncertain. Since it does not blanket Perry Dale or Conies Dale, it could be regarded as Devensian in age, with periglacial meltwater run-off keeping those dry valleys clear. Or, it could be regarded as older, i.e. Wolstonian, or even Anglian, with the dry valley network incised through a loessic blanket as well as into limestone. If the latter view is correct it is surprising that the loessic cover has survived so well; and since the Wolstonian and Anglian glacial limits are far to the south in Middlesex why is there no till associated with those ice sheets around Castleton as there is around Stony Middleton and Bakewell, some 12 km to the south? The last difficulty can be "explained away" by observing that there are traces of till with a few striated erratics in fissures in the Hope Cement Works Quarry, possibly as relics of a more extensive sheet, and also that it is likely that the Castleton area, lying in the lee of Kinderscout and the main Pennine range, was by-passed by the main ice streams anyway, leaving more or less stagnant ice over Castleton, with little resultant till.

The western end of Hope Valley is bordered by the fore-reef limestones of Cowlow, Long Cliff and Treak Cliff on one side and by the sandstones of the lower Millstone Grit on the other. Its floor is in early Namurian shales covered by a solifluction sheet through which the present day streams are incised by a few metres. The spectacular landslip of Mam Tor seems to have no relevance to the cave systems, though of course an ancestral Mam Tor may have had earlier landslips off its flanks, e.g. down the front of Treak Cliff. The floor was interpreted by Waters & Johnson (1958) as being the upstream continuation of the Hathersage Terrace, of "Older Pleistocene" date. Burek (1977) and Ford *et al.* (1983) suggested that this was probably of Hoxnian age (and covered by Wolstonian till at Bakewell), but the incision noted at Bakewell has no comparable incision in the Hope Valley owing to its knick point having been held up by the thick Kinderscout Grit near Grindleford. Minor incision in the Ipswichian yielded the Hope Terrace which appears to be that graded to the Peak Cavern-Russet Well resurgences. The Hope Terrace is only some 10 m below the Hathersage terrace in the lower end of the Hope Valley but the masking sheets of solifluction deposits in the head of the valley mean that two terraces cannot be defined at Castleton itself and only the relative extents and altitudes of vadose canyons and phreatic tubes in the caves suggest any distinction.

Slicing through the reef limestone belt and separating the main part of the limestone massif with its contained Speedwell and Peak Caverns from Treak Cliff with its caves partly developed in mineral veins is the Winnats Pass. This steep, deep gorge presents something of an enigma concerning its origin and consequently its relationship to the evolution of the caves. Various ideas have been proposed for its origin though no single publication has discussed the matter. These ideas may be summarized thus:

1. An inter-reef channel in mid-Carboniferous times, contemporary with the deposition of the reef limestones.
2. An erosional channel cut through the reef belt during the pre-Namurian uplift, i.e. contemporary with the boulder beds, filled in during Namurian times with shales.
3. A collapsed cavern.
4. A dry valley comparable with Perry Dale and Cave Dale, i.e. of late Pleistocene date.

All these present difficulties. Taking them in turn, the fore-reef limestones beds strike across the eastern part of the Pass and the back-reef lagoonal beds strike across the top; clearly these preclude the Pass being an inter-reef channel in its present form and depth. However, there may have been a very shallow inter-reef channel at high-level by late Dinantian times. This latter *may* have focussed erosion of a somewhat deeper channel in pre- to early Namurian times, and the so-called "Beach Beds" outcropping at the foot of the Pass suggest that erosional debris from Brigantian beds no longer present could have been swept down such a channel. Although evidence is scarce, there seems to be at least some indication of a shallow valley being present before the Millstone Grit shales were laid down. Upon exhumation and exposure of the limestone massif such a shale-filled valley could then easily be the focus for further excavation. There is no evidence for it being a collapsed cave, but if the increased run-off associated with melting snowfields in periglacial conditions is visualized, it is possible that the steep gradient permitted accelerated erosion of the less resistant shales and so deepened and widened the pre-Namurian valley into the present form. The problem still arises that the catchment for such run-off, at present only extending as far as Windy Knoll, does not seem large enough. However, if a mass of semi-stagnant ice is visualized in the Rushup Valley, then a much larger catchment could be available. To make such a hypothesis work, most of the Millstone Grit cover on the limestone must have been stripped back and the Hope Valley floor must have been cut down to somewhere approaching the Hope Terrace level. This places the final development of the Winnats Pass as we see it today in the waning stages of the Wolstonian glaciation, with perhaps some trimming and further deepening in the Devensian. It also confirms that the Winnats Pass was effectively not present when water entered Pilkington's Cavern, as noted in the Speedwell Cavern section above. The input into Pilkington's Cavern could have taken place when the proto-Winnats Pass was still full of shale, with a swallet stream meandering across from the vicinity of Windy Knoll. If there had been an ice margin here it might have briefly supplied a melt-water contribution to the Pilkington's Cavern inlet before the shale-filled Winnats Pass was re-excavated and deepened.

The above observations on the surface morphology indicate which features must be taken into account in any attempt to understand the evolution of the underground drainage but until a comprehensive geomorphological analysis is available the full significance remains uncertain.

Discussion

It is pertinent now to ask how far the observations of surface and underground features support the sequence of events outlined at the start of this address. In general they do, but the shortage of absolute dates on speleothems and the uncertainties of the timing of the valley incision and terraces mean that only a tentative sequence can be presented at this stage (Table 2).

Table 2 A suggested sequence of events in the development of the Castleton Cave systems

(partly based on Beck, 1980, and on Ford, Gascoyne & Beck, 1983)

