Karst and Caves of Great Britain

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GCR Editor: D. Palmer

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Chapter 3

Outlying karst areas of the northern Pennines

INTRODUCTION

The northern Pennines contain Britain's most extensive and spectacular karst landscapes, spread across a range of uplands formed in mixed sequences of sandstones and limestones interbedded with shales. Most of the region is dissected by deep glaciated valleys cut between numerous residual summits which rise to over 700 m. The karst is all formed on the Carboniferous limestones which form bands across the whole region (Figure 3.1). The best known and most extensive outcrops are in the southern Yorkshire Dales, and these are referred to in Chapter 2.

Outside the main Yorkshire Dales karst, the karst landforms of northern England are widely scattered on various Dinantian and Namurian limestones which exhibit considerable lithological and structural diversity (George *et al.*, 1976; Dunham and Wilson, 1985). Both the modern structures and the Carboniferous environments are best viewed as features of three positive areas and some intervening troughs. The Pennines form a massive escarpment; the Askrigg and Alston Blocks, separated by the shallow trough of Stainmore, both have limestones dipping gently east from their upper margins along the Dent and Pennine Faults respectively (Figure 3.1). The third positive area is the denuded dome of the Lake District, where the limestone survives as part of an annular escarpment facing the Lower Palaeozoic inlier; these outcrops now lie on the edge of the Vale of Eden and around Morecambe Bay, where, though topographically outside the Pennines, they are geologically related.

The single most important limestone in the northern Pennines is the Great Scar, largely of Asbian and Holkerian age. This massive and pure facies forms most of the karst in the southern Dales (Chapter 2), and extends with very similar lithology into the faulted blocks just east of Morecambe Bay and also into the Stump Cross area just north of its bounding Craven Fault Zone. Northwards the Great Scar Limestone thins considerably, and thick shales occupy much of the Asbian succession. It forms the low escarpment with its many pavements between the Vale of Eden and the Lake District, but its extension onto the Alston Block, as the Melmerby Scar Limestone, has very little exposure beyond the pavements at Helbeck.

The Brigantian rocks are dominated by the Yoredale facies of cyclic shales, sandstones and limestones; these form the Wensleydale Group on the Askrigg Block, and the Alston Group on the block of the same name. The cave systems of Nidderdale are cut in the Middle Limestone, and are the largest karst landforms in the many limestones within these sequences (Figure 1.9). Cyclic sedimentary sequences continue with little change into the Namurian, where the lowest unit is a limestone. Known as the Main Limestone on the Askrigg Block, and as the Great Limestone on the Alston Block, this contains all the largest caves and karst landforms in the Pennines north of Wensleydale. All the Carboniferous limestones are very similar with respect to their karstic erosion; they are strong and generally massively bedded and are broken by thin shale partings; the Brigantian and Namurian limestones are generally darker than the Asbian Great Scar.

Lower Palaeozoic rocks underlie the unconformity which occurs throughout the region at the base of the Dinantian, but have almost no direct influence on the limestone aquifers and their karst morphology. In the Vale of Eden, the Dinantian limestones are underlain by the Holkerian Orton Group of mainly clastic sediments, which were deposited in the contemporary Ravenstonedale Trough.

Most of the limestones in the Pennines are structurally uncomplicated, with dips of 1–3°, widely spaced faults and generally two, well developed, conjugate joint systems. The notable exception is along the major fault zones bounding the Pennine blocks; the Stump Cross and Short Gill caves and the Clouds and Helbeck pavements all owe their character to strong folding of the limestone within these disturbance zones (Figure 3.1). Dips of 10–20° are common in the limestones around the fringes of the Lake District, and block faulting dictates the overall morphology of the hills east of Morecambe Bay.

The karst

Pleistocene ice sheets repeatedly scoured the northern Pennines, and the Devensian ice covered the entire area. The limestone landscapes are therefore dominantly glaciokarsts, except where glacial till totally blankets the outcrops or where landforms on the thinner limestones are lost in a broader topography of glaciated features. Ice sheets flowed south from Scotland, east and south off the Lake District, and almost radially from centres of ice accumulation on both the Pennine blocks, near the head of Wensleydale and over

Cross Fell (King, 1976). The Stainmore Gap was a major iceway across the Pennines, and all the Dales were modified to some extent, so that the glaciated troughs now epitomize the Pennine landscape. Scouring of the shale and soil cover and plucking of the limestone beds occurred across all the limestone outcrops, with varying intensity related to aspect and exposure to the flow of the glaciers and ice sheets.

On the large scale, the main valleys are all influenced by geological structure. The Vale of Eden is a major structural low, the Dent Fault has glaciated troughs along most of its length, and all the main valleys north of Wharfedale drain east with the dip, though at lower gradients. Nearly all the glaciated Dales have low longitudinal gradients, and most of them contain permanent surface rivers. Nidderdale and Dentdale have sections of limestone floor where the drainage is underground except for flood flows. Wensleydale may have an unmeasured underflow through its limestone floor, but this route offers no significant hydraulic advantage and a permanent surface flow is therefore maintained over a long limestone outcrop. The northern Dales cross only narrow outcrops of limestone, and only the River Greta goes underground for a few metres at God's Bridge (Figure 3.1). There are no long dry valleys, but How Stean Gorge in Nidderdale and Hell Gill are two of the more spectacular karst gorges cut through the narrower limestone outcrops by streams in valleys tributary to the main dales.

Limestone scars and pavements form the most conspicuous elements of the northern Pennine karst regions. Low white scars, plucked clean by the glaciers, fringe narrow rock terraces which almost trace the contours in most of the northern Dales, but they are overshadowed by the larger scars in the Great Scar Limestone of the southern Dales. The limestone pavements are much more dramatic, and form huge expanses of bare rock wherever the stronger limestone beds lay in the right attitudes to be stripped clean by Pleistocene ice. The pavements of Morecambe Bay and the Lake District fringe constitute some of the finest glaciokarst landforms in northern Europe (Goldie, 1981, 1993).

Where the Pennine limestones are covered by glacial till, they are distinguished by huge numbers of subsidence dolines. Locally known as shakeholes, these are classic karst features formed by suffosion and ravelling where percolation water washes the unconsolidated till into underlying limestone fissures. Each shakehole is typically 2–10 m across, with sloping sides and a depth limited by the till thickness. Almost all the Pennine limestone outcrops are marked by either zones of shakeholes in a till cover, or strips of pavement on scoured rock surfaces. Even the thinnest of the Yoredale limestones is commonly defined by a line of shakeholes round a hillside. Some larger dolines swallow allogenic stream flows, with open cave entrances or shafts descending into solid limestone, and there are innumerable risings on all the Dales hillsides. The larger are resurgences of sinking streams, many draining from open cave passages, but most are small flows of percolation water emerging from impenetrable fissures.

The caves

Nearly all the Carboniferous limestones have underground drainage; they are massively bedded, strong limestones whose high mass permeability is entirely due to fissure flow with secondary, solutional enlargement along tectonic joints. Most of the limestones are ideal hosts for karstic development, and caves are widespread at favourable sites; a few units of thinly bedded and heavily fractured limestones behave as diffuse aquifers and have no accessible caves.

The relatively thin scatter of known caves across the northern Pennines, in contrast to the very cavernous karst around Ingleborough (Chapter 2), is a function of both geology and drainage patterns. Most of the northern Pennine limestones form units less than 50 m thick and lie almost horizontally, thereby precluding the development of deep caves. Convergence of the underground drainage, or the sinking of large allogenic streams, is necessary to create stream caves of humanly accessible dimensions, and these criteria are generally not fulfilled within the thin limestones of the region. The typical situation has narrow hillside outcrops of the thin limestones, which swallow innumerable tiny streams; each flows underground for a very short distance to a rising at the base of the limestone directly down the hillside, forming one of many, roughly parallel, very small caves. Furthermore, most of the large areas of limestone pavement lie on high ground so that they receive no input of allogenic drainage; rainfall drains into all their fissures and emerges from numerous small risings fed by seepage flows and inaccessibly small cave passages.

Where the geology, topography and drainage

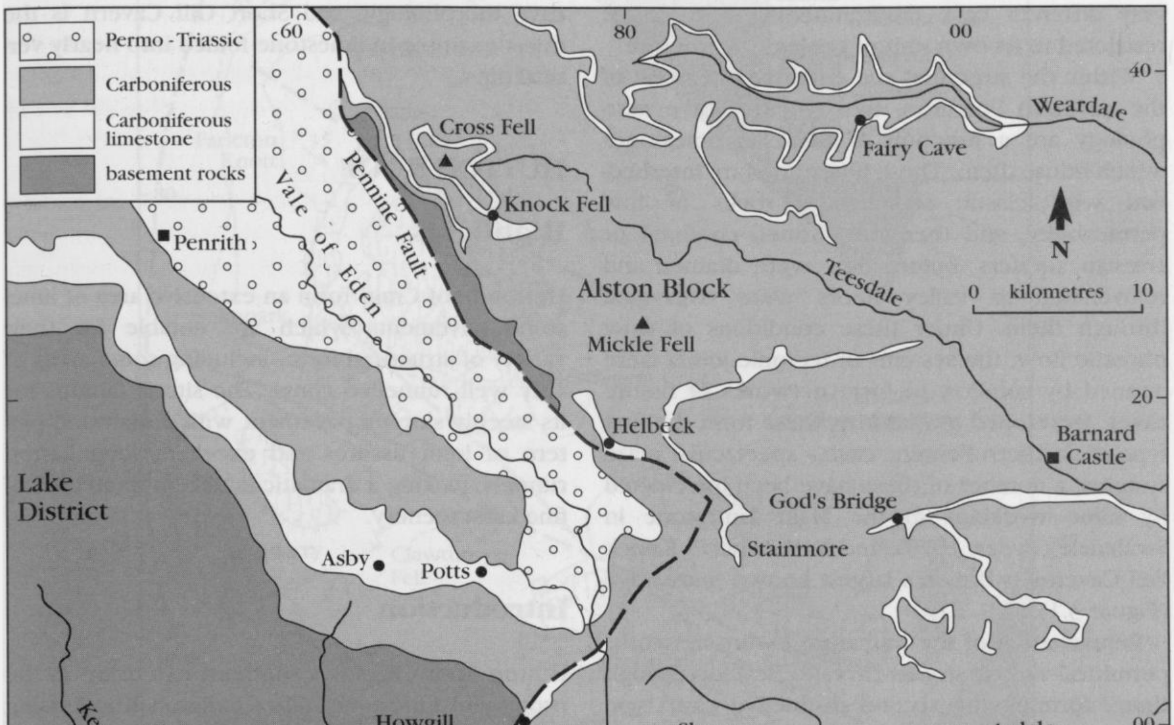


Figure 3.1 Outline map of the karst regions in the northern Pennines, with locations referred to in the text. The other Carboniferous rocks are the non-carbonates of the Orton Group and Yoredale facies of the Dinantian, and the Namurian, but they include thin bands of limestone with lesser karst features not shown on this map. The Carboniferous limestone includes the Dinantian Great Scar Limestone, the Yoredale limestones with significant karst, and the Main or Great Limestone of Namurian age. The basement rocks are Lower Palaeozoic non-carbonates. Details and locations in the southern Dales are shown in Figure 2.1.

are favourable, significant caves are formed, and this region houses three very distinctive and very different cave environments, each almost restricted to its own unit of geological structure.

Within the structural and environmental unit of the northern Pennines, two types of cave morphology are a function of the thin limestones which house them. These limestones are interbedded with clastic sedimentary rocks of low permeability, and therefore formed confined or artesian aquifers, before they were drained and rejuvenated as valley floors were excavated through them. Under these conditions of slow phreatic flow, the systems of tectonic joints were opened by solution to form networks of fissure caves. Developed to maturity, these form the first type of northern Pennine cave - spectacular maze systems; a number of these have been intersected by mine workings in the Main Limestone in Swaledale (Ryder, 1975), and further north Knock Fell Caverns is Britain's largest known maze cave (Figure 3.1).

Rejuvenation of the immature fissure networks permitted vadose stream caves to develop though them, forming the second distinctive cave type within the northern Pennine environment. These vadose canyons are distinguished by zigzag plans where they have followed and enlarged routes through existing interconnected fissures on the conjugate joint systems. The major caves are formed where topography creates a stream sink site at a significant distance updip from a potential resurgence site - in any of three situations. Where a major valley floor exposes limestone, its river drains underground beneath a surface flood route, as in Nidderdale. Where a hillside outcrop follows the gentle dip, a stream can drain through a cave parallel to the surface slope, as at Fairy Holes. Where a limestone dips gently through an interfluve, beneath an impermeable cap, stream sinks in one valley drain to risings in another; a number of sinks in Wensleydale drain to risings, including Cliff Force Cave, in Swaledale (Ryder, 1975).

A second cave environment is provided by the fault blocks of Great Scar Limestone east of Morecambe Bay. There is no allogenic drainage onto the limestone hills, but shallow phreatic flow has created horizontal caves in the hill margins adjacent to Pleistocene lake flats, including Hale Moss (Ashmead, 1969).

The third cave environment is within the strongly folded limestones in the disturbance zones along the major Pennine block faults. Phreatic drainage along the strike dominates the cave morphology, and Short Gill Cavern is the finest example in limestone folded into nearly vertical dips.

HUTTON ROOF

Highlights

Hutton Roof Crags form an extensive area of limestone pavements which are notable for their variety of structural form, including some areas of very well runnelled clints. The site is famous for its steeply sloping pavement with a diamond pattern of joint fissures and excellent long karren runnels, making a dramatic landform in an area of fine karst scenery.

Introduction

Hutton Roof Crags is a southern extension to the prominent limestone hill of Farleton Knott rising above the lowlands east of Morecambe Bay (Figure 3.1). The limestone forms an anticline plunging to the south, and faulted across its northern end; the Kendal Fault bounds it on the west, and the beds steepen into the Hutton Roof Monocline on the south-east (Figure 3.2). The Holkerian and Asbian limestones dip beneath a Brigantian cover east of the monocline, and their base is not exposed. The Hutton Roof limestones mostly dip at 10–20° away from the anticline, but dip more than 30° on the east flank, where the steeply sloping pavements of the Rakes are formed.

Although the steeply inclined limestone pavements of the Rakes are classic karst landforms which are widely known, Hutton Roof has been the focus of little detailed research. Morphometric work on the clints and grikes has compared the main pavements with others in Cumbria and elsewhere (Goldie, 1976, 1981), and the steeply dipping Rakes pavements have been referred to more widely (Williams, 1966; Sweeting 1966, 1974). Specific aspects of the karst morphology of the site have been described by Corbel (1957), Gale (1981a, b), Vincent and Lee (1981) and Pfeiffer (1991). The site is also rated as the second most valuable in Britain for the richness and variety of its flora (Ward and Evans, 1976).

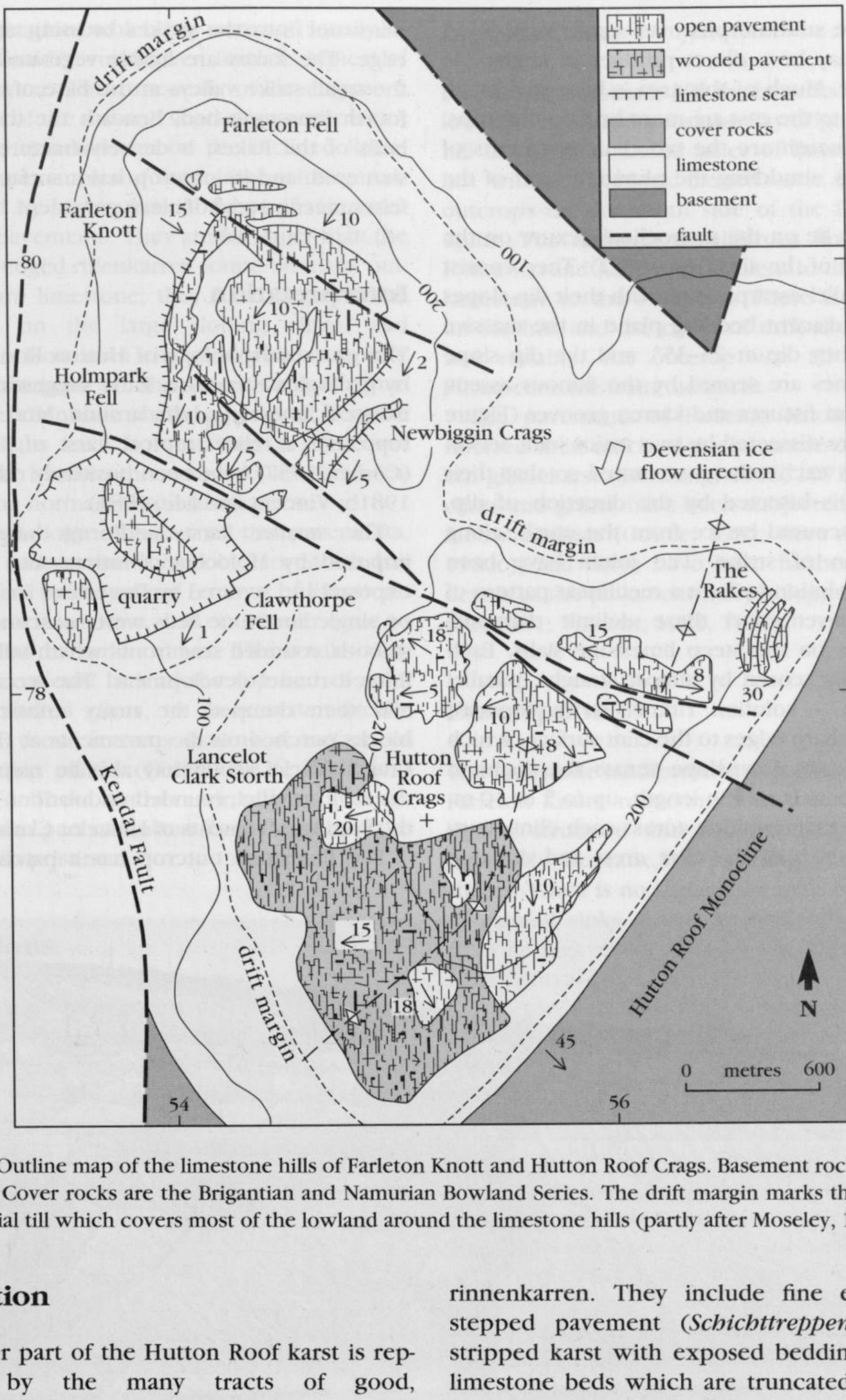


Figure 3.2 Outline map of the limestone hills of Farleton Knott and Hutton Roof Crags. Basement rocks are Silurian mudstones. Cover rocks are the Brigantian and Namurian Bowland Series. The drift margin marks the edge of the thicker glacial till which covers most of the lowland around the limestone hills (partly after Moseley, 1972).

Description

The greater part of the Hutton Roof karst is represented by the many tracts of good, well-dissected pavement, dipping south-west at less than 10°, on the higher parts of the hill west of the monoclinal crest. These gently inclined pavements are broken into small patches by minor structural undulations and faults, but they still display a great variety of surface solution features including kamenitzas, rundkarren and rinnenkarren. They include fine examples of stepped pavement (*Schichttreppenkarst*) – a stripped karst with exposed bedding planes on limestone beds which are truncated to create a stepped profile where the dip is not parallel to the surface slope. A partial vegetation cover only partly disguises this morphology.

