Karst and Caves of Great Britain

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Chapter 2

The Yorkshire Dales karst

INTRODUCTION

The main part of the Yorkshire Dales karst lies on the largest outcrop of the Great Scar Limestone across the southern dales. The finest of the karst landscapes are around Ingleborough and Malham, but many of the major caves lie to the east and west, and the karst is continuous from the Dent Fault, in the west, to the eastern watershed of Wharfedale – a distance of 40 km (Figure 2.1). The topography is dominated by the massive unit of nearly horizontal limestone, whose top surface forms a series of plateaus and benches at around the 400 m level. Outliers, formed largely of shale, rise to summits at around 700 m, and the glaciated troughs of the Dales cut through the limestone to expose basement inliers. The limestone landscapes are the most spectacular in Britain, and have the country's finest glaciokarst landforms, while the geology has proved ideal for the development of large caves.

The Great Scar Limestone Group is the unit of strong Dinantian carbonates that is so conspicuous in the topography of the Yorkshire Dales karst. It consists of limestone beds of massive facies, formed through the Arundian, Holkerian and Asbian stages, locally subdivided into the Kilnsey, Cove and Gordale Formations (Arthurton *et al.*, 1988). The facies includes the Hawes Limestone of the lower Brigantian (Figure 1.9). The Great Scar Limestone is mainly formed of very pure, cream or pale grey, thickly bedded, bioclastic, sparites and micrites; these were a shallow water facies formed on the Askrigg Block, a shelf area partly bounded by faults and surrounded by deep water in the Dinantian sea (Ramsbottom, 1973, 1974). The Porcellanous Band is a fine, cream micrite at the Holkerian/Asbian boundary at the top of the Cove Formation; it is generally only 1 m thick, but may split into multiple units. Thin shale beds throughout the limestone succession greatly influence the cave development (Waltham, 1971b), but reef facies at Malham and in lower Wharfedale are of little significance to the wider karst geomorphology. The limestone is 160–220 m thick, and the variation is almost entirely due to transgression across over 50 m of local relief on the basal unconformity. Beneath the

Figure 2.1 Outline map of the Yorkshire Dales karst, with locations referred to in the text. The Carboniferous limestone shown includes all the Great Scar Limestone (Kilnsey, Cove and Gordale Formations) and also the lower Yoredale limestones (of the Wensleydale Group) where they are hydrologically linked to the Great Scar and are therefore part of the same karst unit. Higher limestones within the Yoredale Series are not marked. Basement rocks are Palaeozoic slates and greywackes. Cover rocks are the Yoredale facies of the middle and late Brigantian Wensleydale Formation and various Upper Carboniferous and Permian clastic formations.

limestone, Lower Palaeozoic greywackes and slates are totally impermeable, and are exposed in the floors of most of the dales; their buried ridges provided the clastic debris for the discontinuous conglomerates at and near the base of the limestone.

The basement inliers in the dale floors are truncated to the south by the North Craven Fault (Figure 2.1). The southern limit of the karst is along the South and Middle Craven Faults, which downthrow to the south by many hundreds of metres. The slice of limestone between the faults is widest where it forms the splendid karst above Malham. The Dent Fault bounds basement rocks to the west, and forms the western edge of the karst. Both the northern and eastern limits of the main karst are formed where the Great Scar Limestone dips gently beneath its cover rocks. The regional dip is just a few degrees north, splaying to the north-west and north-east off the axis of the Pennine anticline. Minor faults occur all across the limestone outcrop.

Above the Great Scar Limestone, an alternating series of thin shales, limestones and sandstones forms the Brigantian Wensleydale Group (Figure 1.9). These were formerly known as the Yoredale Series (Hicks, 1959), but are now described as the Yoredale facies of the Brigantian. They are up to 300 m thick, and have considerable lateral variation; all the limestones have some karstic features, mostly on a small scale. The clastic units between the five lower limestones are locally absent, and the Gayle and Hawes Limestones are inseparable from the Great Scar across much of the Dales area. The Girvanella Band is a nodular, algal limestone about 1 m thick within the Hawes Limestone; it is often regarded as the top of the Great Scar facies. The entrance bedding passages of some of the major caves are within the Hawes Limestone, and east of Wharfedale, the Mossdale and Langcliffe caves in the Middle Limestone drain underground right through to the Great Scar. More significant to the karst than the local stratigraphy is the ubiquitous situation, where the higher slopes of the Yoredale shales provide surface streams that drain onto the main limestone benches.

The karst

Ice sheets scoured the entire Yorkshire Dales karst, during at least four of the Pleistocene cold stages. They interrupted the karstic processes of warmer climates, and their phases of glacial erosion alternated with those of fluvial erosion to impose a sequence of rejuvenations on the pattern of geomorphic evolution. The effects of the Devensian glaciation are most conspicuous within the present landforms. At its maximum, Devensian ice covered the entire area; during its retreat, summit nunataks appeared while the ice still swept over the limestone plateaus, and the final retreat stage saw only shrinking valley glaciers in the dales beneath the limestone benches. Ice flowed from the north, and its impact on the dales varied with the ice catchment as defined by the topography; Wharfedale and Ribblesdale carried the largest glaciers, but the Ease Gill and Malham valleys were both sheltered from major ice scour (Figure 2.1). Except for those two valleys, all the dales are deep glaciated troughs flanked by limestone scars.

All the streams and rivers have dry sections in their surface courses across the limestone. The Ribble and Wharfe maintain their surface flows in all but very dry weather, while most small streams off the shale outliers sink into caves and potholes under all conditions. The limestone high ground is therefore normally streamless. Its fine glaciokarst is best developed on the wider plateaus south-east of Ingleborough and north-east of Malham. The bare outcrops of limestone have great expanses of pavement, deeply incised by solution runnels. Where the fissured limestone is veneered with glacial till, doline fields with thousands of subsidence dolines (locally known as shakeholes) have formed, and are still active. Fluvial erosion of the mature karst has been limited to short periods of periglacial conditions, most significantly during the Devensian ice retreat. There are few dry valleys, but some were formed by subglacial and proglacial meltwater, and include the spectacular gorges of Gordale and Trow Gill, whose walls are now largely dry and therefore preserved. Malham Cove has a more complex origin, but the evolution and survival of its great limestone cliff are further consequences of the changing karstic processes. The large solutional dolines of High Mark (Figure 2.1) are probably the largest relics of interglacial karstic development in the region.

The Yorkshire Dales karst owes its spectacular geomorphology to the combination of so many landforms: the sinks which take all the drainage, the expanses of pavement, the long scars, the deep gorges and the innumerable dolines. The area is strictly a glaciokarst, but Ingleborough and Malham provide the finest limestone landscapes in Britain.

The caves

Nearly half of all Britain's known caves lie in the Yorkshire Dales karst (Table 1.1). This is because the geology presents an ideal cavernous environment: allogenic streams from the shale cover provide input to the top of the limestone, and this drains through to resurgences at or near the base of the limestone exposed in the dale floors (Waltham, 1974a). Most underground stream routes therefore have a simple staircase profile. Shafts are formed on joints or faults which are close to vertical, and nearly horizontal caves lie along the bedding planes and shale horizons within the limestone. Vadose canyons follow the bedding down the gentle dips, while phreatic routes are directed towards the available resurgence sites, regardless of geological structure. Hence looping cave plans are created where passage directions change in response to the hydrology, and patterns are further complicated where faults divert the underground drainage by overriding the bedding influence.

The geology imposes local detail on cave profiles, notably because vadose water descends the first available tectonic fracture. The deep daylight shafts, including the famous Gaping Gill, therefore drain into long sub-horizontal conduits at depth. Many other sinking streams find and follow shale horizons high in the limestone sequence, and therefore drain through long caves at shallow depth; Mossdale Caverns provide the extreme case, but their water does eventually descend to depth, and the Birkwith caves provide the grandest exception by draining out of a perched resurgence.

Vadose flow in the caves is mainly downdip to the north. Phreatic flow is then updip to the south, towards the lower surface levels. This accounts for the long flooded zones in the lower levels of nearly all the Yorkshire Dales caves; Keld Head is the finest example with over 7 km of flooded cave behind the resurgence. The phreatic conduits can also loop up and down between submerged bedding horizons; the route from Ireby Fell Cavern to Leck Beck Head has at least five phreatic lifts, of which the highest carries water more than 60 m up a vertical shaft on a joint or minor fault. The only long vadose streamway out to a resurgence is White Scar Cave, draining downdip into Chapel-le-Dale.

Previous to successive rejuvenations and surface lowering during the Pleistocene, higher levels of phreatic caves developed where the aquifer was impounded behind the impermeable rocks south of the Craven Faults. These caves were then abandoned as the entrenching dales created new resurgence sites, close to where they breached the fault barrier. The old phreatic caves were also developed largely along the bedding, and now form the high-levels, abandoned, invaded or intercepted by the modern, rejuvenated stream caves. The Gaping Gill Cave System has a long system of old sub-horizontal caves at depth beneath the famous daylight shaft, and Sleets Gill Cave has the best examples of abandoned phreatic lifts. These old caves contain extensive calcite and clastic sediment sequences, which record the Pleistocene environments and rejuvenations, but dating of the material has so far been on a modest scale, and much remains to be evaluated (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1983a, b).

The combination of large dendritic systems of active cave passages and intercepted networks of abandoned conduits produces very long caves. The Ease Gill Cave System is the longest in Britain, and its links through to the Kingsdale caves are known to exist. It is only a matter of time and exploration effort before these links are found, and a single cave system over 100 km long will extend the whole way round the southern flank of Gragareth (Figure 2.1).

EASE GILL CAVE SYSTEM (GCR name: Leck Beck Head Catchment Area)

Highlights

The caves under and around Ease Gill form the longest and most complex system in Britain, which ranks among the ten longest caves in the world. They contain an exceptional range of cave geomorphological features, and the passages, sediments and speleothems provide an unparalleled record of karstic evolution and associated surface development through the Pleistocene.

Introduction

The Ease Gill Cave System extends beneath Casterton, Leck and Ireby Fells, around the western and southern flanks of Gragareth Hill (Figure 2.1); it is bisected by the county boundary of Cumbria and Lancashire. A limestone upland is drained by the most extensive and most complex series of caves in Britain. The Dinantian Great Scar Limestone is about 200 m thick and contains numerous shale bands up to 2 m thick; it has a very gentle dip to the north-west. The Dent Fault juxtaposes the limestone against impermeable Lower Palaeozoic greywackes to the west; adjacent to the fault the limestone is folded into steep dips, with several small folds and tear faults in a disturbance zone up to 200 m wide. The south-west margin of the limestone is a clean break along the North Craven Fault, where the limestone has been thrown down to the south by about 200 m; thick glacial till masks the outcrop of the fault and the Yoredale shales beyond it. Away from the marginal faults, the limestone is broken by many minor faults and major joint sets dominated by trends almost north–south and north-west–south-east. A shallow syncline plunging downdip on Leck Fell is one of many minor flexures not yet mapped in detail.

Allogenic recharge of the limestone is derived from shale sequences of the overlying Yoredale facies forming the upper slopes of Gragareth and Crag Hill; all the streams sink close to the limestone margin. The surface topography and hydrology are complicated by thick deposits of glacial till over much of the limestone. This cover collects the runoff and directs it into the numerous subsidence dolines developed where the till is washed into the underlying limestone fissures.

The main surface feature of the area is the narrow valley of Ease Gill Beck (Figure 2.2). In normal weather conditions the beck carries no surface stream between the shale margin and the resurgence at Leck Beck Head, but flood flows reach various sinks down the limestone valley. Leck Beck Head lies just east of the Dent Fault, and is the rising for all the underground drainage between Aygill Caverns in the north and Ireby Fell Cavern in the south-east.

Despite the scientific importance of an integrated multi-level cave system with more than 80 km of passages, containing extensive clastic and speleothem deposits, published work on the underground geomorphology is limited. Accounts of the geomorphology of the caves beneath Casterton Fell have been given by Ashmead (1967, 1974b), and of those beneath Leck Fell by Waltham (1974d). Descriptions of all of the caves are given by Brook *et al.* (1994), and additional reports on particular caves include those by Foley (1930), Atkinson (1950), Simpson (1950), Eyre and Ashmead (1967), Waltham and Hatherley (1983), Yeadon (1985), Eyre (1989) and Monico (1995). A survey of all of the caves then known in the Three Counties System was published by Waltham and Brook (1980a). Aspects of the geology and its guidance of cave development in this area have been further discussed by Waltham (1970, 1971a, b, 1974a) and Lowe (1992b). Speleothem dates have been obtained from several caves (Waltham and Harmon, 1977; Atkinson *et al.*, 1978, 1986; Gascoyne *et al.*; 1983a, b; Gascoyne and Ford, 1984; Baker *et al.*, 1995b, 1996), and the relationship between the caves and landscape evolution has been discussed by Waltham (1986).

Description

The catchment of Leck Beck Head contains more than 80 km of known cave passages, most of which are integrated into the Ease Gill Cave System. The caves are sensibly divided into three sectors. Ease Gill Caverns contain about 58 km of passages, largely beneath Casterton Fell and linked beneath Ease Gill to Link Pot and Pippikin Pot (Figure 2.2). The caves of southern Leck Fell have about 12 km of connected passages (Figure 2.2); they also have a flooded connection with Pippikin Pot, making a single interconnected cave system 71 km long. The caves of Ireby Fell form another system nearly 12 km long which drains into the Leck Fell caves, though the connection has not yet been explored (see Figure 2.6).

Casterton Fell and Ease Gill Caverns

Ease Gill Caverns is a huge dendritic cave system containing more than 58 km of explored passages (Figure 2.2), which include virtually every type and feature of cave passage morphology encountered within the Yorkshire Dales karst. The caves are accessible through more than a dozen entrances, most of which lie in the Ease Gill valley, though four are located high on the fells to the north and south.

The main feature of the cave system is the massive, abandoned phreatic trunk passage which extends east to west under Casterton Fell. It originates beneath the upper reaches of Ease Gill and heads west to the complex of old passages in Lancaster Hole, where it is joined by similar large old passages from Bull Pot of the Witches and turns south to end at sediment chokes in multiple outlets. Parts of the trunk passage are 10 m in diameter; some sections retain their phreatic mor-

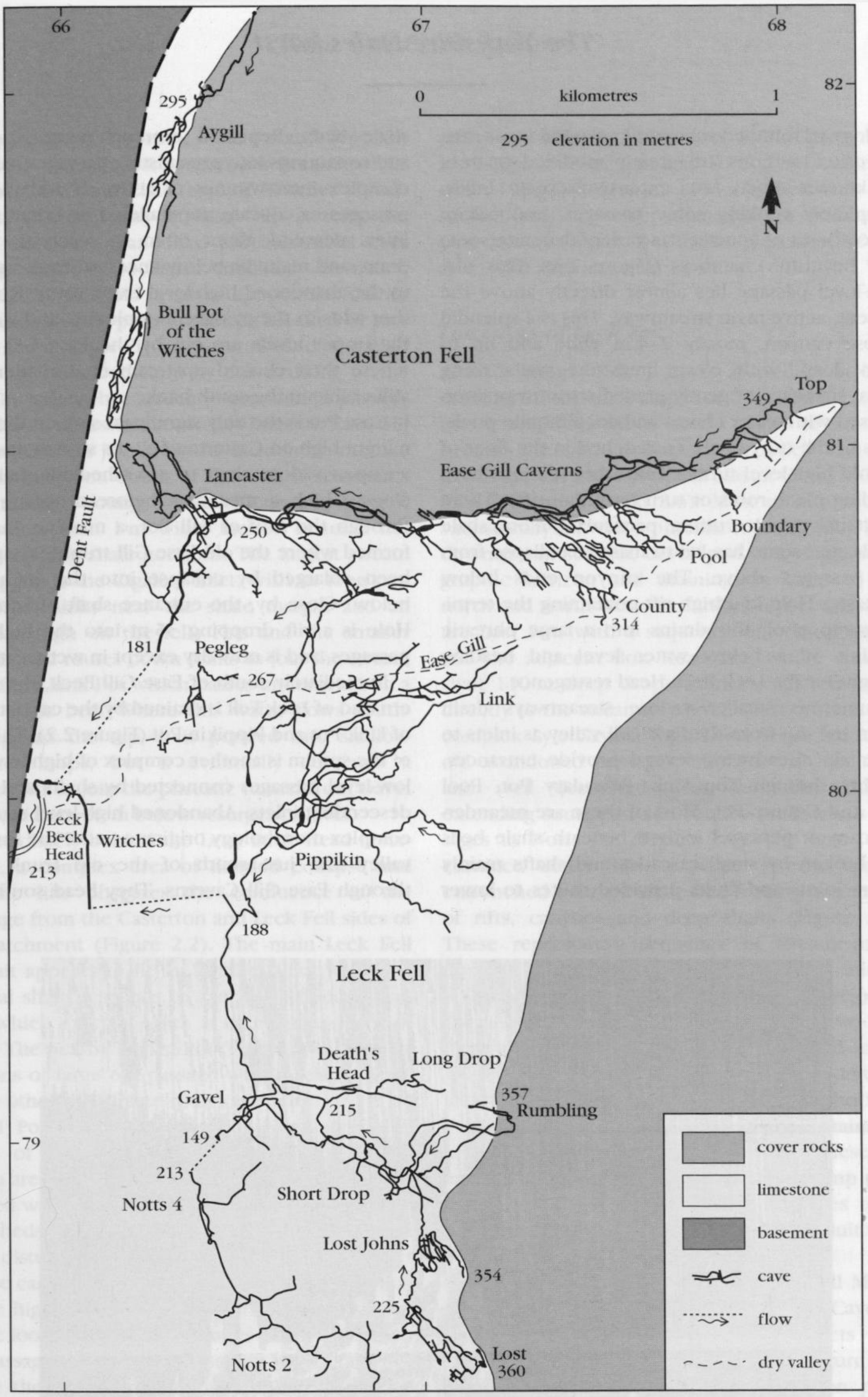


Figure 2.2 Outline map of the Ease Gill Cave System. Limestone is the Great Scar Limestone. Basement rocks are Silurian clastics only exposed west of the Dent Fault. Cover rocks are Yoredale and Namurian shales and sandstones. Notts Pot drains into the lower reaches of Gavel Pot (see Figure 2.5) (from surveys by Red Rose and Happy Wanderers Caving and Potholing Clubs, Northern Pennine Club, Cave Diving Group and many others.)

phology of rounded tubes and enlarged cross-rifts, but other sections are greatly modified by roof breakdown. There are extensive clastic infills, completely choking some passages, and calcite speleothems of spectacular variety decorate some very beautiful chambers (Figure 2.3). This old, high-level passage lies almost directly above the present, active main streamway. This is a splendid vadose canyon, mostly 2–4 m wide and up to 25 m deep, with clean limestone walls rising above stretches of gently graded streamway interspersed with water chutes and deep moulin pools. Parts of the canyon are entrenched in the floor of the old high-level tunnel, but other sections have bedding plane roofs or turn into high rifts. There is extensive undercutting, particularly along shale bands, and some has led to massive collapse from the passages above. The canyon ends below Lancaster Hole in a high rift containing the terminal sump pool; this drains into a large phreatic conduit 30 m below water level and heading straight for the Leck Beck Head resurgence.

Numerous smaller vadose streamways drain down the dip from the Ease Gill valley as inlets to the main streamway; several provide entrances, notably through Top Sink, Boundary Pot, Pool Sink and County Pot. Most of these are meandering canyon passages incised beneath shale beds and broken by small cascades and shafts mainly where joints and faults provided routes to lower shale beds. Repeated entrenchments, captures and re-routings into pre-existing passages have left complex intertwinings of active and abandoned passages on a scale unparalleled in Britain. Most inlets descend about 50 m to reach the main drain, and many lie below ancestral routes graded to the abandoned high-level trunk route. This further adds to the passage complexity, and some of the upper levels are cut by the Ease Gill valley where their choked upstream continuations are still visible in the south bank.

Cow Pot is the only significant sink on the shale margin high on Casterton Fell. Its stream descends an open vadose shaft to a washed-out shale bed along which it meanders before dropping 45 m through the roof of Fall Pot, a massive chamber formed where the old Ease Gill trunk passage has been enlarged by collapse into the streamway below. Close by, the entrance shaft of Lancaster Hole is a rift dropping 35 m into the high-level passages, and is now dry except in wet weather.

Immediately south of Ease Gill Beck, the northern end of Leck Fell is drained by the cave streams of Link Pot and Pippikin Pot (Figure 2.2). This part of the system is another complex of high-level and low-level passages connected by shafts and some descending inlets. Abandoned high-level routes of complex morphology originate under the Ease Gill valley and just south of the old trunk route through Ease Gill Caverns. They head south-west

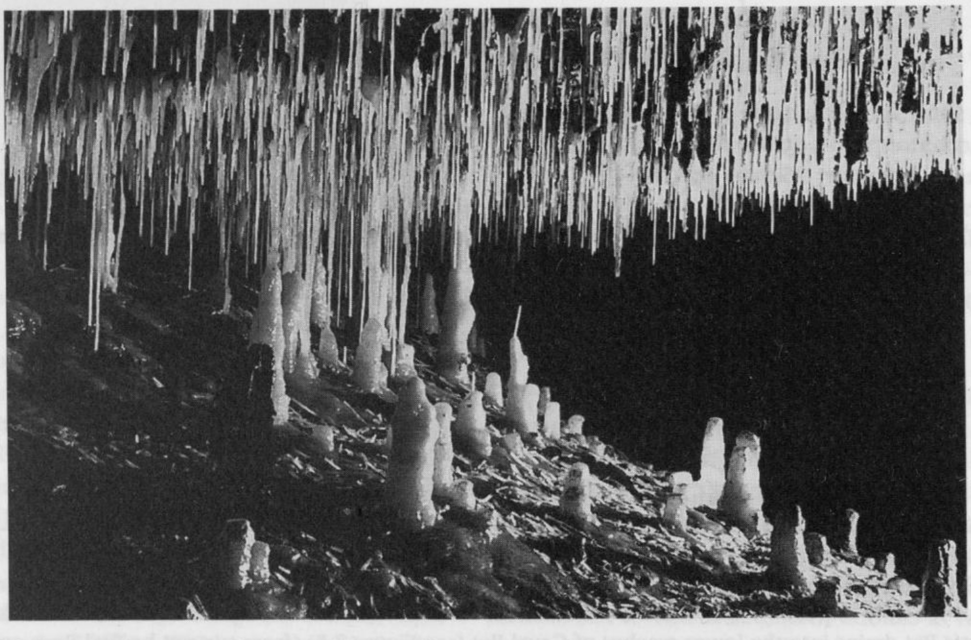


Figure 2.3 Straw stalactites and short stalagmites form a spectacular display in Easter Grotto, part of the high-level passages in Ease Gill Caverns. (Photo: A.C. Waltham.)

and converge on the trunk route through Pippikin Pot which is finally lost beneath the breakdown in the spacious Gour Hall (east of Witches Cave). Like its contemporary in Ease Gill Caverns, the trunk route has abandoned phreatic tubes over 5 m in diameter, collapse modified chambers, thick clastic fills and areas of spectacular calcite decorations; some parts are totally blocked by sediment and collapse. The western limb of the high levels has been breached by downcutting of the Ease Gill valley, but a second abandoned passage provides an accessible route just beneath Ease Gill Beck where it is joined by the incidental entrance shaft of Link Pot. South of the Gill, four streams drain through young, low-level canyon passages, mostly less than 1 m wide, incised beneath the gently dipping shale horizons. The largest stream in Pippikin is the Cigalère inlet, with its long passage from sinks near the shale margin and an entrance high on the fell. This and the smaller streams find routes down joints to join the stream route from Link Pot which passes underneath on a lower shale bed. Where this water flows south-east against the dip, it is ponded into shallow phreatic loops, but it eventually descends a flooded rift to join the phreatic tunnel from Gavel Pot more than 20 m below resurgence level.