Mid Carboniferous:	Limited palaeokarstic development; shallow Winnats channel.
Late Carboniferous, Permian & Triassic:	Mineralization accompanying faulting hydrothermal enlargement of palaeokarstic caves, mineral vugs, mineral linings and fill under cover of partly eroded Upper Carboniferous.
Mesozoic:	No evidence
Mid-Tertiary to early Pleistocene:	Uplift and breaching of Upper Carboniferous cover; establishment of slow vein cavity deep phreatic circulation and solution.
Early Pleistocene:	Initiation of early phreatic tube drainage via bedding planes into vein cavity system.
Cromerian Interglacial:	Possible swallets at Windy Knoll and Winnats Head, and perhaps Pilkington's Cavern. No Perry Dale; Winnats still a shallow channel filled with shale.
Anglian Glaciation:	Possibly some stripping back of shale cover and initiation of Rushup Valley; abandonment of Winnats Head and Windy Knoll swallets? Some development of Hope Valley at high levels?
Hoxnian Interglacial:	Deepening of Hope Valley to Hathersage Terrace level; initiation of Peak Cavern vauclusian spring; Treak Cliff Cavern swallet off former extent of Mam Tor? Speedwell and Peak Cavern phreatic tubes operative. Perry Dale shallow valley draining Rushup valley roughly along swallet line. Some deepening of Winnats Pass. Vadose canyon phase in caves initiated.
Wolstonian Glaciation: (largely under waxing and waning phases)	Headward incision of Hope Valley (to Hope Terrace level?) Abandonment of Treak Cliff Cavern as a swallet. Deepening of Winnats Pass under peri-glacial run-off conditions. Some deepening of Perry Dale with extensive excavation of Rushup Valley. Vadose canyons further developed. Some clay fills derived from loess. Lip of Peak Cavern vauclusian spring lowered.
Ipswichian Interglacial:	Lower phreatic ends of Peak and Speedwell Caverns partly drained as lip of vauclusian spring is cut away. Final cutting of dry valley system of Winnats, Perry Dale and Cave Dale. Speleothem deposition widespread in caves. Cave systems largely in their present form.
Early Devensian Glaciation:	No ice in immediate area, but much evidence of periglacial conditions. Partial filling of Peak Cavern gorge with frost scree blocked cave drainage. Loess washed in to pseudophreatic caves to yield clay fill. Dry valleys probably partly filled with scree and loess. Snow melt-water run-off. Solifluction deposits in Rushup Valley block swallets.
Chelford Interstadial:	Partial drainage of caves again, renewed speleothem growth.
Late Devensian:	Progressive removal of fill from swallets, vadose canyons and Peak Cavern gorge. Incision of Peakshole Water trench into solifluction sheet.
Post-glacial:	Further removal of fills, dry valleys abandoned by drainage and swallets fully functional. Renewed speleothem deposition.

The mid-Carboniferous erosion phase certainly produced a karstic landscape on Treak Cliff and Windy Knoll and may have caused a shallow incision of the Winnats Pass by a few metres. Of any caves developed at this time, there are no recognizable relics except the Blue John-lined mineralization vugs of Treak Cliff. Some of these may have channelled water off the former extent of the Millstone Grit cover in earlier Pleistocene times into both Blue John and Treak Cliff Caverns, but their subsequent draining by falling base levels mean that they cannot be related to the other cave networks.

Folding, faulting and mineralization were episodic in end Carboniferous, Permian and Triassic times. Mineral deposition tended to fill underground voids, as with the Blue John deposits, but crystal-lined vugs in the middle of rakes and scrins were almost certainly left open and were thereafter available for slow-moving phreatic waters. The solutional erosion of vein minerals and walls would have been minimal until uplift in the mid-Tertiary orogenic phase and the breaching of the Millstone Grit shale and sandstone cover permitted an increased flow rate.

No date can be placed on the breaching of the cover rocks but it is likely to have been in Mio-Pliocene times. Once breaching had been established at two points at different altitudes on the vein systems the movement of phreatic water through the mineral vein cavities would have been greatly accelerated and, with increased aggressiveness from run-off from the Millstone Grit, a series of complex U-tubes oriented more or less vertically along the east-west vein system would be the initial stage of speleogenesis.

From the establishment of the deep vein-cavity phreatic drainage to the stripping back of the cover to its present position and the initiation of the swallet drainage is a problem in that there are no dateable deposits on the plateau; also it is a period beyond the limits of the uranium series dating method (350,000 years) and no terrace remnants have been recognised above the Hathersage terrace of probable Hoxnian date in the Castleton area.

The resurgence of the underground drainage, then as now, was in or close to the entrance of Peak Cavern which must have operated as a vauclusian spring to a valley floor some tens of metres above the present Hope Valley floor, i.e. the spring may have overflowed well above the Hathersage terrace valley floor of Hoxnian date. Uranium dates on speleothems indicate that much of the cave system was drained by Ipswichian times, so that the lip of the vauclusian spring must have been cut away before the Ipswichian Hope Terrace, perhaps as a result of Wolstonian melt-water run-off. The steep head of Hope Valley must have been cut during this phase too. (It has been somewhat modified by the Mam Tor landslip since then). The development of the steep valley head had the effect of uncovering Treak Cliff, with an intermediate stage of allogenic flow into Treak Cliff Cavern, and thereby setting the scene for the periglacial run-off excavation of the Winnats Pass, probably largely in post-Hoxnian times.

The corollary of the incision of Hope Valley is that retreat of the shales from the limestone plateau margins across the reef complex seems to have been rapid, as no earlier generations of swallets are known.

This sequence of events leads to a scenario of deep phreatic drainage via vein cavities followed by allogenic input into the limestone via the present swallets with drainage following bedding planes and joints into the vein cavities. This means that the limestones away from the veins went through an early bedding-controlled phreatic tube phase, but as soon as vigorous flow was possible, water-tables fell and vadose drainage was established down dip to the nearest vein cavity system.

A phase of infill by derived loess followed, filling many early tube passages apparently before much vadose incision had taken place. In fact, there may have been more than one phase of loessic infill. Re-excavation of the fill and incision into tube floors was effected almost down to present water-table by Ipswichian times, but there was a phase of solifluction infill to parts of Giant's Hole thereafter during early Devensian times. Phases of underground morphological change have been noted in Giant's Hole and P8 swallet, but at present these are of stream routes only, with no absolute dating available.

The limestone plateau with its cover of loess is also diversified by a series of shallow dry channels cut into the loess near Hazard Mine and by deep doline-like hollows with solution collapse features, as at the Portway "Gravel" Spar pits. The channels clearly represent run-off flowing across the loessic sheet in waning periglacial conditions, and they drain into hollows on the line of mineral veins, presumably overlying vein-cavities. In a few cases, as at Thistle Pot and Conies Dale Pot, the channels have cut through the loess cover and revealed the limestone beneath to have potholes going vertically downwards. Choked with boulders these require excavation and Thistle Pot is currently being dug at nearly 20 m depth. The nearby Nettle Pot was dug through comparable fill to open at a 50 m depth into caverns developed along a thin lava horizon, with vast fault-guided cavities extending below to a final depth of about 160 m.