The western outcrops, at Lancelot Clark Storth (Figure 3.2), are well preserved dipping pavement, some of which have unusual undulations with a wavelength close to 5 m; most of these appear to be stratimorphs over small, local folds, but some may be a direct product of large-scale glacial scour. Much of this area is bare pavement, but upslope to the east are more broken outcrops, and further south are the wooded pavements of Dalton Crags, straddling the plunging crest of the anticline.

The Rakes lie on the monoclinal flexure on the eastern edge of the site (Figure 3.2). They consist of three parallel escarpments, with their dip slopes formed on adjacent bedding plane in the massive limestone; they dip at 25–35°, and the dip slope bedding planes are scored by the famous assemblages of joint fissures and karren grooves (Figure 3.3). They are dissected by two major joint sets at about 90° to each other, orientated so that their intersection is bisected by the direction of dip. They were scoured by ice from the north, along the direction of strike. The joints have been opened by solution to form a rectilinear pattern of deep kluftkarren, and these delimit diamond-shaped clints on the steep limestone slabs. Each clint is deeply scored by almost straight, parallel rinnenkarren - solution runnels with rounded troughs and sharp edges to the clint surface, which lie symmetrically downslope across the diamond clints. The runnels vary in length, up to 5 or 10 m, according to their position across each clint, starting not far short of the clint crest and draining rainwater into the grykes crossing at the lower edge. The Rakes are lightly vegetated, except in the small strike valleys at the base of each slab. A fourth limestone bed, beneath the three massive beds of the Rakes, is densely fractured and frost shattered, and its outcrop has a surface veneer of felsenmeer instead of clean pavement.

Interpretation

The gross morphology of Hutton Roof is defined by geological structure. Early suggestions that the isolated limestone hills around Morecambe Bay represent a relict tropical karst of Tertiary age (Corbel, 1957) have been positively refuted (Gale, 1981b; Vincent and Lee, 1981).

The smaller karst landforms have all been imposed by Holocene solution onto limestones exposed and scoured by Devensian ice. Scar edges on single limestone beds were ice-scoured, leaving smooth, rounded scar fronts which still have only limited runnel development. The ice also moved and then dumped the many erratic limestone blocks perched on the pavements at Hutton Roof Crags. Glacial scour may also be responsible for the long, parallel, rounded undulations on the gently dipping pavements of Lancelot Clark Storth.

The limestone outcrop has a patchy cover of

Figure 3.3 The distinctive inclined limestone pavements of the Rakes above Hutton Roof, with the deep rinnenkarren raking down the diamond-shaped slabs between the joint-guided kluftkarren. (Photo: A.C. Waltham.)

soil and vegetation, which has retreated locally to reveal the rounded rundkarren features typical of subsoil solution. The time-scale of development and removal of the soil and vegetation cover is not known. The rinnenkarren on the inclined Rakes are excellent examples of these large solution runnels formed by high subaerial flows of rainwater on sloping pavements. They are far larger than the little, sharp-edged rillenkarren found on many outcrops of bare limestone; they have large rainfall catchments on the large sloping clints, and develop into Hortonian channels which are only slightly convergent on the steep slabs of limestone. They retain their sharp upper rims, because the steep slabs have not retained a soil cover which could blanket them and round their features into the normal subsoil rundkarren.

The morphology of some of the pavements, notably on and around Lancelot Clark Storth has been modified by the recent removal of limestone for garden rockery stone, and on a lesser scale to feed limekilns in earlier times. The results vary from the occasional lack of the top bed of solutionally runnelled clints, to areas systematically stripped of these features leaving a surface of rough bedding planes (Goldie, 1976; Ward and Evans, 1976). There has been virtually no damage on the eastern part of Hutton Roof Crags, and the Rakes remain pristine.

Conclusions

Hutton Roof Crags contains diverse and unusual limestone pavement features of national and international importance. The steeply dipping pavements at the Rakes contain the finest rinnenkarren in Britain, and their diamond patterns of deep kluftkarren are uniquely spectacular with their diagonal fluting by the rinnenkarren.

FARLETON KNOTT

Highlights

Farleton Knott is a prominent limestone hill with large expanses of spectacular pavements across its summit and flanks. These have a great variety of limestone pavement types and a range of solutional features reflecting the different aspects, slopes, minor structural features and sparse drift cover on the site.

Introduction

Farleton Knott stands 200 m above its surrounding lowland, east of Morecambe Bay (Figure 3.1). The hill is a fault bounded inlier of limestone which lies within the block faulted zone of limestone outcrops on the south side of the Lake District uplift. The massive, fossiliferous limestones are Holkerian and Asbian, equivalent to the Great Scar Limestone in the Pennines. There is no caprock on the hill, and the cover of drift and soil is thin and variable; the outcrop was all scoured by Pleistocene ice from the north.

The pavements of Farleton Knott have been referred to in much of the literature on the northern glaciokarst (Sweeting, 1966, 1972, 1974), the clints and grikes have been subjected to morphometric analysis (Goldie, 1981; Rose and Vincent, 1986c), and there have been further studies on details of the pavement morphology (Vincent and Lee, 1981; Vincent, 1981, 1982).

Description

The limestone landforms vary considerably across Farleton Knott, reflecting both the changing geological structure and the geomorphic history, especially beneath the invading Pleistocene ice sheets. There is no surface drainage on the hill, as all rainfall sinks almost immediately, to emerge from springs around the perimeter; there are no known caves large enough to enter.

Farleton Fell forms the northern end of the Knott (Figure 3.2), and its north-facing slope is well fractured beneath a blanket of talus. Pavements are formed on the south-facing slope, and those near the crest are steeply inclined, with small clints, on beds which dip 14–20° south into a small syncline. South of the fold axis, the pavement is nearly horizontal, and well developed with good rectangular clints and numerous transported limestone boulders on protected pedestals. Clints average 2.75 m long and 1.05 m wide, reflecting the fracture patterns of the folded and faulted limestone, and grikes average 1.2 m deep, reflecting bed thickness (Goldie, 1981). The solutional details on the sloping limestone include kamenitzas and solutional ripple marks, some akin to trittkarren. Runnels are poorly aligned on the smaller clints, but larger clints to the west have runnels with stronger downslope alignment.

The limestones at Holmepark Fell, on the southwest side of Farleton Knott (Figure 3.2), dip at

3–8° south-west, and were strongly scoured as Pleistocene ice swept downhill. These pavements are the most smoothly scoured of all on the Knott; they are prominently runnelled by large rundkarren with rounded floors and sharp rim contacts to the pavement surface. The downdip edges of the pavements are more closely runnelled by smooth rundkarren, characteristic of a pavement edge which was once covered by soil and vegetation. They are the least dissected of the Farleton Knott pavements, with average clint dimensions of 3.15 m by 2.32 m (Goldie, 1981). This area also has many transported limestone boulders which are the remains of glacially plucked scars. At its southern end, much of the outcrop on Clawthorpe Fell has been quarried away, but an 'island' of pavement survives with excellent large clints, deep convergent rundkarren and many kamenitzas; it is gaining a new cover of vegetation now that it cannot be grazed by sheep (Figure 3.2). Very large clints on surviving pavements south-west of the quarry have gently sloping tops scored by rinnenkarren runnels up to 15 m long.

On the south-east side of the Knott, Newbiggin Crags (Figure 3.2) is important for its beautiful, nearly horizontal pavements, with outstanding networks of rundkarren (Figure 3.4). The more massive limestone beds form very striking edge scars, 2–3 m high, scored by fine vertical solution grooves and with fallen blocks below. The large rectangular clints, many up to 2 m across, are scored by spectacular rundkarren systems with deep runnels converging down the gentle dip. North of Newbiggin Crags, the outcrops are poorly runnelled as much of the original fretted surface bed has been artificially removed.

Figure 3.4 The excellent pavements with square clints deeply scored by rundkarren on Newbiggin Crags. (Photo: A.C. Waltham.)

Interpretation

Standing well above surrounding lowland, Farleton Knott received the full impact of Pleistocene ice flowing south from the Lake District. On the north face the limestone was broken and ground down by the ice under pressure, while the more gentle lee slopes facing south were plucked and scoured – to leave the bare rock slabs subsequently fretted by solution. Some blocks of limestone were transported and dumped as erratic boulders on the pavements; many of these now stand on pedestals of limestone, which have been sheltered from direct rainfall. It is unlikely that any features survive unmodified from before the Devensian glaciation.

Geological structural has influenced much of the geomorphic variety at Farleton Knott. Several faults extend across the site, and are responsible for topographic breaks including low scars, small structural depressions and dry valleys. The largest structural valley lay along the fault on the southern margin of Holmepark Fell, and was partly floored by pavements, until it was completely removed by the quarry (Figure 3.2). The pavements at Newbiggin Crags are the best of the many on Farleton Knott which show a rectangular pattern (Figure 3.3), influenced by the dominant north-west and north-east orientated joint sets (Moseley, 1972). A third set of north–south joints creates some triangular clints, and influences some runnel patterns.

The great variety of runnel types, dimensions and patterns on the Farleton Knott pavements reflects contrasts in the limestone lithology, structure, slope, aspect, glacial history and vegetation history between individual locations. Grike morphometry at Holmepark Fell revealed a bimodal distribution in histograms of grike widths, suggesting that the group of narrower grikes may be postglacial, while the group of wider grikes inherited a component of preglacial opening (Rose and Vincent, 1986c); it was estimated that about 72 mm of grike opening has taken place since the Devensian glaciation. The same data revealed lower proportions of wide grikes than at comparable pavement sites at Underlaid and Longtail Woods, near Morecambe Bay, which may indicate less glacial scouring at Holmepark Fell than at the other sites. However, morphometric data for the whole of Farleton Knott (Goldie, 1981) suggest that Holmepark Fell was probably the most scoured part of this particular hill. Trittkarren occur on sloping pavements which have probably remained free of soil and vegetation since deglaciation (Vincent, 1983). Around snow patches on Farleton Fell, contemporary processes are largely confined to intermittent freeze-thaw action on the clitter-strewn slopes. Meltwater infiltrates through the limestone clitter, and this helps the karstic hollows to deepen beneath the snow; the hollows are thus polygenetic (Vincent, 1982).

The landforms on Farleton Knott have been extensively affected by human activities. Large areas of Newbiggin Crags, the central part of the limestone pavement area, and parts of Holmepark Fell have displaced clints, rough bedding plane surfaces and veneers of rubbly debris, all of which result from the removal of the top layer of solutionally fretted clints (Goldie, 1981). On the low plain east of Newbiggin Crags, grass regrowth has been encouraged on the rough, artificially stripped limestone surfaces, and only small isolated clints now remain exposed.

Conclusions

The surface of Farleton Knott has a number of excellent limestone pavements, whose morphology exhibits considerable variety. This reflects contrasts in surface slope, geological structure and exposure to scour by Pleistocene glaciers. The spectacular, square cut, clint fields and deep runnels on the pavements of Newbiggin Crags are of national importance and international repute.

GAIT BARROWS

Highlights

Gait Barrows is an extremely important limestone pavement site, being the finest of the many pavements on the low limestone hills east of Morecambe Bay. It is distinguished for its botanical and zoological features, as well as for its wide range of karstic surface landforms.

Introduction

The pavements at Gait Barrows are on the gentle southern slope of a low limestone hill south-east of Arnside (Figure 3.1). They are developed on a fault block of Carboniferous limestone of Asbian age which has a southerly dip of about 3°. The limestone is thickly bedded, and some sparite beds reach 3 m in thickness. The whole site lies at altitudes under 50 m, and was scoured by Devensian ice from the Lake District (Rose and Vincent, 1986c).

An extensive literature about Gait Barrows is primarily concerned with the botany, with passing references to the geomorphology. The site has been described as the single most important limestone pavement in Britain for its richly varied flora (Ratcliffe, 1977; Ward and Evans, 1976). The quality of the pavements gives Gait Barrows almost equal geomorphological importance (Ashmead, 1974a; Goldie, 1986), and Rose and Vincent have studied the spring waters (1986a) and the kamenitzas (1986b) of the site.

Description

The Gait Barrows pavements contain an exceptional range of morphologies within an area of less than a square kilometre. The density of vegetation cover varies considerably and defines three zones within the site (Figure 3.5). The outer zone is thickly wooded, and covers about half the area of the limestone outcrop; the two inner zones contain the open pavements, and have shrubs and trees scattered thinly over them, rooted in the grikes or on patches of soil on the limestone surface.

The most important part of the site is the central exposure (Figure 3.5), with three expanses of massive, open pavement, undisturbed by any clint removal, on a few beds of limestone locally as thick as 3 m. Massive clints are up to 30 m long, with clean surfaces on limestone scored by thin mineral veins (Figure 3.6). They slope gently to the south, and slight flexures in the regional dip produce broad undulations in the pavement. The small-scale karst landforms include a great range

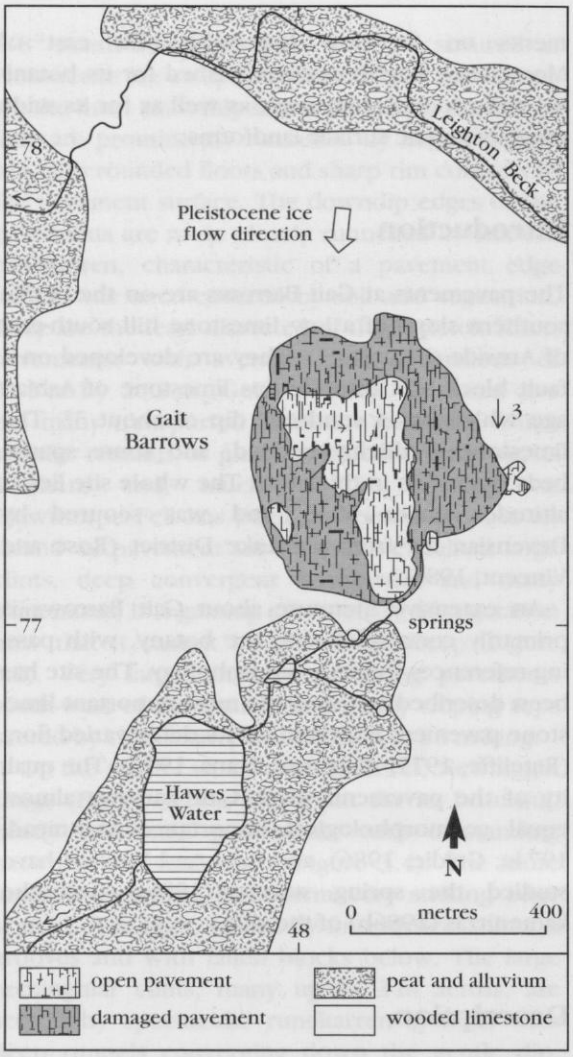


Figure 3.5 Outline map of the limestone pavements on Gait Barrows.

of kamenitzas, at varying stages of development, immature but deep grikes which commonly do not intersect, and pedestals of protected limestone beneath erratic boulders. Some kluftkarren grikes are more extensive, and some are concentrated along zones of tectonic fractures. There are also many of the small, sharp-edged rillenkarren solution grooves on the edges of some of the clints. The pavement has many small erratics of Namurian sandstone, including some wedged in the grikes.

Around the central area of open, massive pavement, there are several areas of more broken and dissected pavement (Figure 3.5). Some of these are in their natural state on more fractured limestone, while others are artificially stripped; these expose bedding planes from which the top bed of clints has been removed within the last 100 years, revealing some of the subsurface morphology. There are also areas where removal of the original pavement was distinctly scrappy, and clint blocks were left loose, tilted or overturned, providing different faces exposed to modern subaerial erosion.

The third zone of the Gait Barrows limestone is densely vegetated. The rock surfaces are completely covered by ground vegetation, including mosses and low flowering plants, so that their morphology is extremely difficult to see. Close examination shows that these areas are well dissected pavement with large clints; beneath the organic cover, the dominant morphology is that of well rounded rundkarren. Good, intact pavement with a largely rectilinear pattern of grikes lies east and west of the central area. Many clints are a few metres in length, though they are often narrow due to the local dominance of any one major joint set. Some areas towards the southern boundary with the peatlands have clints which are smaller and produce many naturally loose blocks of limestone.

Interpretation

These pavements are formed on limestones close to sea level which were overrun by sediment-laden Pleistocene glaciers spreading over lowland plains. Any erosional effects on the limestone landforms by high sea levels during the Pleistocene have not survived the Devensian glaciation. The excellent quality of the Gait Barrows pavements is a function of both the massive limestone beds at surface level and also the aspect which the site presented to ice erosion. The gentle southerly dip combined with the southward flow of the glaciers to maximize the scale of ice plucking on the lee of the hill, so leaving the cleanest of rock surfaces ripe for subsequent solutional fretting. The main pavements have large, bare clints on the massive limestone beds, separated by kluftkarren grikes which are largely postglacial in origin. Some grikes have significantly greater widths, which suggest that they have a component of preglacial solutional opening, and these contain large numbers of small erratic blocks of Namurian sandstone.

Kamenitzas are numerous on the central area of massive pavement. They probably started to form soon after the Devensian ice retreat, but their water chemistry shows that they could form within only a fraction of Holocene time (Rose and

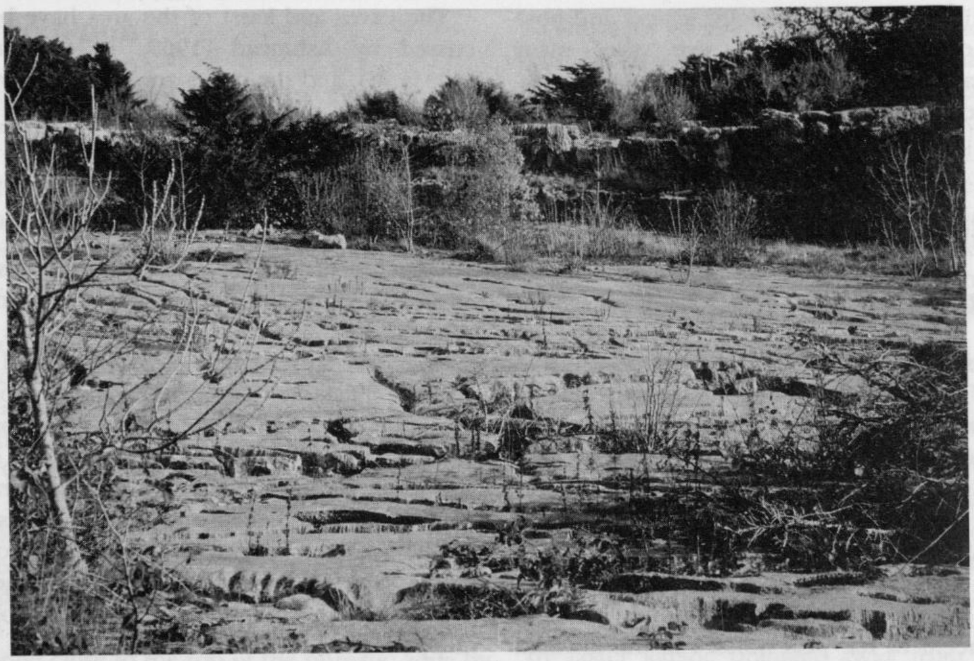


Figure 3.6 The very large clints in the central open pavements on Gait Barrows. (Photo: A.C. Waltham.)