Immediately behind the Leck Beck Head resurgence, a complex area of flooded collapse and phreatic lifts obscures the confluence of the drainage from the Casterton and Leck Fell sides of the catchment (Figure 2.2). The main Leck Fell conduit appears to lie in Witches Cave, where a vertical shaft descends to a massive flooded passage which extends south at an average depth of 30 m. The nearby Pegleg Pot (Figure 2.2) contains sections of large old passage whose relationships to the other abandoned routes is unclear.

Bull Pot of the Witches contains a complex series of old high-level passages (Figure 2.2), which are abandoned phreatic tunnels extensively choked with clastic sediment. They largely follow shale beds along the axes of folds within the Dent Fault disturbance zone. Beneath them a younger vadose canyon drains into a phreatic loop through to the high-levels of Lancaster Hole; downstream of the loop, the stream cascades down a younger rift passage to reach the Ease Gill main drain just above the terminal sump. Aygill Caverns are an upstream continuation of the active and abandoned passages in Bull Pot of the Witches, but the connecting links are either choked or flooded.

Calcite speleothems from several parts of the Ease Gill caves have been dated by uranium-series analysis (Waltham and Harmon, 1977; Gascoyne *et al.*, 1983a, b; Gascoyne and Ford, 1984; Atkinson *et al.*, 1986; Baker, *et al.*, 1995a, b). Relatively few speleothems are older than 140 ka, and many post-date the main Devensian glaciation of the area, with ages less than 13 ka.

The caves of Leck Fell

A small group of deep caves are fed by streams draining off the shale slopes of Gragareth, and link into a single system of nearly 12 km of passages beneath the southern slopes of Leck Fell. The core of this system is the Leck Fell Master Cave, 1500 m long (Figures 2.2 and 2.6). Most of it is a large vadose canyon, with a phreatic roof half-tube in its downstream section, developed at a single stratigraphic horizon and draining downdip to the north and north-west. Its furthest upstream inlets are Lost Pot, with a sequence of vertical shafts, and the adjacent Box Head Pot, where a single shaft 110 m deep drops from a small shakehole directly to the streamway level. West of these, the complex Lyle Cavern High Level Series has large, old abandoned passages, choked with sediment and well decorated with secondary calcite, extending south-east and south-west towards passages in Notts Pot (Figure 2.6). The Lost Johns entrance series has a single stream canyon entrenched below a shale bed feeding a complex of rifts, canyons and deep shafts (Figure 2.5). These represent a sequence of stream routes invading a complex of tectonic fractures initially enlarged by phreatic solution. All routes rejoin at the fine waterfall shaft of Wet Pitch (Figure 2.4), from where bedding guided canyons lead to the Master Cave. Downstream, the main conduit collects further inlets, and drains through the Long Pool, a perched flooded section which retains the phreatic tube morphology; it then descends another vadose trench to the terminal sump pool, where an active phreatic tube continues to an underwater junction with the trunk conduit from Notts Pot.

Just 100 m directly above the Leck Fell Master Cave, the main streamway of Short Drop Cave is a meandering vadose canyon fed by inlets from sinks along the edge of the limestone (Figure 2.2). It contains sections of large, old canyon partly choked by sediment and collapse, but since reinvaded and undercut by the much smaller and younger vadose stream. The old vadose passage descends into a contemporary phreatic tube at the Gavel Pot entrance. It is almost choked by sedi-

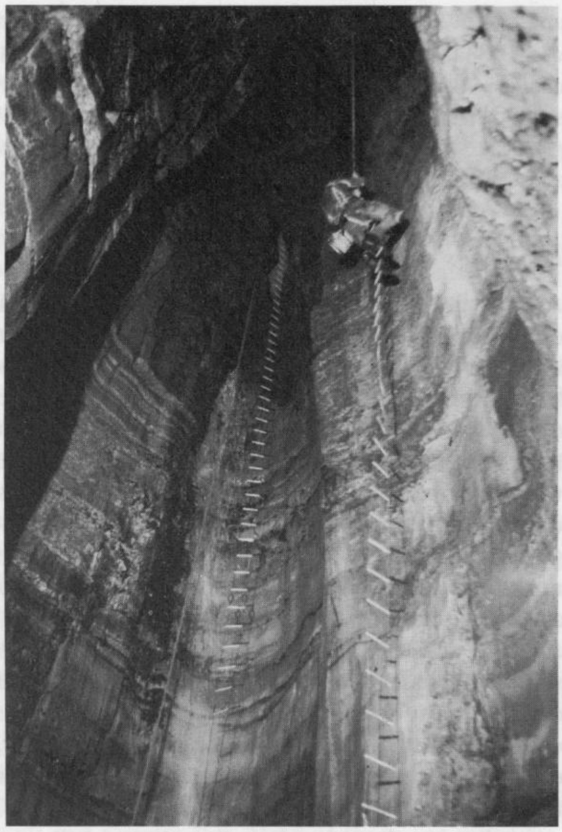


Figure 2.4 A few horizontal bedding planes score the cleanly washed walls of the waterfall shaft at Wet Pitch in Lost Johns Cave. (Photo: A.C. Waltham.)

ment and collapse where it passes beneath the large dolines of Gavel Pot and Ashtree Hole. The stream flows through the chokes and continues as an underfit in the drained phreatic tunnels beyond; it then descends a series of vadose shafts to a sump which is a window into the phreatic conduit from Notts Pot.

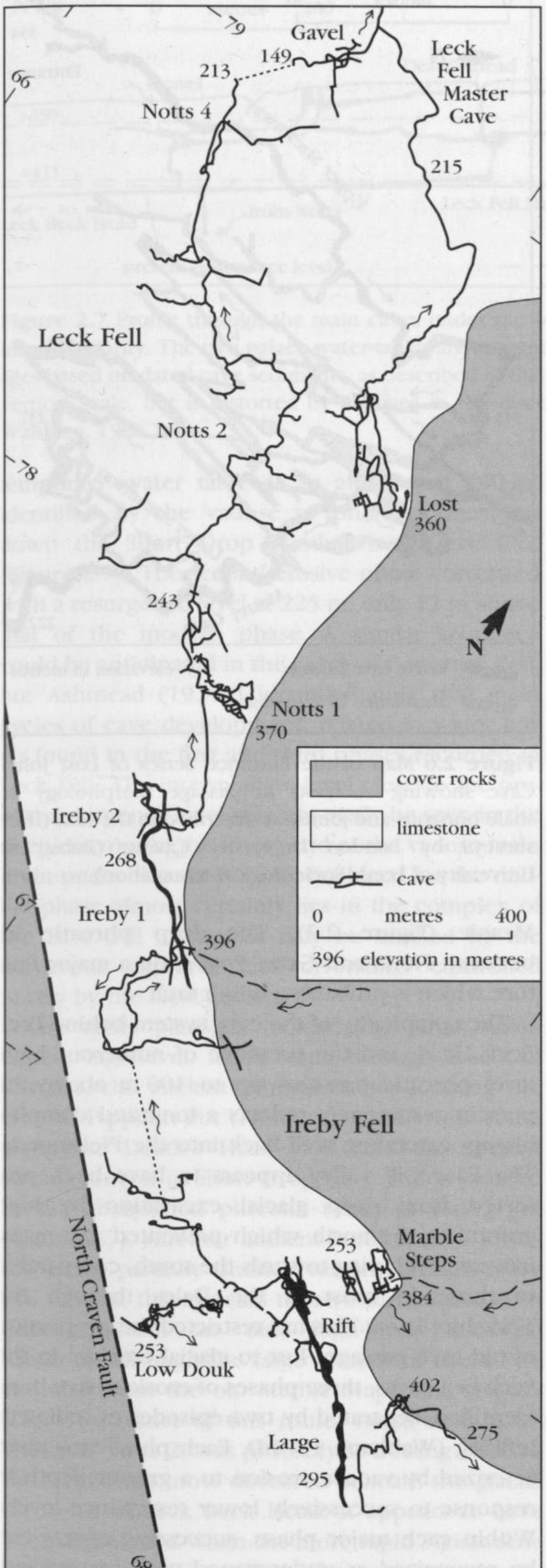
North of the Leck Fell Master Cave, the deep shafts of Big Meanie, Death's Head Hole and Rumbling Hole are developed on a single vertical fault. In Rumbling Hole the stream descends a series of cascades towards the east, to reach a long, narrow canyon tributary to, and cut below the same inception horizon as, the Master Cave. The shafts of Death's Head Hole and Big Meanie intercept an abandoned phreatic tube aligned on the fault. Extensive clastic fills block its old inlet from Rumbling Hole and its old outlet to the abandoned high levels of Gavel Pot. A small stream flows through it, from Long Drop Cave to a choked link to its inlet in the Master Cave below.

Absolute ages have been determined for calcite stalagmites and flowstone from Gavel Pot and Lost Johns Cave (Waltham and Harmon, 1977; Atkinson *et al.*, 1978, 1986; Gascoyne *et al.*, 1983a, b; Gascoyne and Ford, 1984). All sampled material proved to be either postglacial, <13 ka, or from a period of 140–85 ka spanning the Ipswichian interglacial and the early part of the Devensian.

Ireby Fell Cavern and Notts Pot

A major cave system with nearly 12 km of passages lies beneath Ireby Fell (Figure 2.6). It swallows two small streams at the entrances of Ireby Fell Cavern and Notts Pot, collects a large flow of percolation water, and drains out under Leck Fell. Ireby Fell Cavern has a fine meandering vadose canyon which descends a series of small shafts for more than 100 m to enter a large abandoned phreatic trunk passage more than 6 m in diameter. This is choked by sediment at both ends. Its stream is an underfit, which is ponded in the shallow sump into Ireby 2, before leaving the large old tunnel in a younger passage to the north. This follows a single bedding downdip, down a vadose canyon and then down a submerged tube to a phreatic lift up a fault into the lower galleries of Notts Pot. Higher levels of abandoned phreatic passages are known in both Ireby 1 and Ireby 2, connected to the lower levels by invading inlets, including the entrance passage. One small inlet has been dye tested from the abandoned high-levels in Rift Pot (Figure 2.6).

Notts Pot contains the most complex vertical maze of closely spaced, parallel shafts in any British cave. A small stream descends 120 m through this maze, cascading down routes which change when the flow is diverted by accumulations of clastic debris. Some high-level chambers and abandoned outlets are at similar levels to the Lyle Cavern high levels above the Leck Fell Master Cave. The shafts form the entrance series, known as Notts 1, which is merely an inlet to the drainage route beneath from Ireby Fell Cavern into Notts 2 (Figure 2.6). From the terminal sump of Notts 1, a phreatic loop drains into the long stream passage of Notts 2. The upstream end of this is a fine phreatic tube which can be followed for 700 m to a knickpoint, beyond which the stream descends in a narrow vadose canyon; the whole passage follows a single inception horizon downdip to the north-west. There are many tributaries, both active and abandoned, and the cave continues through further shallow phreatic loops into Notts 3 and Notts 4.



Underwater sediment chokes prevent progress downstream from Notts 4, into the continuation reached in the bottom of Gavel Pot. At least some of the flow appears to descend to depth, guided by unknown structural features, and then rise up a vertical flooded shaft in the Gavel Pot sump, forming a spectacular phreatic lift from a depth of 64 m. The top of the lift is on a bedding horizon just below water level, and a phreatic tube continues downdip to the north (Figure 2.2). The Gavel Pot stream joins it through a shaft in its roof, and the Leck Fell Master Cave joins it in a tube on the same horizon. It continues to a depth of 25 m where it is joined by the inlet from Pippikin Pot, and the continuation to Witches Cave remains unexplored.

Interpretation

Inception and development of the caves of Leck and Casterton Fells have proceeded within a framework of close controls imposed by geological structure and lithology. The role of bedding planes in directing underground flow is seen in the predominance of vadose passages draining down the dip to the north-west; these include the numerous inlet passages draining from sinks in the Ease Gill valley into the trunk drain of Ease Gill Caverns. The Leck Fell Master Cave, the main streamway in Notts 2–4, and the flooded conduit which takes both their flows to the submerged link with the Pippikin drain, all appear to be on the same bedding horizon. This is a spectacular example of a major inception horizon; the cave only leaves it in the deep, fracture-guided, phreatic loop which has its rising segment in the Gavel Pot sump (Figure 2.7).

Beneath Leck Fell many of the vadose stream caves follow constant stratigraphical horizons, and are guided in plan where they converge on trunk routes down the axial zone of a shallow, gently plunging syncline. The control which this fold has exerted on cave development is clearly seen

Figure 2.5 Outline map of the cave systems under the southern flank of Gragareth. Ireby Cavern and Notts Pot drain north into the Ease Gill Cave System, joining the water from the Leck Fell Master Cave, where the high-level passages in Lost Johns and Short Drop Caves have been omitted for clarity (see Figure 2.2); Marble Steps and Large Pot drain east to Keld Head (see Figure 2.8) (from surveys by Northern Pennine Club, Northern Cave Club and others).

where the Short Drop cave system lies directly above the Leck Fell Master Cave; both drain along the fold axis, aligned just north of west, and the drainage only converges after the high-level Short Drop stream has descended deep shafts on the joints in Gavel Pot. Where the Leck Fell Master Cave originally entered its contemporary phreas, it turned north, obliquely updip out of the synclinal trough. This created a shallow phreatic loop, only partially drained by subsequent rejuvenation and vadose entrenchment through the crest of the loop, creating the low airspace which exists today through the lake (Waltham, 1974d).

In similar style, a second shallow syncline appears to have collected the cave streams into its trough, along the line of both the Ease Gill Master Cave and the abandoned trunk passage directly above it. This is adjacent to an anticline down the line of the surface gill, south-east of which another syncline collects the drainage in Pippikin. Deeper synclinal troughs exert comparable controls over some passage locations in Bull Pot of the Witches and Aygill Cavern, adjacent to the Dent Fault. Elsewhere, the shale bands within the almost horizontal limestone influenced the development of the caves on distinct levels (Waltham, 1970), which were considered by Sweeting (1950) and Ashmead (1974b) to correlate with earlier base levels.

Fracture control of the passages and shafts is seen clearly in many parts of the cave system. Joint control is particularly well developed in the entrance series of Lost Johns Cave; the upper and lower streamways are developed along shale horizons, and a complex of active and abandoned rifts descend over 100 m between them, developed almost entirely on two intersecting systems of joints (Figure 2.6). The rifts were first partially opened by phreatic solution on the joints, far below the initial stream route which followed the upper streamway and then headed north, still following the shale beds in a continuation now totally blocked by sediment and flowstone. Rejuvenation prompted vadose drainage down through these rifts into a new streamway on the lower shale bed, and this captured the stream from above. The multitude of joints allowed frequent re-routing to form the parallel shafts and rifts seen today. The complex vertical maze of Notts Pot has also developed at the intersection of a number of joints and small faults. The influence of larger faults is clearly seen in the shafts and linear phreatic rifts and tubes along the fault through Rumbling Hole, Death's Head Hole and Big

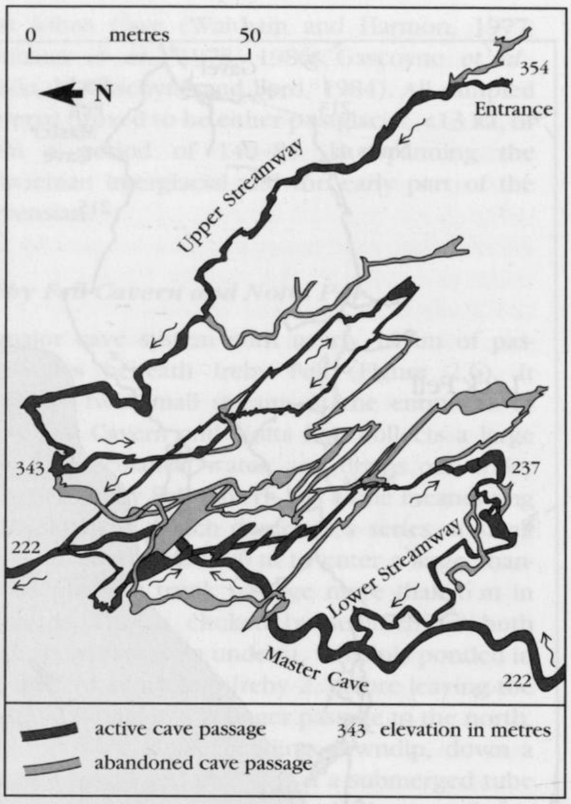


Figure 2.6 Map of the Entrance Series of Lost Johns Cave showing contrasts in passage morphology on shale horizons and joints, as described in the text (from surveys by London University Caving Clubs and University of Leeds Speleological Association).

Meanie (Figure 2.2). The deep phreatic lift between Notts and Gavel Pots is on a major fracture which is probably a minor fault.

The complexity of the cave system behind Leck Beck Head, and the presence of numerous high-level phreatic passages up to 100 m above the present resurgence, reflects a long and complex history extending well back into the Pleistocene. The Ease Gill valley appears to have been protected from deep glacial excavation by high ground to the north which prevented any major iceway developing towards the south, comparable to those in most of the Dales through the Yorkshire karst. This has restricted the proportion of old cave passages lost to glacial erosion. In the Leck Fell caves, three phases of erosion have been identified, separated by two episodes of sediment infilling (Waltham, 1974d). Each phase was characterized by vadose erosion to a greater depth in response to successively lower resurgence levels. Within each major phase, successive events can be recognized as underground captures evolved within the karst. The first erosive phase had a con-

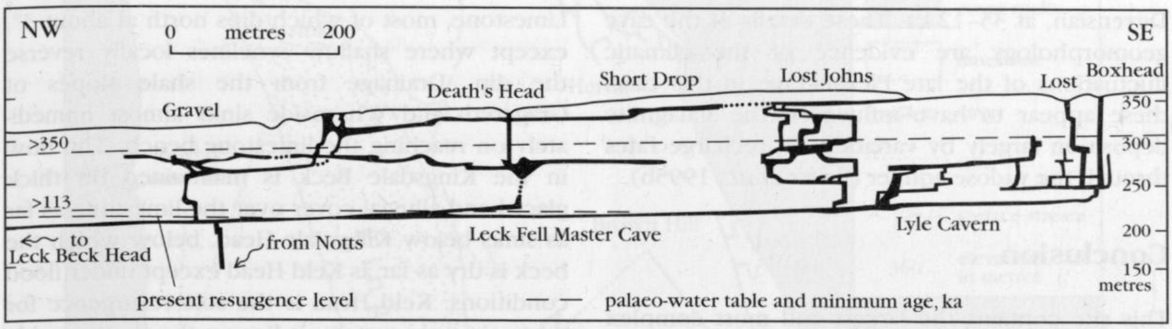


Figure 2.7 Profile through the main caves under the southern part of Leck Fell, with many passages omitted to improve clarity. The two palaeo-water tables are recognized from the cave morphology, and are ascribed minimum ages based on dated cave sediments, as described in the text. The horizontal scale is approximately the same as the vertical scale, but is distorted by changes in the direction of projection. (After Waltham and Hatherley, 1983; Waltham, 1986.)

temporary water table at an altitude of 290 m, identified by the vadose to phreatic transition down the Short Drop conduit into Gavel Pot (Figure 2.7). The second erosive phase correlated with a resurgence level at 225 m, only 12 m above that of the modern phase. A similar sequence could be anticipated in the caves of Casterton Fell, but Ashmead (1974b) identified only two main cycles of cave development, related to water levels found in the first and third phases recorded in Leck Fell. The intermediate level close to the present resurgence level may not easily be seen in the deep canyons at the lower end of the vadose main drain under Lancaster Hole. Evidence for the middle phase almost certainly lies in the complex of the Ease Gill inlets, but may be masked by the numerous captures and diversions controlled purely by the local geology.

The older passages include the large, abandoned, high-level, trunk route through Ease Gill Caverns, the ancient phreatic tubes forming the core of Pippikin Pot (Figure 2.2), the trunk route along the Death's Head fault, and the ancient stream canyon in Short Drop Cave which drained to the abandoned phreatic tubes of Gavel Pot (Figure 2.7). Another ancient conduit now forms the large, partially drained tunnel through Ireby Fell Cavern; this appears to have carried the main drainage from an old, high-level, ancestral Kingsdale through the large tunnels of Large Pot, and also from the old Marble Steps sink (Figure 2.5). The outlet of this route, north-west of its choke in Notts 2, was probably to a rising close to the Dent Fault, now obscured beneath the glacial till south of Leck Beck Head. It appears to have been abandoned when the more rapid Pleistocene deepening of Kingsdale, where it crosses the Craven Faults, diverted the flow to Keld Head.

By analogy with other sites, the abandoned, high-level, trunk caves under both Leck and Casterton Fells are likely to be at least half a million years old. Most of the dated stalagmites are much younger, from a major phase of deposition spanning 60–140 ka, though this included several long interruptions. Two flowstones from the high level in Ease Gill Caverns show only that this route was abandoned by 290–350 ka, and it was probably drained long before this. More significant are the flowstones in the Leck Fell Master Cave, which show that the resurgence was no more than 12 m above its present level at an age of about 115 ka. Since about 300 ka, the maximum rate of mean surface lowering in the Ease Gill Valley appears to have been only 0.2 m/ka (Waltham, 1986).

There are clear gaps in the recorded periods of calcite deposition within the caves, and there are also interruptions to the growth patterns in many sectioned samples. Calcite deposition was widespread during the Ipswichian interglacial, between 140 and 85 ka, but speleothem hiatuses show that the high-level main passage of Ease Gill Caverns was filled or flooded at least once between 200 and 140 ka. Detrital layers also show that deposition was interrupted, probably by flooding, in the Lyle Cavern high-levels between 128 and 123 ka. Baker *et al.* (1995b) have found a remarkably good correlation between the timing of speleothem growth in Lancaster Hole and periods of maximum solar insolation during the last 130 ka; the main periods of deposition were at about 130, 85 and 60 ka. Erosion of speleothems indicates that the lower part of the caves was again in the phreatic zone between 85 and 38 ka, and there was major flooding and reworking of the cave sediments during the latter part of the

Devensian, at 35–12 ka. These details of the cave geomorphology are evidence of the climatic fluctuations of the late Pleistocene; in this case, these appear to have influenced the stalagmite deposition largely by variations in recharge rates through the vadose aquifer (Baker *et al.*, 1995b).

Conclusion

This site contains the largest and most complex dendritic cave system in Britain, containing splendid examples of almost every type of cave morphology. The caves exhibit a clear influence by a variety of geological factors. The evidence from cave morphology, configuration, sediment and speleothem content is extremely important in studies of the Pleistocene history of the northern Pennines.