To the east Cavedale is incised into the plateau in much the same fashion as Perry Dale. Its lower reaches are graded to the Hope Valley floor, i.e. the Hope terrace, but it appears to have a strong knick point (Knighton, 1975) about halfway. However, this is less likely to be a real knick point than a structural interruption for it occurs just where the thick Cavedale lava outcrops. Cavedale lies partly above Peak Cavern but this seems to be coincidental and no genetic connection between them has been proposed. True, there is a small stream in part of Cavedale which sinks on a thin mineral vein and re-appears as the heavy shower in Roger Rain's House beneath, but this seems to be fortuitous and of no genetic significance. Indeed, the Cavedale Lava lies in the limestones over much of the inner part of Peak Cavern precluding percolation reaching the passages 150 m below. The wide amphitheatre of lower Cavedale lies directly above the Great Cave of Peak Cavern with the only connection being a very narrow fissure, now blocked. Indeed the lack of relationship between Cavedale and Peak Cavern supports the concept that the dale is a young dry valley cut whilst the cave below was frozen.

A periglacial event during the Devensian may have been the final incision of Perry Dale, as a dry valley draining the Rushup Valley to a slightly lower altitude, but taking the water into the River Wye catchment. This would have had the effect of accentuated shale-margin retreat at Perryfoot with the consequent development of the morphologically young swallets of Perryfoot Cave and Dr. Jackson's Hole. These now feed water into the vein cavity system at Coalpithole Mine whence it resurges via Speedwell Cavern at Russet Well.

The present situation is of an immature karstic conduit drainage system partly utilizing vein cavities far below the water table, partly in vadose canyons and partly in phreatic tubes, collectively crossing beneath the topographic watershed from the Wye drainage basin into the Derwent's (Fig. 10).

Conclusion

Many years of exploration of the Castleton cave systems have revealed a complex history of speleogenetic development from mid-Carboniferous times to the present. Unlike many karstic drainage systems there are additional factors which have affected both speleogenesis and geomorphological changes. These include the presence of the marginal reef belt of limestones with highly variable dip of bedding planes and widely spaced curved joints; the mineral vein cavity systems deflecting phreatic drainage to great depths; the pre-Namurian unconformity with attendant boulder beds and palaeokarst; and a multiglacial history with both depositional and erosional effects. The lowering of the Hope Valley floor was relatively rapid in pre-Ipswichian times; the Winnats Pass is an overdeepened mid-Carboniferous valley once partly filled with shales and scoured to its present depth by snow-melt run-off.

There is a need for many more speleothem dates to establish a full sequence of cave development, and there is a need for a more detailed geomorphological analysis of Hope Valley itself.

Acknowledgements

Thanks are due to the many speleologists with whom I have been underground or discussed ideas over the years, in particular to John Beck, John Gunn, Noel Christopher, Richard Shaw, Tony Waltham and Clive Westlake. Modified versions of some of their diagrams are included in mine.

References

Beck, J.S. 1980. *Aspects of Speleogenesis in the Carboniferous Limestone of North Derbyshire.* Unpub. Ph.D. thesis. Univ. Leicester.

Burek, C. 1977. 'The Pleistocene Ice Age and after'. Chap. 7, in Ford, T.D. 1977 *Limestone and Caves of the Peak District, Geo-books*, Norwich.

Christopher, N.S.J., Trudgill, S.T., Crabtree, R.W., Pickles, A.M., & Culshaw, S.M. 1981. A hydrological study of the Castleton area, Derbyshire. *Trans. Brit. Cave Res. Assoc.* 8, 189-206.

Farr, M. 1981. Reports on Peak Cavern. In *Cave Diving Group Newsl.* 60, 24-28, & 1982, *Newsl.* 64, 18-19.

Ford, D.C. 1971. Geologic structure and a new explanation of limestone cavern genesis. *Trans. Cave Res. Grp. G.B.* 13, 81-94.

Ford, D.C. & R. Ewers, 1978. The development of limestone cave systems in the dimensions of length and depth. *Canadian Jour. Earth Sci.* 15, 1783–1798.

Ford. T.D. 1966. The underground drainage systems of the Castleton area, Derbyshire, and their evolution. *Cave Science* (old Brit. Speleo. Assoc. series), 5, 369-396.

Ford, T.D. 1969. The Blue John fluorspar deposits of Treak Cliff in relation to the Boulder Bed. *Proc. Yorks. Geol. Soc.* 37, 153–158.

Ford, T.D. 1977. *Limestones and Caves of the Peak District.* Geo-books, Norwich, 469pp.

Ford, T.D. 1985. Palaeokarsts in Britain. *Cave Science*, II, 246–264.

Ford, T.D., Gascoyne, M. & Beck, J.S. 1983. Speleothem dates and Pleistocene chronology in the Peak District of Derbyshire. *Cave Science* (Trans. B.C.R.A.) 10, 103-115.

Ford, T.D. & Worley, N.E. 1977. Mineral veins and cave development. *Proc. 7th Internat. Speleo. Cong.* (Sheffield) pp. 192-3.

George, T.N. 1964. Tectonics and palaeogeography in Northern England. *Science Progress*, 51, 32-59.

Ineson, P.R. & Mitchell, J. 1972. Isotopic age determination on clay minerals from lavas and tuffs of the Derbyshire orefield. *Geol. Mag.* 109, 501-512.

Johnson, R.H. 1967. Some glacial, periglacial and karstic landforms in the Sparrowpit-Doveholes area of north Derbyshire. *East Midld. Geogr* 4, 224-238.

Knighton, A.D. 1975. Form adjustment in a limestone dry valley at Castleton, Derbyshire. *East Midld. Geogr.* 6, 130-135.

Palmer, A.N. 1984. Recent trends in karst geomorphology. *J. Geol. Education*, 32, 247-253.

Pigott, C.D. 1962a. Soil formation and development on the Carboniferous Limestone of Derbyshire, part 1: Parent materials. *J. Ecol.* 50, 145-156.

Pigott, C.D. 1962b. Estimates of the age of the plateau deposits on the Derbyshire limestone. *Adv. Sci. London*, 19, 435 (abstract).

Pilkington, J. 1789. *A view of the present state of Derbyshire.* (2 vols). Derby.

Pitty, A.F. 1968. The scale and significance of solutional loss from the limestone tract of the southern Pennines. *Proc. Geol. Assoc.* 79, 153-178.

Rieuwerts, J.H. & Ford, T.D. 1985. The mining history of the Speedwell Mine or Oakden Level, Castleton, Derbyshire. *Bull. Peak Dist. Mines Hist. Soc.* 9, No. 3, 129-170.