Vincent, 1986b). Their solution environment, and consequent morphology varies under the influence of plant growth, ice formation and other factors. All the kamenitzas at Gait Barrows are formed over calcite veins in the limestone (Rose and Vincent, 1986b). It is not clear how the veins have become the loci for kamenitza development; they may have provided mechanical weaknesses scoured into hollows by overriding ice, or their mineralogical contrast may have become the focus of solution and cavity inception. Ultimately further solution on the veins beneath the pools creates fissures which drain the ponds and terminate the kamenitza enlargement. The pavements are also penetrated by small, deep potholes and elongate fissures, again on the mineral veins. Their shapes contrast those of the circular kamenitzas, but they also collect pool water and plant material which enhances their deepening; they ultimately coalesce into kluftkarren.

On the massive central pavements, islands of shrub and tree vegetation are rooted in organic soils; beneath and around these the limestone is scored by the rounded runnels of rundkarren which are typical of subsoil solution. Elsewhere on the site, less permeable, inorganic soils lie on uncorroded limestone which they have protected from solution. The influence of plants on limestone solution is also shown by the spring waters on the site. The solute loads of these vary directly with the proportion of soil and vegetation cover within their catchments (Rose and Vincent, 1986a); the lowest solute load is in the spring issuing from the downdip end of the main open, bare pavements (Figure 3.5). The springs do not discharge clastic sediments and no large conduits are known under the site.

Around the main intact pavements, large areas of broken rock outcrop are the result of removal of the top bed of limestone clints for the garden rockery trade (Ward and Evans, 1976; Goldie, 1986). The freshly exposed bedding planes are developing new solution features, where they are not being covered over by evolving vegetation and soil. Shallow depressions, some scalloping and sharp rillenkarren are forming on some of the stripped surfaces which have remained bare.

Conclusions

Gait Barrows has limestone pavements of exceptional quality, lying at low altitude and partly covered by vegetation; the large expanses of bare clints are of national and international repute. The coastal lowland environment is in contrast to that of the many pavements at high altitude in the Yorkshire Dales karst, but the morphological contrasts are slight. Within the site, the small-scale karst landforms show considerable variation, which is influenced by lithology, aspect and post-glacial evolution. Notable are the many kamenitzas at various stages of development, which are all located on mineral veins in the limestone.

HALE MOSS CAVES

Highlights

The caves of Hale Moss are the best examples in Britain of network caves which may have formed in narrow zones marginal to former lakes and within the range of their water table fluctuations.

Introduction

Network caves are a feature of the low limestone scars adjacent to the peat mosses in the lowland karst east of Morecambe Bay (Figure 3.1). The mosses occupy broad depressions in the limestone which may have originated as poljes enlarged by base level solution. They were modified by Pleistocene ice transgressions, and now have outwash fills (Oldfield, 1960) and sub-aerial drainage outlets across the limestone. Along the western margin of Hale Moss, bluffs of Dinantian limestone form the high ground adjacent to the peat bog; this is massively bedded but well jointed, and dips at up to 6°. There are ten short cave systems in the limestone; all are almost horizontal and lie within a narrow altitude range of 23–27 m.

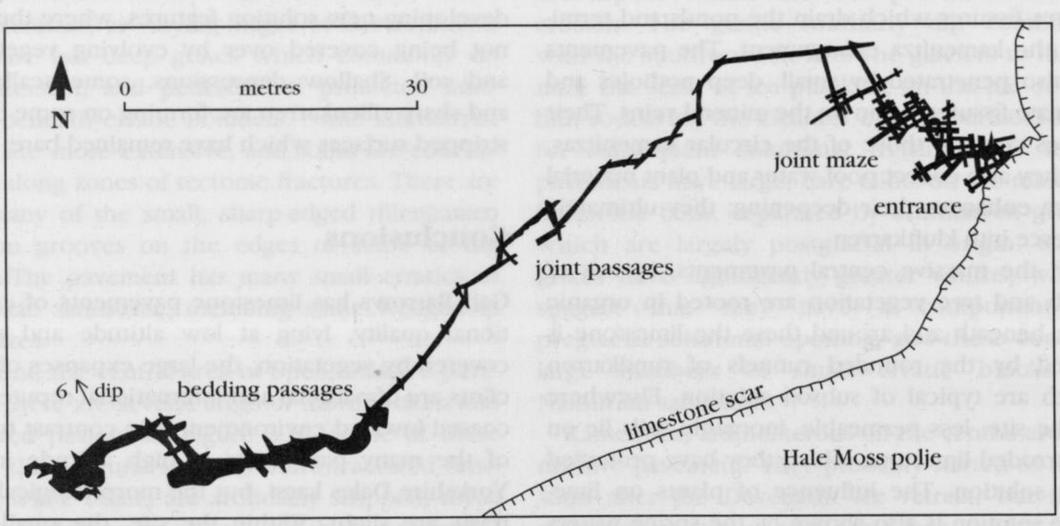


Figure 3.7 Outline map of Hale Moss Cave (from survey by Red Rose Cave and Pothole Club).

The caves and karst of the area have been discussed by Ashmead (1969, 1974a) and Gale (1981a, b), and the caves are described by Brook *et al.* (1994).

Description

The main passage style in the known caves at Hale Moss is a joint controlled maze in the limestone adjacent to the margin of the peat moss (Figure 3.7). A few larger trunk passages extend further into the limestone bluffs, and some sections have developed as low, wide bedding plane passages. Most of the cave passages are less than 1 m high, and those formed on the joints are generally less than 1 m wide. Because of their small size and consequent inaccessibility, many of the joint networks have not been entered, and the trunk passages occupy an unduly large proportion of the mapped caves.

The ten known caves at Hale Moss have a total of over 1 km of passages, but this can represent only a fraction of the inaccessible, choked, unknown or undersized fissure networks in this zone of the karst. Hale Moss Cave is typical, with over 200 m of joint maze, joint guided trunk route and bedding passages, all on the same level in the dipping limestone (Figure 3.7). Hazel Grove Cave is a longer system of passages of similar style, and is formed on two levels, 2 m apart (Ashmead, 1969). All the other caves are shorter, and many are just fragments exposed by degradation of higher benches in the limestone.

Interpretation

The caves of Hale Moss include excellent phreatic maze caves of the type normally developed by slowly moving water (Palmer, 1975). They are true three-dimensional mazes in that their rift openings have developed by solution of multiple intersecting joint systems and also of the bedding planes. Their macro-appearance as two dimensional mazes is only due to the solution being confined to narrow zones of altitude by external hydrological factors. Most of the cave passages lie at an altitude of 25–27 m, just below a poorly defined limestone bench; some passages in Hazel Grove Cave lie at a separate level about 2 m lower, which is very close to the top surface of the sediment fill within the Moss (Ashmead, 1974a).

There is debate over the environment of development of these cave systems. Ashmead (1969, 1974a) interpreted the Hale Moss caves as having developed close to the top of the phreatic zone by very slowly circulating water around the margins of the lake which formerly occupied Hale Moss. This accounts for the horizontal development of each cave, where preferential flow within the shallow phreatic network led to the development of the more linear trunk passages. Gale (1981a) considered the phreatic network caves to represent mere fragments of typical karst drainage systems formed by water flowing under hydrostatic pressure. Wall scallops are evidence of flowing water, small phreatic avens indicate higher contemporary water tables, and the horizontal development of the caves is related to flow along the strike.

The two hypotheses only differ in emphasis. The maze caves may be the only true examples in Britain of cave development at the water table adjacent to a lake margin, with their altitudes correlating with former lake levels. The linear caves associated with them indicate higher flow regimes away from the lake margins, in a more normal environment of efficient karst drainage. Hale Moss Cave has both types of passage (Figure 3.7). The morphology of these caves stands comparison with other sites. Maze caves, foot caves and trunk routes are all developed at water table levels in most areas of tropical limestone, perhaps typified by the Mulu karst in Borneo (Waltham and Brook, 1980a, b), but this has no implications of a tropical palaeokarst at Hale Moss. Horizontal networks of blind passages, without associated trunk caves, are developed in steeply dipping Carboniferous limestone around the margins of the Killarney lakes in Ireland (Priesnitz, 1985).

The ages of the inland terraces and perched lake levels east of Morecambe Bay are not yet known, but the presence of glaciofluvial fills indicates the pre-Devensian origins of the rock basins. The caves must have a similar age, and the multiple levels at Hazel Grove suggest a sequence of stages in their development. Glacial modification of the surface topography may have been slight in this lowland karst (Gale, 1984), but it has created access to the caves, while rejuvenation has led to their abandonment and fossilization.

Conclusion

The caves of Hale Moss contain mazes of phreatic passages which appear to be the result of solution by groundwater in the limestone margins of subaerial lakes, now filled with sediment and peat. They also have linear conduits which developed by faster karstic drainage away from the lakes. They are the finest of the many small caves in the Morecambe Bay karst, which are the only ones in Britain whose origins are directly related to past water levels in adjacent lakes.

SHORT GILL CAVERN

Highlights

The caves in Short Gill are the finest and most easily accessible of those formed in the nearly vertical limestone adjacent to the Dent Fault. Their tall rift passages along bedding planes are an unusual expression of stratigraphic controls on cave development.

Introduction

Short Gill Cavern lies under the eastern slopes of Barbondale, south-west of Dent (Figure 3.1). Short Gill is a tributary stream to Barkin Beck, which drains the glaciated trough of Barbondale along the line of the Dent Fault. Silurian mudstones and slates form the hills west of the fault. Carboniferous limestone crops out on the east side, and the upper slopes of Barbon High Fell consist of almost horizontal Yoredale limestones and shales. Drainage from these slopes feeds the streams, including Short Gill, which drain onto the narrow outcrop of Great Scar Limestone adjacent to the fault; nearly all of them have short associated cave systems. The Great Scar Limestone is steeply inclined against the fault, and the steepest dips of 75–90° are exposed in the narrow gorge of Short Gill. The Barbondale caves have been described by Sutcliffe (1974) and very briefly by Brook *et al.* (1994).

Description

The entrance to Short Gill Cave is through a narrow fissure in the floor of the gill, which is active only in times of flood. The entrance fissure drops into an abandoned phreatic tube, which is choked beneath the gill, but continues north only partially blocked by sediment banks, deep gour pools and a fine stalagmite false floor. It joins the main stream passage, carrying water from sinks at Short Gill Pot and south of the gill. This continues as a high narrow rift along the strike of the nearly vertical bedding. A high-level passage in the roof is choked with speleothems, and the stream enters a vadose canyon which zigzags to cut across the bedding. This descends to a sump where the flooded passage must head south, cutting further across the bedding and passing beneath the lower course of Short Gill to reach the resurgence in the floor of Barbondale.

The other significant cave in this site is Short Gill Pot, a short distance to the east, a 34 m deep rift developed along a washed-out vertical shale bed. Over most of its length it is 1–2 m wide, with some wider sections due to solutional enlargement. Water sinking here must subsequently utilize joints to cross through the bedding, to emerge at the upstream sump in Short Gill Cave.

Interpretation

These caves have developed in a structural setting, unusual in Britain, where water has drained down the vertical bedding to enter rift conduits along the strike. Drainage has then escaped via joint fissures cutting across the strike, to reach a resurgence in the valley floor which is also aligned on the strike. Shale beds lie on the main bedding planes utilized by the cave, and their mechanical removal has contributed to passage enlargement. Short Gill Pot is a nearly vertical rift 34 m deep in the bed of Short Gill, and is formed in a washed out shale bed with only limited solutional excavation of the limestone walls.

The relict phreatic tube in the entrance series of Short Gill Cave lies 20 m above the level of the Barbondale floor. Its alternating clastic and calcite sediment sequence, though undated, suggests that its history extends back into the Pleistocene, predating valley floor excavation to the present depth. Alternatively, it could have developed within a phreas perched behind the vertical limestone beds which clearly have lower transmissivity across their bedding than along the strike.

Conclusion

The caves and potholes of Short Gill are the finest of a small group in Barbondale, which are the only caves in Britain developed in nearly vertical limestone. Their morphology of vertical rifts along bedding planes and shale beds is therefore distinctive, and the shafts and strike conduits, both developed on the bedding, are an unusual expression of stratigraphic control over cave development.

UPPER DENTDALE CAVES

Highlights

The caves of Upper Dentdale constitute an excellent example of a karstic drainage system which has been developed and partly intersected beneath a limestone valley floor. The passages show strong geological controls in their structure, including cavern modification by collapse.

Introduction

The glaciated trough of Dentdale is cut just deep enough to expose the Great Scar Limestone in a stretch of its floor east of the village of Dent (Figure 3.1). The River Dee traverses the limestone outcrop in a shallow rocky gorge which is dry in normal weather for 1500 m, when all the flow is underground. Sinks and open cave entrances swallow the water into a major sub-valley conduit, where the main flow is joined by tributary streams sinking along the southern side of the dale (Figure 3.8). As the main caves, below river level, are frequently flooded, many passages and entrances are choked by debris, and only a fraction of them have yet been entered. The limestone outcrop lies across a very gentle anticline,

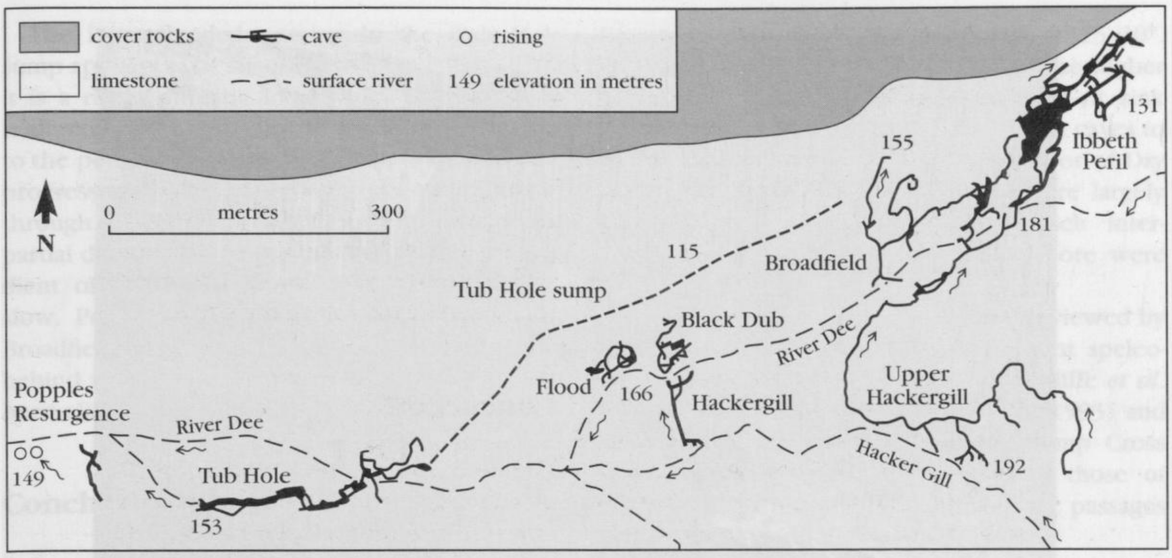


Figure 3.8 Outline map of the caves of Upper Dentdale. The line of the flooded section in the upstream sump of Tub Hole is only approximate (from surveys by Kendal Caving Club, British Speleological Association, Cave Diving Group and others).

plunging with the regional dip to the north, and is locally disrupted by steep dips in shatter zones; the carbonate succession is broken by shale beds up to 2 m thick, and includes the Gayle and Hawes Limestones which are contiguous with the Great Scar.

The geomorphology of the main caves in Dentdale was first described by Long (1971) and Lyon (1974) before further significant discoveries were made (Monico, 1992, 1995; Allwright *et al.*, 1993; Brook *et al.*, 1994; Holmes, 1994) and a number of speleothem dates were obtained from the site (Gascoyne *et al.*, 1983a, b; Gascoyne and Ford 1984).

Description

There are numerous sinks into rifts and bedding planes along the course of the River Dee. The furthest upstream are 1 km after it crosses onto the limestone outcrop, and they are spread over the next 2 km of riverbed as far as the Ibbeth Peril plunge pool, below a small waterfall which is normally dry. Water from all these sinks enters a conduit which is only partially explored and appears to be largely flooded; the sinks are at altitudes of 220 down to 185 m, the caves at Ibbeth Peril reach water levels at 155 m, and the Popples resurgence is at 148 m.

Most of the known caves in Dentdale are tributaries or flood distributaries of this main conduit, which has only been reached in the flooded section of Tub Hole (Figure 3.8). The Ibbeth Peril Caves have a main entrance beside the waterfall and plunge pool, from where a downstream passage heads north-east into the Main Chamber. This is one of the largest cave chambers in the Pennines, covering 30 m by 60 m with a height of up to 14 m; its floor is a chaos of massive limestone blocks which have fallen away from the roof. Several stream passages converge on the chamber, and the combined outlet drains north-east to a sump and a complex flooded zone. Flowstone overlying fluvial or fluvio-glacial sediments in an almost choked side passage is postglacial, giving dates of 6–29 ka (Gascoyne and Ford, 1984).

The pattern of cave streams draining downdip to the north-east, almost directly opposite to the surface valley flow, is repeated in the other active inlets. The aptly named Upstream Downstream Passage lies directly beneath the surface stream, yet the vadose cave stream flows in the opposite direction. A very old phreatic bedding passage, under the north side of the riverbed connects the inlets in the Ibbeth Peril and Broadfield Caves. Drainage from the upper sinks in Hacker Gill flows north through the Upper Hackergill Caves, which continue downstream as the Upstream Downstream Passage in Ibbeth Peril (Figure 3.8); a distributary takes some of the water under the river, into the small streamways in Broadfield Caves (Figure 3.9). Water from the lower sinks in

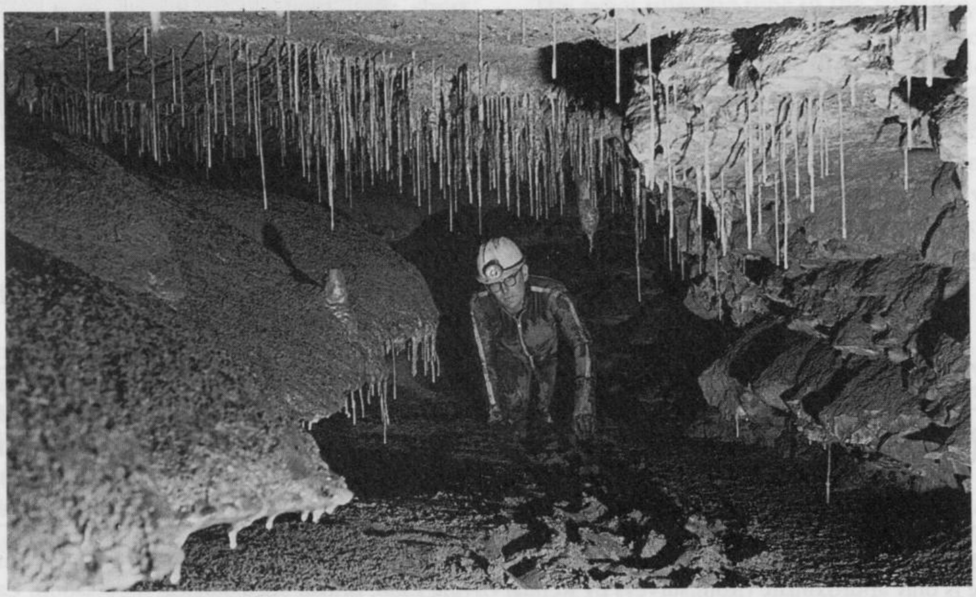


Figure 3.9 Tributary passage in Broadfield Cave with calcite deposits in a shallow vadose canyon cut beneath a bedding plane. (Photo: M.H. Long.)