KINGSDALE CAVES

Highlights

The long and deep, dendritic cave system under Kingsdale contains four drainage routes which have been followed and mapped for the whole way from their sinks to the single resurgence. These include influent caves on both sides of the deep glaciated valley, and one trunk route passes completely beneath the valley floor. The lowest level of the cave system include the longest series of submerged passages known in Britain.

Introduction

Kingsdale is one of the smaller of the Yorkshire Dales, cut into the limestone due north of Ingleton (Figure 2.1). It is notable for the very fine caves which lie under the limestone benches of both flanks and also beneath the valley floor, many of which are connected into a single underground drainage system feeding the resurgence of Keld Head. Kingsdale is a straight, glaciated trough descending gradually from the north towards the scarp of the Craven Faults. The valley is floored by clastic sediment up to 20 m thick, deposited as an alluvial sheet grading into the lake sediments which accumulated behind a late Devensian retreat moraine; this barrier lies at the southern end of the dale, and is breached by a postglacial ravine.

The Kingsdale trough is cut into the Great Scar Limestone, most of which dips north at about 3°, except where shallow synclines locally reverse the dip. Drainage from the shale slopes of Gragareth and Whernside sinks almost immediately on reaching the limestone bench. The flow in the Kingsdale Beck is maintained on thick glacial and alluvial cover over the limestone as far as sinks below Kingsdale Head, below which the beck is dry as far as Keld Head except under flood conditions. Keld Head is the sole resurgence for the main cave system; it lies on the western side of the alluviated valley floor, close to the base of the limestone.

Comprehensive descriptions of the Kingsdale caves include those of West Kingsdale by Brook and Crabtree (1969a) and Brook (1971b), of the flooded passages behind Keld Head in Monico (1995), of some of the East Kingsdale caves by Gascoyne (1973), of Rift Pot by Davies (1984) and of all the cave passages in Brook *et al.* (1994). The development of Kingsdale and its caves has been discussed by Brook (1969, 1971b, 1974a), and Waltham *et al.* (1981). The chronology of the cave and valley development was discussed in the light of dated cave sediments by Waltham and Harmon (1977), Atkinson *et al.* (1978) and Waltham (1986), and further dates were published by Gascoyne *et al.* (1983a, b) and Gascoyne and Ford (1984). Aspects of the geology and geomorphology of the caves have been discussed by Waltham (1970, 1971a, 1974c), Lowe (1992b) and Halliwell (1979b).

Description

More than 35 km of passages have been mapped in the cave systems beside and beneath Kingsdale. The cave passages fall into four groups: the largely integrated caves of West Kingsdale, the influent caves under the eastern bench of Kingsdale, the submerged conduits in the phreas behind Keld Head, and the more isolated caves to the west around Marble Steps Pot.

West Kingsdale Cave System

The dry weather flow of Kingsdale Beck is lost into choked sinks near the head of the glacial trough, and is next seen in an active phreatic conduit east of Rowten Pot (Figure 2.8). This follows the bedding updip, into a partially drained series of canals, and then into the head of the West Kingsdale Master Cave. This is a splendid vadose

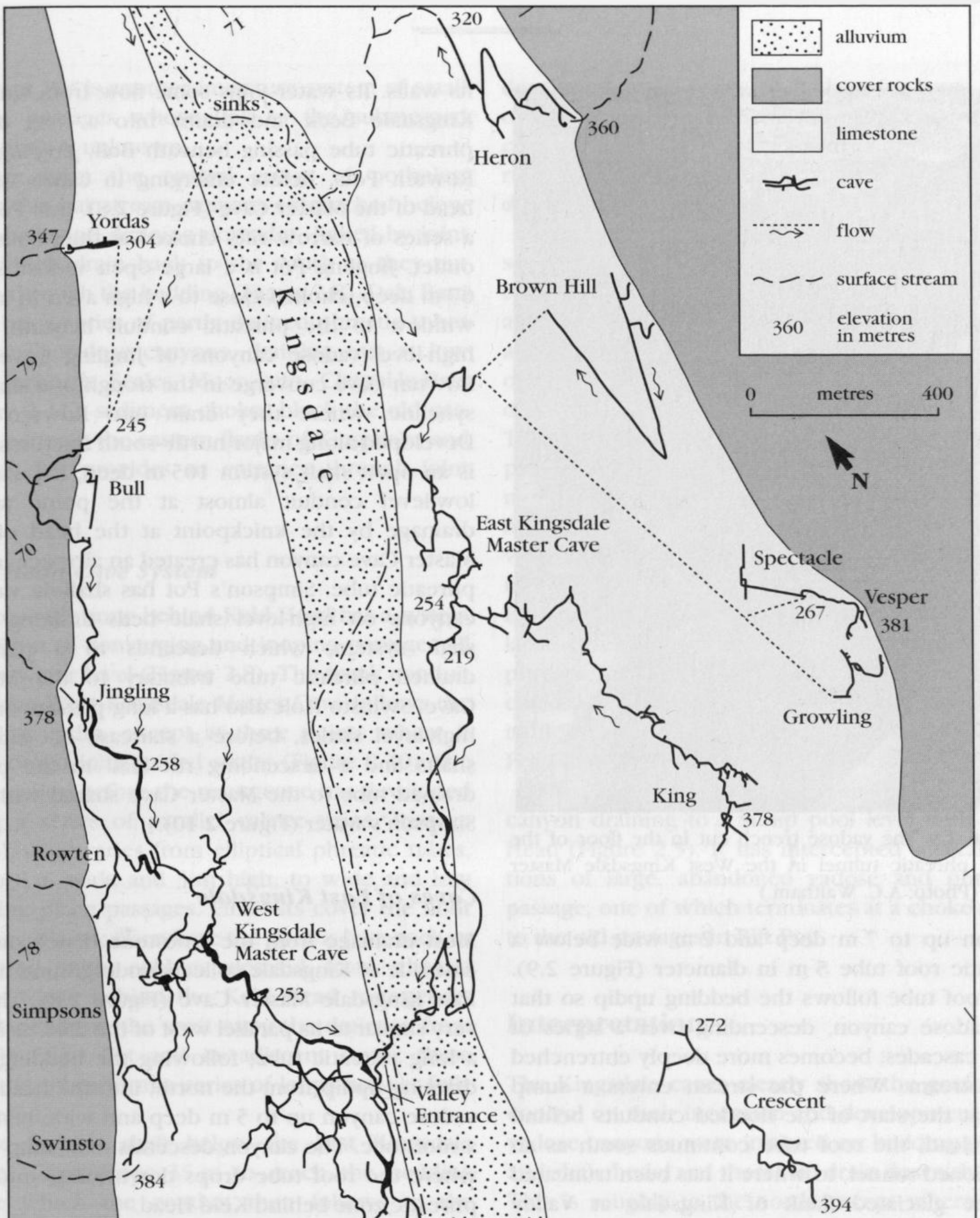


Figure 2.8 Outline map of the caves of Kingsdale. These include 7.5 km of caves behind Keld Head, at the southern end of the system and beneath the valley floor, which are totally flooded (from surveys by University of Leeds Speleological Association, Cave Diving Group and others).

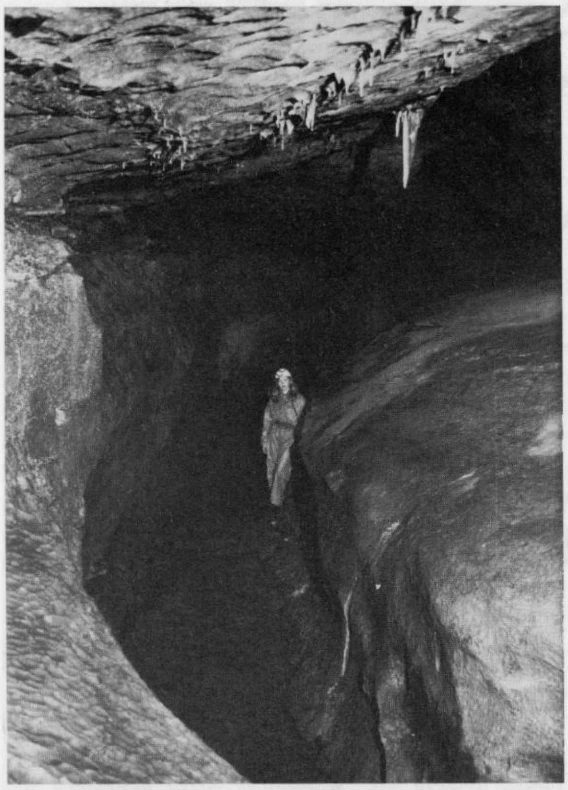


Figure 2.9 The vadose trench cut in the floor of the broad phreatic tunnel in the West Kingsdale Master Cave. (Photo: A.C. Waltham.)

canyon up to 7 m deep and 2 m wide below a phreatic roof tube 5 m in diameter (Figure 2.9). The roof tube follows the bedding updip so that the vadose canyon, descending over a series of small cascades, becomes more deeply entrenched downstream. Where the stream enters a sump pool at the start of the flooded conduits behind Keld Head, the roof tube continues south as an abandoned tunnel, to where it has been truncated by the glaciated flank of Kingsdale at Valley Entrance. Flowstone from the Roof Tunnel has been dated at 320–168 ka, but not yet with enough detail and accuracy to ascribe it to a sequence of Pleistocene stages. Divergent, abandoned tubes extend west of Valley Entrance, and intercept one vadose inlet well decorated with calcite speleothems, before becoming choked.

The main conduit beneath West Kingsdale is joined by inlets from a line of sinks along the shale margin on the limestone bench which stands 60–130 m above the dale floor. The most northerly of these is Yordas Cave, where a stream cascades down a series of rifts into the Main Chamber, 55 m long and 15 m wide, containing remnants of calcite-cemented sediments high on its walls. Its water joins some flow from sinks in Kingsdale Beck and drains into a long active phreatic tube passing beneath Bull, Jingling and Rowten Pots, before emerging in canals at the head of the Master Cave (Figure 2.8). Bull Pot has a series of narrow rifts choked at their southern outlet. Jingling Pot is a large open vadose shaft, 67 m deep, choked close to a high aven in a roof window to the phreatic conduit beneath. The high-level vadose canyons of Jingling Cave and Rowten Cave converge in the trough of a shallow syncline, where they drain into Rowten Pot. Developed along major north–south fractures, this is an open shaft system 105 m deep; it joins the low-level conduit almost at the point where drainage by the knickpoint at the head of the Master Cave canyon has created an airspace in the phreatic tube. Simpson's Pot has shallow vadose canyons on high-level shale beds draining to a shaft system, which descends to a partially drained phreatic tube tributary to the Master Cave. Swinsto Hole also has a long passage on the high-level shales, before a staircase of waterfall shafts and a descending rift lead to the partly drained tube to the Master Cave shared with the Simpson's water (Figure 2.10).

Caves of East Kingsdale

Most drainage from the limestone bench on the east side of Kingsdale collects underground in the East Kingsdale Master Cave (Figure 2.8). This is very similar to its parallel west of the dale, as it has a long phreatic tube, following the bedding and draining updip from the north, into the head of a vadose canyon up to 5 m deep and wide beneath a roof tube. The canyon descends to a sump pool where the roof tube drops down joints into the phreatic zone behind Keld Head.

On the limestone bench above, Brown Hill Pot has descending rift passages draining to the south, against the dip, along a major fracture; a flooded tube then drains north from a sump pool level with its outlet in the Master Cave (Figure 2.8). The flooded conduit upstream from the Master Cave has a branch carrying water from choked sinks in the floor of Kingsdale. Spectacle, Vesper and Growling Pots all have short passages on high-level shale beds, and deep shafts on fractures which descend to chokes close to the Master Cave level. King Pot has a long sequence of small shale-guided, downdip canyons, shafts and narrow rifts descending 120 m to a drained phreatic tube which joins the roof tube of the Master Cave.

Crescent Pot is another immature system of small stream passages whose link to the submerged main drain is unknown.

Away from the central group of potholes, Heron Pot has stream canyons entrenched below shale beds and draining downdip, linked by joint rifts which drain back to the south as they cut down through the bedding (Figure 2.8). Dale Barn Cave has a series of partly drained phreatic tubes and small vadose canyons, draining east at low level beneath Scales Moor into Chapel-le-Dale (Figure 2.11); sediment chokes block the old passages beneath the eastern flanks of Kingsdale, and Illusion Pot provides an entrance through joint rifts.

Keld Head Cave System

The phreatic zone behind Keld Head has a system of 7.5 km of converging and looping passages all below water level (Figure 2.8). The trunk conduit from the West Kingsdale Master Cave follows the bedding updip, except at three points where it steps down joint-guided shafts (Figure 2.10); the final section before the resurgence has developed along a series of parallel calcite veins. Passage morphology varies from elliptical phreatic tubes, up to 8 m wide and 3 m high, to wide and low bedding plane passages. Fine silts cover the floor in many places; elsewhere the floor is bare rock or scattered with cobbles derived from choked inlets. Close behind the Keld Head resurgence, tributaries from the west carry the drainage from Marble Steps Pot and its adjacent caves; these phreatic tubes form a series of loops not yet fully explored.

The flooded shaft below the East Kingsdale Master Cave drops 35 m to reach the bedding plane which the conduit then follows to the south-west, to connect with the main Keld Head phreas (Figure 2.8). This passes beneath Kingsdale in the 20–30 m of limestone that remains between the glaciated rockhead and the underlying basement rocks.

Caves of the Marble Steps area

The southern slopes of Gragareth, west of Kingsdale (Figure 2.1) are underlain by cave passages including those of Marble Steps Pot, whose streamways drain to Keld Head. Marble Steps Pot is a massive sinkhole which swallows a large moorland stream in times of flood (Figure 2.5). An upper series of chambers, rifts and shafts are developed on a series of hading fractures, and contain extensive fluvioglacial sediments which choke their outlet. A series of smaller, joint-guided rifts and shafts further to the south-west drop to a deep flooded rift at the same level as Keld Head.

Large Pot has a small streamway descending a series of immature vadose rifts and vertical shafts to a sump, which also drains to Keld Head. An abandoned distributary extends south to meet another streamway, which drains through a series of narrow rifts to a magnificent circular shaft 46 m deep into the large, old chamber of Necropolis. This is a section of abandoned, phreatic, trunk passage containing thick banks of clastic sediments. It continues north-west, beyond a series of boulder chokes, into another large chamber which can be reached by a 60 m deep shaft from the narrow entrance rifts of Rift Pot (Figure 2.5). Passages heavily choked with sediment and collapse extend westwards to intercept another old phreatic trunk route 3–4 m in diameter. This is choked in both directions, but a stream sinking in its floor has been dye tested to an inlet in Ireby Fell Cavern.

Low Douk Cave has a meandering vadose canyon draining to a sump pool level with Keld Head (Figure 2.5). It has intercepted several sections of large, abandoned vadose and phreatic passage, one of which terminates at a choke close to the old passages in Rift Pot.

Interpretation

The Kingsdale caves clearly show the geological control on their inception and development. The vadose canyons were initiated on bedding planes and shale beds, and therefore drain down the dip. This is roughly to the north except where local folding is stronger than the regional dip around Rowten and Simpson's Pots. Canyon streamways converge in the troughs of two shallow synclines, before finding fractures which allow them to drop to lower levels (Waltham, 1970). Most phreatic trunk passages are also developed along the bedding, except where they gain depth by dropping down joints to reach lower bedding planes. They then drain gently updip, following the hydraulic gradient to the south towards the lower ground and lower resurgence sites. Most of the bedding planes, which were the inception horizons for the caves, contain thin beds of shale; these are seldom seen in surface exposures, but their stratigraphical distribution underground adds an extra component to interpretations of cyclicity in the limestone deposition, and also accounts for levels of cave development unrelated to erosion levels (Waltham, 1971a, b).

Joints have determined the location of many cave passages, including the series of rifts in Marble Steps Pot and the zig-zag course of Heron Pot. The large vadose shafts and rifts in the potholes of East Kingsdale are developed on faults; many other shafts, including the sequence in Rowten Pot, are aligned on joints, which allow streams collected on the higher shale beds to drop down to the level of the main phreatic trunk passage. Joints have also influenced the phreatic flows, notably within the Keld Head phreas, where the passages drop down joint-guided shafts to lower bedding planes.

The section of the West Kingsdale Cave System between Swinsto Hole and Keld Head has been proposed as the type site for cave development in the Yorkshire Dales karst (Waltham *et al.*, 1981). The route from sink to rising is completely explored and mapped, and contains all the main types of cave passage: a vadose canyon drains downdip on shale beds, to shafts and a rift on joints, through old caves just below an ancient water table, down into a partially drained phreatic zone with canyons entrenched in tube floors, and into an active phreatic conduit largely updip on the bedding (Figure 2.10).

The sequences of abandoned high-level passages show that the Kingsdale caves have had a long history extending well back into the Pleistocene. Their development is linked to that of the adjacent Ease Gill caves, and to the fluvial and glacial excavation of the Kingsdale valley.

The oldest cave passage in Kingsdale appears to be the large abandoned phreatic conduit through the lower levels of Large and Rift Pots; it is likely that Marble Steps Pot was a major tributary sink into these passages. For much or all of their history, they drained to the north-west, through Ireby Fell Cavern, to an ancient resurgence in the lower Ease Gill valley. During subsequent glacial episodes, these passages and their resurgence have been largely or wholly choked with glaciofluvial clastic sediment. Parts of this trunk route were later invaded by smaller vadose streams, which now drain through lower outlets to both Keld Head and Leck Beck Head. This cave carried water sinking in an immature proto-Kingsdale whose floor was still well above the 300 m level of the passage in Large Pot. There were also inlet caves from sinks along the shale margin around Kingsdale, but only fragments of these abandoned passages are now seen at high levels intersected by the modern stream caves. It is conceivable that an even earlier stage had underground drainage from Gragareth feeding to a resurgence in Chapel-le-Dale, which is a much lower and older valley. If this route existed, the Rift–Large passage first carried a flow to the south-east, and the downstream conduits have either been eroded away by surface retreat on Twisleton Scar End, or remain undiscovered beneath Scales Moor.

During the Pleistocene Ice Ages, Kingsdale carried a major ice flow from the north and was deepened much more rapidly than the sheltered Ease Gill valley. The outlet to the Ease Gill resurgence was therefore abandoned in favour of new resurgences where the entrenched Kingsdale approached the Craven Fault scarp (Figure 2.1). The enlarged limestone catchment around the deeper Kingsdale supplied drainage to the developing low-level trunk routes, which are still at the core of the cave system. The sequence and levels of the resurgences in Kingsdale are largely unknown, but one old outlet was subsequently truncated at the Valley Entrance by deepening of the glacial trough. A later, lower route was out through Keld Head. Either or both of these truncated conduits could have continued beneath Scales Moor, perhaps through parts of Dale Barn Cave (Figure 2.11). Truncation by the side of the dale at Keld Head rejuvenated the first fractures upstream to rise above the new lower outlet level – and the West and East Master Caves were entrenched by knick-point retreat in the two main conduits.

Calcite flowstone from the Roof Tunnel, inside the West Kingsdale Valley Entrance, has been dated to 168, 230 and 239 ka (Gascoyne and Ford, 1984; Waltham, 1986). These indicate that this passage was abandoned and the outlet to Keld Head was active by late Hoxnian times, if not before. This then implies that there was very little glacial deepening of Kingsdale in the post-Hoxnian and Devensian stages. The glacial trough is fresh and uneroded, but its large lateral and retreat moraines may indicate that there was more deposition than erosion during the Devensian. The caves would have been flooded or inactive while ice occupied Kingsdale, and the low levels were temporarily flooded when the lake was impounded behind the retreat moraine. A more detailed chronology of the successive deepening of Kingsdale and the evolution of its caves cannot yet be established.

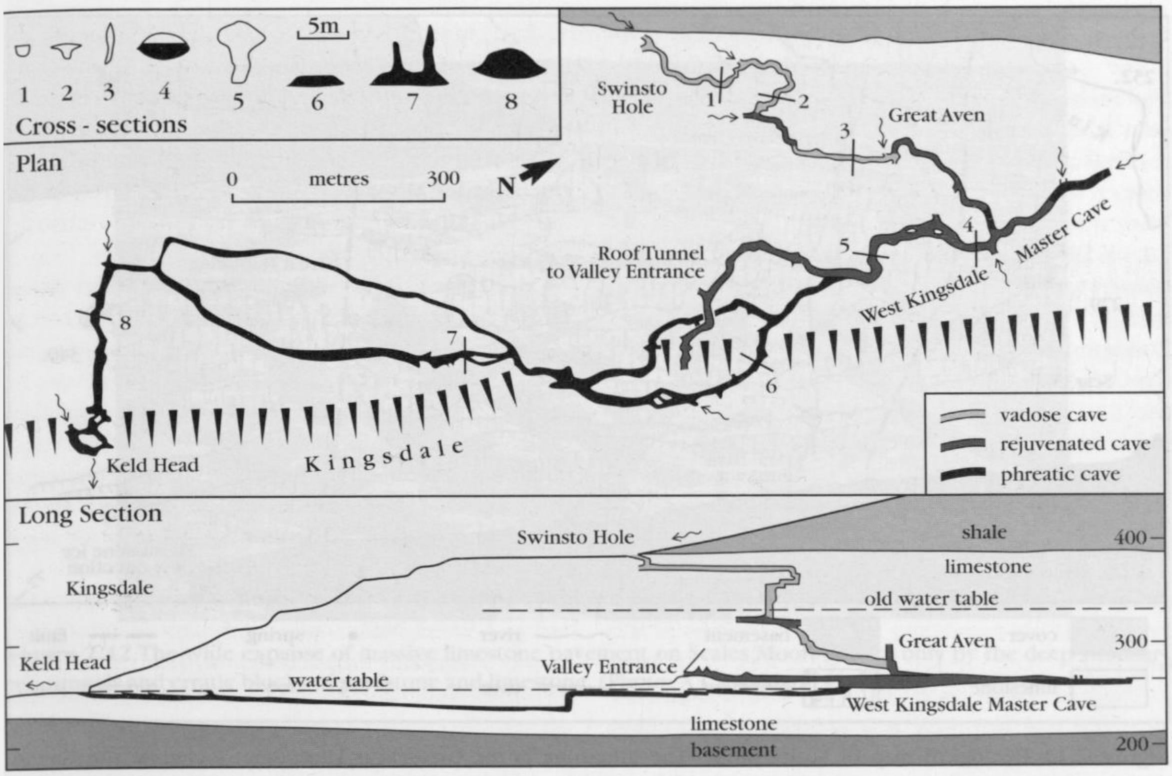


Figure 2.10 Swinsto Hole to Keld Head, the type example of a Yorkshire Dales cave, and part of the Kingsdale cave system. Only the main passages along the underground drainage route are shown; there are additional vadose inlets, abandoned passages and phreatic loops. The vertical scale of the long section is exaggerated by a factor of 1.5. (Mainly after Waltham *et al.*, 1981.)

The history of Dale Barn Cave is unclear, and there are old abandoned passages at both ends of the system which relate to early phases of the drainage of both dales. The main passage is at low level, and appears to represent recent drainage from Kingsdale towards a lower resurgence in Chapel-le-Dale, when the latter was deepened more rapidly by larger ice flows in the Devensian and perhaps earlier glaciations.