Shaw, R.P. 1983a. Rediscovery of the lost Pilkington's Cavern, Castleton, Derbyshire. *Cave Science* (Trans. B.C.R.A.) 10, 1-8.

Shaw, R.P. 1983b. Pilkington's Cavern, Castleton. *Bull. Peak Dist. Mines Hist. Soc.* 8, 296-300.

Simpson, I.M. & Broadhurst, F. 1969. A boulder bed at Treak Cliff, Derbyshire. *Proc. Yorks. Geol. Soc.* 37, 141-152.

Smith, P.B. & Waltham, A.C. 1973. The P8 Cave System. *Cave Science* (B.S.A. series), vol 7, (No. 50), pp. 21-28.

Trudgill, S. 1985. *Limestone Geomorphology*. Longman, London. 196 pp.

Walsh, P.T., Boulter, M.C., Ijtaba, M. & Urbani, D.M. 1972. The preservation of the Neogene Brassington Formation of the Southern Pennines and its bearing on the evolution of upland Britain. *J. Geol. Soc. London.* 128, 519-559.

Warwick, G.T. 1964. Dry valleys of the Southern Pennines. *Erdkunde, Bd.* 18, 116-123.

Waters, R.S. & Johnson R.H. 1958. The terraces of the Derbyshire Derwent. *East Midld. Geogr.* 2, 9, pp. 3-15.

Westlake, C.D. 1967. Giant's Hole and Oxlow Cavern: some notes on the development and recent exploration of the system. *Proc. 5th Ann. Conf. Brit. Speleo. Assoc.* pp. 1-12.

Trevor D. Ford
Geology Dept.,
University of Leicester,
Leicester LE1 7RH.

Front Cover

Stalactites and stalagmites in Treak Cliff Cavern, Castleton. Though some stalagmite growth can be dated to the last Interglacial, more recent growth rests on inwashed loessic clay.

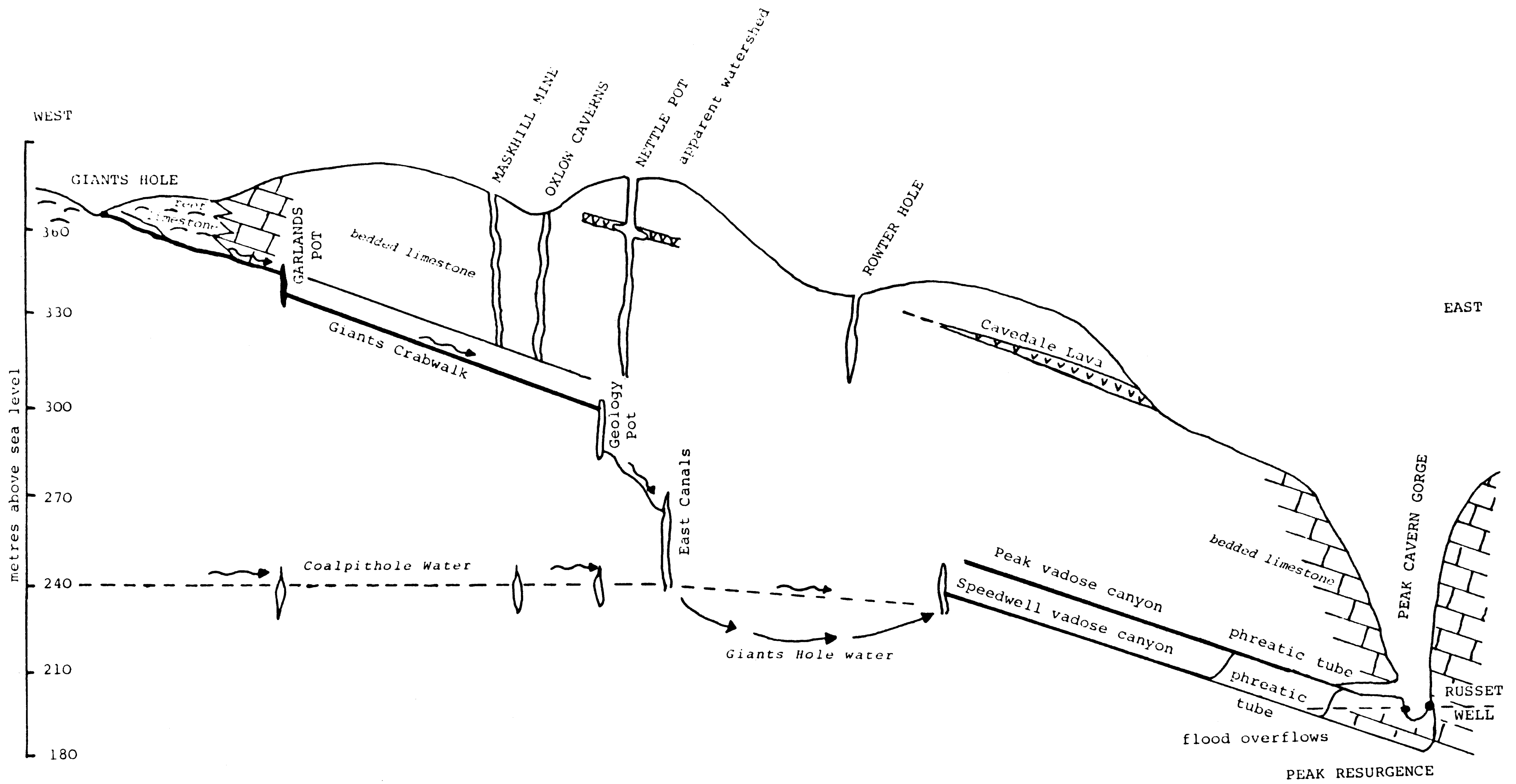


Fig. 10. Diagrammatic long profile to show the relationship of the Giant's Hole swallet to the deep phreatic drainage system (including water from the Coalpithole Mine "swallow", to the vadose and phreatic passages of Speedwell and Peak Caverns, and to the resurgence in Peak Cavern gorge.