Hacker Gill drains to risings in the south bank of the Dee riverbed and then sinks again into short caves on the north side, which are assumed to drain into the main conduit.

Just upstream of the impenetrable bedding planes of the Popples resurgence, a flood channel joins the River Dee from the Tub Hole rising. Feeding this flood resurgence, a wide cave passage has a flat roof left by extensive collapse of bedding slabs. Where the dry cave passes under the surface riverbed, holes lead down into a complex zone of flooded passages. The main phreatic tunnel extends downdip to reach depths of 34 m at the exploration limit almost beneath Broadfield Caves (Figure 3.8). In low flow conditions the water in this passage drains to the west, but in normal conditions the flow is to the east (Monico, 1992); and in flood conditions a massive flow pours from Tub Hole. The explored cave all appears to be part of a series of loops which form only part of the main conduit system; the complex flow patterns suggest that there are more, parallel conduits further downdip to the north.

Interpretation

The modern drainage of the floor of Dentdale feeds sinking streams which drain downdip through vadose caves, until they meet flooded conduits which carry the flow along the strike to a single resurgence. In this respect, the valley provides a perfect example of karstic drainage influenced by geological structure. Bedding planes, mostly marked by thin shale beds, have provided the main horizons of cave inception. Most of the tributary stream caves follow the limestone dip to the north-east, whereas the surface drainage is to the west. The main sub-valley conduit is unexplored, but it probably takes the line of a series of shallow phreatic loops following bedding planes under the northern, downdip side of the valley. Thick shale beds, and local zones of contorted and fractured limestone, in the Ibbeth Peril Caves created areas of weakness which were exploited by solutional undermining and collapse to create the large chambers.

In detail, the situation is more complex as many of the drained, vadose passages have features of phreatic morphology, suggesting that they developed before the riverbed cut down to its present level. Speleothem dates of up to 29 ka (Gascoyne and Ford, 1984) indicate that the shallower parts of the system had largely attained their present size, and had been drained, before the Devensian glaciation. The wide phreatic bedding passage connecting the two main inlets of the Broadfield Caves probably represents an earlier sub-valley drainage route towards the resurgence.

The large flooded passage in the Tub Hole sump appears to be the present main conduit, but it is a rising phreatic loop which is now being undercut by development of a lower route direct to the permanent resurgence. Base-level lowering progresses up the valley by successive erosion through the rising phreatic loops and complete or partial draining of the downloops. The gentle gradient of Dentdale ensures that this process is slow. Perched sump levels in and upstream of Broadfield Caves may correspond to ponding behind rising phreatic loops which have not yet been eliminated by vadose entrenchment.

Conclusion

The caves of Upper Dentdale provide clear examples of all stages of development of karstic drainage beneath a major valley floor. Both vadose and phreatic parts of the cave system show clearly the influence of geological controls on drainage routes, and earlier phases of phreatic cave have been drained, incised and partially filled by calcite, clastic sediment and collapse in the vadose environment.

STUMP CROSS CAVES

Highlights

The Stump Cross and Mongo Gill Caves contain a complex of active and abandoned passages closely related to geological structure within a plunging anticline crossed by faults and mineral veins. Calcite flowstones and fossiliferous clastic sediments record climate fluctuations during the late Pleistocene.

Introduction

The two cave systems of Stump Cross Caverns and Mongo Gill Hole are connected into a network with 5800 m of mapped passage. These all lie beneath the western end of Greenhow Hill, between Wharfedale and Nidderdale (Figure 3.1). The Dinantian limestone is heavily faulted and mineralized in a small inlier on the crest of an anticline, which is orientated almost east–west, immediately north of the North Craven Fault (Dunham and Stubblefield, 1945). The caves lie under the northern limb of the fold, where the limestone dips north and north-east at 15–30°. From the north and east, streams off the higher outcrop of the Namurian Grassington Grit sink into the limestone, and drain through the caves to the Timpony Joint resurgence in the floor of Dry Gill west of Stump Cross. The caves are largely accessible through mined shafts which intersected them when veins rich in lead ore were worked early in the last century.

The cave geomorphology is briefly reviewed by O'Connor *et al.* (1974), and subsequent speleothem dates have been obtained by Sutcliffe *et al.* (1985), Atkinson *et al.* (1986), Baker (1993) and Baker *et al.* (1996). The caves of Stump Cross were described by Cook (1950) and those of Mongo Gill by Judson (1964), and all the passages are documented in Brook *et al.* (1988).

Description

The combined cave system of Stump Cross Caverns and Mongo Gill Hole has a complex of passages (Figure 3.10) which roughly fall into three major levels of development, all within an altitude range of 370–317 m. Part of the upper level is operated as a show cave at the Stump Cross end of the system.

The upper, show cave, level has short sections of large phreatic tube containing extensive sediment deposits and a fine array of speleothems. Most of these fragments of old passage end in major collapses, some of which contain debris run in from the surface. Reindeer Cavern and the Wolverine Cave are named after the many bones of *Rangifer tarandus* and *Gulo gulo*, respectively, found in the sediments washed into them from surface fissures now impenetrably choked. Calcite stalagmites and flowstones from this upper level range in age up to 170 000 years (Sutcliffe *et al.* 1985; Atkinson *et al.* 1986; Baker *et al.* 1995c). Keep Chamber is an isolated fragment of this same passage level, well decorated with calcite and now only reached through a mined shaft. An upstream continuation of the abandoned level heads east through the Heaven passage, through some major chokes containing slumped clay, and into larger passages, with another mined entrance through Shockle Shaft. The upper level continues through Mongo Gill Hole, which has some of the largest tunnels and old phreatic chambers in the system. These are locally modified by roof collapse, and contain extensive clastic sediment fills; they also have

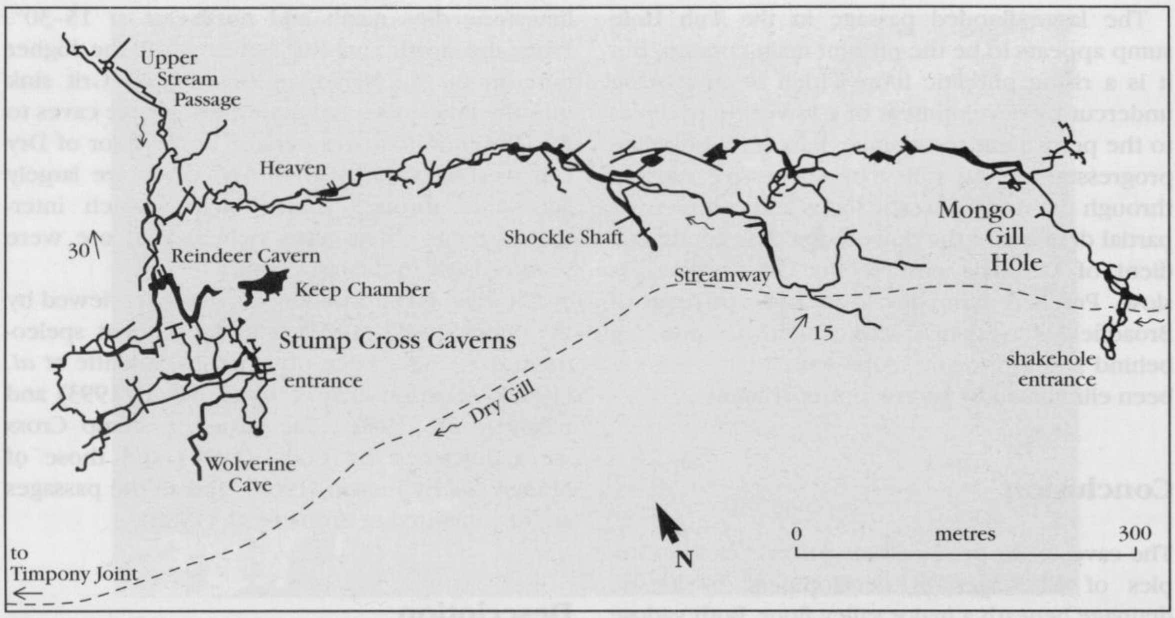


Figure 3.10 Outline map of the cave passages in Stump Cross Caverns and Mongo Gill Hole (from survey by Craven Pothole Club).

very beautiful calcite deposits, which were more abundant before the caves were invaded by the lead miners. The eastern end of Mongo Gill Hole swings round with the strike, to pass beneath Dry Gill to the only natural entrance in a doline shakehole.

The middle level of the cave system is a much more extensive, abandoned phreatic network of rifts, developed along joints and mineral veins, with sections of phreatic tube on some beddings. Most of these passages are at least half filled with fluvioglacial sediments, which are locally covered and interlayered with stalagmite.

The lower level of Stump Cross Caverns consists of constricted streamway canyons interrupted by short flooded sections. It drains from the Upper Stream Passage, south beneath the western end of the high level networks, and is fed by impenetrable sinks along the northern edge of the limestone outcrop. Water sinking in the upper reaches of Dry Gill drains through a low level streamway in Mongo Gill Hole (Figure 3.10); this also has alternating vadose and phreatic sections, but is now only active in flood conditions since the lead miners drove adits to lower the water table. The downstream end of the active system, behind the rising of Timpony Joint, remains permanently flooded.

Interpretation

The Stump Cross caves closely reflect the geological structure. The main abandoned trunk passages carried drainage to the west by following the strike of the bedding in a sweep around the anticline, which plunges east; this pattern is still recognizable in the remnants of choked and truncated passages shown on the cave survey (Figure 3.10). The main original cave drainage was through Mongo Gill Hole, but the old inlets and the earliest resurgence passages at high level were removed by glaciation (Judson, 1964). The modern drainage route through the lower levels of Mongo Gill has sections of vadose streamway between shallow phreatic loops aligned on joints and bedding planes.

Most of the phreatic passages follow the bedding but are aligned on the closely spaced fractures, and the mineral veins, within the limestone. The middle level of Stump Cross Caverns was formed partly by drainage from sinks in the north, which was ponded as it flowed against the dip to reach the main conduits and the outlets in Dry Gill. The main network of joint rifts was formed by this slow moving water, and rejuvenated sections are being entrenched by the modern streams between downloops which are

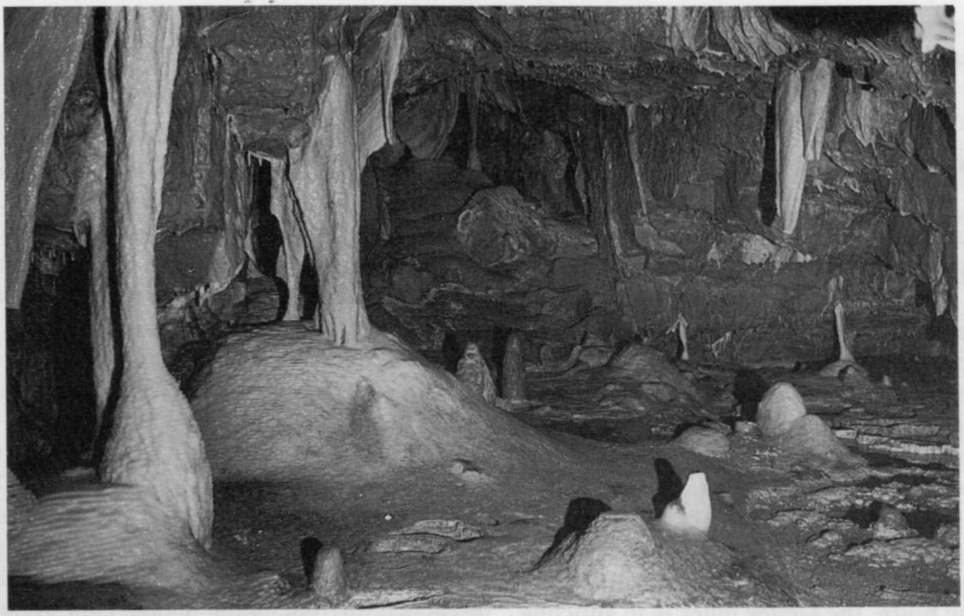


Figure 3.11 Thick flowstone deposits in a suite dated to 83 000 ka in the Wolverine Cave in Stump Cross Caverns. (Photo: A.C. Waltham.)

still flooded. At the resurgence, the flow is up the dip from a phreatic loop.

The sequence of passage levels and their subsequent modification indicate a long history of cave development, dated by speleothems from the early Devensian, and with older phreatic phases which must date back at least as far as the Hoxnian. Further dating of the older flowstones and their intercalated fluvioglacial sediments should be most significant at this site where the caves lie under the interfluve between two of the glaciated dales – Wharfedale and Nidderdale.

The speleothem dates already obtained imply that the expansion of the Devensian ice sheet into the area did not occur until after 26 000 years ago, which is contemporary with the ice advance over the Assynt karst. Stalagmite growth through the last 170 000 years, in the Wolverine Cave of Stump Cross, occurred only during interstadial phases, and ceased during full glacials and also during the interglacials (Figure 3.11). These interruptions are attributed to permafrost expansion during the glacial stages, and to flooding of the system during the warm stages; the latter are unusual, as most other sites have calcite deposition correlating with times of maximum solar insolation (Baker *et al.*, 1996).

Conclusion

The caves of Stump Cross and Mongo Gill are part of a complex, largely phreatic system, developed in folded Great Scar Limestone with close control by the geological structure. Some passages were drained only recently by mining activities. Others are much older and rejuvenated, and have considerable geomorphic significance for their interfluve location. Dated flowstones in Stump Cross Caverns record an unusual history of intermittent growth during the late Pleistocene, interrupted by both freezing and flooding.

NIDDERDALE CAVES

Highlights

The limestone inliers of the upper part of Nidderdale provide windows into a major cave system largely developed beneath the sandstone which forms the outcrop along the valley floor. The positions of shallow phreatic loops in the flooded zone of Goyden Pot are constrained within thin beds of limestone which cross a number of faults. Tributary caves exhibit further geological controls, and include some associated with the subaerial limestone gorge at How Stean.

Introduction

An important group of caves lies in the upper valley of Nidderdale, and its tributaries, upstream of Lofthouse (Figure 3.1). The easterly dip off the Pennine anticline carries the Great Scar Limestone well below the floor of Nidderdale, although it lies at the same altitude as Wharfedale, which is cut 150 m deep into the Great Scar. Nidderdale is cut largely into the Namurian Grassington Grit, which locally oversteps and cuts out much of the Brigantian succession of Yoredale beds. The valley floor reaches through the Grit to expose Yoredale limestone in a sequence of three inliers (Figure 3.11). In the north, the Limley inlier is an anticline confined within a triangular fault block. Lesser faults cross the valley downstream and a southerly upthrow on the Dry Wath fault returns the limestone to outcrop in the Thrope inlier, until it again dips very gently to the south beneath the Grit. The Lofthouse inlier is the largest of the three, has a gentle dip to the east, and is faulted along its southern margin. The limestone in Nidderdale forms a unit 40 m thick; most of this is the Middle Limestone, which is locally contiguous with the overlying Five Yard and Three Yard Limestones (Wilson, 1983).

Allogenic water from the Grassington Grit catchment to the north and west flows along the River Nidd until it sinks into the fractured limestone of the Limley inlier. Mild flood flows reach on the surface to the sink into Goyden Pot, but the river bed downstream is normally dry as far as the resurgence inflows in the Lofthouse inlier. From Manchester Hole to Nidd Heads the underground drainage route is within the limestone, which is about 40 m thick. The caves of How Stean Beck and Blayshaw Gill lie in the same limestone in the Lofthouse inlier.

The geology and geomorphology of the Nidderdale caves have been described by T.D. Ford (1964b) and Davies (1974a), and passage development in New Goyden Pot was further discussed by Davies (1974b). Descriptions of the cave passages are given by Yates (1934), Brindle (1956) and Brook *et al.* (1988), and of the flooded caves between Goyden and Nidd Heads in Monico (1995).

Description

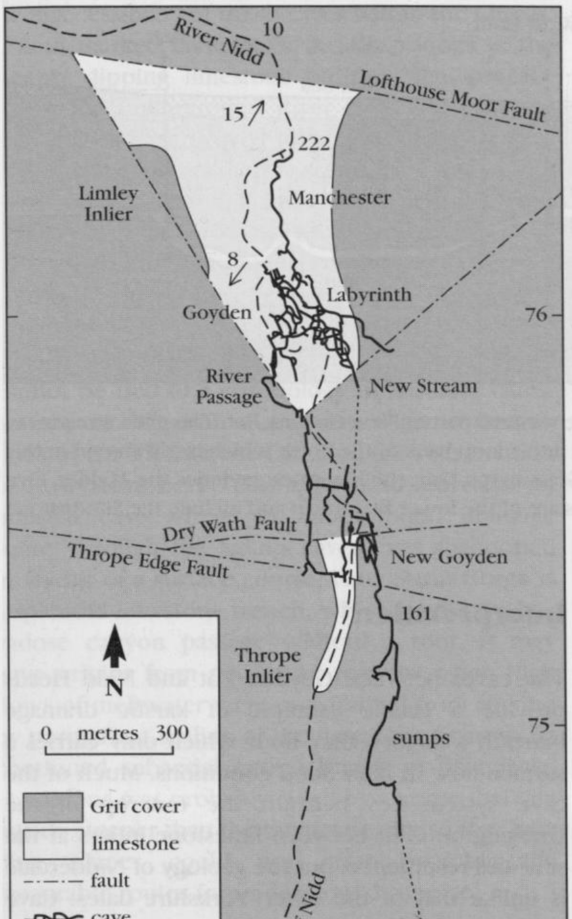
The caves of the River Nidd

Goyden Pot is the main cave on the River Nidd and has flooded connections to Manchester Hole and New Goyden Pot, creating a single system downstream from the sink (Figure 3.12). This has a mapped length of more than 6.3 km, descending 61 m, and another 1.2 km of flooded passage has been explored upstream from the Nidd Heads resurgence.

Under normal flow conditions the River Nidd sinks in fissures in the Middle Limestone on the northern side of the Limley anticline to enter the main river passage of Manchester Hole. This is a single large canyon, up to 12 m high and 6 m wide, extending south for 500 m to a sump. Over the crest of the Limley anticline, the cave river has breached the base of the Middle Limestone exposing the underlying shale and the Simonstone Limestone in the canyon walls. The main chamber of the cave is heavily modified by massive block collapse.

The downstream sump is a short phreatic loop which ends at multiple outlets into the open cave passages of Goyden Pot, which are joined by a large flood route from the gaping entrance in the surface river channel. Following the western edge of the Goyden Pot network, the River Passage is a splendid, wide canyon strewn with sandstone boulders. This descends 35 m by following the bedding obliquely down dip; fractures guide it around sweeping loops, with chert nodules projecting from the walls, beneath a sloping bedding roof, and then downdip into a sump. East of the River Passage, the Labyrinth is a sloping network of small phreatic tubes, chambers and tall rifts, lying updip in the same bedding planes (Figure 3.12). This area is now largely inactive, except where an underfit stream flows in the New Stream Passage before entering a flooded phreatic loop through to New Goyden Pot. Many of the Labyrinth passages are choked with clastic sediments, and there are some calcite speleothems which show evidence of erosion and re-solution. Upstream of the sump in the River Passage, high-level rifts provide a dry route into another short section of canyon passage, and then into a series of shallow phreatic loops.