Conclusion

The caves of Kingsdale include the drainage route from Swinsto Hole through to Keld Head; this contains elements of vadose, phreatic and rejuvenated passages, and is completely mapped from sink to rising; it is the type example of cave development in the Yorkshire Dales. The 24 km of cave passages include a conduit which passes beneath a major valley, and the 7.5 km within the active phreas constitute the longest flooded cave system known in Britain.

The caves also represent past and present drainage links between Kingsdale and its neighbours, Chapel-le-Dale and the Ease Gill valley, and these provide evidence of the contrasting glacial histories of the three valleys.

SCALES MOOR

Highlights

Extensive limestone pavements on the limestone bench of Scales Moor, overlooking Chapel-le-Dale, are among the finest examples of horizontal pavements in Britain, and include some massive, undissected clints. Below the bare limestone plateau, Twisleton Scars form excellent sequences of terraces, scars, screes and pavements. Deep beneath the plateau, Dale Barn Cave carries drainage from Kingsdale through to Chapel-le-Dale.

Introduction

The Scales Moor pavements lie on the main limestone bench between the southern shoulder of

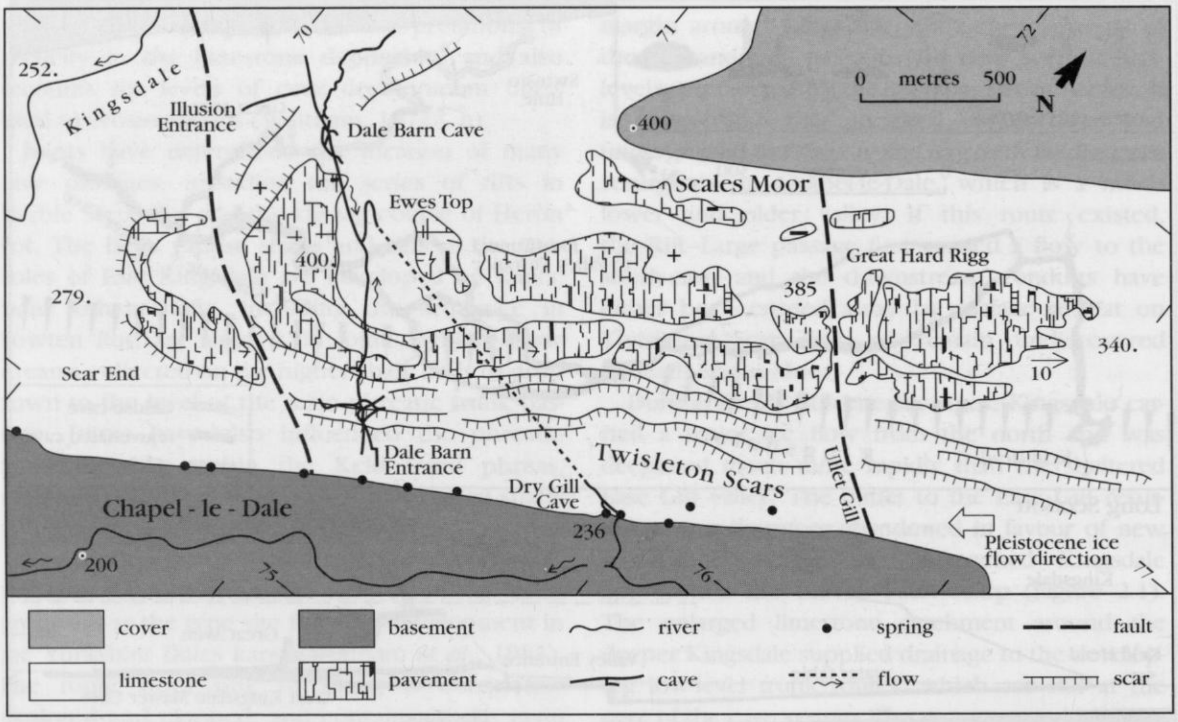


Figure 2.11 Geological map of Scales Moor. The limestone is the Great Scar Limestone, including the Hawes Limestone. Cover rocks are mainly clastic units in the Wensleydale Group. Basement rocks are Palaeozoic slates and greywackes. Only the larger areas of pavement are marked, and there are thin strips of pavement along the crest of nearly all the scars. Dale Barn Cave lies close to the base of the limestone, about 150 m below the main limestone pavements (cave survey from Northern Cave Club).

Whernside and the glaciated trough of Chapel-le-Dale (Figure 2.1). With a width of 800 m over a length of nearly 4 km, the bench constitutes one of the largest areas of nearly level limestone outcrop in the Yorkshire Dales karst. Most of its top surface stands at an elevation of just under 400 m, where it is formed on the top beds of the Great Scar Limestone. These are strong, massively bedded, sparry, bioclastic limestones; they are almost horizontal across most of the site, but north of the Ullet Gill fault they dip about 10° north-east (Figure 2.11). Drainage is entirely underground but the only known caves are close to the base of the limestone.

The morphology and solution processes on both the pavements of Scales Moor and the terraces of Twisleton Scars were studied and described at length by Sweeting (1966). Subsequent morphometric studies were carried out by Goldie (1973), and the glacial history of Chapel-le-Dale has been assessed in the light of dated sediments from its adjacent caves (Atkinson *et al.*, 1978; Waltham, 1986, 1990). Dale Barn and the various other caves are described by Brook *et al.* (1994) and Gascoyne (1973).

Description

From Ewes Top to Great Hard Rigg, Scales Moor contains wide expanses of bare limestone, littered with erratic boulders of locally derived limestone and sandstone; there are belts of acidic grassland, but the plateau is devoid of tree or shrub vegetation. On the main pavements, this empty rock landscape is very dramatic (Figure 2.12), but the panoramas soften towards the southern tip at Scar End, where terraced pavements drop to lower levels and are slightly better vegetated in the shelter below the main plateau.

Variations in the pavement surfaces were mapped by Sweeting, who recorded much of the northern part of Scales Moor as a very flat, glacially scoured pavement, dissected by few grikes and very few solution runnels (Sweeting, 1966). Further south much of the bench surface has more mature limestone pavement, with its surface morphology dominated by large clints, deep grikes and excellent runnel development of large rounded rundkarren. Many clints have centripetal runnel systems converging on small potholes which puncture the horizontal limestone surfaces.

Figure 2.12 The wide expanse of massive limestone pavement on Scales Moor, broken only by the deep rundkarren runnels and erratic blocks of sandstone and limestone. (Photo: A.C. Waltham.)

There are some very large clints on Scales Moor, with the average lengths in some sample sites exceeding 5 m (Goldie, 1986). The largest clints occur in the pavements just north and south of the Ullet Gill fault, and smaller clint sizes typify the areas south of Ewes Top. This is clearly a function of the spacing of tectonic joints in the limestone, and the southerly decrease may be related to the approach towards disturbed ground along the North Craven Fault (Figure 2.1). Not all these clints are truly massive, as some have a distinctly flaggy top clint while retaining large lateral dimensions. Some pavements at Ewes Top show lamellar weathering of the clints, giving them a flakey appearance, and other clints display honeycomb weathering, especially on their most exposed aspect (Sweeting, 1966).

Twisleton Scars forms a remarkable staircase of rock terraces, descending 150 m from the plateau rim to the base of the limestone, just above the valley floor (Figure 2.11). They form a spectacular sequence of limestone scars, each with an apron of scree along its foot; each scree overlaps onto a veneer of discontinuous glacial till, which has a soil cover and is punctured by small subsidence dolines (shakeholes). The till thins out onto a strip of pavement along the crest of the next scar (Sweeting, 1966). The scars are between 2 m and 15 m high, probably reflecting the spacing between thin shale beds which eased glacial plucking of the overlying beds. Alternatively, the terraces and pavements may have formed simply on the stronger limestone beds, but these commonly underlie the thin shale horizons within the lithologically varied limestone sequence (Schwarzacher, 1958; Waltham, 1971b; Ramsbottom, 1973). Clint dimensions on the terraces are generally 0.8–2.9 m (Goldie, 1976), and there is some tree and shrub cover in the more sheltered sites.

There is no surface drainage on Scales Moor. Rainfall runs into the deep grikes, but after heavy rain streams can be heard and occasionally seen flowing down the bedding planes 1–3 m below the surface of the inclined pavements of Great Hard Rigg. Ultimately all the water finds joints to descend to greater depths. Much of it resurges from the well defined spring line along the base of the limestone (Figure 2.11), but water in the dipping limestone probably flows north-east to join the main drains feeding God's Bridge (Figure 2.13). Dale Barn Cave lies very close to the base of the limestone. Streamways from the two entrance areas carry water from both Kingsdale and Chapel-le-Dale to a confluence almost directly beneath the topographic divide, and then drain to the Dry Gill resurgence (Figure 2.11). Abandoned passages occur above all three entrance areas, mostly at levels no more than 15 m above the streamways.

Interpretation

The main plateau surface of Scales Moor is formed on the top of the Great Scar Limestone at an altitude of about 400 m. It is clear that much of the surface is a stratimorph (Waltham, 1970), as it follows the dip down the inclined pavements north of the Ullet Gill fault. The main horizontal bench also forms part of a conspicuous erosion surface, widely recognized in the Yorkshire Dales (Sweeting, 1950). Present opinion tends towards the lithological explanation of the gross form of the limestone benches in the Dales, and glacial scour has been clearly the dominant process in the most recent stripping of the Scales Moor pavements (Waltham, 1990). Ice flowed from the north-east and was powerfully erosive as it swept up the dipping slabs and then across the horizontal limestone, even though the glaciated trough of Chapel-le-Dale must have acted as an adjacent ice-way.

The most striking areas of pavement on Scales Moor are on the more massive limestones where they were subjected to the most intensive glacial scour, but the solutional features are dominated by rounded rundkarren, whose origins relate to past covers of soil and vegetation. Over many years the position of the contact line between bare limestone and vegetation cover was monitored on a terrace-top site on Twisleton Scars (Sweeting, 1966). After 13 years the grass cover had advanced slightly over the inner part of the pavement, outwards from the till and scree below the upper scar. Rock exposure in the centre of the pavement was unchanged, but the grikes had increased vegetation, and soil depth within them had locally increased by as much as 100 mm.

On Scales Moor, Sweeting (1966) observed limestone surfaces cleared of drift with rock hollows over 800 mm in diameter containing erratics 500–600 mm across. These depressions appear to have existed before the erratics were deposited in them, and were therefore formed before the last glaciation; the implication is that some of the grikes may have a preglacial component to them, and merely continued to evolve since the Devensian glaciation. There is no evidence to support the alternative concept that the hollows were enlarged by solution beneath the drift. An area of limestone freshly exposed in 1947 was re-examined in 1960 having been subject to solutional attack by peaty water (Sweeting, 1966). Some parts of the exposed surface had been lowered by 30–50 mm in this period. At another test site on Scales Moor, solution runnels 70–150 mm deep had been cut into the limestone by waters coming off a peat slope for 13 years. Mean solution rates measured in the area over a wide range of local conditions extrapolate to indicate about 500 mm of surface lowering in the last 12 000 years; the enormous local variations within this average account for the variety of pavement morphology.

The pavements of Scales Moor suffered modification through the mechanized removal of clints during the 1960s, and surface limestone was used to build sheep folds and other structures in earlier periods (Goldie, 1976). Known areas of clint removal on Scales Moor became well vegetated with moorland grasses within the following ten years. Scales Moor is also heavily grazed by sheep, which help to confine tree and shrub vegetation to the grikes.

Little is known of the cave drainage beneath most of Scales Moor. Infiltration through the pavements probably descends rapidly to lateral conduits near the base of the limestone; high avens do feed water into the Dale Barn streamways. Patterns of flow are difficult to predict in the horizontal limestones, but drainage occurs from Kingsdale because its floor is nearly 50 m above the level of the base of the limestone exposed in Chapel-le-Dale. Except for some truncated fragments in Ullet Gill, there are no known relict caves at high levels under the fell, though some may have been removed when Twisleton Scars were cut back by the Chapel-le-Dale glaciers.

Conclusions

Scales Moor has some of the finest examples of level and gently inclined, little dissected limestone pavements in Britain. Both on the plateau and in the scar sequences, there is a wide variety of pavement types related to glacial plucking and varying joint densities. The karst has been an important research site, yielding data on solution rates, erosion processes and vegetation changes, with wide implications on glaciokarst studies in Britain and elsewhere.

INGLEBOROUGH KARST

Highlights

A broad limestone bench surrounding the summit mass of Ingleborough constitutes Britain's finest single area of glaciokarst. It contains spectacular limestone landscapes, which have an unparalleled scale of surface and underground karstic development. Ingleborough has virtually every type of karst feature, and is one of the best documented and most visited karst areas in Britain.

Introduction

The Ingleborough benches form a triangular block of limestone nearly 10 km across, bounded by the glaciated troughs of Ribblesdale and Chapel-le-Dale and by the Craven Fault scarp across the south-west (Figure 2.1). An outlier of sedimentary rocks dominated by shale forms the summit mass, which rises as one of the well known Three Peaks above the limestone plateau of the Craven Uplands. The summit reaches an altitude of 723 m, the top surface of the gently sloping limestone bench lies at 350–440 m, and base level in the dale floors is at about 220 m. Ingleborough forms a magnificent limestone landscape of wild open country, containing an impressive range of splendid glaciokarstic and fluviokarstic landforms. Its conservation values are regarded as a special case within the Yorkshire Dales National Park, and the whole mountain is designated as a Site of Special Scientific Interest for its geological and biological features.

Ingleborough is remarkable for the excellence of both its surface and underground karst landforms. Within any mature karst landscape, the processes and evolution of the cave drainage systems are totally interrelated with the progressive development of the surface topography, and they should be viewed together. The sheer scale and significance of the geomorphological interest in the Ingleborough karst dictates that its description and interpretation are subdivided, and separate reviews of the surface karst and the caves are more appropriate than a geographical subdivision. The caves are described in the next section.

Geologically, Ingleborough lies on the upstanding southern edge of the Askrigg Block, bounded to the south by the Craven Fault system which separates it from the Craven lowlands. The main karst is formed on the Dinantian Great Scar Limestone, consisting of nearly 200 m of pale grey, fine-grained, bioclastic limestones (Hughes, 1909; Moseley, 1973; Doughty, 1968). There is considerable local variation in the carbonate lithology, and individual beds are mostly 0.5–5.0 m thick, commonly separated by thin partings of shale. The limestone is well jointed, has a high secondary permeability and is well karstified; it generally dips a few degrees to the north. Above the limestone, the summit outlier consists of the cyclic sequences of interbedded shales, sandstones and thin limestones of the Yoredale facies of the Brigantian Wensleydale Group. Ordovician and Silurian slates, mudstones and greywackes form the basement to the karst aquifer. They lie beneath a strong unconformity, which is exposed in the floors of Chapel-le-Dale, Clapdale, Crummack Dale and Ribblesdale.

The diversity of karst features on Ingleborough has prompted a long history of research, of which the earlier work is reviewed by Halliwell (1974). The geology of the area has been described by Garwood and Goodyear (1924), Dunham *et al.* (1953), Rayner (1953), Wilson (1974), Waltham (1974b), Arthurton *et al.* (1988) and many others. Further research on the Great Scar Limestone includes that by Schwarzacher (1958), Sweeting and Sweeting (1969), and Waltham (1971b), and the Yoredale beds were described by Hicks (1959). The karst geomorphology of Ingleborough is reviewed by Sweeting (1950, 1966, 1974) and Waltham (1970, 1990), Waltham and Davies (1987) and Waltham and Tillotson (1989); the various erosion levels were further described by Trotter (1929), Hudson (1933), King (1969) and Clayton (1966, 1981). Dating of stalagmites from some of the caves has provided limited evidence for the rates of valley entrenchment and the chronology of geomorphic evolution of Ingleborough (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1983a, b; Gascoyne and Ford, 1984; Waltham, 1986).

Description

The diversity of the karst landforms on Ingleborough is due in large part to geomorphic contrasts produced by the patterns of the Pleistocene glaciations; the ice scoured and eroded some of the limestone outcrops, while protecting and burying others beneath till. During each cold stage of the Pleistocene, ice moved from the north, and the main flows diverged around Ingleborough to continue down Chapel-le-Dale and Ribblesdale. During the glacial maxima, ice covered the entire landscape, and the two dales were iceways beneath an ice sheet which spread over and scoured the limestone benches. During advance

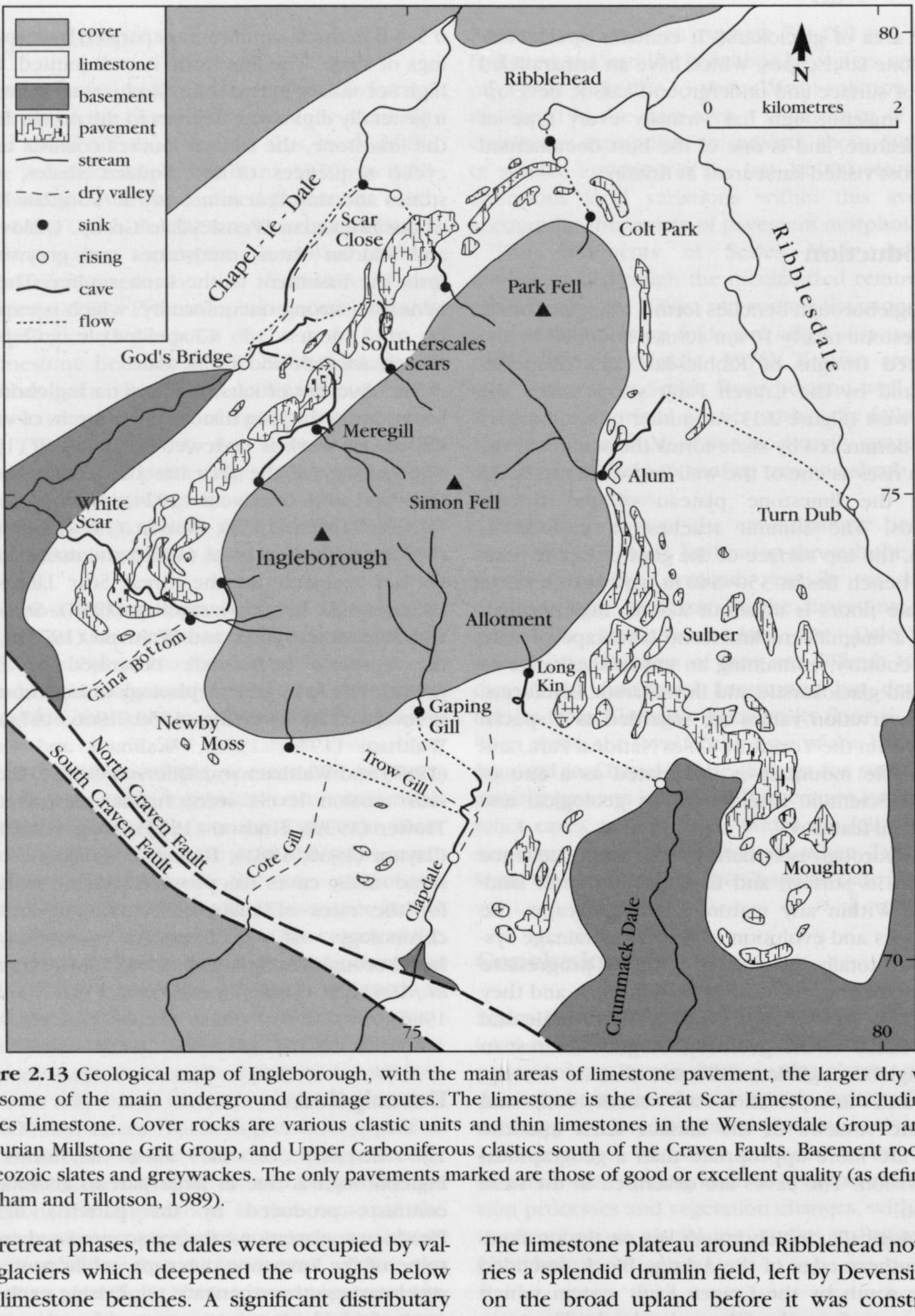


Figure 2.13 Geological map of Ingleborough, with the main areas of limestone pavement, the larger dry valleys and some of the main underground drainage routes. The limestone is the Great Scar Limestone, including the Hawes Limestone. Cover rocks are various clastic units and thin limestones in the Wensleydale Group and the Namurian Millstone Grit Group, and Upper Carboniferous clastics south of the Craven Faults. Basement rocks are Palaeozoic slates and greywackes. The only pavements marked are those of good or excellent quality (as defined by Waltham and Tillotson, 1989).

and retreat phases, the dales were occupied by valley glaciers which deepened the troughs below the limestone benches. A significant distributary ice flow left the Ribblesdale iceway and crossed the eastern benches of Ingleborough to drop into Crummack Dale and Clapdale (Figures 2.13, 2.14). Areas of lesser ice flow became the main zones of glacial deposition, and the thickest till mantles the limestone outcrop on Newby Moss, lying in the protected lee of the Ingleborough summit mass. The limestone plateau around Ribblehead now carries a splendid drumlin field, left by Devensian ice on the broad upland before it was constrained southwards between the Three Peaks.

Stream sinks, dolines and shakeholes

Ingleborough is commonly cited as a textbook example of karst landscape, due to the huge number of closed depressions on the limestone benches. These include deep potholes, open cave entrances, active sinkholes, blind valleys, large solutional and collapse dolines, drained structural depressions, and the thousands of shakeholes which are subsidence dolines in the till cover.

Streams draining off the summit slopes of Ingleborough sink into the top of the limestone all around the shale outlier (Figure 2.13). More than 250 cave entrances are known, providing access to over 54 km of mapped caves. Some lead into almost level cave passages formed along shale horizons between the upper beds of limestone. Many are vertical potholes, with fluted limestone walls disappearing out of daylight as they reach depths of 10–100 m; the large open shafts of Gaping Gill, Alum Pot and Meregill Hole are just the better known of many impressive shafts. The cave systems fed by these sinks are described below, but they have developed almost radially to resurgences in the floors of all the adjacent dales (Figure 2.13). Some of the larger potholes, including Great Douk Cave, Alum Pot and Gaping Gill, lie out on the limestone benches, and may be close to past positions of the retreating shale margins (Sweeting, 1974; Waltham, 1990).