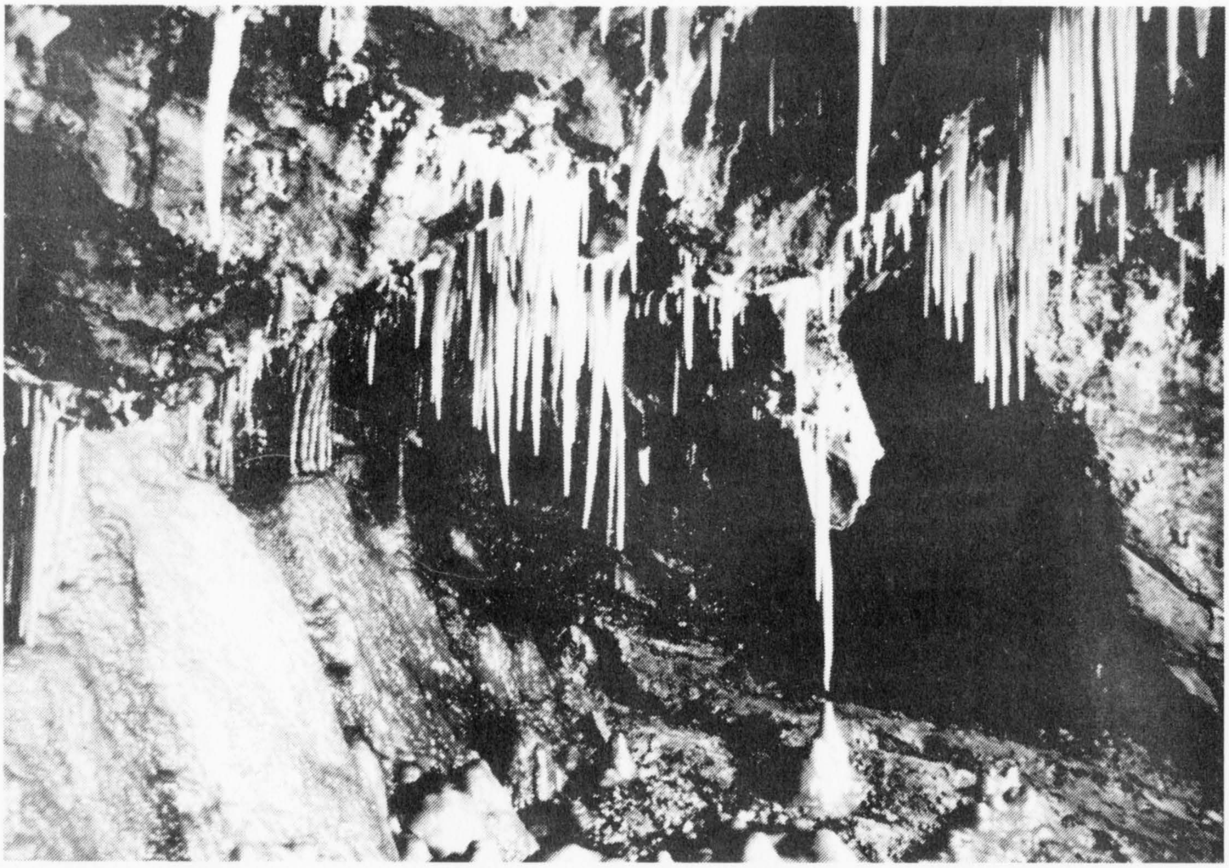


Plate 3A.

Treak Cliff Cavern showing the speleothems of the Dream Cave, with stalagmites resting on the derived loessic clay floor.

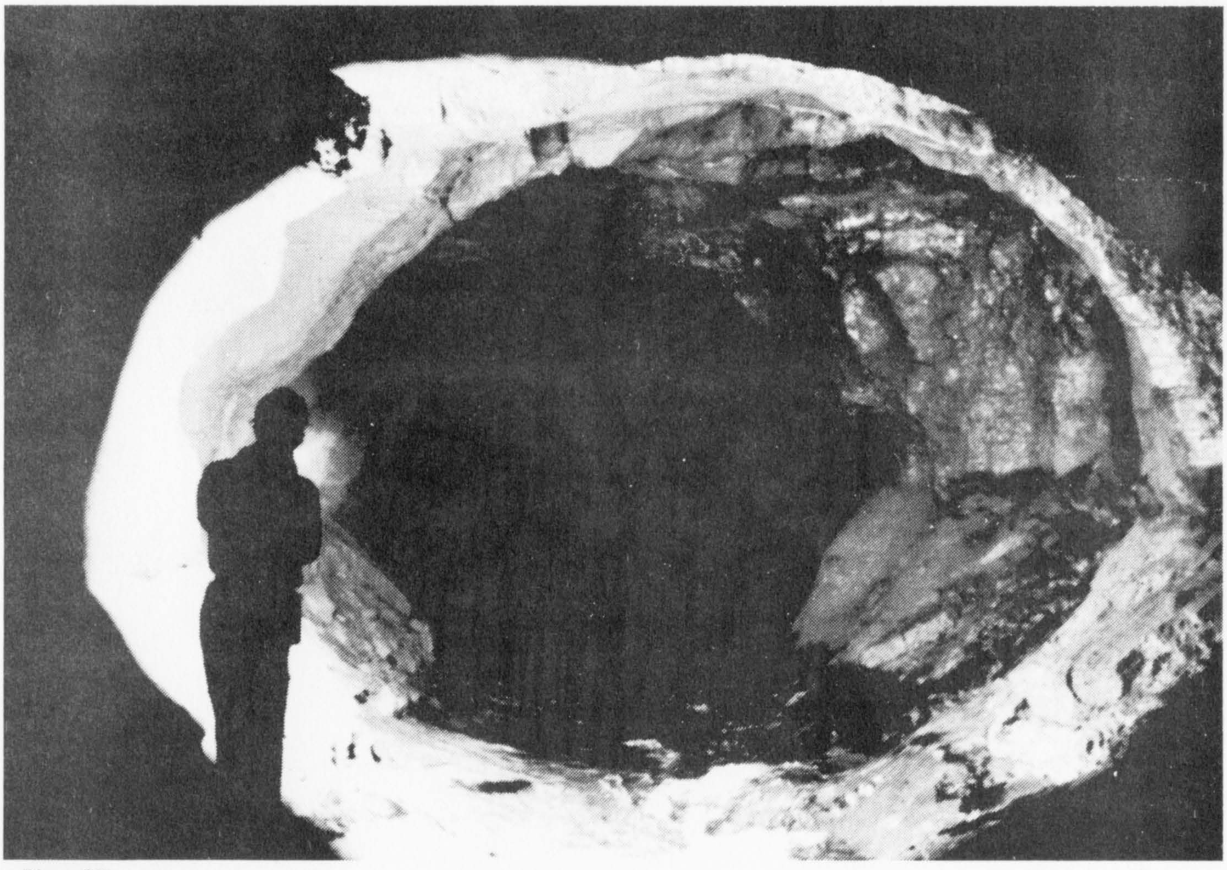


Plate 3B.