New Goyden Pot contains another section of the underground River Nidd flowing through large passages, which are reached by two shafts drop-



ping down a fault from a small entrance in the surface river bed (Figures 3.12 and 3.13). The river emerges from shallow phreatic loops where the cave passage follows almost horizontal bedding horizons within each fault block (Figure 3.13), and steps in their profile lie where each fault is crossed (Davies, 1974b). The long crest of a loop between the Dry Wath and Thrope Edge Faults has the gently graded stream flowing along the floor of rejuvenated phreatic tunnels which take a large double bend towards the east, collecting the tributary flow from the Goyden Pot New Stream (Figure 3.12).

South of the Thrope Edge Fault the underground River Nidd enters further shallow phreatic loops, separated by very short lengths of vadose cave over some of the loop crests. Banks of gravel and cobbles are common in the downloops, and almost block the flooded passage at the present limit of exploration. It is likely that the continuing passage is mostly underwater, but sections of descending open streamway must occur as the water levels in downstream New Goyden are a few metres above the level in Nidd Heads. Upstream from the resurgence, a complex of passages to the twin risings are distributaries from a trunk conduit, which has been followed for over 700 m without meeting airspace. Most of this flooded cave is nearly level, but in at least two places the flow rises steeply up rifts from depths of more than 30 m.

The caves of How Stean Beck

How Stean Beck is a tributary of the River Nidd, which flows through a spectacular limestone gorge up to 15 m deep, currently operated as a commercial tourist attraction. On the north side of the gorge, a group of caves contains almost 2.5 km of mapped passages, traversed by underfit streams. Eglin's Hole lies upstream of Low Eglin's Hole (only the latter appears on Figure 3.12), to form a single, linear, vadose system draining down the limestone dip, partly guided by chert beds. Both caves have low bedding plane passages, locally up to 15 m wide where loops and inlets coalesce. Some of the

Figure 3.12 Geological map of the caves in the upper part of Nidderdale. Limestone includes the Middle, Five Yard and Three Yard Limestones. Grit cover is the Grassington Grit and some overlying Namurian beds on the higher slopes. Eglin's Cave extends off the map to the west. (Outcrop geology after Wilson, 1983; cave surveys from Yorkshire Underground Research Team, Cave Diving Group and others.)

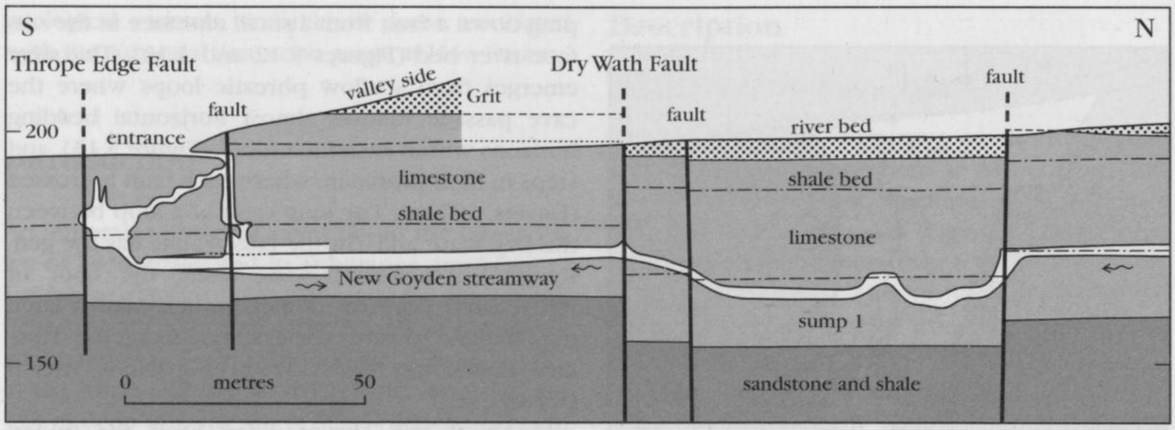


Figure 3.13 Profile of the geology and cave passages in the western part of New Goyden Pot. The main streamway flows south towards the Thrope Edge Fault, and then turns into a loop back to the north which is not shown in this profile downstream of the entrance shaft. The grit is the Grassington Grit; the limestone includes the Middle, Five Yard and Three Yard Limestones; the sandstones and shales are of the lower Brigantian and include the Simonstone Limestone at an unknown depth. (After Davies, 1974b.)

bedding openings have shallow vadose floor trenches, and others are choked with boulders or blocked by roof collapse. The main water enters from choked sinks which are minor leaks from How Stean Beck. The vadose caves descend nearly 50 m to a sump where the bedding plane passage continues below the level of the resurgence, which is a rising through the Nidd alluvium.

The How Stean Gorge is a subaerial canyon which carries a larger stream flow than the parallel caves; its floor lies about 10 m below the caves. A single tributary on its south side flows for 50 m through How Stean Tunnel, and Tom Taylor's Cave is a rift on the north side carrying flood flows from the Eglin's caves (Waltham, 1984; Brook *et al.*, 1988).

The caves of Blayshaw Gill

Adjacent to the mineralized faults on the south side of the Lofthouse inlier, the two potholes in Blayshaw Gill enter fragments of an old phreatic cave intersected by the modern valley (Figure 3.12). Multiple levels add to a total of more than 950 m of mapped passage, much of it now choked with ochreous clay and boulder falls. Blayshaw Beck sinks into the Five Yard Limestone and a well developed cave passage crosses a fault directly into the Middle Limestone, where it continues following bedding planes downdip to the east. The modern stream has cut a vadose canyon in the floor of the older cave, as far as a sump at the level of the alluviated resurgence 30 m below the sinks.

Interpretation

The caves between Goyden Pot and Nidd Heads provide a classic example of karstic drainage beneath a major valley floor which only carries a surface flow in high flood conditions. Much of the cave system lies beneath the outcrop of the Grassington Grit, between limestone inliers at the sink and resurgence, but the geology of Nidderdale is unlike that of the other Yorkshire dales. Cave inception in the buried limestone was probably accelerated by seepage of aggressive water from the surface soils down though the permeable sandstone, as the unconformity at the base of the Grassington Grit has locally cut out the intervening Brigantian shales.

All the caves in the valley show strong control by bedding planes within the limestone unit which is only 40 m thick. The extensive phreatic Labyrinth in Goyden Pot is formed on dipping bedding planes, and the vadose caves beside How Stean Beck drain directly downdip. The major cave passage carrying the River Nidd drains obliquely down the dip in Goyden Pot, and takes a circuitous course through almost horizontal limestone in New Goyden Pot. In both cases, segments of the cave passages are aligned on joints which are enlarged into tall rift fissures and chambers.

The many faults across the line of the underground drainage have been utilized to link sections of nearly horizontal cave conduit formed on just a few inception horizons within the limestone. This has created a stepped profile in the shallow, phreatic loops across downfaulted blocks (Figure

3.13), in a pattern rarely seen because of the intrinsic inaccessibility of these caves within the phreas: it is in marked contrast to the deep loops in the steeply dipping limestone off the Mendip Hills. Along the underground River Nidd some of the fault planes have proved to be sites of cave inception, linking the bedding horizons. In contrast, the caves of Blayshaw Gill cut cleanly across a fault plane, whose only role has been to bring two limestone beds into hydrological continuity.

The history of development of the Nidderdale caves is clearly long, as there are many series of abandoned and rejuvenated phreatic passages, but cannot be tied to a chronology of absolute dates. Surface modification during the climatic fluctuations of the Pleistocene included the rejuvenation of How Stean Beck. This appears to represent an unusual case where an underground drainage route, through the Eglin's caves, was abandoned in favour of a surface course. How Stean Gorge is a splendid limestone trench, which is effectively a vadose canyon passage without a roof. It may have origins from periglacial regimes when high flows of meltwater were constrained from sinking by permafrost sealing of the limestone fissures. Its continued subaerial entrenchment in postglacial conditions was probably aided by a gorge thalweg mostly steeper than the limestone dip, so that bedding planes could not offer hydrologically favourable routes for underground capture.

Conclusion

Nidderdale contains a major cave system carrying the entire valley drainage. Large vadose canyons descend from the main sinks to the head of a long phreatic series, where a staircase of flooded downloops is interrupted by short sections of vadose cave over loop crests dictated by geological structure. The influence of faults on the pattern of conduit development through the karstic aquifer is seen more clearly than anywhere else in Britain. The tributary of How Stean Beck has a series of vadose caves which have lost their drainage to a subaerial gorge, in a reversal of the usual role of underground capture in a youthful karst landscape.

HELL GILL

Highlights

The section of Hell Gill cut into the limestone is one of the finest examples in Britain of a gorge formed entirely by subaerial fluvial action. It admirably demonstrates the role of subaerial erosion in the formation of gorges in karst areas.

Introduction

Hell Gill Beck is the largest of the streams draining off the Namurian shales and sandstone of Mallerstang Common, and is the highest headstream of the River Eden (Figure 3.1). It cuts through the horizontal Main Limestone in a deep and narrow ravine. This is clearly of subaerial origin, and yet lies adjacent to caves formed by parallel streams. Except for its lack of roof, the gorge is very similar in morphology to vadose canyons in cave systems, and clearly shows the similarity between subaerial limestone gorges and underground cave passages. Although very impressive and locally well known (Waltham, 1984), Hell Gill has not been studied and documented in any serious investigation. The adjacent caves are recorded by Brook *et al.* (1994).

Description

The Hell Gill gorge is cut into the Namurian Main Limestone by a stream draining off a hillside of horizontal, interbedded shales, sandstones and thinner limestones within the Carboniferous Alston Group (Figure 3.14). The Main Limestone is the thickest limestone exposed on the fell, but is only 20 m thick. Hell Gill descends between altitudes of 425 and 395 m, following the limestone dip; it is a narrow, twisting, rock gorge 500 m long, mostly less than 5 m wide, and up to 15 m deep. The stream descends steadily through moulins and connecting trenches, and cascades over three small falls into deep, round plunge pools. The sides of the gorge are mainly vertical, smooth and polished, with the stream occupying the entire floor width, locally undercutting the walls in deep swirls. Immature cave development is represented by various short rifts, and some of the flow passes through short parallel loops which are intersected phreatic fissures; a rock bridge stands across the gorge where the stream has enlarged an underground short cut. At the lower end of the gorge, the stream flows onto the underlying sandstone, and then breaks out from the low limestone scar into the valley.

Many of the neighbouring, parallel streams on the fellside sink underground where they reach

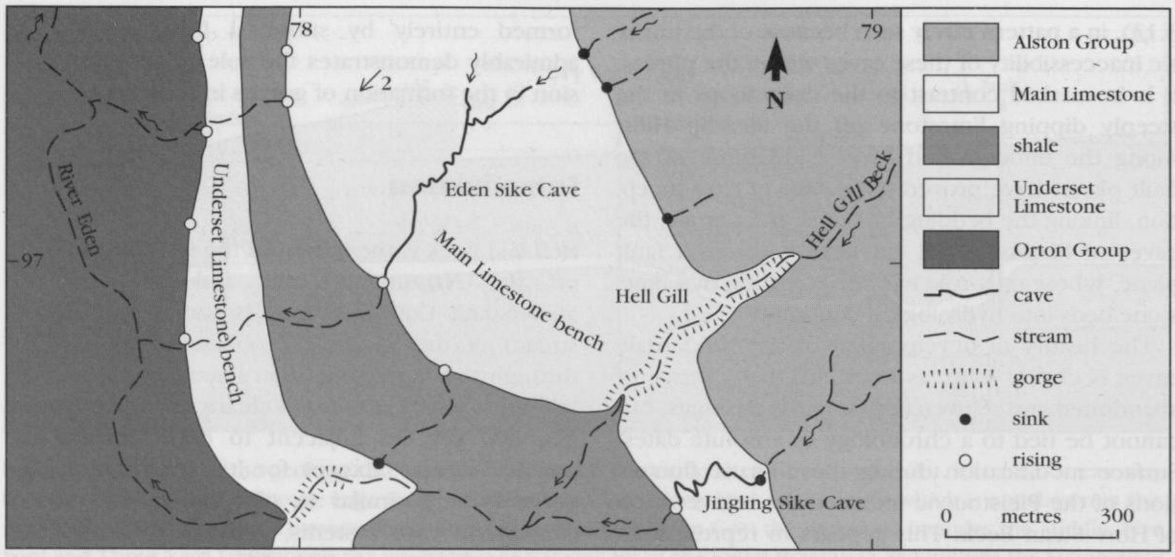


Figure 3.14 Outline map of the limestone bench containing the Hell Gill gorge and various sinkholes, risings and cave on the adjacent streams.

the top of the Main Limestone, and resurge several hundred metres to the south-west at the base of the same limestone outcrop (Figure 3.14). Jingling Sike goes underground through 300 m of cave just to the south, and streams feeding Eden Sike flow through 770 m of cave just to the north, both in the Main Limestone. The streams have cut subaerial ravines through most of the thinner limestone bands on the fell, and Hell Gill Beck flows through a shallow rock canyon cut in the Underset Limestone (Figure 3.14). Percolation water feeds small risings at the base of all the limestones.

Interpretation

There is no evidence in the Hell Gill gorge of any cave roof or wall collapse, currently or in the past. Cave development in the gorge is limited to flow through short fissures in the immediate walls and floor, which is part of the normal mechanism of entrenchment in a limestone river bed. The location, and the dimensions consistent with the modern flow of Hell Gill Beck, suggest that the ravine is entirely a surface feature cut by the stream which it still contains. Its youthfulness, the absence of fill, and the lack of deep weathering in its walls suggest that it was excavated during the Pleistocene, though it may have been initiated by meltwater flow as the Devensian glaciers retreated from the area.

Apart from details of plant colonization and minor weathering on its upper walls, the gorge is very similar to many large vadose canyons in the Pennine cave systems. The ability of Hell Gill Beck to maintain its surface course across the limestone outcrop is the result of its high discharge. This ensures that the floor of the gorge is lowered by solution and mechanical abrasion fast enough to unroof, expose and incorporate fissure openings developed in its floor by slow solution alone. The smaller parallel streams of Eden and Jingling Sikes have not been able to entrench their beds fast enough, and have subsequently been captured by underground drainage forming small cave systems of joint rifts and bedding passages with little or no collapse.

Conclusions

The gorge on Hell Gill Beck provides an excellent example of subaerial fluvial action in a karst terrain. It is especially significant as it can clearly be demonstrated to be of subaerial origin, and yet lies adjacent to caves cut by smaller, parallel streams through the same limestone. It also demonstrates the similarity between surface fluvial gorges and underground vadose canyons, and has important implications for the understanding of process in limestone gorges.

CLIFF FORCE CAVE AND THE BUTTERTUBS

Highlights

Cliff Force Cave is the finest known example of an inter-dales cave, in which geological structure has allowed the underground drainage to cross beneath a major surface watershed. The Buttertubs are a series of spectacular potholes developed by small sinking streams meeting a thin limestone, with open shafts descending directly to the underlying aquiclude.

Introduction

The well known Buttertubs potholes and the entrance to Cliff Force Cave lie within 150 m of each other on opposite sides of the Cliff Beck valley. This is cut into the steep fells of Muker Common, descending from the Buttertubs Pass on the south side of Swaledale (Figure 3.1). Cliff force Cave has a long stream passage with drainage from the Wensleydale slopes passing beneath the topographic divide. The Buttertubs swallow small streams from the valley sides into large entrance shafts which belie the very short distances to their resurgence. Both features are developed where the Namurian Main Limestone is exposed in the valley sides (Figure 3.15); this forms a bed about 25 m thick, with clastic sedimentary rocks both above and below. The sequence dips very gently to the north-west and is broken by mineralized faults orientated north-east.

Cliff Force Cave has been documented briefly by Langthorne (1976), Clough and Clough (1981), Ryder (1981) and Brook *et al.* (1988). The Buttertubs are widely cited as examples of limestone potholes, but further comment on their morphology is only brief (Waltham, 1984).

Description

Cliff Force Cave contains about 2000 m of passages reached through an abandoned exit just above the present resurgence (Figure 3.15). The Entrance Series consists of narrow, joint-guided, phreatic rifts and avens, partly blocked by collapse and fluvioglacial fill; they lie above a short inaccessible section of the stream route. Beyond them the Lower Streamway is a vadose canyon, initially more than 3 m high and wide, developing into a narrow rift with undercuts at stream level, oxbow loops and a few collapse chambers. Above the streamway, the Spar Shop Series is an abandoned gallery largely formed as a sequence of interconnected rifts and now partly filled with clastic sediment. The two levels join in Fault Hall, a chamber 15 m in diameter developed on a mineralized fault. The stream cascades into Fault Hall

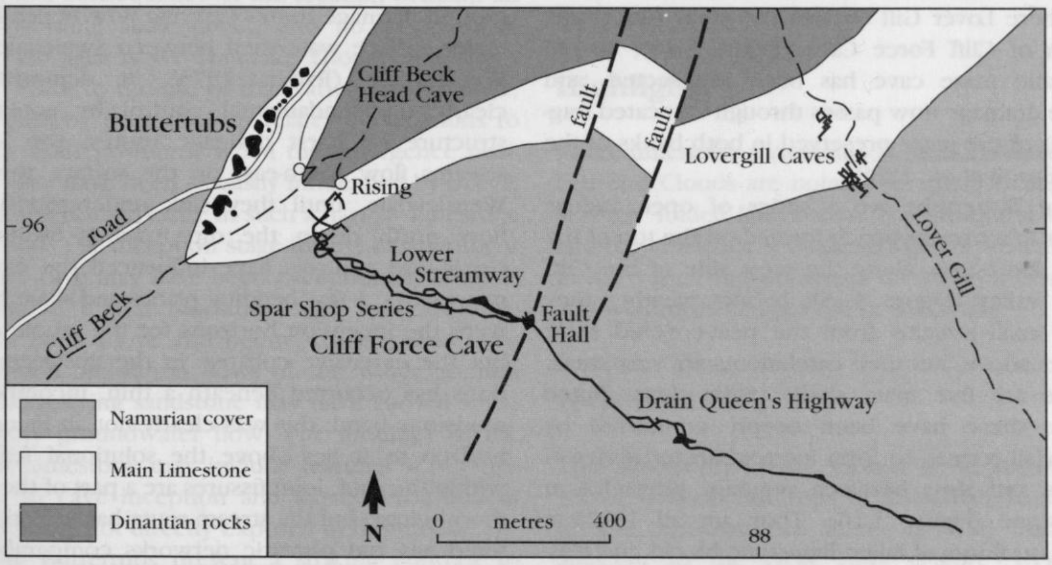


Figure 3.15 Geological map of Cliff Force Cave and the Buttertubs. Both the Namurian cover and the underlying Dinantian rocks include thin limestones not shown and not connected to the Main Limestone (cave survey from Moldywarps Speleological Group).