The few blind valleys on Ingleborough are cut only into the glacial till where streams have found routes into the buried limestone, so none exceeds

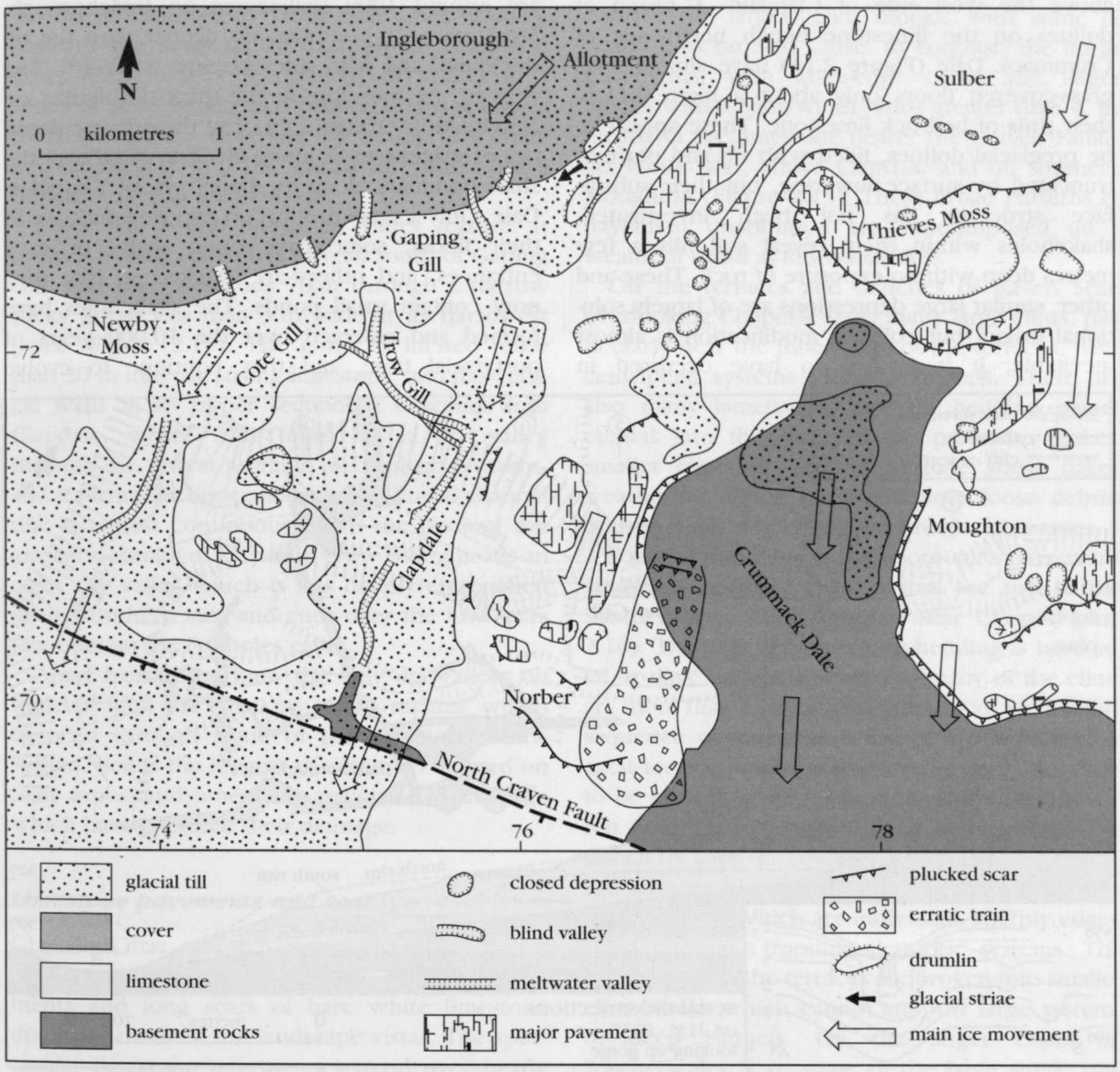


Figure 2.14 Geomorphological map of the southern sector of Ingleborough. The main pavements in the eastern half of the map area were scoured by ice moving down Ribblesdale, while the limestone in the western half is extensively veneered by glacial till deposited in the lee of the Ingleborough summit mass (from Waltham, 1990).

a depth of about 10 m; Gaping Gill is the best known example, and there are others along the buried shale boundary to the east and west (Figure 2.14).

Most of the limestone benches were scoured by Devensian ice, and large solutional dolines have not developed in the short period of postglacial time. The only solutional features larger than the main open shafts are some preglacial depressions now wholly or partly filled with clastic sediment. Braithwaite Wife Hole, on the bench north of Meregill (Figure 2.21) is a conical hole 60 m across and 25 m deep, with sides of slumped till which mask most of the rock profile. Wider but not as deep is the partially filled solutional doline above the west side of Clapdale. A group of dolines on the limestone bench north-west of Crummack Dale (Figure 2.14) have almost level grass-covered floors only about a metre below their rims of bedrock limestone. These appear to be preglacial dolines, filled with till and perhaps truncated by surface lowering, but their subsurface structure has not been investigated; shakeholes within them reveal soil fills a few metres deep with no exposure of rock. These and other, similar large depressions are of largely solutional origin, but collapse modification is almost inevitable; it is known to have occurred in Braithwaite Wife Hole where a tributary cave passage gives access to a zone of collapse reaching 30 m below the floor of the surface depression.

Large, shallow closed depressions on Thieves Moss (Figure 2.14) are structural basins within the limestone, each excavated to a single bedding plane by glaciers. They are not karstic, except that they remain dry due to underground drainage.

Where the limestone benches of Ingleborough are covered with glacial till or any other clastic soils, the ubiquitous feature of the karst is the shakehole. This style of subsidence doline is formed by the soil cover ravelling into the fissures in the buried limestone as rainwater filters through and creates small piping failures. There are around 3000 shakeholes on Ingleborough. Most are 1–10 m across, no deeper than the till thickness, and with sides sloping at 10–40°. The deepest are therefore in the thick till blanket on Newby Moss (Figure 2.14), but the greatest densities of shakeholes lie along the strip of till over the shale boundary along the bench above Chapel-le-Dale. Only a small proportion expose limestone in their floors; some have open shafts or cave entrances, and others are blocked so that they now contain small ponds. The shakeholes have formed and enlarged over the 10 000 years of postglacial time, and they continue to evolve

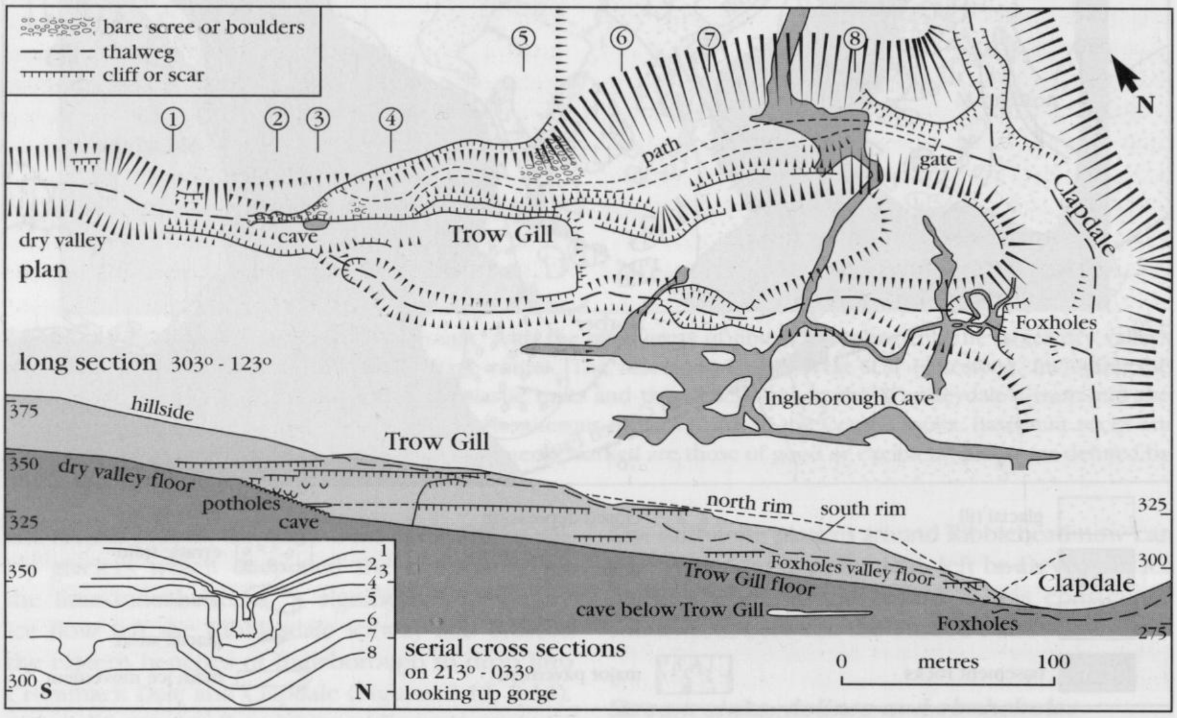


Figure 2.15 Topographic map and projected long profiles of Trow Gill and the underlying caves. Some cave passages have been omitted to improve clarity, and all the caves lie below the level reached on the serial cross-sections; the thalweg down Trow Gill lies along the centreline of the path (from Waltham, 1990).

today. New shakeholes are occasionally recorded, but many more old shakeholes periodically deepen or widen as their soil fills slump into hidden limestone fissures. In 1980, a massive failure enlarged the shakehole containing Marble Pot when hundreds of tons of soil and debris ran into the chamber below and blocked the outlet cave passage (Waltham, 1989).

Dry valleys and gorges

The largest dry valleys on Ingleborough are all cut into the southern slopes (Figure 2.13). Crina Bottom is the longest and deepest, and has a thin alluvial fill along part of its floor; its headwaters have been captured by White Scar Cave, draining beneath the scars to the north-west, but flood flows reach down the normally dry valley to a series of sinks which feed parallel drainage routes to Chapel-le-Dale. Cote Gill is a smaller dry channel, largely cut into the glacial till which fills a broader valley in the bedrock.

Trow Gill is the finest dry valley feature. It forms a trench across the plateau south of Gaping Gill, and then descends 70 m through a narrow rocky gorge less than 3 m wide at its narrowest point (Figure 2.15). The gorge is incised more than 20 m into the strong limestone, and has vertical walls in its upper section. It descends into Clapdale, where it is joined by a dry valley through the retreat moraine in Clapham Bottoms, and it forms the upper reaches of a fluvial channel that is almost continuous down the floor of the glaciated trough of Clapdale. Trow Gill beheads an older dry valley which is less deeply entrenched on its southern side and ends over the low scars that contain the Foxholes cave.

Apart from these four, the only dry valleys on Ingleborough are shallow rocky ravines which descend through some of the limestone scars. Sulber Nick is the longest of a number aligned on fault zones, and others are associated with caves which have captured their drainage.

Limestone pavements and scars

Glaciation has sculpted many of the landforms present on Ingleborough, and the extensive pavements and long scars of bare white limestone dominate many of the landscape vistas. The spectacular limestone pavements extend over nearly 400 ha (Ward and Evans, 1976), and lie on the plateaus and benches which received the full impact of glacial scour by ice moving down both the west and east sides of the Ingleborough summit mass (Figures 2.13, 2.14). The very variable quality and morphology of the Ingleborough pavements were assessed in a survey by Waltham and Tillotson (1989). They found that the pavements of the finest quality all lie in two narrow belts, around Scar Close and between Alum Pot and Thieves Moss, both at the cores of the main pavement zones west and east of Ingleborough.

The Ingleborough pavements are extremely varied, presenting suites of pavement landform types, from great undissected sheets of scoured limestone, to closely fractured linear clints. The most massive pavements lie in two smaller areas, on Scar Close and west of Thieves Moss, and these contain the largest clint blocks, with some of nearly 2 ha on Scar Close. In contrast, the linear pavements, with knife-edge clints and larger blocks with length/width ratios greater than 4, lie mostly in the limestone nearer the Craven Faults, on White Scar, above Clapdale and on southern Moughton (Figure 2.13). These broad patterns of pavement distribution are superimposed on a wealth of detail at individual sites.

On the terraces and benches of Raven Scar, overlooking Chapel-le-Dale, many large clints, particularly near the inner edge of the terraces, have centripetal systems of deep runnels. There are also many lamellar clints with bedding planes etched into the walls of the perimeter grikes; smaller clints in flaggy limestone show flakey weathering which produces more loose debris. Scattered sandstone boulders are glacial erratics.

Some of the finest of Ingleborough's pavements lie below Meregill Hole, across the top of the Southerscales Scars and into Scar Close (Figure 2.16). The exposed limestone bedding is horizontal or dips 1–5° north-east, and many of the clints are more than 10 m across. There is an identifiable sequence of variation across the pavements on each terrace, with a tendency for the large clints to be etched by very smoothly rounded rundkarren near the inner boundaries where strips of glacial till survive. Towards the central sections of the terraces, the larger clints still have deep runnels, many of which are individual, sharply edged rillenkarren not forming dendritic systems. The outer edges of the terraces are broken into smaller clint blocks which cannot support large systems of deep runnels. On the larger clints on Southerscales Scar, some of the large single runnels are tadpole-shaped, and each drains downdip from the remains of a kamenitza.

The main pavement in Scar Close has been pro-

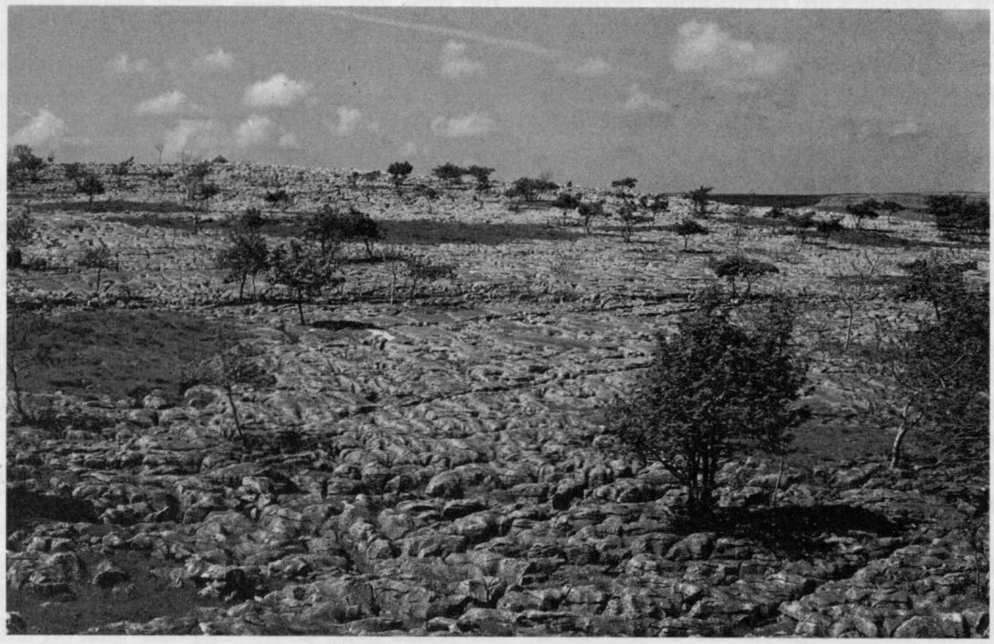


Figure 2.16 The limestone pavements of Southerscales Scars, on the north-western bench of Ingleborough. (Photo: A.C. Waltham.)

tected from grazing sheep since 1960; it is therefore developing a new natural plant cover of mosses, heather, juniper, yew, ferns and flowering shrubs. Very large rectangular clints commonly have a central hump down their length, etched by short rundkarren draining to either side. There are also some extensive, undissected surfaces which carry rich vegetation on islands of remnant till and peat (Gosden, 1968). Dissection of the limestone is by dendritic runnels originating from drainage off these islands, and also off the marginal shale cover, as well as by grikes on the rectangular networks of tectonic joints.

At the head of Ribblesdale, Colt Park contains a stretch of pavement retaining a mature, natural vegetation cover; ash dominates a thick woodland which hides a dense undergrowth with deep moss over a massive pavement with very deep grikes. Borrins Moor Rocks, south of Alum Pot, has some excellent, massive clints with deep rounded runnels. Massive pavements continue to the south along the outcrop of the strong beds of limestone near the top of the Great Scar sequence; they extend west of Thieves Moss, where the largest clints occur, and on to the scars east of Clapdale. Extensive pavements are developed on the lower limestone beds which extend over the gently sloping Moughton plateau (Figure 2.14); there is great variety in the karren morphology, but the clints are generally smaller to the south where the Craven Faults are approached.

To the west, the margin of the shale cover is largely obscured by drift, but a small pavement by Long Kin East Cave (Figure 2.18) is notable for its glacial striae. These are preserved on limestone sealed beneath an impermeable till cover which is slowly retreating. Newly exposed striae are removed by rainfall solution within about 10 years, and the limestone is then etched by new solution runnels (Tiddeman, 1872; Sweeting, 1966, 1974). Further south, the Norber ridge is famous for its perched glacial erratics of greywacke (Figure 2.17). These were derived from outcrops in Crummack Dale and carried obliquely upwards onto the limestone outcrop (Figure 2.14). They now stand on pedestals of limestone which have been protected from corrosion by direct rainfall while the surrounding limestone surface has been lowered by subaerial and subsoil solution. As the protected pedestals are mostly 400–500 mm high, the mean rate of lowering of the exposed surface has been about 30–40 mm/ka since the Devensian ice retreat (Sweeting, 1966). The narrowness of the pedestals, and their incision by solution grooves, may be accounted for by dripwater flowing down the underside of the boulders.

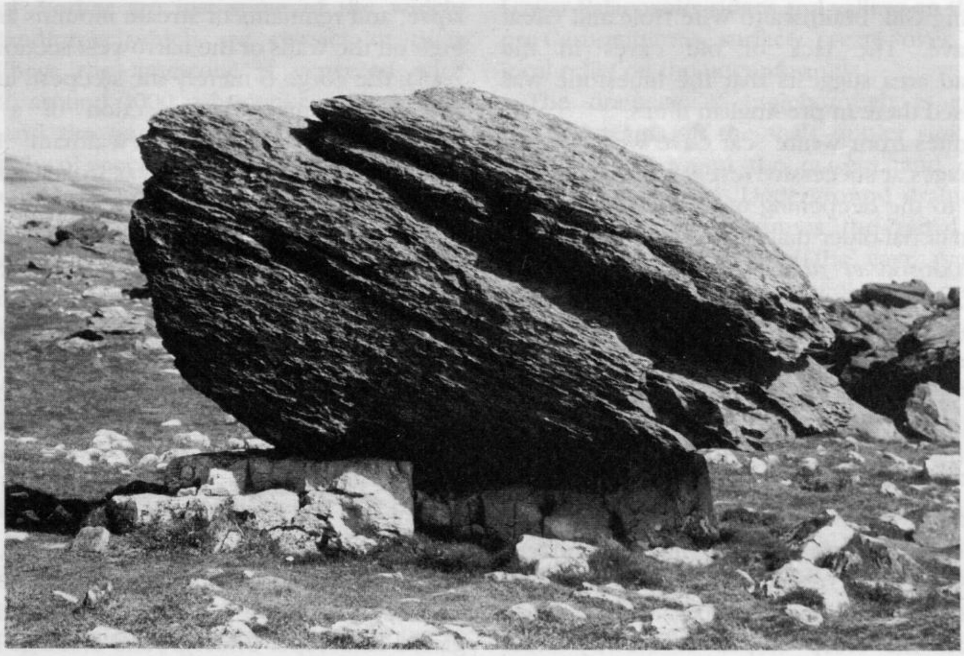


Figure 2.17 Glacial erratic of Silurian greywacke on the Norber bench of southern Ingleborough. The erratic is 2 m across and stands on a plinth of limestone which has been protected from solution by direct rainfall. (Photo: A.C. Waltham.)

The limestone scars are best developed where ice moved obliquely along them or down over them, maximizing the scale of glacial plucking. The scars south of Moughton and Sulber (Figure 2.14) are vertical cliffs, while the Raven Scars along the south side of Chapel-le-Dale form a series of terraces each capped by a stronger bed of limestone. There are few scars along the western side of Ribblesdale, where the ice was moving obliquely up the limestone slope onto the Sulber plateau.

Interpretation

The summit of Ingleborough has been regarded as a remnant of one of a series of old erosion surfaces (Trotter, 1929; Hudson, 1933; King, 1969). The regional drainage pattern was probably initiated on the earliest of these, with rivers originally flowing east, before tectonic warping diverted some of the drainage south. Subsequent denudation was ascribed to four phases by Sweeting (1950); the first was the formation of the 400 m surface, during which the limestone suffered a widespread planation, and this was followed by the 'First Rejuvenation Stage', causing dissection of the 400 m surface, during which underground drainage was initiated; the subsequent 'Dales Stage' was one of relative stability, where the major rivers were able to grade to their base level, after which there was another rejuvenation, forming the master caves of the area. Modern interpretations suggest that large parts of the 400 m surface are stratimorphs, developed on the top of the resistant limestone, and the cave levels ascribed to the successive stages may be a feature of the distribution of inception horizons on shale beds unevenly distributed through the limestone (Waltham, 1970). Though fragments of erosion surfaces can be recognized cutting across the limestone bedding, geological influences on the karstic landforms above and below are strong and tend to mask the effects of past erosion levels. Attempted reconstructions of palaeosurfaces of the late Tertiary and early Quaternary (King, 1969; Clayton, 1981) have little bearing on the modern karst features for which Ingleborough is renowned, other than to outline the broadest geomorphic patterns.

The earliest palaeogeography of Ingleborough for which a tentative reconstruction has been proposed is one with an age of 500 ka, just prior to the Anglian glaciation (Waltham, 1990). The interpreted position of the former shale margin is based on the presence of old cave passages older than 350 ka in Gaping Gill and Newby Moss Cave, and the sites of the major old sinkholes of Alum

Pot, Gaping Gill, Braithwaite Wife Hole and Great Douk Cave. The lack of old caves in the Ribblehead area suggests that the limestone was not exposed there in pre-Anglian times.

Stalagmites from White Scar Cave were formed after passages at successive levels were drained in response to the deepening of Chapel-le-Dale, and include material older than 350 ka from the upper levels (Atkinson *et al.*, 1978; Gascoyne *et al.*, 1983a, b; Gascoyne and Ford, 1984); these indicate a maximum mean rate of incision of 0.2 m/ka over this period. Reconstruction of pre-Anglian valley floor profiles for Chapel-le-Dale, based on the stalagmite dates, suggests that 80–100 m of surface lowering has taken place over the last 400–500 ka, both in the glacial trough and around Ribblehead (Waltham, 1986, 1990). Whether the major surface lowering was by fluvial or glacial processes, in their respective climatic stages, is open to debate. The minimal retreat of the shale margin on the steep slopes of Newby Moss (Waltham, 1990) reflects overall low rates of fluvial surface lowering, and also local protection from glacial excavation in the lee of Ingleborough; the implication is that ice erosion accounted for much of the surface lowering over the larger part of the area, which lacked the protection.

Over the last 500 ka, Ingleborough has been subjected to two or three major glaciations, two long interglacial periods of fluvial environments, and several intervening periglacial phases. In each glacial maximum, ice covered the entire area, perhaps reaching thicknesses of 300 m over Ingleborough, and modified the older surface profiles. Few except the largest surface landforms remain from pre-Devensian times, and many of the modern surface features can be attributed to advance and retreat of the Devensian ice.