The phreatic tube at the lower end of the main stream cave of inner Peak Cavern. Developed by solution outwards from the central bedding plane it has been drained in recent geological times and now has a misfit stream on the floor.

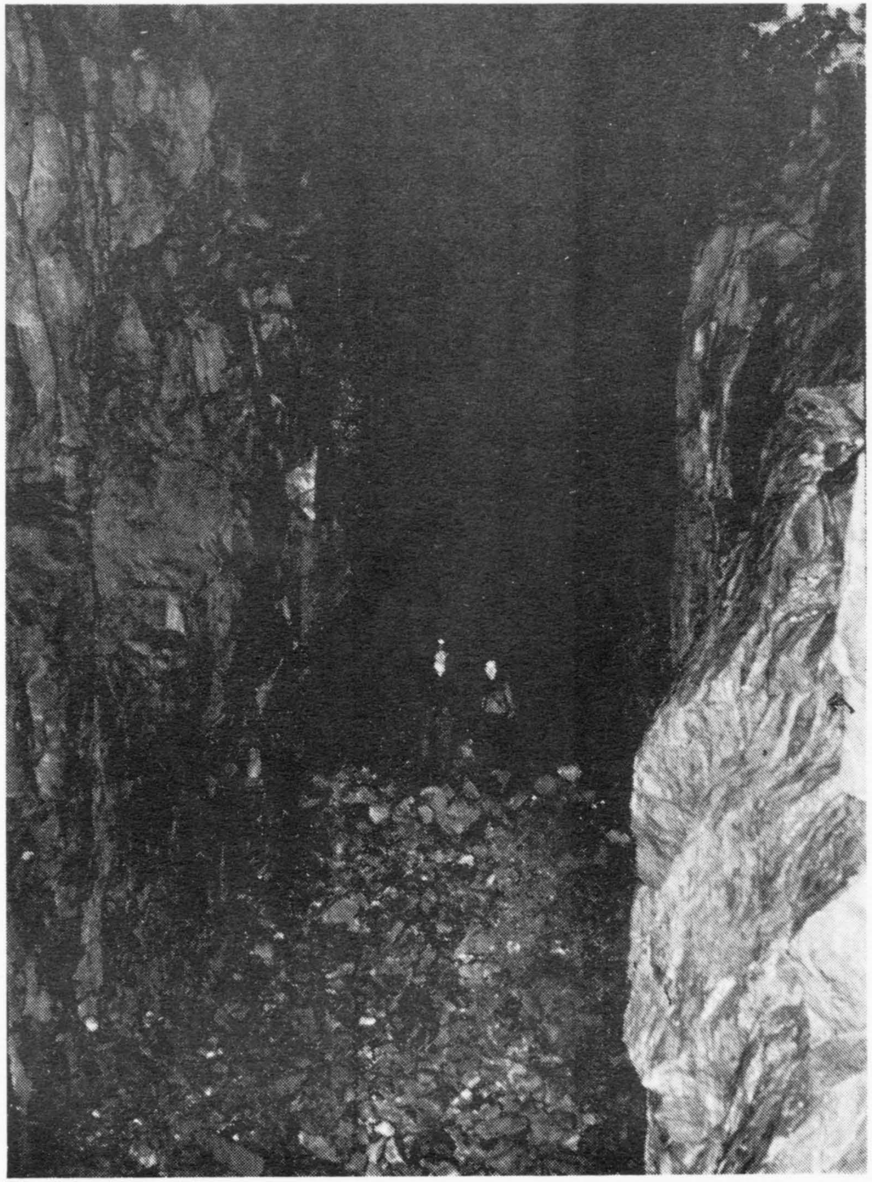


Plate 4A.

The vast West Chamber of Oxlow Cavern — a vein cavity developed by phreatic solution along Horse Stones Rake.

Plate 4B.

Near Base Camp Chamber in Giant's Hole: the right-hand wall is largely flowstone-covered solifluction gravel once attached to the boss behind the caver on the left. The present stream has cut a channel through the gravel fill in the centre.