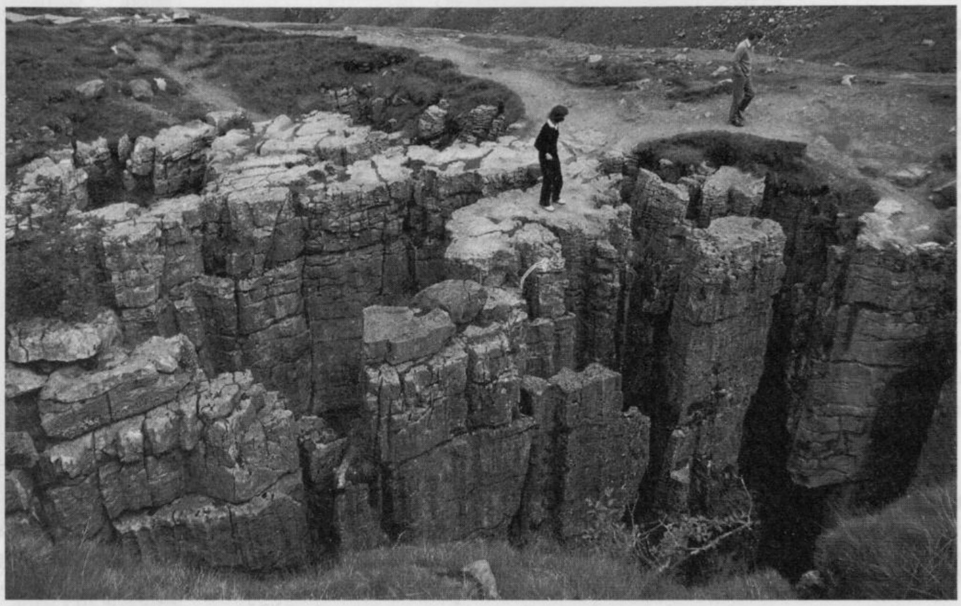


Figure 3.16 The fluted potholes and limestone pinnacles at the Buttertubs. (Photo: A.C. Waltham.)

from the Drain Queen's Highway, a phreatic passage mostly 3 m high and wide with prominent rock flakes projecting from the walls. The Room of Dangling Doom is the start of a long zone of heavily collapsed phreatic passage developed just below a thin mudstone which is exposed in parts of the roof. Further passages are flooded, but the water has been traced from a group of sinks in the Main Limestone at Sargill, nearly 3 km south-east of their resurgence. These lie in valleys whose surface thalwegs descend into Wensleydale.

Where Lover Gill crosses the Main Limestone, north of Cliff Force Cave (Figure 3.15), an old phreatic maze cave has been intersected, and some drainage now passes through truncated fragments of the maze preserved in both banks of the gill (Brook *et al.*, 1988).

The Buttertubs are a series of open vadose shafts in a narrow bench formed on the top of the Main Limestone along the west side of the Cliff Beck valley (Figure 3.15). In wet weather they take small streams from the peat-covered shale slopes above, but their catchments are very small. There are five main shafts, with clean, fluted walls; these have been deeply crenulated by waterfall retreat, to form interconnected series of shafts and slots between remnant pinnacles of limestone (Figure 3.16). They are all 15–20 m deep, to floors of fallen limestone blocks and clastic sediment, and their streams drain either through the floor debris or into impenetrable wall fissures. All this water resurges from Cliff Beck Head Cave, which lies directly down the bank from the Buttertubs (Figure 3.15), about 25 m lower down. This has small converging stream passages formed on joint/bedding intersections close to the base of the Main Limestone, and sandstone is exposed in the beck just below the rising.

Interpretation

Cliff Force Cave is one of a number of underground drainage routes carrying flow beneath the major surface watershed between Swaledale and Wensleydale (Ryder, 1975). It demonstrates clearly the fundamental control by geological structure on karst drainage routes; the Sargill streams flow south-east on the surface towards Wensleydale, until they sink underground and flow north down the dip towards Swaledale. Geological controls have influenced the cave in many ways. A few bedding planes and shale bands were the inception horizons for the whole cave, but the extensive collapse in the upstream sections has occurred beneath a thin, incompetent mudstone band; this was clearly not an inception horizon as it lies above the solutional features within the roof. Joint fissures are a part of the cave morphology, but the stream route has not encountered any old phreatic networks comparable to the maze fragments breached by Lover Gill. Phreatic solution and collapse along the mineralized fault which crosses the drainage line has produced the large Fault Hall; however, the cave has continued to follow the bedding, perhaps because the fault has none of the older phreatic rifts on the scale of those on faults in the karst of north Wales and the Peak District.

Unlike many caves in the thin limestones of the northern Pennines, Cliff Force Cave has evolved through several levels of passage development. Upstream of Fault Hall there is only a single phreatic passage, barely modified since it was partially drained. Downstream of Fault Hall there are three levels, of which only the active streamway is lower than the upstream passage. For much of the cave's history, water in the upstream passage was ponded behind a small phreatic lift on the fault. The highest level is only represented by passages close to the resurgence entrance; these may have been reached by a second phreatic lift, perhaps part of an old vauclusian resurgence system now obscured by glacial debris on the valley side. The second level is represented by the Spar Shop Series feeding to the dry passages and the present entrance; this was also active via the Fault Hall phreatic lift. The active streamway has a third level of initial phreatic development, followed by rejuvenation and vadose entrenchment.

The three cave levels are all primarily phreatic, and appear to reflect successive stages of phreatic flow on lower inception horizons within a maturing aquifer. Only the last stage of vadose incision can be directly related to lowering of the resurgence. A scarcity of calcite speleothems in the cave is a consequence of the location beneath an impermeable shale cover, and no evidence of absolute ages is yet available. Though the stages may relate to the glacial excavation of Swaledale, it would be premature to relate rejuvenations to valley floor positions, when the resurgence position may have been so easily influenced by details of geological structure in such a narrow limestone outcrop. The inception stage for the development of this cave may have been exceptionally long, as it lies in a thin limestone with non-carbonate rocks both above and below; these would have excluded infiltration flows of soil water, though the underlying sandstone may have carried some primary groundwater flow. The lithology of the Main Limestone may include features very pertinent to cave inception and karstic evolution in carbonates not directly exposed to the surface.

The Buttertubs present a striking contrast to Cliff Force Cave. They are classic examples of invasion vadose shafts developed close to a steep valley side, with horizontal cave development only at the base of the limestone where the underlying aquiclude has perched the groundwater flow. Relaxation opening of the limestone fractures, towards the destressed hillside, may have accelerated early development of the shafts, whose position and lack of fill are essentially post-Devensian. The deeply fluted shafts demonstrate the role of small flows of corrosive water rich in carbon dioxide and organic acids from soil and peat. In both these respects, the Buttertubs are not typical of the many Pennine potholes which are at large stream sinks feeding cave drainage routes to distant resurgences. They are, however, spectacular and very accessible karstic shafts.

Conclusion

Cliff Force Cave is the prime example of a cave developed in a thin limestone by drainage passing beneath a major surface watershed. Geological controls, both structural and lithological, have influenced the configuration and morphology of the cave, producing a cave system on multiple phreatic levels, which is unusual in the thinner limestones of the northern Pennines. The Buttertubs are the product of entirely vadose development in the same limestone, with simple vertical shafts descending to the underlying aquiclude and draining rapidly into the adjacent valley.

THE CLOUDS

Highlights

Three limestone pavements at Stennerskeugh and Fell End Clouds are notable for their location on strongly folded limestones. The structural variety and the consequent range of aspects are reflected in the varied morphologies of the well dissected and well runnelled pavement landscape.

Introduction

The pavements of the Clouds lie at altitudes of 350–470 m on outcrops of Dinantian Limestone on the north-western slopes of Wild Boar Fell, adjacent to the Dent Fault (Figure 3.1). The exposed limestones are the top beds of the Asbian Great Scar Limestone and also the Robinson Limestone, which is the lowest in the Brigantian shale and limestone sequence. The folding is all within the narrow belt where the western edge of the Askrigg Block is crumpled against the Lake District block across the Dent Fault (Underhill *et al.*, 1988).

Description

Most of the pavements are on the eastern limb of a minor anticline (Figure 3.17), where the limestones dip into the hill at 10–30°. The Great Scar Limestone has the wider outcrop, and is overlain by a thin shale, followed by the Robinson Limestone. The stratigraphy shows some variation along the strike outcrops, but these two limestones form the main pavements, which ease in gradient over the anticline in the Great Scar Limestone. The folded limestones support pavements on many bedding planes with varying aspects to the Devensian ice which swept over them from the south. The lower slopes are masked in scree, head and peat soils. The slopes above the main pavements are formed in the overlying mixed Brigantian rocks of the Alston Group, with low scars, thin strips of pavement, lines of

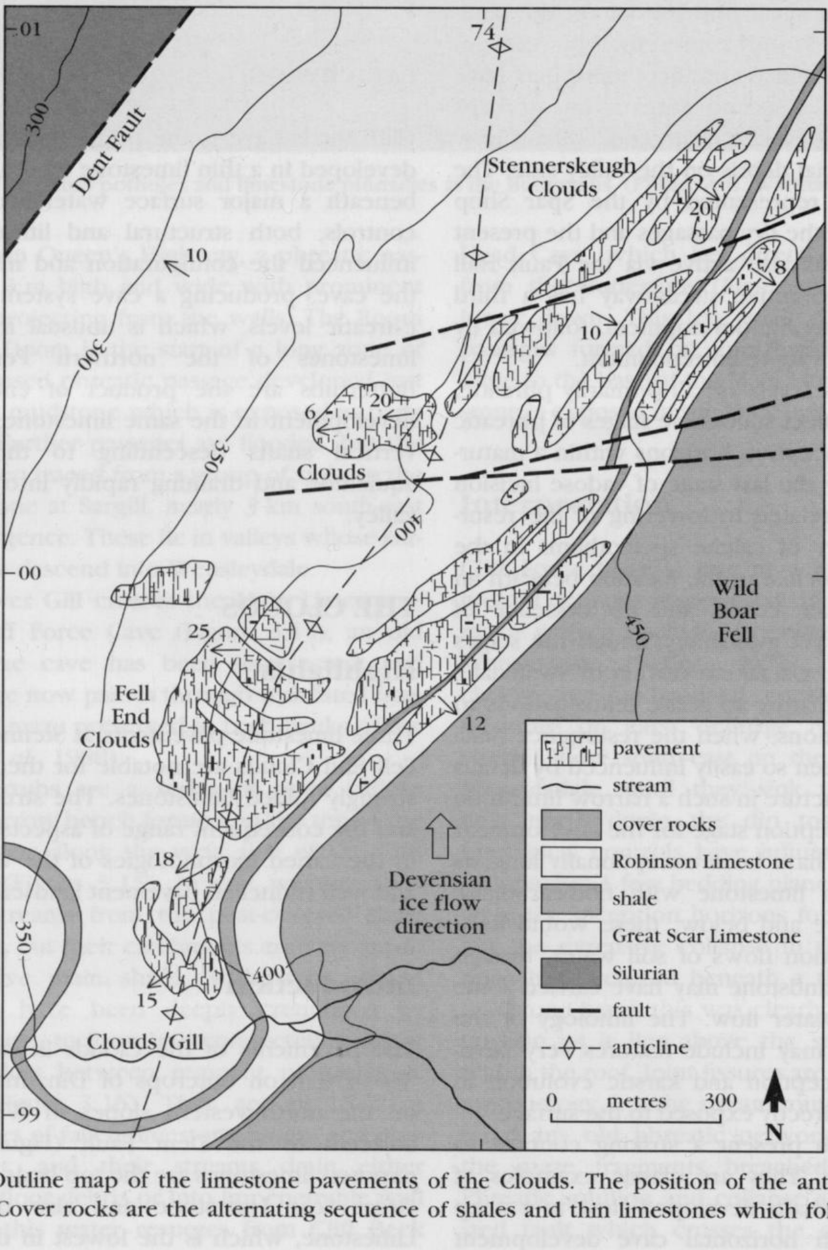


Figure 3.17 Outline map of the limestone pavements of the Clouds. The position of the anticline axis is only approximate. Cover rocks are the alternating sequence of shales and thin limestones which follow in the Alston Group.

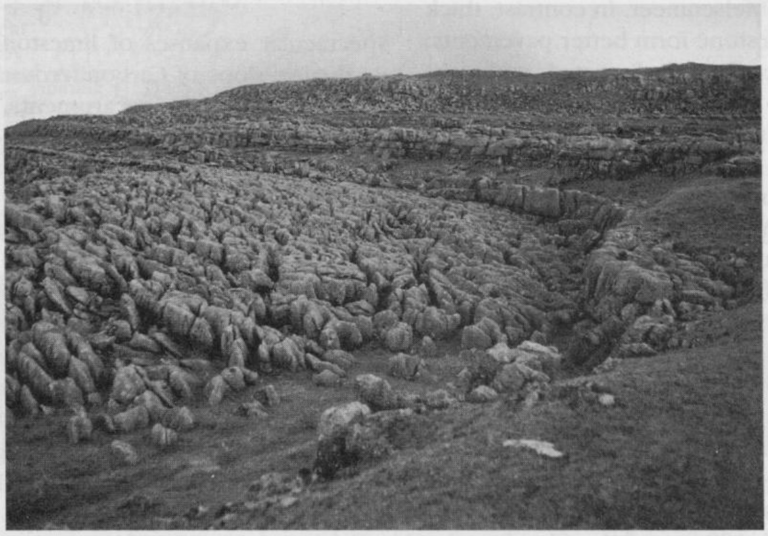


Figure 3.18 Crescentic scars in strong beds of limestone folded over the anticline crest on Fell End Clouds. Pleistocene ice moved from right to left, leaving deeply runnelled pavement in the immediate lee of the scars. (Photo: H.S. Goldie.)

sinkholes and small caves in the thin limestones.

A distinctive form of stepped pavement (*Schichttreppenkarst*) is well developed on Stennerskeugh Clouds where steeply dipping limestones in the higher outcrops form long ridges of narrow pavements sloping to the south-east. Clints are large and diamond shaped at the northern end but decrease in size to knife-edge ridges further south. Deep narrow grikes separate the larger clints, and surface solution features include converging rundkarren systems and kamenitzas which vary in shape from elliptical to round. The small, knife-edge clints are separated by shallow grikes, and have both laminar and honeycomb weathering. A few erratic blocks of sandstone lie wedged in the grikes. Further east on Stennerskeugh Clouds, the stepped pavements dip at angles up to 30°, with considerable local variation across the small-scale folds. Long rectangular clints in the north are replaced southwards by narrower knife-edge clints.

Most of the limestone pavements on the west side of the Clouds are on bedding planes dipping west at up to 30°, with joints aligned diagonally to the slope. The clints are generally less than 1 m long and 0.3 m wide. Higher on the fell, the dips lessen over the anticline and some of the exposed limestone beds are more massive, so forming larger clints.

At Fell End Clouds, the strike and outcrops of the beds swing round the anticline which plunges to the south-west (Figure 3.17). The more massive limestones are higher in altitude and lower in the sequence to the north-east. Some of the more thinly bedded limestones produces a shattered surface of felsenmeer, in place of a pavement. The steeper fold limbs have stepped pavements dipping as much as 30°, with small, knife-edge clints between narrow, shallow, V-shaped grikes containing wedged sandstone erratics. Near the highest part of Fell End Clouds, there are some striking embayments in gently dipping limestone over the crest of the anticline. Small scars, 2–3 m high, mark the inner edges of crescentic arcs of pavement with massive, well runnelled clints (Figure 3.18). The inner zones of these pavements, below the succeeding scar, are scored by large and deep rundkarren; the outer zones, at the top of the scar to the next bed below, are less well runnelled and are merely well fractured. There is no significant cover of drift or vegetation, and the dominant joints are orientated NNE parallel to the Dent Fault.

Interpretation

Pavement morphologies at the Clouds are influenced by both lithology and geological structure. Thinly bedded limestones produce shattered surfaces with thin, easily broken clint tops; debris from these fills the grikes and extends into scree aprons and sheets of felsenmeer. In contrast, thick beds of massive limestone form better pavements; even these are generally well dissected, with relatively small clints, due to the closely spaced tectonic jointing in the disturbance zone adjacent to the Dent Fault. This limits complex runnel development, though many small clints are incised by deep rundkarren of the type inherited from solution beneath a soil and vegetation cover. Low scars, narrow benches, knife-edge clints and areas of stepped pavement are all features dictated by the steep local dips.

An important influence on the morphology of the Clouds pavements was their location close to a Pleistocene ice centre on Wild Boar Fell, immediately to the south-east. The scale of scour from such a nearby and small ice source may not have been great (Mitchell, 1994), and the Clouds pavements may have escaped severe glacial scour. This would explain the presence of the very mature rundkarren in front of the small scars near the top of Fell End Clouds. At this site the pavement edges have not been plucked and scoured to form the smooth scar edges typical of much of the Pennine glaciokarst; instead they have partly bevelled slopes from one bed to the next, with weathered and runnelled limestone preserved on the inclined bedding planes in the protected troughs below the next scar. This karren distribution contrasts with the typical Pennine case where the deeper karren are in the more exposed sites above the scar edges. The Fell End Clouds scars face north, so that the ice advanced down over them, and the well dissected pavements in their lee may retain some elements of early Pleistocene erosion not removed by Devensian ice.

Conclusions

The Clouds contains a fine range of well dissected pavements demonstrating the influences of structure and lithology on the details of karst morphology. The combination of tight folds and closely spaced fractures provides a geological environment for the pavements which is unique within Britain. The site was close to a basal ice shed in the Pleistocene, which resulted in some elements of the landform features surviving from before the Devensian.

GREAT ASBY SCAR

Highlights

Spectacular expanses of limestone pavement lie on the dip slope of Carboniferous limestone forming the Orton–Asby escarpment. The pavements are the most extensive outside the Ingleborough karst, and have a wide variety of well developed pavement morphologies.

Introduction

Asbian limestones from the Lower Carboniferous succession form a long, rounded escarpment north of the Howgill Fells, where they dip off the Lake District dome beneath younger rocks flooring the Vale of Eden (Figure 3.1). The crest of the south-facing escarpment reaches an altitude of only 412 m; the main pavements, separated by grassland grazed by sheep, extend down into farmland to the north. The regional dip of 5–10° north is interrupted by shallow flexures with axes aligned roughly downdip. All the pavements are formed on the massively bedded limestones of the Asbian Great Scar. They are underlain by the mixed sedimentary sequence of the Holkerian Orton Group; limestone beds within the Orton Group are the cause of the numerous shakeholes in the lowland below and south of the Great Scar escarpment, but they form no pavements. Brigantian shales and limestones of the Yoredale facies overlie the Great Scar; the lowest of these limestones is the Robinson, but its karstic expression is minimal.

There has been little research into the geomorphology of the Asby pavements, though they are briefly described by Goldie (1986, 1993) with reference to their damage by exploitation for rockery stone. The best developed and least damaged pavements are now protected within a National Nature reserve, and this also reflects the high botanical value of the pavements (Ward and Evans, 1975, 1976; Ratcliffe, 1977).