The dry valleys of Ingleborough are essentially the product of meltwater erosion, and probably all date largely to periglacial environments during the retreat phase of the Devensian ice. Crina Bottom may have been a marginal channel carrying snowmelt water off Ingleborough beside the Chapel-le-Dale glacier. The smaller features were probably only active for a short period, carrying surface drainage over the exposed frozen limestone until underground capture caused their abandonment as the climate ameliorated. Trow Gill may have a more complex history. The narrow profile of its gorge section has led to speculation that it may be a collapsed cavern (Waltham, 1970). This concept is now not accepted, as there is no positive evidence of collapse, and remnants of stream moulins are visible high on the walls of the narrowest section (Figure 2.15); the gorge is merely the steepest, and therefore most entrenched, section of a fluvially excavated subaerial valley (Waltham, 1990). It was cut when the ground was frozen and impermeable, and lost its stream when karstic drainage was re-established. There is scope for debate as to whether the dry valleys and gorges were carved by subglacial or proglacial meltwater (Pitty *et al.*, 1986). Trow Gill is fed by no channel of significant size from the higher slopes of Ingleborough; its source could have been the snout of an ice lobe from the north-east ending on the limestone bench, or could have been crevasses and glacier moulins in a subglacial situation.

Since the Devensian ice retreated, karstic processes have become dominant once more, largely superimposing texture onto the inherited glacial landscape. Underground drainage has been re-established, enlarging the modern stream caves. The limestone pavements have matured on the stronger beds exposed in the bare rock surfaces left by the glacial retreat. Tectonic fractures were widened by solution of their walls to form the grikes around the clints, and karren runnels drained into them. The rounded form of the rundkarren suggest that much of their development took place beneath a permeable, organic soil cover; this may have been of the type now present in Colt Park, or like that now expanding on Scar Close. Most of the original plant cover was then lost due to artificial clearance of the protecting trees, and sheep grazing has precluded regrowth of anything except grass. The lack of rillenkarren may be due largely to the ubiquitous lichen cover which acts as a substitute for a soil cover in facilitating solution over the ridges between the runnels. The preserved ice striae near Long Kin East Cave demonstrate that there has been almost no limestone solution beneath the impermeable mineral soils of glacial till.

Conclusions

The glaciokarst of Ingleborough constitutes some of Britain's finest limestone landscape. It is of international reputation and importance, and is probably the most used karst teaching example in the country. The dry gorge of Trow Gill, the dry valley of Crina Bottom, the sinkhole of Gaping Gill, the open shaft of Alum Pot, and the perched erratics of Norber are just some of the widely known landforms which are classics of their types. Where the limestone is veneered with glacial till, around 3000 subsidence dolines have formed, and the bare limestone outcrops have nearly 400 ha of spectacular limestone pavements. These include the massive clints of Southerscales Scars and Thieves Moss, and also the protected area of Scar Close with its new plant colonization. The limestone plateaus scoured by ice, the adjacent glaciated troughs and the potholes around the retreating shale margin combine to provide a record of glacial erosion through the late Pleistocene.

INGLEBOROUGH CAVES

Highlights

The caves of Ingleborough include examples of almost every type of cave morphology. They include the finest group of deep potholes and shafts in the country, as well as the largest cave chamber and the highest waterfall in Britain. The caves form a complex and varied system of underground karstic drainage, which is an essential component of the spectacular glaciokarst of the Ingleborough surface landscape.

Introduction

Ingleborough forms a magnificent block of karst between Chapel-le-Dale, Ribblesdale and the Craven Fault scarp (Figure 2.1). It has a plateau, nearly 10 km across, formed on the top surface of the Great Scar Limestone at an altitude of about 400 m, with a central summit mass of shales, sandstones and thin limestones rising to 723 m (Figure 2.13). The summit rocks belong to the Yoredale facies of the Wensleydale Group, except for the Namurian grit cap. The Great Scar Limestone is a strong, fine-grained, massive carbonate with bedding planes mostly 0.5–5.0 m apart and commonly marked by thin shale horizons; it ranges in age from Arundian to Asbian, and is about 200 m thick. Most of the Ingleborough limestone dips 1–3° north, but the south-eastern sector has many shallow folds and local dip variations; it is well jointed and there are many small faults with mainly horizontal displacements. The base of the limestone is a marked unconformity over the folded and faulted, impermeable rocks of the Lower Palaeozoic; ridges and valleys on the buried pre-Carboniferous surface create over 30 m of local relief on the unconformity.

The drainage of Ingleborough is essentially radial. Streams off the shale outlier sink into the limestone all round the margin, and over 250 caves are recorded. Underground drainage from the larger sinks continues the radial pattern, except for deflections of the cave conduits in response to the immediate geology. There is some convergence of underground drainage, most of which feeds to ten major resurgences; most of these lie on or close to the basal unconformity, and the largest are marked on Figure 2.13.

Though the caves of Ingleborough are important components of an important karst, the inhospitable nature of the deep, cold shafts has limited the extent of detailed scientific studies in them. Descriptions of nearly all of the known caves on Ingleborough are given in Brook *et al.* (1991), and are summarized in Waltham (1974a). The more comprehensive descriptions of individual caves and areas include those of White Scar Cave (Waltham, 1977b), the Meregill area (Brook and Crabtree, 1969b), Chapel Beck (Monico, 1995), Alum Pot (Milner, 1972), the Allotment potholes (Booth, 1905; Brodrick, 1905; Griffiths, 1927) and the Gaping Gill area (Brindle, 1949; Patchett, 1953; Glover, 1974; Ford, 1975; Beck, 1984). The geology and geomorphology of the Gaping Gill caves were considered in detail by Glover (1974), and the geomorphology of the Ingleborough karst was reviewed by Waltham and Tillotson (1989) and Waltham (1990). Particular features of the cave geology have been discussed by Halliwell (1979b), Halliwell *et al.* (1975) and Waltham (1970, 1971b, 1977a). The chronology of cave development, based on speleothem dates, and its relationship to landscape evolution has been discussed by Waltham and Harmon (1977), Atkinson *et al.* (1978), Gascoyne and Ford (1984), Gascoyne *et al.* (1983a, b) and Waltham (1986, 1990). The underground drainage was determined by a programme of water tracing by Carter and Dwerryhouse (1904), and further aspects of the cave hydrology were discussed by Pitty (1974), Richardson (1974), Waltham (1977b) and Halliwell (1980).

Description

More than 55 km of cave passages are known within the Ingleborough limestone. The radial

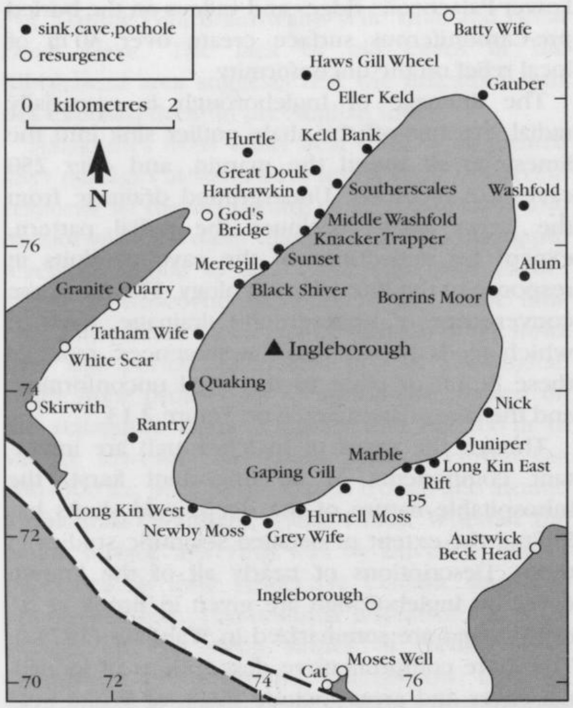


Figure 2.18 Outline map of Ingleborough, with locations of the main caves referred to in the text. Geology as in Figure 2.13.

drainage pattern has caused these to form a series of discrete caves, and there is no integration into large dendritic systems comparable to those of Ease Gill and Kingsdale. Furthermore, the caves within the different sectors around the Ingleborough summit mass have considerable contrasts between them, imposed by local variations in the geology and topography. The influent caves lie all round the perimeter of the shale outlier (Figure 2.18), and fall into groups which are largely defined by their shared resurgences. No long drainage routes have yet been followed from sink to rising, and most known caves reach only from a sink to a sump at the head of a phreatic conduit.

Caves of White Scars

The limestone bench between Chapel-le-Dale and Crina Bottom is named after its extensive, bare pavements and scars (Figure 2.13). Much of it is drained by White Scar Cave, which carries water from sinks in Crina Bottom to the resurgence exit in Chapel-le-Dale (Figure 2.19); it has 6500 m of mapped passages, and is operated as a show cave as far as the Battlefield Chamber. Except for a few high avens, all the known cave is developed in the lowest 30 m of the Great Scar Limestone; Ordovician slates form the floor of the passages to the resurgence and the show cave entrance, and also at a small cascade up the Far Streamway. The main stream emerges from the flooded tubes of the Phreatic Series, and drains over a knickpoint cascade into a fine streamway canyon which is continuous to the cave exit. Deep lakes are ponded behind sediment banks and collapse debris from avens, and there are numerous small inlets. The tube from the Phreatic Series continues as a roof tube over part of Far Streamway, creating a splendid keyhole cross-section; it then turns away to the west where the dry passage is heavily choked. Sleepwalker is an old phreatic tributary, now drained and carrying an underfit stream from choked sinks in Crina Bottom. Just downstream of the Sleepwalker junction, the old phreatic tunnel diverges from the line of the streamway; it continues on the west side for 150 m, beyond which it is choked with sediment. Further north, the Battlefield is a large old chamber whose collapsed floor has been partly undermined by the modern streamway; it is part of an isolated segment of abandoned trunk cave 20 m above stream level. All the abandoned passages contain thick deposits of sand and mud; straw stalactites, stalagmites and flowstone are spectacular in many parts and also in sections of the streamway (Figure 2.20). Stalagmites from the Battlefield and Sleepwalker passages have been dated to over 350 ka (Gascoyne and Ford, 1984), while flowstone from the roof of Far Streamway has an age of 225 ka (Atkinson *et al.*, 1978).

Floodwaters which overflow the Sleepwalker sinks in Crina Bottom go underground at Rantry Hole, and are joined by some drainage from Newby Moss before resurging at Skirwith Cave (Figure 2.18). They pass through old, choked tunnels beneath Crina Bottom and then into the kilometre of small streamway known in Skirwith Cave.

At the head of Crina Bottom, Quaking Pot has a series of narrow, immature, vadose canyons and shafts, aligned along a fault. This drains into a meandering streamway which reaches a depth of 143 m, where it has invaded an older, largely choked, chamber on a fault; the water is next seen in White Scar Cave. The next large sink to the north is Tatham Wife Hole, where a deep, meandering, vadose canyon intercepts the Tatham Wife Fault; the rest of the cave consists of tall, inclined rifts developed along the fault, and it drains to Granite Quarry Rising.

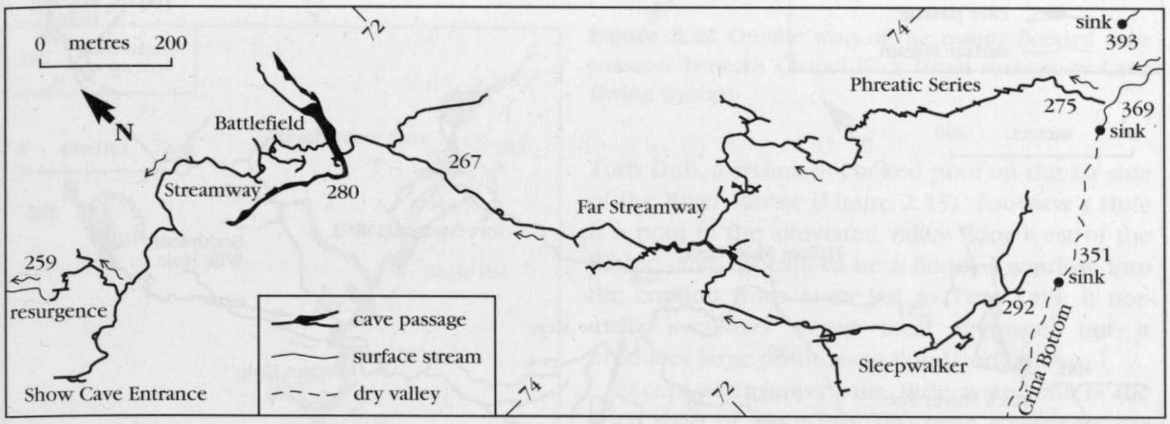


Figure 2.19 Outline map of White Scar Cave (from survey by Happy Wanderers Cave and Pothole Club).

Figure 2.20 Long calcite straw stalactites in the Far Streamway of White Scar Cave. (Photo: A.C. Waltham.)

Caves around Meregill Hole

Meregill Hole takes the largest sinking stream on the Chapel-le-Dale flank of Ingleborough (Figure 2.13). Its entrance is a fault-guided rift 50 m long and 5 m wide, with vertical walls dropping 15 m to The Mere, a perched lake 25 m deep. The lake outlet is into a tall rift passage, which extends south-east under the shale margin and drops 120 m down a series of shafts developed along a fault (Figure 2.21). The stream canyon then drains north, down the dip of its bedding plane roof. At a level of 225 m, this drains into bedding controlled phreatic tubes which rejoin and continue through the lower, flooded passages of Roaring Hole. Black Shiver Pot has a long upper series of low bedding-plane passages, leading to joint-guided cascades and a massive vadose shaft dropping 90 m down a fault. From the foot of the shaft, the streamway follows the bedding planes again, passes through a flooded section, and becomes a tributary to the lower streamway in Meregill Hole. Roaring Hole has a sequence of rifts and canyons descending steeply to join the flooded conduit from Meregill Hole.

Directly above the deep bedding plane caves of Meregill's lower level, a parallel series of caves drain downdip along the bedding planes and shale beds near the top of the limestone. These include Hallam Moss Cave, Sweetwater Hole and Sunset

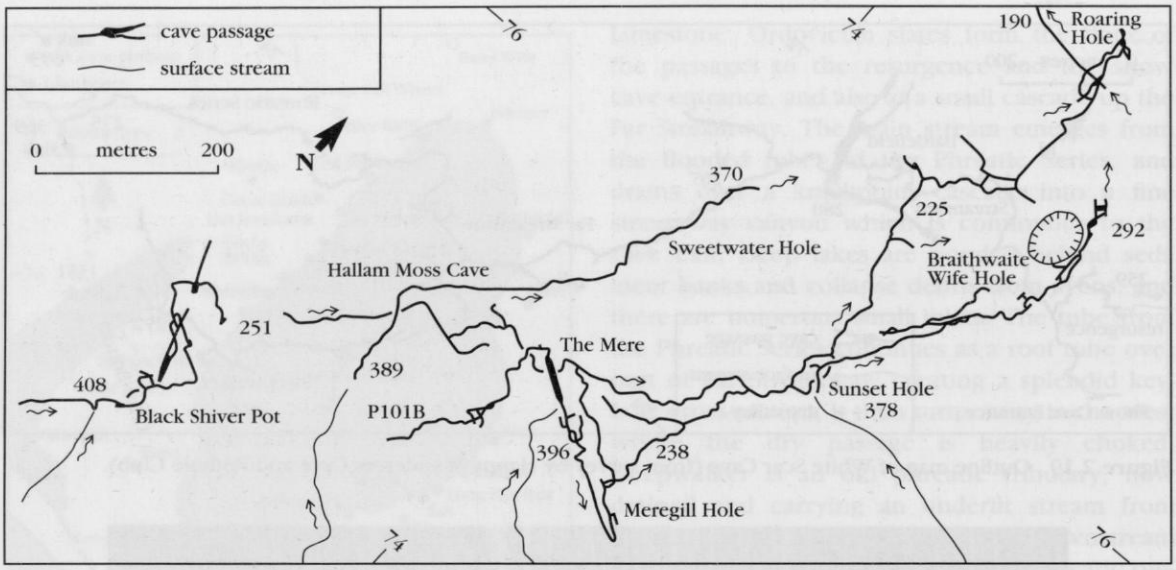


Figure 2.21 Outline map of the cave systems of Meregill Hole; the flooded passage downstream of Roaring Hole is known to continue for another 300 m. Numbers given refer to elevation in metres (from surveys by University of Leeds Speleological Association).

Hole (Figure 2.21). The Sunset stream canyon can be followed into a complex of chambers modified by collapse and fill beneath the large old doline of Braithwaite Wife Hole.

A series of influent caves lies further north along the shale margin (Figure 2.18). Knacker Trapper Hole has narrow stream canyons leading to a large fault-controlled rift which descends to the south-west, against the dip, to a perched sump at a depth of 98 m; some high-level chambers are well decorated with calcite stalactites. Another stream cave drains into the shaft of Hardrawkin Pot. Sinks at Middle Washfold Cave and Southerscales Pot feed long streamways which converge on the large collapsed pothole of Great Douk Cave, where the downstream route is lost in narrow fissures and collapse debris. Keld Bank Sink is one of a series of small, shallow caves which eventually drain to the perched risings at Eller Keld. Round the northern tip of Ingleborough, the caves are young and immature; Gauber Pot feeds Batty Wife Cave through passages too small to be followed.

Caves of Chapel Beck

Chapel Beck crosses the limestone at the head of Chapel-le-Dale and its course is normally dry between the main sink at Haws Gill Wheel and the resurgence at God's Bridge (Figure 2.18). An almost completely flooded cave system has over 4 km of active phreatic conduits, beneath a surface channel which carries only floodwater. Weathercote Cave, Jingle Pot and Hurtle Pot are all shafts in or beside the river bed. In Weathercote Cave, the main flow drops from a high-level bedding cave, down a waterfall and into rifts and collapsed bedding caves descending to sump pools; the other two are normally dry windows into the phreas, whose water surface is at 225 m. The phreatic conduits downstream of Jingle Pot mainly follow the limestone bedding, which rises gently to the south; joints provide the alignment of some sections, cause enlargements on cross rifts, and guide some sections into phreatic loops which reach depths of 30 m.

The main Chapel-le-Dale conduit is known from Jingle Pot to Midge Hole, south of which it may continue under the west bank (Figure 2.22). A complex overflow route lies at shallow depth in the northern part of Joint Hole, where it joins a deeper route from the east carrying water from sinks high on the limestone bench. Chapman's Rising and Meregill Skit are flood outlets from the main submerged trunk routes, which continue to the perennial God's Bridge resurgence.

Caves around Alum Pot

Alum Pot is a massive open shaft, 30 m long, 10 m wide and 70 m deep, developed on a minor fault. From its foot a tall rift follows the fault north into a chamber, with a sump pool in its floor. The flooded passage has been followed for 385 m, along the fault and then north-east at depths of up to 25 m. The resurgence is through the floor of

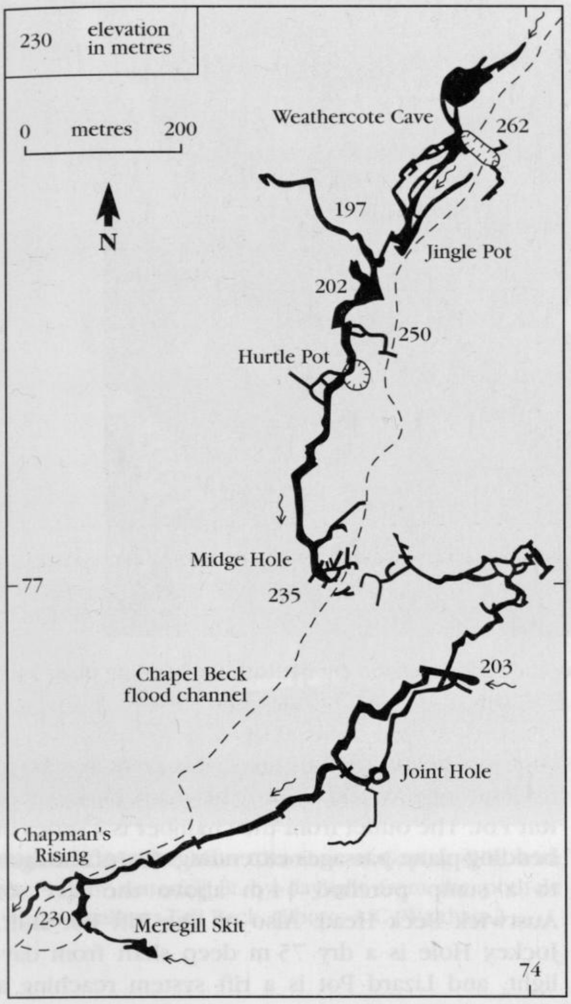


Figure 2.22 Outline map of the mainly flooded cave passages beneath Chapel Beck (from surveys by Cave Diving Group).

Turn Dub, a sediment-choked pool on the far side of the River Ribble (Figure 2.13). Footnaw's Hole is a pool in the alluviated valley floor west of the Ribble, and appears to be a flooded window into the conduit from Alum Pot to Turn Dub; it normally swallows minor local drainage, but it produces large outflows in flood conditions.

Except after heavy rain, little water enters the open shaft of Alum Pot. The main streams of the area drain into youthful vadose caves less than 10 m below the surface. Borrins Moor Cave is a shallow dendritic system fed by several sinks, which drains into the Upper and Lower Long Churn Caves, and then into Diccan Pot (Figure 2.23); the four caves are separated by short unroofed and collapsed sections of the stream course. The main passages are splendid vadose canyons with clean, scalloped walls and floors of pale limestone; these are cut beneath the wide roofs of initial, shallow elliptical openings etched out of thin shale beds (Figure 2.24). They drain downdip until they meet the Alum Pot fault; in Diccan Pot, the active streamway drops 100 m down a series of spectacular waterfall shafts into the lower chamber of Alum Pot.

Washfold Pot lies further north (Figure 2.18) and also drains beneath the river to Turn Dub. A stream sinking at the shale margin flows north-east, down the dip, for more than 300 m in a shallow vadose canyon, before descending a

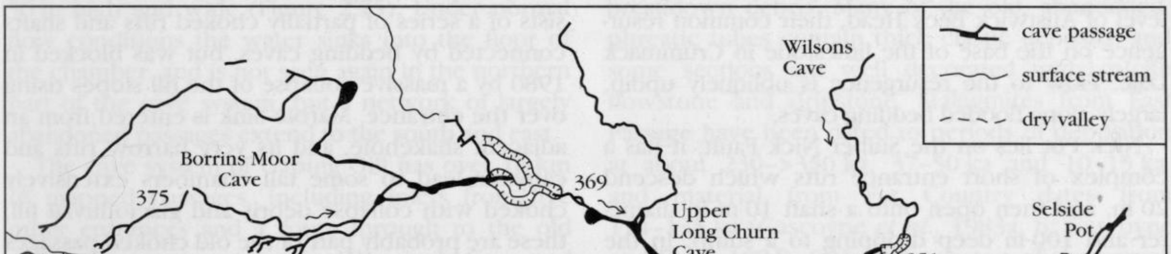


Figure 2.23 Outline map of the Alum Pot cave system; the Alum Pot sump is known to continue for another 220 m beyond the margin of this map (from survey by University of Leeds Speleological Association).