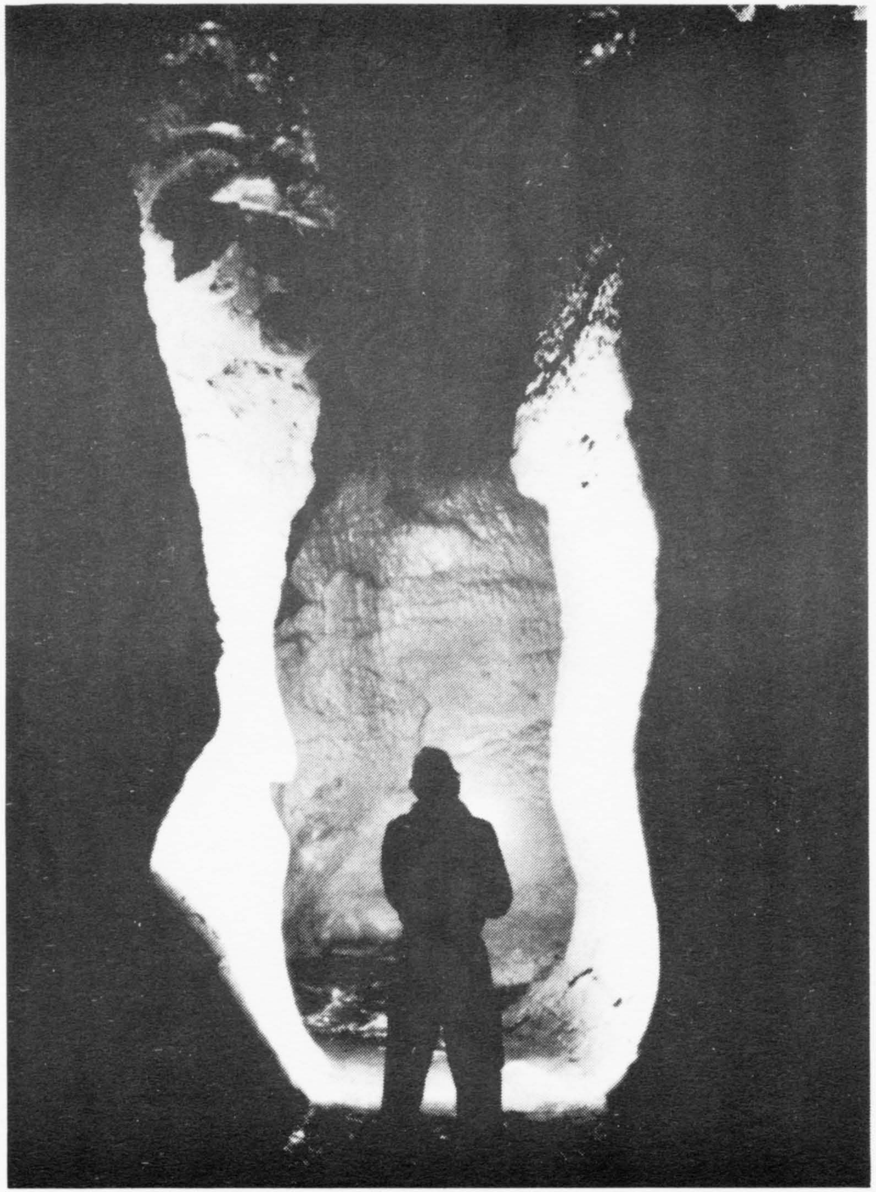


Plate 5A.

The lower part of the deep and narrow incised vadose canyon in the main streamway of inner Peak Cavern.

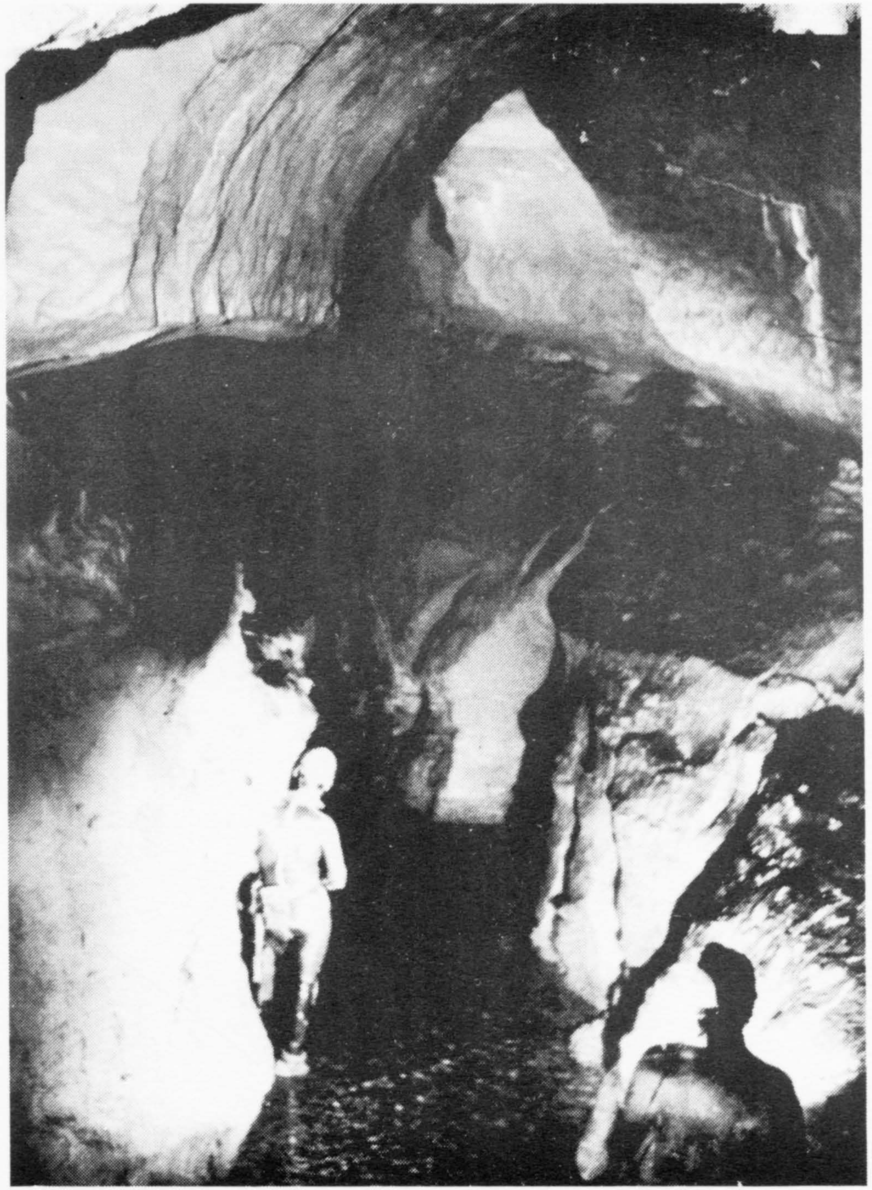


Plate 5B.

The main stream passage of Speedwell Cavern, near the entrance to Cliff Passage. A classic phreatic tube forms the roof with a canyon cut into its floor.

Plate 6A.

Peak Cavern Resurgence in the gorge outside the entrance, seen in flood conditions. Water rises from a still-active phreatic tube.