Description

Extensive and varied pavements cover much of the dip slope along the escarpment east of Orton. The highest and most spectacular area is known as Great Asby Scar, rising to a summit near Castle Fold (Figure 3.19). The limestone extends east

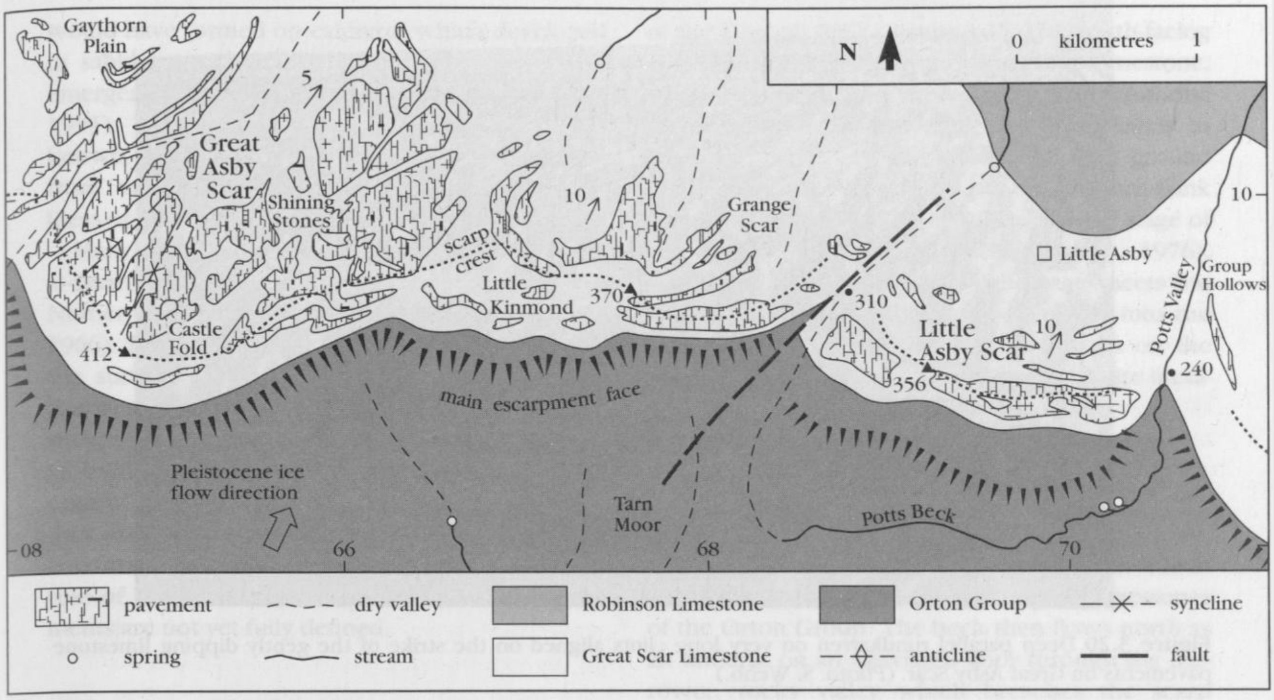


Figure 3.19 Outline map of the karst features on the limestone escarpment between Great Asby Scar and Potts Valley. The Robinson Limestone includes a thin shale separating it from the Great Scar.

through Little Kinmond to poorer pavements on Grange Scar, beyond which a shallow col breaks the escarpment along the line of a fault. East of the fault, the pavements of Little Asby Scar reach to Potts Beck, in a deeper valley through the escarpment. Pavement morphologies vary along the outcrop, and are best reviewed in sequence from west to east.

Gaythorne Plain lies low on the dip slope, with a large outcrop of thinly bedded limestone, of which about 80% of the original surface rock has been removed or disturbed. Clints are small, and runnels are poorly developed; there are scattered sandstone erratics. Just to the south, a higher and stronger bed forms a more massive pavement, with large clints and deep runnels, sloping northwest off a stratimorphic ridge on a gently plunging anticline. Grikes are mostly less than 1 m deep, but some are up to 2 m wide where close, parallel joints originally enclosed a blade of limestone or a calcite vein now totally removed by solution. Some clints within these pavements stand on pedestals about 100 mm high, which they overhang by about 100 mm. There are also areas of cleanly scoured bedding slabs with simple systems of large, sharp-edged rinnenkarren runnels.

Great Asby Scar has the most varied and best preserved pavements of the escarpment, with the greatest variety of solution features on the outcrops near Shining Stones and Castle Fold. Variations in slope, aspect, joint density, lithology and length of exposure to subsoil or subaerial solution are responsible for the enormous range of small karstic landforms. Long clints between joint grikes aligned on the strike have spectacular sets of deep parallel runnels cut into their downslope edges (Figure 3.20). Across the centre of the area, a synclinal valley contains the best of the pavements, and the anticline to its west provides structural variety within them. From the trough of the plunging syncline, excellent pavements rise towards Castle Fold where an ancient settlement stood on a low knoll formed by a remnant of a higher limestone bed. Massive, large rounded clints are underlain by pedestals of well fractured limestone to form mushroom-shaped features. These change eastwards through a development sequence, as the pedestals become less developed, the top clint less runnelled, and the grikes narrower, until a pavement of massive clints disappears under the debris cover around the Castle Fold outlier. The west side of the synclinal valley has pavements with deep rinnenkarren sloping east at about 15°, while gently sloping clints on the anticlinal crest are cut by deep, convergent rundkarren runnels. Further down the main dip

Figure 3.20 Deep parallel rundkarren on very long clints aligned on the strike of the gently dipping limestone pavements on Great Asby Scar. (Photo: S. Webb.)

slope, an area of very large clints with smooth surfaces, little scored by solutional runnels, is aptly known as the Shining Stones.

Little Kinmond and Grange Scar have less continuous pavements in bands along the crests of bedding scars continuing east along the escarpment. North of Little Kinmond, there are areas of massive pavement sloping north at 3–10° with some undulations over shallow plunging folds. The larger clints have kamenitzas and convergent runnel systems.

Interpretation

Pleistocene ice flowed from the Howgill Fells north-east across the limestone outcrop (Mitchell, 1991, 1994). Its flow against, then up and over the escarpment precluded the development by ice plucking of terraced limestone scars and capping pavements on the scarp face, which presents a very rounded profile. Ice flow down the dip slope efficiently stripped the exposures down to bedding planes on the stronger beds, where postglacial solutional fretting has created the finest and largest pavements. An iceway over the low point on the scarp crest produced deeper scouring along the fault line trough east of Grange Scar, while more selective scouring in the lee of the high point on the escarpment created the stratimorphic topography on Great Asby Scar. Pavements survive right across the synclinal valley floors which have never carried subaerial stream drainage.

Some of the larger runnels on the pavements appear to exceed the dimensions that can be realistically attributed to solution at modern rates throughout the Holocene. The survival of pre-Devensian relics appears to be incompatible with the site's glacial history and exposure to scouring, and the rounded forms of the karren ridges can not be attributed to rapid and deep excavation by meltwater during glacial retreat. The well rounded rundkarren are indicative of slow evolution beneath a cover of acidic soil and vegetation, but could have been formed by the postglacial rounding of older, subaerial features with sharper profiles. Past solution rates could have been higher in an environment of enhanced levels of biogenic carbon dioxide in soil waters from beneath a denser cover of shrubs and trees. The presence of early settlements at Castle Fold and other sites on the limestone suggest that there has been a richer soil and vegetation cover in the recent past, and pollen profiles from Sunbiggin Moor, south of the escarpment, support this concept (Webster, 1969).

The pavements east of Castle Fold are broken by numerous pits, each up to 7 m in diameter and several metres deep. They are unrelated to the tectonic joint patterns, and may be exhumed palaeokarstic features of Carboniferous age; these would have formed on calcretes which developed in sabkha environments during short periods of emergence from the shallow shelf seas (Vincent, 1995). The origin of their clay fills is not yet known, but may be Carboniferous soil evolved from volcanic ash, rather than Permo-Triassic loess or Devensian till.

Many clints stand on pedestals which are about a quarter of the height of those beneath the Norber glacial erratics on Ingleborough (Sweeting, 1966). This may suggest that solutional lowering of the surface has only lasted about 2500 years, if Holocene erosion rates are comparable at the two sites, and therefore conflicts with the environmental evidence of the large runnels. However, the evidence of some of the pedestals is invalid where they are lithologically defined by undercutting in bands of weaker, rubbly limestone. The extent and role of past soil covers on the Great Asby pavements are not yet fully defined.

Conclusions

The pavements at Great Asby Scar are nationally outstanding for their very large expanses of bare solutionally fretted limestone, and their wide range of morphologies related to the gently folded limestone structure. Past environments of contrasting soil and vegetation cover have also influenced the details of the solution features. Despite a sad record of destructive clint removal from large parts of the outcrop, much very beautiful and very varied pavement remains intact.

LITTLE ASBY SCAR AND POTTS VALLEY

Highlights

Little Asby Scar and the adjacent Potts Valley contain a distinctive area of limestone pavements, cliffs, scree and rough grassland which has origins traceable to pre-Devensian glacial erosion. Many of the pavement features appear to have preglacial elements.

Introduction

The Potts Valley is a major breach through the eastern end of the limestone escarpment which extends between Orton and Kirkby Stephen, north of the Howgill Fells (Figure 3.1). The south-facing escarpment is formed of the Great Scar Limestone, whose structure and lithology broadly continue those of the Great Asby Scar site immediately to the west. Little Asby Scar forms the high ground just west of the Potts Valley, whose western flank provides the type sequence for the Asbian stage of the Lower Carboniferous (George *et al.*, 1976), where the Holkerian Ashfell Sandstone meets the Asbian limestones and shales passing up into the Great Scar Limestone. Published research on the karst geomorphology is minimal and the site literature is incidental (Ward and Evans, 1975).

Description

South of the main scarp, Potts Beck drains a lowland formed on the shales and impure limestones of the Orton Group. The beck then flows north as an underfit on an alluviated floor through the narrower, rocky valley which breaches the scarp (Figure 3.19). Springs from the Orton limestones add to the flow of the beck, but infiltration to the Great Scar Limestone drains to various small risings on the dip slope to the north. Limestone screes and inclined scars form the western slope of the valley, but are largely obscured by a bank of glacial till on the eastern side.

The major part of the gently graded scarp face is formed in the mixed sedimentary sequence of the Orton Group, where the thin limestones form a few low scars. Only the crest of the escarpment is formed by the Great Scar Limestone. The pavements are formed only on the more massive beds within this unit, and lie in the terraced, sloping benches above small scars on the upper part of the scarp face. The northern flank of the escarpment is hardly a dip slope, as the dip is steeper than the surface profile, and the pavements again form on only narrow outcrops.

On Little Asby Scar the main pavements slope north at 10–18°, and are very well dissected. The more massive beds have some large clints, scored by mature rundkarren runnels and shallow kamenitzas. Most grikes are deep and 100–200 mm wide, but those in a distinctive sub-set are 1–2 m wide, shallow and commonly infilled. These wider grikes are common near the ridge crest and are formed on the same systems of tectonic joints as the deep and narrow kluftkarren; they are mostly spaced 10–30 m apart. The pavements are noticeably discontinuous, forming strips only a few metres in width along the tops of some of the scars. East of Potts Valley, the limestone has a generally thicker cover of soil and grass. There is no significant surface drainage.

Interpretation

Potts Beck originally had a much larger catchment, before capture of its headwaters by the River Lune. The valley through the limestone escarpment was cut by a larger river draining much of the northern slopes of the Howgill Fells (McConnel, 1939; King, 1976), and was probably incised to close to its present depth early in the Pleistocene. Subsequently, the valley may have acted as an iceway, or carried subglacial meltwater, but modification by glacial scour was probably very limited, as the site lay at a basal ice shed (Mitchell, 1994). This protection from glacial erosion may account for the survival of many older landforms on the higher parts of the escarpment, and it is likely that some components of the limestone pavements predate the Devensian glaciation, though there are no absolute dates to confirm this.

The bimodal distribution of grike widths provides evidence for some inheritance of older features. The narrow grikes are clearly postglacial, but those of the wider sub-set appear to be pre-Devensian relics, as solution rates recorded widely on the Pennine limestones (Sweeting, 1966; Rose and Vincent, 1986c) could not account for kluftkarren 2 m wide within the 10 000 years of the Holocene. The very dissected nature of the pavements also reflects their considerable age, but the bulk of the rundkarren runnels are less than 400 mm deep and could therefore be entirely postglacial. This suggests the possibility that glacial scour removed a top bed of limestone, with its older runnels, and the surviving grikes are just the lower parts of interglacial kluftkarren which reached down through two or more beds.

Conclusions

The limestone outcrops on Little Asby Scar have well dissected limestone pavements within an area which lay on a basal ice shed through much of the Pleistocene glaciations. It is likely that many of the pavement landforms were inherited from preglacial features which escaped complete removal by glacial erosion. The site also contains the type section of the Asbian stage of the Carboniferous.

HELBECK SCARS
This is a proposed GCR site, not yet designated as an SSSI

Highlights

Helbeck Scars form an extensive area of open limestone pavement high on the Pennine escarpment. The limestones are well folded, and consequently the pavements contain a wide range of solution forms. The larger clints have kamenitza and rundkarren, and more jointed areas are reduced to outcrops of knife-edged clints.

Introduction

Helbeck Scars is the collective name given to a series of limestone outcrops just below and west of the crest of the Pennine escarpment overlooking the Vale of Eden, north of Brough (Figure 3.1). They range across altitudes of 350–600 m. The pavements form an almost continuous band 300 m wide and 4 km long, from Helbeck Intake, north-west across Key Scar, Musgrave Scar and Middle Fell, to Long Fell. They are all formed on the Dinantian Great Scar Limestone, exposed between the Swindale Beck and Barnarm Faults near the top of the Pennine scarp face. Mixed sequences of shale, sandstone and limestone of the Alston group overlie the Great Scar, and similar rocks of the Orton Group lie below. The regional dip is to the east, but local folding and block faulting produce considerable dip variation across the limestone outcrops. The limestone outcrops therefore include both wide pavements and narrow scars.

Most of the site lies within the Warcop military ranges, which probably accounts for the small degree of human damage to the pavements. There has been almost no geomorphological research on these little known but very spectacular pavements. The botanical values were assessed by Ward and Evans (1975) and in recent unpublished reports for English Nature.

Description

Pavement morphologies vary considerably across the site, in response to geological structure, outcrop pattern and aspect. They are best reviewed sequentially from south-east to north-west (Figure 3.21).

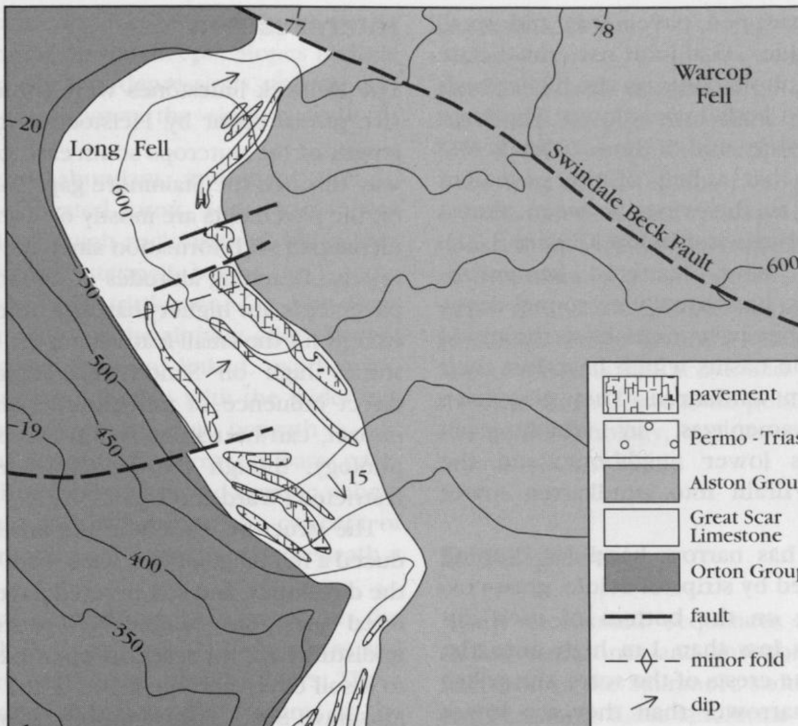


Figure 3.21 Geological map of the pavements on the Helbeck Scars. The Alston Group includes thin limestones with low scars and narrow pavements which are not marked.

Helbeck Intake has outcrops across its southern slope with narrow bands of scar top pavement dipping north at 30°. Deep and narrow grikes separate elongated clints which are reduced to linear, knife-edge blades as narrow as 20–30 mm in areas of close jointing. At the western end of the scars, the beds dip over an eroded anticline, where parallel runnels develop on the larger and steeper clints. A large expanse of undulating pavement in the north of the Intake stands on limestone bedding planes dipping 10–25°, with curved grikes between clints with well developed rundkarren, kamenitzas and solution pits.

Key Scar has stepped pavements and small scars up the hill side. Local joint patterns dictate the shapes of rhomboid clints on the higher beds and more elongate beds lower down. The large outcrop at the western end of the scar lies across a monocline, so that a belt of the pavement slopes at 15–20° to the west, between almost level pavements above and below (Figure 3.21). The level areas have scattered kamenitzas 20–200 mm across, but virtually no runnel development. The steeper pavements have rhomboid clints with solution basins which have lost their front rim to form trittkarren. They also have sequences of kamenitzas, in which each overflow into its lower neighbour, and the stepped systems drain into rundkarren lower down the clint.

Musgrave Scar has narrow bands of dipping pavement separated by strips of acidic, grass-covered soil forming on the bottom of each dip slope below scars less than 1 m high onto the next bed. Along the crests of the scars, the grikes are deeper and narrower than they are lower down the same bedding planes. Natural breakdown is degrading the scar edges, most rapidly in areas of closer jointing and thinner bedding. Runnels are broad, shallow and convergent, but steepen and deepen into the grikes. Some grikes, inclined at 30° from the vertical, have well developed flutes on their lower surfaces. Kamenitzas are shallow and locally stepped.

Middle Fell has wide pavements formed across a synclinal flexure, where dips of 30° east at the scar edge ease to 10° further into the slope (Figure 3.21). Clints are up to 1 m across but are smaller and increasingly knife-edged towards the scar edges. Deep rundkarren score the clints, and some start as stepped series of kamenitzas. Protogrikes form along lines of weakness, commonly parallel with mature grikes. Further north, a group of larger depressions, 2–10 m across, have formed in a band within the stepped and dipping pavements, and a line of active sinks along the rear of the pavements swallows drainage from the overlying sandstone.

Long Fell has the most northerly and highest of the pavements. Narrow outcrops and small scars have deep, narrow grikes between small rhomboid and triangular clints with poor runnels. Further west the highest limestones of the Great Scar form dip slope pavements with larger clints on the massive beds between zones of broken rock on the outcrops of more rubbly beds.

Interpretation

The Helbeck limestones were subjected to intensive glacial scour by Pleistocene ice moving the length of the outcrops south-east towards the iceway through the Stainmore gap. Solution features on the pavements are mostly on a small scale commensurate with formation since the Devensian ice retreat. Reaching altitudes of 600 m, the Helbeck pavements are higher than any others in England, except for the small features on the Yoredale limestones high on Simon Fell, Ingleborough. No direct influence of this altitude, and its climatic impact, can be recognized in the pavement morphology, though the modern flora is certainly restricted (Ward and Evans, 1975).

The structural variety in the limestone has produced a full range of bed scars, bare pavements on the dip slopes, and soil-covered pavements in sheltered sites. The Middle Fell pavements stretch undisturbed from scar top open pavement down to a soil cover and the scree of the next scar. On Musgrave Scar, narrow dipping pavement grades downslope into bands of acidic grassland dominated by *Nardus stricta*, probably growing on accumulations of windblown loessic silt at the lowest point of each dip slope. Breakdown of the narrow bands of pavement is accelerated by unloading fractures close to the scar edges. Closely spaced tectonic joints create the linear knife-edged clints of Helbeck Intake and Musgrave Scar.

Limestone lithology also influences pavement morphology. On Long Fell, adjacent beds at outcrop include an upper pseudobrecciated, rubbly limestone with no recognizable karren forms, over a lower massive limestone developing a smooth pavement surface with gently rounded solution features. The upper bed degrades and retreats to reveal the fresh surface beneath, but there is no clear pattern related to the retreating cover in the morphology of the lower pavement. Some pedestal clints have developed on Middle Fell where a massive bed overlies an easily degraded rubbly limestone.