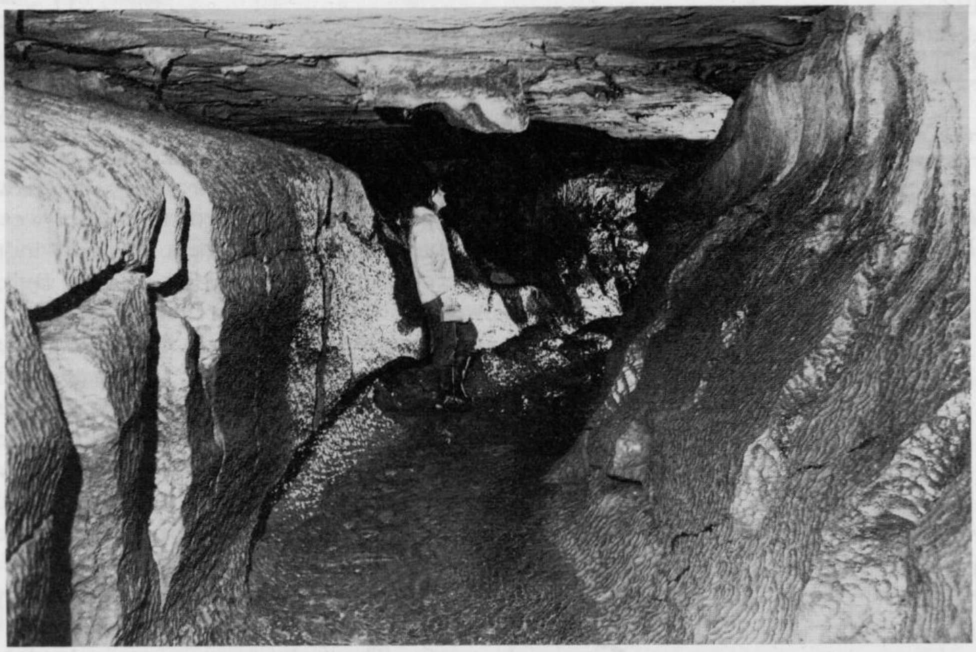


Figure 2.24 Sharply scalloped limestone forms the walls of the vadose canyon cut beneath the bedding plane roof in the streamway of Upper Long Churn Cave. (Photo: A.C. Waltham.)

series of vadose shafts; these are developed obliquely down a major fracture, as far as a flooded shaft 10 m above resurgence level.

Potholes of the Allotment

On the eastern flank of Ingleborough, the Allotment contains a group of deep and spectacular potholes, largely developed on minor faults in the limestone close to the shale margin (Figure 2.18). They all descend steeply to sumps at or close to the level of Austwick Beck Head, their common resurgence on the base of the limestone in Crummack Dale. Flow to the resurgence is obliquely updip, largely along flooded bedding caves.

Nick Pot lies on the Sulber Nick Fault; it has a complex of short entrance rifts which descend 20 m, and then open onto a shaft 10 m in diameter and 100 m deep dropping to a sump. In the adjacent shakehole, Hangman's Hole has a series of rifts and shafts descending the same fault obliquely to the east. Juniper Gulf is a magnificent pothole with a long fissure entrance, deep rifts, massive shafts and fine underground waterfalls, all developed on a vertical fault. Slasher Hole is an adjacent system of narrower rifts on another fault.

Rift Pot has a sequence of deep shafts developed on a brecciated fault zone with slickensides visible on the rift walls. Long Kin East Cave has a long, meandering, vadose canyon with a shale bed roof just below ground level; this ends at a 60 m underground waterfall into the main chamber of Rift Pot. The outlet from the chamber is a series of bedding-plane passages extending east of the fault to a sump perched 14 m above the level of Austwick Beck Head. Also on the Rift Pot fault, Jockey Hole is a dry 75 m deep shaft from daylight, and Lizard Pot is a rift system reaching a depth of 90 m.

Marble Pot lies at the end of a spectacular blind valley cut in thick glacial till. The cave below consists of a series of partially choked rifts and shafts connected by bedding caves, but was blocked in 1980 by a massive collapse of the till slopes rising over the entrance. Marble Sink is entered from an adjacent shakehole, and its very narrow rifts and canyons lead to some tall chambers extensively choked with collapse debris and glaciofluvial fill; these are probably part of the old choked passages below Marble Pot.

Gaping Gill Cave System

Gaping Gill Hole is the best known pothole in Britain, and is the sink for Fell Beck, the largest stream on Ingleborough. Its water falls 110 m down the Main Shaft, forming Britain's highest waterfall. The shaft is about 10 m in diameter, until half way down where it breaks through the roof of the Gaping Gill Main Chamber; this is the largest

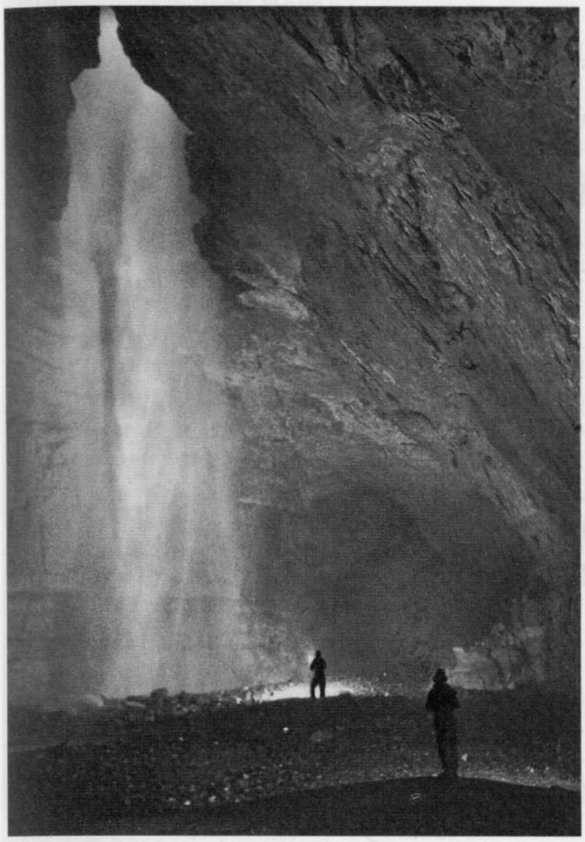


Figure 2.25 The Main Chamber of Gaping Gill, with the 110 m waterfall lit by daylight from the pothole which swallows Fell Beck. (Photo: A.C. Waltham.)

known cave chamber in Britain, 140 m long and 30 m high and wide (Figure 2.25). Under normal flow conditions the water sinks into the floor of the chamber, and is not seen again in the northern part of the cave system, but a network of largely abandoned passages extend to the south and east.

The cave system of Gaping Gill has over 16 km of mapped passages, including inlets from five other entrances and a route through to the old and new resurgences at Ingleborough Cave and Clapham Beck Head (Figure 2.26). The main passages form a low-level distributary system spreading out from the Main Chamber; nearly all are abandoned phreatic tubes, developed into rifts along some of the faults in the limestone. Probably the oldest passage is the highest route, through the large muddy tunnels of East Passage, Mud Hall and part of Car Pot; a branch at a lower level continues through Whitsun Series, and may relate to the tubes of Far Waters. Another old route heads south and joins fault guided rifts and tubes including Sand Cavern; clastic sediment chokes many of the outlets, but they may once have continued through to Mountain Hall. Between these two old trunk routes, Hensler's Passage starts as a remarkable bedding cave; it is over 300 m long, mostly 5 m wide and all less than 1 m high. This leads to a large entrenched vadose canyon, and an abandoned high-level which continues as the Far Country phreatic network.

A complex of shafts and chokes in the Far Country drops to a series of active phreatic tubes carrying the water from the Main Chamber. These drain into the Inauguration Series of Ingleborough Cave, then into partially flooded bedding caves and totally flooded rifts through to the gently descending streamway in Beck Head Stream Cave, and out to the Clapham Beck Head resurgence. One abandoned distributary leads to daylight through the old phreatic tubes of Ingleborough Cave, now accessible as a show cave, and another emerges at Foxholes.

There are few passages above or below the main network which forms a series of levels stepping down only 70 m in total from the Main Chamber to the resurgence. Stream Passage and Disappointment Pots have fine streamways and shafts from active stream sinks. Car, Bar and Flood Entrance Pots are largely abandoned inlet systems. Various shafts reach below the main cave level, but are flooded windows into the phreas that hides the main conduit at an unknown depth for most of its route from the Main Chamber.

Some of the larger chambers and fault rifts have been modified by collapse and are choked with breakdown debris. Many of the old, abandoned, phreatic tubes contain thick clastic deposits, and some sections are well decorated with calcite flowstone and dripstone. Stalagmites from East Passage have been dated to periods of deposition at about 230–>350 ka, 37–50 ka and 10–15 ka, and material from Far Country dates from 114–135 ka (Gascoyne *et al.*, 1983a, b; Gascoyne and Ford, 1984). Stalagmite on top of the varved sediments in Sand Cavern is only 800 years old.

Grange Rigg Pot has a small, descending streamway unconnected to Gaping Gill but also draining to Clapham Beck Head. Above it, the blind valley of P5 feeds a shaft system into Grange Rigg, and also a separate small streamway into a complex of abandoned phreatic tunnels (Figure 2.26). Hurnell Moss Pot has a vadose shaft dropping 65 m into a section of very large, ancient, phreatic tunnel along a fault (Figure 2.18).

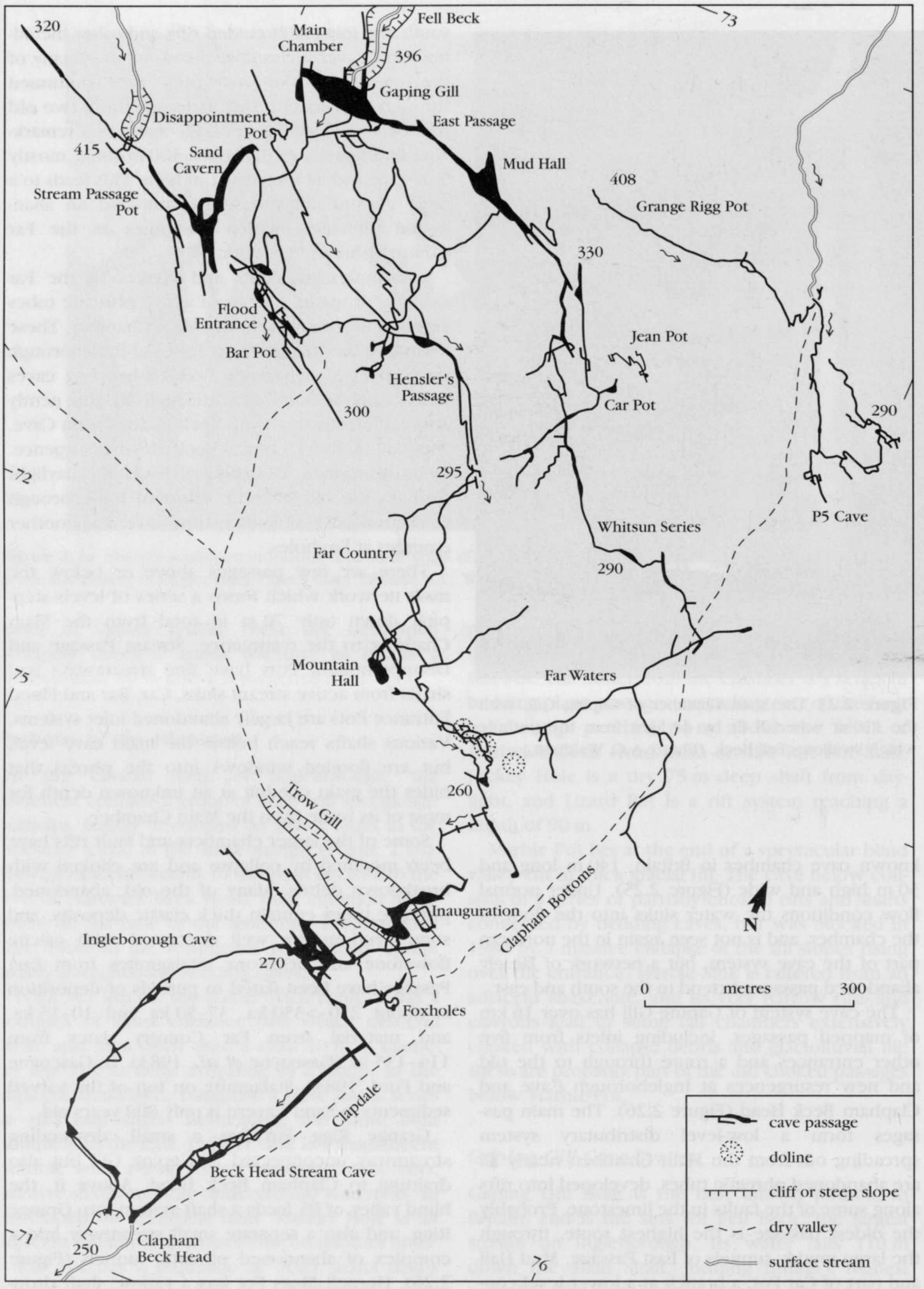


Figure 2.26 Outline map of the Gaping Gill Cave System, including the passages of Ingleborough Cave and Car Pot. Figures given represent elevation in metres. (From surveys by Bradford Pothole Club and many others.)

Potholes of Newby Moss

The south-west corner of Ingleborough contains over 20 caves characterized by deep vertical shafts developed on faults, with almost no horizontal passages (Figure 2.18). Long Kin West is the deepest, and the foot of its second great shaft is choked by breakdown at a depth of 168 m. Grey Wife Hole and Newby Moss Pot contain short lengths of canyon passage, but neither reaches a depth of 100 m. Lying further east on Hurnell Moss, the short passage fragment of Newby Moss Cave contains flowstone dated to over 350 ka (Gascoyne *et al.*, 1983a, b; Gascoyne and Ford 1984). Most water sinking on Newby Moss resurges from Moses Well, but flood flows emerge from Cat Hole (Figure 2.18), and some appears in Ingleborough Cave; sinks west of Long Kin West drain into White Scar Cave.

Interpretation

The cave systems of Ingleborough are many and varied, and between them provide fine examples of almost every feature of underground morphology. Most notable are the many cave features that demonstrate the clear influences of geological guidance.

Stratigraphic control of cave inception and development is evident in both the vadose and phreatic passages in many of the caves. Many bedding planes within the limestone succession contain thin partings of shale, and the downdip vadose streamways guided by these are major elements in many cave systems. Meregill Hole provides the finest example, in the parallel formation of vadose canyons close to the surface and more than 100 m down in the main drain. The Long Churn streamways into Alum Pot provide some of the best and most easily accessible examples of shallow vadose canyon passages in Britain. The only long vadose streamway out to a resurgence is in White Scar Cave, because the limestone basement is exposed in a dale side downdip of the sinks, and there is no high basement ridge to create ponding within the aquifer. The active phreatic tubes below Chapel Beck largely follow bedding horizons updip, and the old drained phreatic tubes in White Scar Cave can be seen to follow the bedding, but also step up joints to change horizons.

Some bedding planes contain no shale, and purely lithological contrasts within the carbonate sequence can provide horizons of cave inception. The most conspicuous of these is the Porcellanous Band, formed by less than 1 m of very fine-grained micritic limestone. Many of the old trunk passages in Gaping Gill lie just above this band, and Hensler's Passage lies directly on top of it, forming the longest and most spectacular bedding cave in Britain.

The buried topography of impermeable rocks, expressed in the local relief on the unconformable base of the Great Scar Limestone, has influenced groundwater flow and cave development in the lowest beds of the karst aquifer. Most of the current main resurgences lie at or close to the basal unconformity, and the flooded caves behind God's Bridge are a feature of both the updip drainage direction and the ponding behind a ridge in the basement rocks (Waltham, 1990). The resurgence from White Scar Cave is on the unconformity, but the cave passages inside are nearly all perched on shales and bedding planes in the limestone above the basement (Waltham, 1977a, b); phreatic inception of nearly all the caves minimizes the gravitational flow of groundwater to the limestone floor except where the aquifer is fully drained close to the valley resurgence site. Where underground drainage has to pass over impermeable basement ridges, horizons which just clear these become the favoured inception lines; a basement ridge beneath Clapham Bottoms probably accounts for the perching of the Clapham Beck Head and Ingleborough Cave passages (Glover, 1974).

The limestone of Ingleborough is broken by numerous minor faults, some of which contain breccia zones up to 1 m thick; there are also many major joints with no recognizable displacement. Both types of fracture influence the morphology of the caves. Vertical shafts are conspicuous on the fractures; they include those of Alum, Nick and Rift Pots, Long Kin West and the Main Shaft of Gaping Gill. A steeply dipping fault also appears to guide the sloping roof of the Gaping Gill Main Chamber where it cuts away south from the Main Shaft. Other caves are developed obliquely down the faults along sequences of rifts and shafts; Juniper Gulf and Meregill Hole are the best examples of this type. Many horizontal passages are formed along fracture/bedding intersections; the lower reaches of Tatham Wife Hole are a clear example, and many of the old conduits in Gaping Gill are guided in this style.

An understanding of the chronology of cave development under Ingleborough is complicated by the contemporaneous development of many discrete conduits; these drained to disparate resurgence sites, each subject to its own cycles of surface lowering and karstic rejuvenation. The Pleistocene climatic cycles and glaciations provided common links, but the geomorphic histories of many caves are independent of their neighbours. A number of older caves may be recognized by their sink entrances away from the retreating shale margin. These include Alum Pot and Great Douk Cave, both 500 m from the shale cover. Newby Moss Cave contains stalagmite dated to >350 ka (Gascoyne and Ford, 1984); it lies almost at the modern shale margin, and is unlikely to have formed beneath the shale cover. These sites therefore indicate greater erosion and slope retreat on the north side of Ingleborough, exposed to the Pleistocene ice flows from the north; the lack of old cave passages in the limestone around Ribblehead may be a consequence of a complete shale cover until removal by glaciers in the late Pleistocene (Waltham, 1990). The clean vadose canyons are the youngest caves, but many of them appear to have origins which predate the last glaciation, as modern rates of passage entrenchment (Gascoyne *et al.*, 1983a) are too low for their development entirely within the last 13 000 years.

The Battlefield passages in White Scar Cave may be remnants of an ancient trunk cave beneath an ancestral Chapel-le-Dale at higher level, perhaps analogous to the modern Chapel Beck caves, and resurging against the North Craven Fault. Stalagmites, dated to over 350 ka, were formed after the phreatic route was largely drained and abandoned. Flowstone from the roof of the main streamway has an age of 225 ka, and must have been above the contemporary resurgence level in Chapel-le-Dale. The levels of the old passages in White Scar Cave indicate a maximum of 0.35 m/ka of valley floor lowering in Chapel-le-Dale, since the caves were drained (Waltham, 1986).

The very old abandoned phreatic passages of the Gaping Gill Cave System, with their thick sediment sequences and stalagmite layers, may prove to contain the most complete record of Pleistocene climatic change and landscape modification in the Yorkshire Dales. However, the evolution of this complex network of abandoned passages has only been assessed in outline (Glover, 1974), and stalagmite dating has only shown that some passages are older than 350 ka (Gascoyne *et al.*, 1983a, b; Gascoyne and Ford 1984), when they are probably much older. Interpretation of the Gaping Gill geomorphology is made more difficult by the strong geological controls, by faults and a thin band of stratigraphical levels, so that past resurgence levels are not easily recognized in a complex profile of deep phreatic loops. Old outlets from the Gaping Gill caves may include Bar Pot (as a vauclusian rising), the roof passage over Mountain Hall (Figure 2.26), a depression in the Foxholes valley (Figure 2.15) and the floors of Clapham Bottoms and Trow Gill, but all are obscured by debris and collapse. Gaping Gill appears to be one of the older caves in the Yorkshire Dales karst, but its history remains largely unknown.

Conclusion

Ingleborough provides Britain's finest example of cavernous karst, as it has not only a spectacular suite of surface landforms but also an excellent range of associated caves. As a teaching site it is without parallel, and many of the individual features are classics of their type. The cave morphology is strongly influenced by many geological factors, and the many deep shafts are the clearest expression of fracture control of cave development. Gaping Gill is among the best known karst landforms in Britain, and its cave system may span a time range longer than any other in the Yorkshire Dales karst.

BIRKWITH CAVES

Highlights

The caves of Birkwith are unusual in that the entire karst drainage remains perched high above the adjacent valley floor. They demonstrate the importance of shale beds as cave inception horizons which can guide a perched conduit within a well fractured limestone aquifer.

Introduction

The Birkwith caves lie in the upper part of the Great Scar Limestone, under the flank of Birkwith Moor where it forms the eastern slopes of Ribblesdale (Figure 2.1). All the streams flowing west from the shale slopes of Birkwith Moor sink into the limestone, but the surface topography and hydrology is complicated by a spectacular drumlin field which lies across the terraced limestone outcrop. This ice-moulded till was left on the retreat of the broad, Devensian glacier which flowed south down Ribblesdale. The Great Scar Limestone dips very gently to the north-west, and is broken by strong joint sets aligned roughly to the NNW and north. All the cave passages are developed within the top 40 m of the Great Scar Limestone, which has a full thickness of over 150 m. The resurgences are perched more than 100 m above the base of the limestone, and the streams issuing from them follow a surface course descending 75 m over limestone and glacial drift to the alluviated floor of Ribblesdale.

The cave passages are all described briefly by Brook *et al.* (1991), and Red Moss Pot was documented by its explorers (Hartley, 1972).

Description

A major cave system with over 4500 m of known passages extends between the sinks of Red Moss Pot and the resurgence at Birkwith Cave (Figure 2.27). Its main feature is the remarkably linear main streamway, draining almost due north along the main fractures from Canal Cavern to the junction inside Birkwith Cave. Over most of its length, this main streamway is a vadose rift passage 2 m wide and up to 10 m high, largely occupied by ponded, slowly moving water. The floor and roof levels vary along the rift, partly under the influence of the low bedding dip; parts are therefore deep canals, and there are four submerged sections of deep flooded fissures. Some parts of the rift above water level are well decorated with calcite speleothems. The cave only descends at two sequences of cascades, one at the upstream end, and one below the Old Ing inlet; the latter cascades are formed where the cave sidesteps between parallel joint fissures.