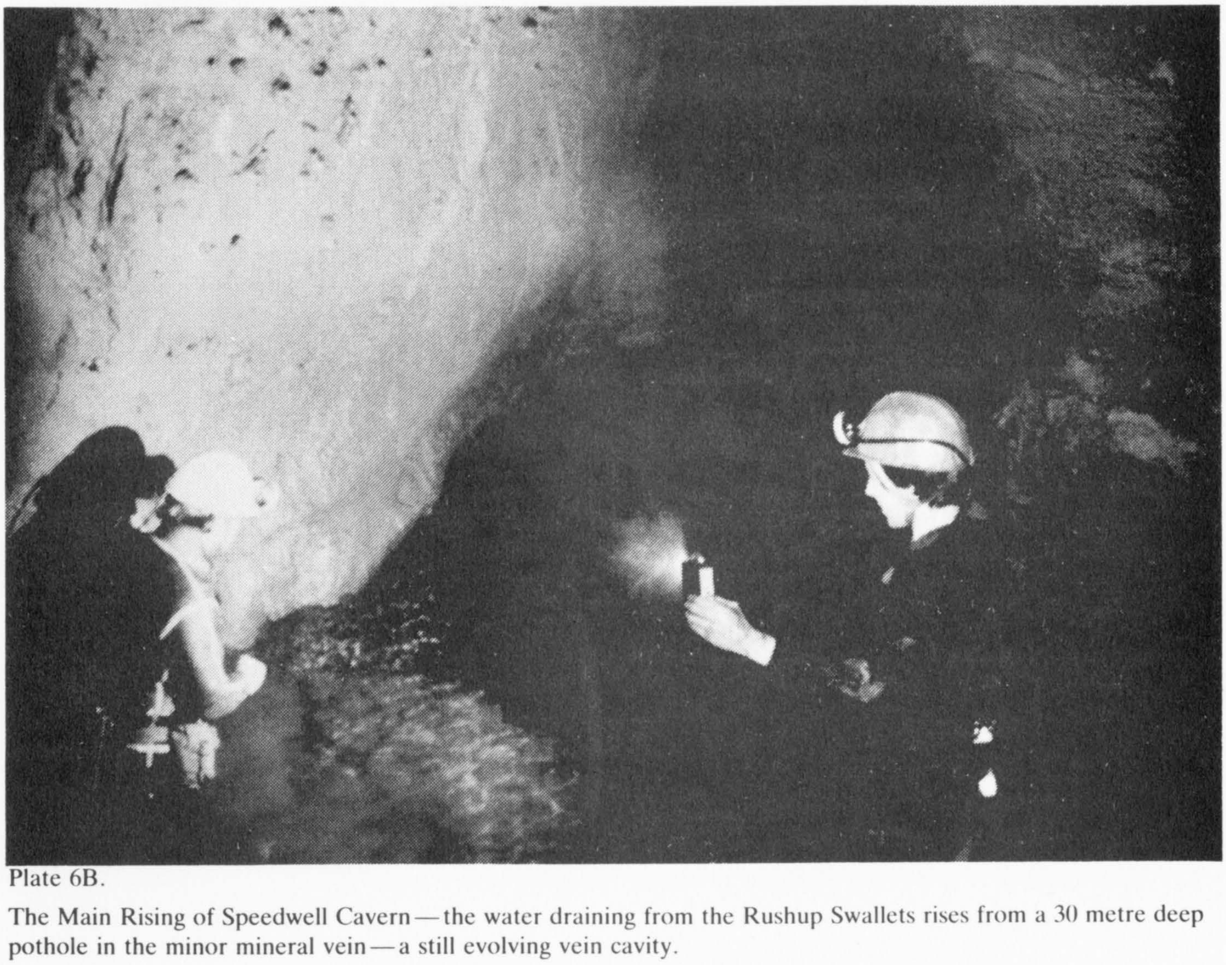


Plate 6B.

The Main Rising of Speedwell Cavern — the water draining from the Rushup Swallets rises from a 30 metre deep pothole in the minor mineral vein — a still evolving vein cavity.

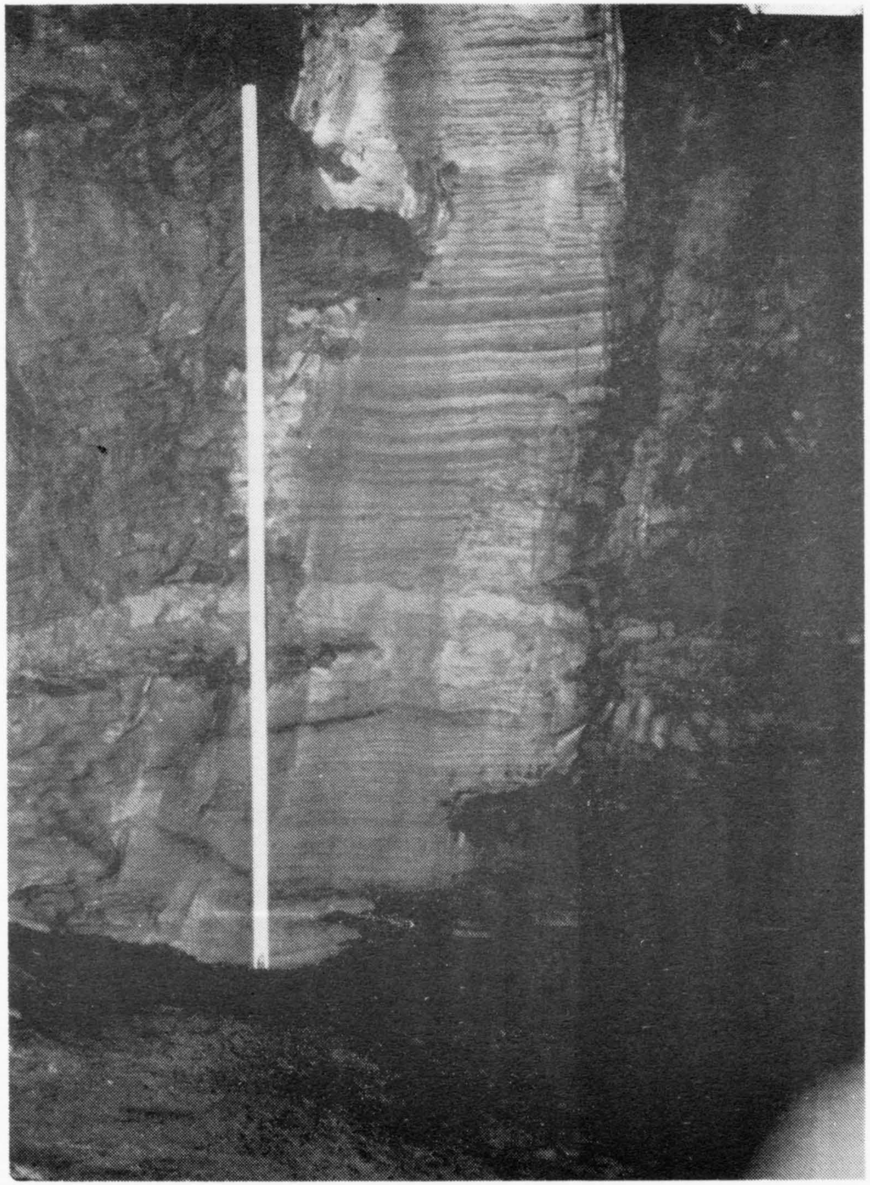


Plate 7A.
A 0.5 metre section of laminated silts and clays in an old phreatic tube near Cliff Cavern, probably representing repeated inflows of derived loess from the surface some 200 metres above Speedwell Cavern.

Plate 7B.
Eldon Hole — a 60 metre deep pothole developed by solution and collapse along a minor northwesterly fault.