Solutional features on the massive beds of limestone are well developed and show morphological response to the local dips and clint slopes, which vary so much across the folded limestone. Rundkarren develop below smooth areas of clint which are not runnelled. The relationship between dip and morphology is clear, with parallel, straight runnels on the steeper dips and branching, meandering forms on the more gentle slopes. Catchments on the steeper slopes include broad, tapering, shallow depressions, and runnels steepen into flutes down the sloping walls of grikes.

Kamenitzas are abundant, and many link to form cuspate elongated forms. Some kamenitzas eventually drain through rock fissures, but others overflow, to create stepped basins, and some appear to evolve into trittkarren. On Key Scar, many of the runnels on the sloping clints appear to originate as sequences of linked, overflowing kamenitzas. This may conflict with the wider evidence that rundkarren develop beneath a soil cover, whereas kamenitzas form on bare pavements where they catch water and organic debris. The relationship adds support to the concept of rounding the rundkarren crests merely beneath a lichen cover.

Eight circular depressions, in a group on the north of Middle Fell, are each 2–20 m across and up to 2 m deep, with level, grassed floors. These are distinctly larger than any other features on the Helbeck Scars, and appear to be relics of pre-Devensian landforms. An annular zone of pavement about 50 m wide around these basins has more mature karren morphologies, with runnels up to 400 mm deep in large, smooth, rounded rundkarren.

Conclusion

Helbeck Scars have the only extensive pavements on the limestones of the Alston Block, at higher altitude than any other large pavements in Britain. They are formed on folded limestones which support a wide range of pavement types and features in response to variations in structural dip and lithology. Abundant kamenitzas appear to be genetically related to rundkarren, and there are very fine linear, knife-edged clints in the densely jointed limestones.

GOD'S BRIDGE

Highlights

The natural limestone span crossing the River Greta at God's Bridge is the best example of a natural limestone bridge in Britain. Cave development in a thin limestone in the valley floor has now captured much of the river flow.

Introduction

The River Greta drains a large area of the fells of Stainmore Forest in the northern Pennines (Figure 3.1). Its headwaters lie on impermeable rocks, but 4 km west of Bowes, the river crosses a thin bed of Carboniferous limestone, where several generations of caves have developed. The progressive development and subsequent collapse of a sub-valley floor cave system has produced a natural limestone bridge spanning the river. A lower system of caves is still active and captures much of the river flow. There is no published study of the site geomorphology, but the caves are described in Brook *et al.* (1988).

Description

Nearly horizontal sequences of Carboniferous shales, sandstones and limestones form the high fells around the Stainmore saddle over the northern Pennines. Karst landforms are limited in the thin limestones, of which many outcrops are hidden beneath glacial till. The River Greta is an underfit in a broad valley which carried substantial flows of Pleistocene ice through the Stainmore gap. God's Bridge is developed where the River Greta crosses the outcrop of the Great Limestone, which is about 20 m thick and lies at the base of the Namurian succession.

The river flows onto limestone a few hundred metres above the Bridge, and has developed a series of caves below the valley floor. God's Bridge is a bedrock span over a cave 12 m long, 2 m high and about 4 m wide through which the river flows, and is large enough to accommodate almost all the modern flood flows. The Bridge is made from two beds of limestone and is only about 2 m thick (Figure 3.22). There is limited block collapse at the upstream end, while a shallow rocky gorge represents the unroofed continuation of the cave on the downstream side. The upper surface of the bridge is bare rock, exposed to weathering and ultimately destined to collapse by a combination of thinning, fissuring and undercutting. Part of the river flow now passes through a lower cave system, extending 500 m from sinks upstream of the Bridge to resurgences downstream. Most of this cave is a series of low, wide, bedding passages with oxbow loops, and parts of the route are permanently flooded (Brook *et al.*, 1988).

Figure 3.22 The upstream side of the limestone span of God's Bridge across the River Greta. (Photo: A.C. Waltham.)

Interpretation

God's Bridge is the last surviving relic of a valley floor cave system. Early solution by the River Greta of the limestone at outcrop produced a cave system below the valley floor, which was subsequently unroofed and dissected as valley lowering proceeded. The natural bridge is part of this earlier generation of sub-valley floor caves, and the rocky gorge downstream is an unroofed section of the same cave. Continued solution has created a younger and lower cave system extending parallel to the Bridge site from new sinks upstream. This new cave has developed along bedding planes downdip of the surface river bed, so that it forms a drainage loop beneath the north bank. Ultimately, this new cave will suffer the same fate as its predecessor and will be unroofed, leaving temporary fragments spanning the river.

There is no positive evidence of the age of the caves. The river bed location is compatible with youthful caves, but abandoned loop passages in the lower cave system north of the surface river suggest that even this may not be entirely Holocene. The caves can only have developed where the limestone was exposed in the valley floor with a downstream outlet for their drainage, and so cannot be older than the time taken for surface lowering to pass through the 20 m thickness of the limestone. However, this is greater than the 15 m of valley floor lowering attributed to a single glacial episode in some of the Pennine limestone valleys (Waltham, 1986). It is therefore possible that the caves were overridden by Devensian ice. The section of river channel downstream of God's Bridge is a cave which may have been unroofed by glacial plucking; this would have been greater downflow of the old cave exit than where the ice overrode the upstream entrance.

Conclusions

There are at least three sites in the limestone Pennines known as God's Bridge. All are cave remnants which provide convenient natural routes over rivers or streams. The God's Bridge of Stainmore is the finest of them. It is a truncated fragment of a formerly more extensive valley floor cave passage, and has a similar, but newer, cave system now developing parallel to it.

KNOCK FELL CAVERNS

Highlights

Knock Fell Caverns is the finest example in Britain of a joint-guided phreatic maze cave, with more than 4500 m of passages known within a single thin limestone in an area of less than 3 ha.

Introduction

Knock Fell Caverns lies at an altitude of 750 m directly beneath the surface watershed along the crest of the Pennine escarpment north of Knock

Fell (Figure 3.1). The cave is developed in the Namurian Great Limestone, which is about 20 m thick and dips very gently to the north-east; mixed sequences of sandstones and shales lie both above and below the limestone. There are numerous shakeholes in the soil and drift over the limestone outcrop, and one contains the 7 m deep entrance shaft to the Caverns. Underground drainage within the limestone resurges at a strong spring near the head of Knock Ore Gill. The cave was mapped and described by Sutcliffe (1985).

Description

The shaft entrance to the cave lies on a joint intersection modified by collapse which has broken through to the surface. All the main passages are formed at one level within the Main Limestone. They are vertical phreatic rifts, all formed along joints, and they intersect in a maze of spectacular complexity (Figure 3.23). Most are less than a metre wide, and narrower joint fissures with fretted walls extend above and below the main solutional enlargement to give total passage heights of 5–10 m. Horizontal rock ribs and blades protrude from many of the passage walls, left by selective solution of closely spaced lithological contrasts within the limestone (Figure 3.24). Most of the known cave system, which has a total passage length of more than 4500 m in an area roughly 320 m by 120 m, lies beneath the cover of shales and sandstones. Passages to the west extend under the shakeholes on the limestone bench; these are largely choked by boulder falls and inwashed gravels, which now fill the floor rifts in adjacent passages. The eastern extremities of the cave reach towards the Teesdale flank of the ridge, and are also choked by sediment.

The entire cave is formed on joint fissures, and the tectonic fracture patterns therefore control the maze topography. Joints are more closely spaced in the southern half of the cave, while a more open maze has formed on more widely spaced fractures to the north. Some wider passages and chambers with rectangular profiles have formed by the breakdown of narrow blades of rock between solutional fissures on close, parallel joints. Part of the northern end of the main cave is underlain by a discrete lower level, the Inferiority Complex, with smaller phreatic passages forming a denser network than those in the main maze about 5 m above. Below this may lie younger, active caves draining towards Knock Ore Gill

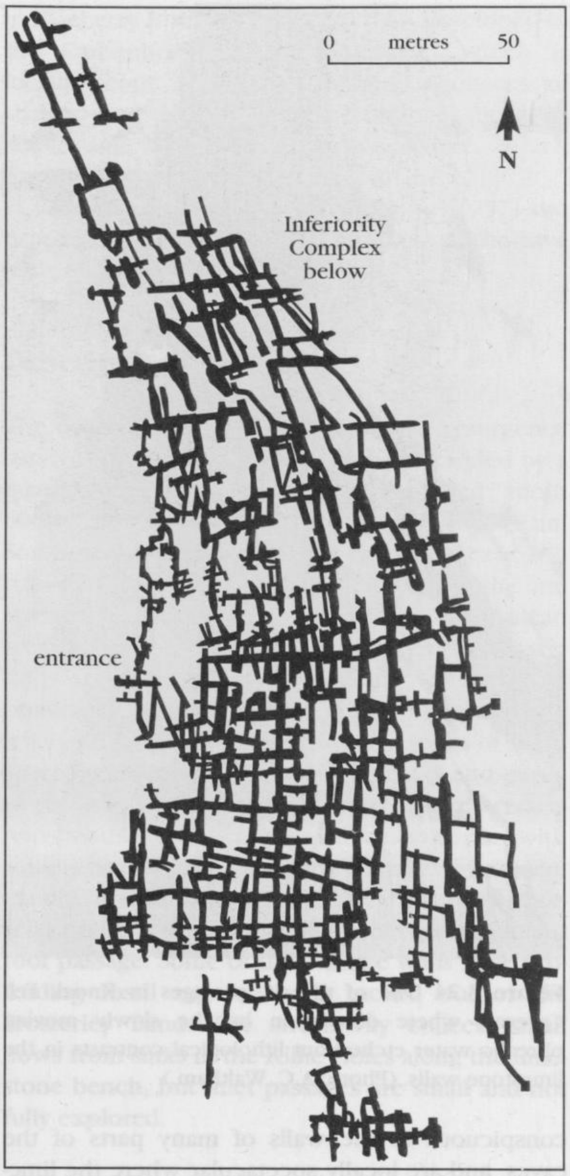


Figure 3.23 Outline map of Knock Fell Caverns, without the much shorter lower series which are omitted for clarity (from survey by Gritstone Club).

Head. The known cave is dry, apart from percolation water entering from roof fissures.

Some roof fissures reach to the top of the limestone, and the undermined shale has partially failed. Several wider avens on joint intersections reveal the sandstone roof which overlies the thin shale. The sandstone is fissured sufficiently to allow acidic water to percolate down from the blanket peat above. This water is mostly aggressive as it etches the cave walls, but small secondary calcite deposits have formed in a few places. The fossil corals of the Frosterley Band are

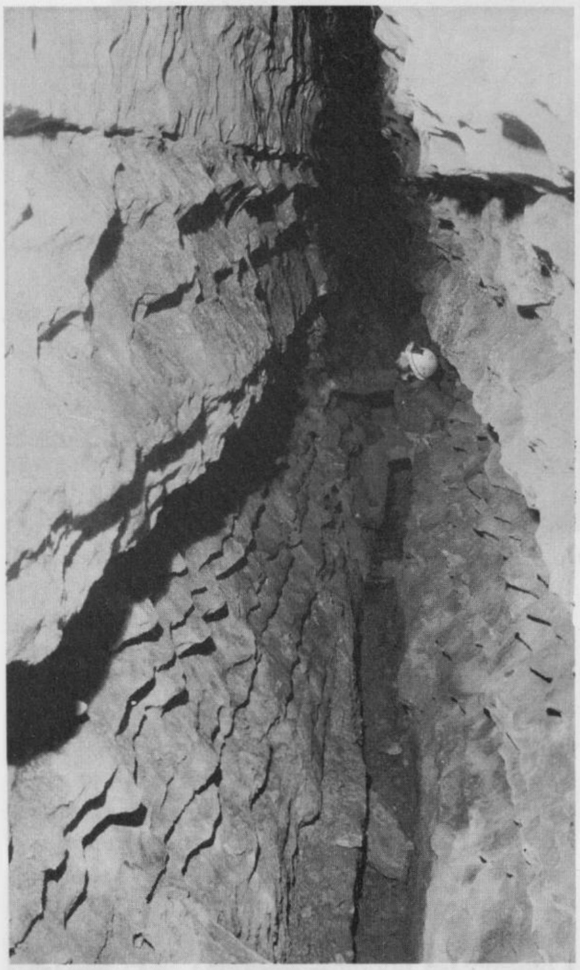


Figure 3.24 One of the rift passages in Knock Fell Caverns, where dissolution by the slowly moving phreatic water etched out lithological contrasts in the limestone walls. (Photo: A.C. Waltham.)

conspicuous in the walls of many parts of the caves, and are locally spectacular where the limestone has been etched from around them by the aggressive percolation water.

Interpretation

Knock Fell Caverns represent the finest of the complex phreatic maze caves which are a feature of the thin Yoredale limestones in the northern Pennines. It is more extensive than the comparable mazes intersected by mine workings in Swaledale (Ryder, 1975), and all of these have much denser passage networks than the rectilinear stream caves of Mossdale Caverns and other comparable sites. Knock Fell Caverns is typical of the dense mazes of cave passages formed by slowly moving water in confined aquifers (Palmer, 1975); solution takes place along all the fractures without selective enlargement on those fissures with hydraulic advantage in an environment of high flow rates. No flow patterns have been recognized in the cave.

Permeable, jointed sandstones lie both above and below the cavernous limestone, in each case separated by only thin shale beds which are seen to be breached in some of the roof shafts. These sandstone aquifers could have provided, via the fractures, a diffuse input of aggressive water into the limestone, in the style recognized in many other maze caves (Palmer, 1975). This could have taken place with either upward or downward flow when the limestone was deeply buried in an artesian phreas. Alternatively, it may be much later, with downward flow through an exposed sandstone cap into a limestone phreas perched on shale, and unable to drain across the low dip into distant surface valleys. In either case, the phreatic development was terminated when surface lowering left the cave perched just beneath the watershed cap. Vadose modification has been minor.

The cave lies at very high altitude, close to both the Pennine fault scarp and a long dipslope down to the Milburn Forest. Hence much of the phreatic passage development may be very old, substantially predating the surface landforms. Clastic and calcite deposits within the cave represent the only material suitable for absolute dating in this part of the Pennines, and hence may provide a valuable record of the valley incision and geomorphological history of the area.

Conclusion

The scale and complexity of the phreatic maze of Knock Fell Caverns are unparalleled in Britain. Its configuration and position, with a joint network enlarged by solution in limestone beneath a permeable sandstone, suggest that it was probably formed by diffuse recharge to a confined aquifer with very slow drainage.

FAIRY HOLES

Highlights

The long, almost horizontal cave passage in Fairy Holes carries a small stream and has few tributaries. It is the finest and longest of the linear

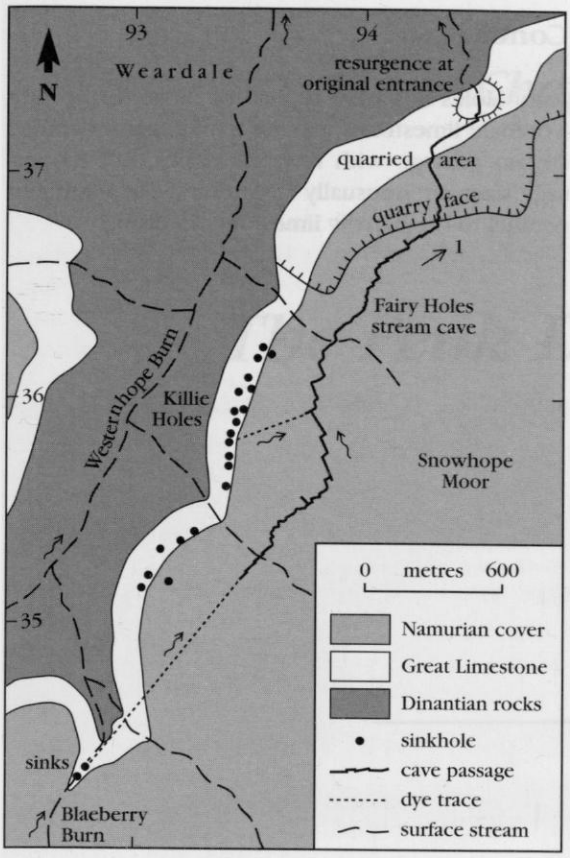


Figure 3.25 Outline map of Fairy Holes and the limestone bench which it drains. The cave and outcrops are shown in their original form, previous to development of the quarry; the limestone has been largely removed from its outcrop southwards to the quarry face, which has also cut into part of the non-carbonate cover. Except for a tiny fragment behind the original resurgence entrance, all the cave passage north of the quarry face has been destroyed (from cave survey by University of Leeds Speleological Association).

caves with the simple underground drainage patterns which are common in the thin Yoredale limestones exposed in the hillsides of the northern Pennines.

Introduction

Fairy Hole lies under the southern flanks of upper Weardale, between Eastgate and Westgate (Figure 3.1). It is the prime example of cave development in the Yoredale limestones of the northern Pennine dales, where one or very few sinks feed a rising via a single passage with few tributaries. The single cave stream passage has been explored from the rising for most of the 3.5 km to the main sinks, in Blaeberry Burn (Figure 3.25). It is developed in the Carboniferous Great Limestone, which is locally about 18 m thick. Mixed sequences of shales, sandstones and thin limestones lie both above and below the Great Limestone, which forms the lowest unit in the Namurian.

The passages are described by Jones (1957) and Brook *et al.* (1988), but lack of access to the cave has precluded any scientific studies.

Description

The original cave entrance above the resurgence survives in a remnant of limestone, encircled by a quarry which has completely removed about 600 m of stream passage immediately upstream. South of the quarry face, the truncated cave still has 3200 m of passages, nearly all forming the one streamway (Figure 3.25). Most of this is a clean vadose canyon over a metre wide, but most sections are aligned on joints which were initially opened by phreatic solution. An abandoned upper level of the cave survives partly as a series of loops where it is offset from the active cave, and partly as roof sections of the streamway. There are sections modified by blockfall and wall collapse, with some chambers up to 30 m long and 6 m wide, mainly formed where the active streamway intersects and undercuts wider parts of the abandoned roof passage. Some of the passage walls have protruding fossil rugose corals etched out of the Frosterley Band. The streamway collects small flows from sinks in the Killie Holes along the limestone bench, but inlet passages are small and not fully explored.

Interpretation

The thin Yoredale limestones offer limited scope for the development of complex multi-level cave systems, and most underground drainage in them is simple and direct. Fairy Holes is typical in that it has a single, youthful, vadose streamway between sinks and a rising on the edges of the modern outcrop. The cave stream has invaded, linked and modified an earlier generation of phreatic rifts. These are widespread in the Yoredale limestones, and were formed by solution in a confined aquifer before it was drained by incision of the adjacent valley, probably in the late Pleistocene. The vadose stream drains downdip through the fissured limestone, which carries it from the sinks parallel to the Westernhope Burn. This accounts for the large distance to the downdip rising within a very narrow limestone outcrop. Aggressive percolation water sinking into the exposed limestone along its hillside bench enhances cave excavation by solution in the rock immediately below; the Fairy Holes stream cave, just behind the outcrop bench, is therefore larger and more accessible than is normal in these limestones.

Conclusion

Fairy Holes is a cave typical of those in the thin Yoredale limestones, having a long, gently graded stream passage with few tributaries, but its passage sizes are unusually large due to its alignment parallel to the narrow limestone outcrop.