Access to the main rift streamway is gained via inlet passages from the east. Allogenic streams flow off the shale cover, whose buried boundary is close to the eastern margin of Figure 2.27, and sink where they breach the thinner till between the drumlins. From the entrances of Red Moss Pot, twisting vadose canyons descend over cascades and through small collapse chambers, uniting in a passage which then descends to the main streamway. The longest inlet is well decorated with calcite straws and stalagmite, but cannot be followed to daylight. From its shakehole entrance, Old Ing Cave has a series of cleanly washed vadose canyons and rifts which carry a stream to a

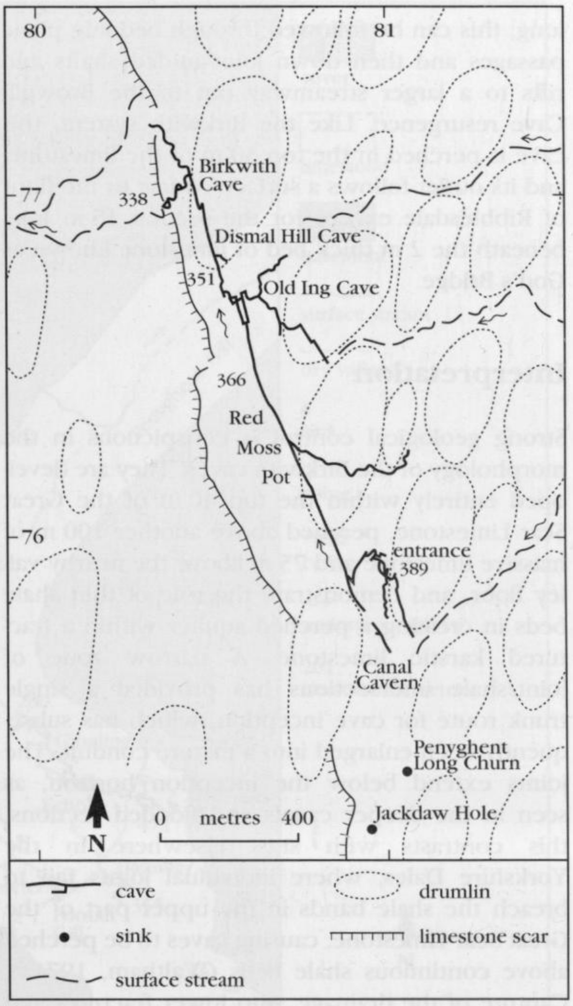


Figure 2.27 Outline map of the caves of Red Moss and Birkwith, draining the limestone bench beneath part of the Ribblesdale drumlin field. Figures given represent elevation in metres (from surveys by Burnley Caving Club and others).

flooded confluence with the Red Moss water. Dismal Hill Cave is another inlet series of narrow rifts and low bedding plane passages. Beyond a last flooded section the main rift streamway drains south-west and descends through sections of bedding-controlled gallery to reach the resurgence exit of Birkwith Cave (Figure 2.27). The abandoned passage north of the junction extends through low bedding planes partly choked with clastic sediment to a small exit below the scar north of the resurgence.

South of Red Moss Pot, Jackdaw Hole is an old choked shaft, and Penyghent Long Churn is an active rift cave which drains south to the New Houses rising. North of Birkwith Cave (and just north of Figure 2.27), Calf Holes is an open waterfall shaft 11 m deep into a fine stream cave, 850 m long; this can be followed through bedding plane passages and then down joint-guided shafts and rifts to a larger streamway out to the Browgill Cave resurgence. Like the Birkwith system, this cave is perched in the top 30 m of the limestone, and its outlet follows a surface course to the floor of Ribblesdale except for the section 15 m long beneath the 2 m thick bed of limestone known as God's Bridge.

Interpretation

Strong geological control is conspicuous in the morphology of the Birkwith caves. They are developed entirely within the top 40 m of the Great Scar Limestone, perched above another 100 m of massive limestone and 75 m above the nearby valley floor, and demonstrate the role of thin shale beds in creating a perched aquifer within a fractured karstic limestone. A narrow zone of joint/shale intersections has provided a single trunk route for cave inception, which has subsequently been enlarged into a mature conduit. The joints extend below the inception horizon, as seen in the deeper canals and flooded sections; this contrasts with sites elsewhere in the Yorkshire Dales, where individual joints fail to breach the shale bands in the upper part of the Great Scar Limestone, causing caves to be perched above continuous shale beds (Waltham, 1971a). Capture of the drainage, into lower fractures and bedding planes, is minimal at present, even though the cave now stands far above a base level determined by potential resurgence sites in the floor of Ribblesdale; some leakage may be taking place to Low Birkwith Cave, a rising 600 m down the beck, whose flow is only partly accounted for by known sinks.

The Birkwith caves are perched and immature. The lower parts of the Great Scar Limestone have no significant cave development where they are traversed by the surface streams flowing from the resurgences. The inlet passages of the cave system all drain from between the drumlins, and there are no known passage terminations at chokes underneath the drumlins. All the evidence points to the caves being comparatively young, and many of the passages may be post-Devensian. The natural drainage of the fracture limestone is west towards the scar edge with a descent into Ribblesdale. The main cave is therefore an anomaly, developed along the joints and downdip until the scar was intersected north of the present resurgence.

Prior to the excavation of Ribblesdale, and also when the glacial trough was occupied by ice, the groundwater drainage would have been towards the lowland to the south. Phreatic initiation of the main rift passage may date back to these conditions, but no morphological evidence of such an early phase has yet been recognized. Abandoned high-level passages in the Old Ing and Birkwith sections are features of local rejuvenation through phreatic uploops, and the outlet passage may have developed in response to a retreat phase of the scar in which the resurgence now lies. Dates of calcite speleothems from the caves may provide evidence for the evolution of both the caves and the local surface morphology, but they are not yet available.

Conclusion

The cave system at Birkwith consists of relatively immature stream caves which clearly demonstrate the significance of shale beds in cave development. Despite their linear, joint-controlled plans, the cave's trunk conduit remains perched at shale horizons far above base level, and drains downdip against the pattern of surface drainage.

BRANTS GILL CATCHMENT CAVES

Highlights

The karst drainage of the Brants Gill catchment is uniquely complex, transmitting water both updip and downdip from widely separate sinks to a single perennial resurgence and two flood risings. Complex series of active and abandoned cave passages include flood overflow routes and a site where the underground drainage has been seen to be diverted in response to evolution of the cave.

Introduction

The caves of the Brants Gill catchment lie beneath the western slopes of Penyghent Hill and Fountains Fell, along the east side of Ribblesdale (Figure 2.1). The Great Scar Limestone forms an extensive outcrop along the middle and lower benches, below outliers which are dominantly shales of the Yoredale facies and form the higher slopes of both Penyghent and Fountains Fell. Lower Palaeozoic basement rocks are exposed in the floor of

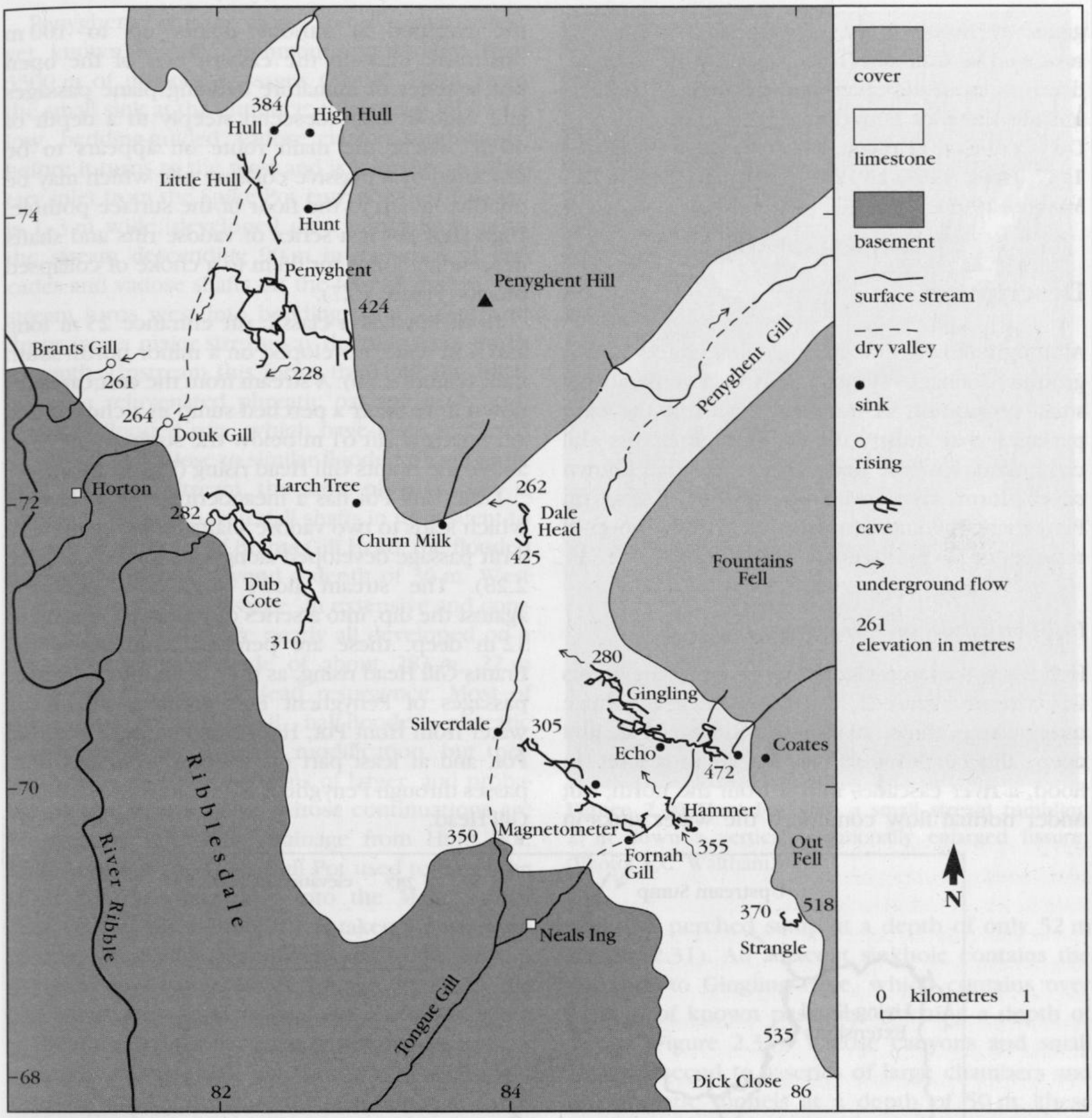


Figure 2.28 Outline map of the cave systems within the Brants Gill catchment. The limestone includes the Great Scar, Hawes and Gayle Limestones. Cover rocks are the shales and higher limestones of the Wensleydale Group. Basement rocks are Palaeozoic slates and greywackes. Only the main cave passages are marked. Flow from all the main sinks is to Brants Gill Head, except when floodwaters emerge from Douk Gill Head (from surveys by University of Leeds Speleological Association, Northern Pennine Club and Cave Diving Group).

Ribblesdale (Figure 2.28). The unconformable base of the limestone, on these greywackes and slates, has considerable relief, reaching a maximum in the lower part of Silverdale where a basement ridge almost 100 m high is exposed. The general dip of the limestone is about 1° north, across many small faults but relatively undisturbed by minor folding. All the upland streams sink on reaching the top of the Great Scar Limestone, and there are more than a dozen, known, major cave systems, together with many smaller caves and choked sinkholes. More than 25 km of passages have been mapped in the catchment. The cave waters all emerge at three risings, of which only Brants Gill Head has a permanent flow. All three risings are located in the basal beds of the limestone sequence, and they lie over 270 m below the highest sinks.

Descriptions of most of the cave passages are given by Brook *et al.* (1991) and were briefly reviewed by Waltham (1974e). The more significant descriptions of the caves by their original explorers include those of Penyghent Pot (Monico, 1989c), Dub Cote Cave (Monico, 1995), Hammer Pot (Batty, 1957; Heys, 1957) and Gingling Hole (Batty, 1967; Monico, 1995).

Description

Although linked into a single integrated underground drainage system, only a comparatively small proportion of the total length of the cave passages that must exist within the Brants Gill catchment has yet been explored. The known caves form two main groups of sinks, on Penyghent Hill and Fountains Fell, and a group of resurgence caves (Figure 2.28).

Influent caves on Penyghent Hill

Hull Pot is the largest single sink feeding the Brants Gill system (Figure 2.28). Its entrance is a huge quarry-like pothole, 90 m long and 20 m wide and deep, aligned WNW–ESE along a minor fault. In flood, a river cascades into it from the north, but under normal flow conditions the water sinks in the riverbed at various points up to 100 m upstream. Beneath the eastern end of the open pot, a series of immature bedding plane passages and vadose shafts descend steeply to a depth of 60 m, where the main route on appears to be obscured by a massive collapse pile which may be continuous up to the floor of the surface pothole. High Hull Pot is a series of vadose rifts and shafts descending joints for 65 m to a choke of collapsed blocks (Figure 2.27).

Hunt Pot has a classic rift entrance 25 m long and 4 m wide, developed on a minor north–south fault (Figure 2.30). A stream from the east cascades down it, to enter a perched sump in a choked and very narrow rift 61 m below the surface and 75 m above the Brants Gill Head rising (Figure 2.28).

Little Hull Pot has a meandering vadose canyon which leads to two vadose shafts dropping 60 m to a rift passage developed along a minor fault (Figure 2.28). The stream flows south-east, obliquely against the dip, into a series of phreatic loops up to 12 m deep; these are perched 24 m above the Brants Gill Head rising, as they drain into the lower passages of Penyghent Pot. Probably all of the water from Hunt Pot, High Hull Pot and Little Hull Pot, and at least part of the flow from Hull Pot, passes through Penyghent Pot on its route to Brants Gill Head.

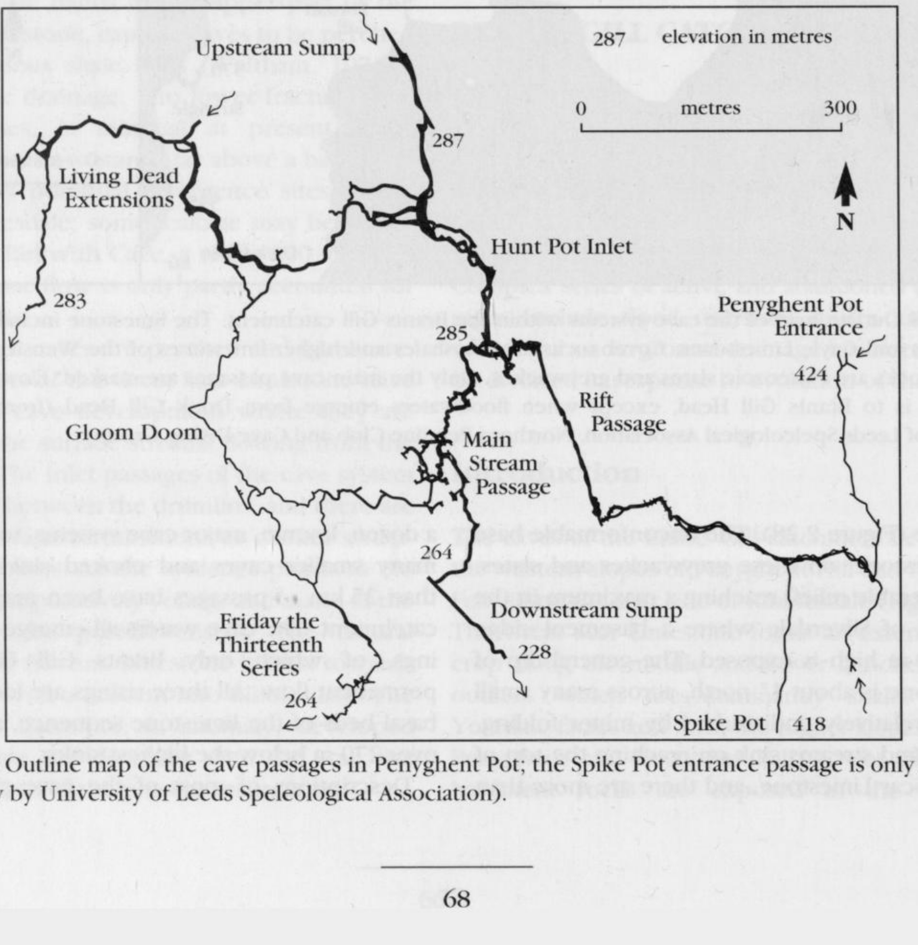


Figure 2.29 Outline map of the cave passages in Penyghent Pot; the Spike Pot entrance passage is only sketched in (from survey by University of Leeds Speleological Association).

Penyghent Pot is the most extensive cave system yet known in the catchment, with more than 5500 m of mapped passages (Figure 2.29). From the small sink at the entrance, the stream follows a low, bedding-guided, vadose canyon southwards, before it turns to the west and is joined by a tributary inlet from the Spike Pot entrance. Rift Passage is 1–3 m wide, developed on a minor fault, with the stream descending 90 m in its series of cascades and vadose shafts. At the foot of the rift, the stream turns west into bedding plane caves, and drops into a major streamway draining from north to south. Upstream this forms the Hunt Pot Inlet, where a rejuvenated phreatic passage leads to a series of flooded rifts, which have been explored to a point very close to similar flooded rifts in Little Hull Pot. Downstream, the same phreatic tube is interrupted by two waterfall shafts in its descent to a sump at the level of Brants Gill Head; the flooded passage continues beyond a depth of 36 m. West of the Main Stream Passage, an extensive and complex series of caves are nearly all developed on a shale bed at an altitude of about 283 m, 22 m above the Brants Gill Head resurgence. Most of these passages are small, half-flooded, phreatic tubes with limited vadose modification, but they intersect some short sections of larger, and probably older, phreatic tubes whose continuations are blocked by sediment. Drainage from Hunt Pot, Little Hull Pot and High Hull Pot used to enter the Hunt Pot inlet and flow into the Main Stream Passage but, since 1986, it has taken a new route through the Living Dead Extensions to the west. A separate small stream flows through the Friday the Thirteenth Series and drops down shafts to a sump at the same level as the main downstream sump.

South of Penyghent Pot there are several small caves at sinks just below the shale margin. Larch Tree Hole and Churn Milk Hole are large old sinks choked with boulders; Churn Milk swallows a small stream which resurges at Brants Gill Head (Figure 2.28). Dale Head Pot is the only cave on this section of fell yet explored to great depth (Figure 2.28). A small, meandering vadose canyon follows the dip to the north, to the head of a series of vadose shafts and narrow rifts, developed on a series of closely spaced joints; these enter a sump at the same level as Brants Gill Head.

Influent caves on Fountains Fell

The two largest streams on Fountains Fell converge on the Gingling Wet Sinks, where they drain through a series of constricted bedding planes and

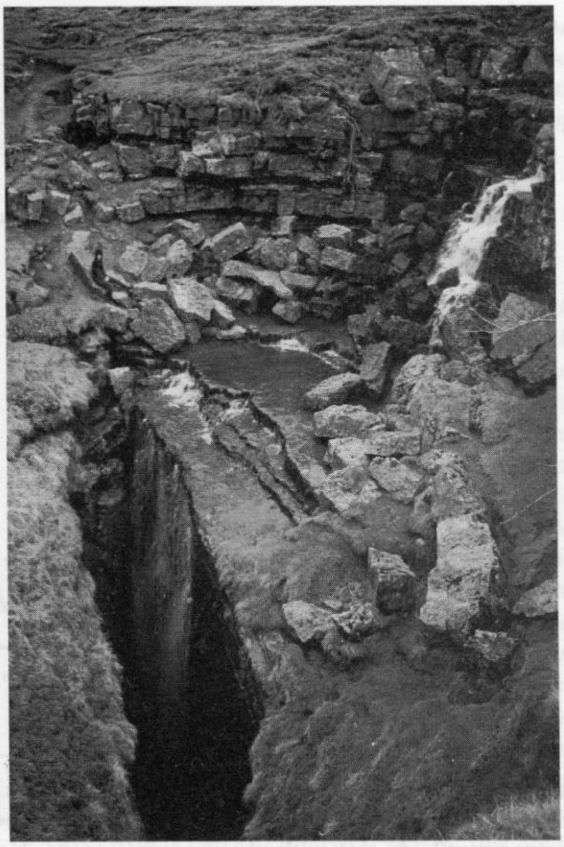


Figure 2.30 Hunt Pot with a small stream tumbling 27 m down a vertical, solutionally enlarged fissure. (Photo: A.C. Waltham.)

rifts to a perched sump at a depth of only 52 m (Figure 2.31). An adjacent sinkhole contains the entrance to Gingling Hole, which contains over 5200 m of known passages, reaching a depth of 192 m (Figure 2.31). Vadose canyons and small shafts descend to a series of large chambers and old phreatic tunnels at a depth of 50 m; these include Stalactite Chamber and Fool's Paradise, both exceptionally well decorated with calcite straws and dripstone (Figure 2.32). The main passage continues north down a series of narrow rifts and shafts to a junction, where two sets of rifts and shafts descend north-west–south-east joints in parallel for nearly 90 m to sumps at the same level. The sump in the southern rift is a perched phreatic loop which is an inlet to the complex of passages forming the Fountains Fell Main Drain. A large stream flows to the north-west, emerging from a flooded link from the Wet Sinks, and finally flowing into the remote Terminal Sump, about 20 m above the level of Brants Gill Head. The main passages are phreatic tubes 2–3 m in diameter and vadose canyons 2–5 m deep. Small

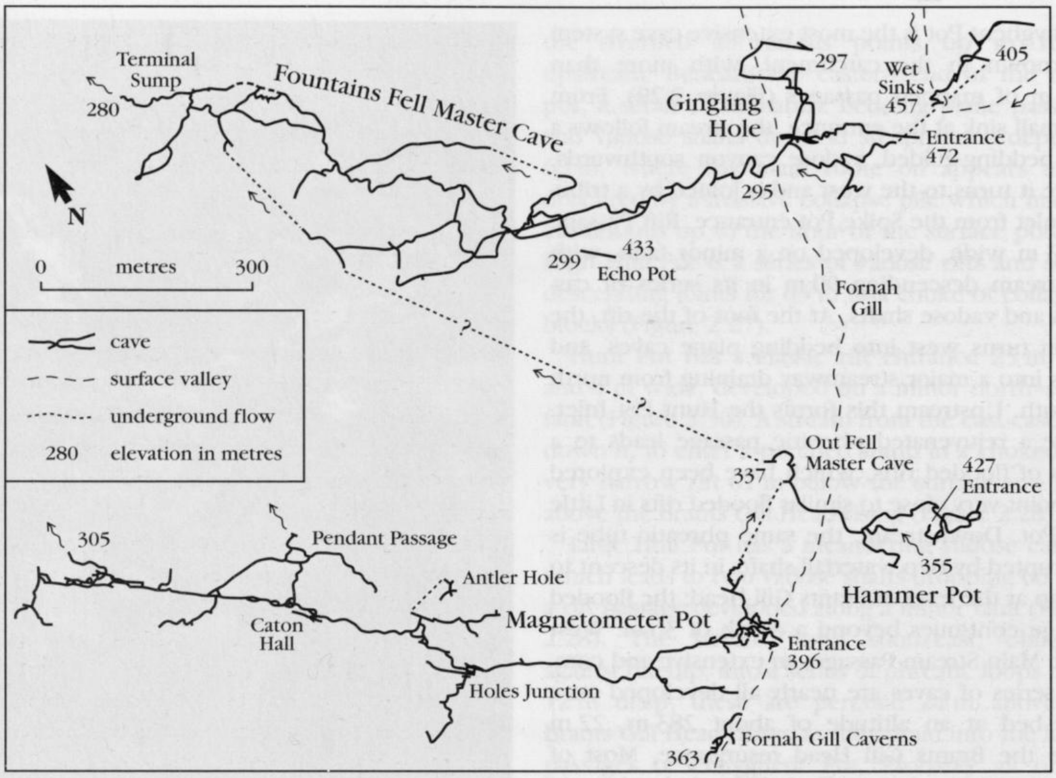


Figure 2.31 Outline map of the main caves of Fountains Fell; the drainage links into the Fountains Fell Master Cave are not proven (from surveys by University of Leeds Speleological Association, Northern Pennine Club and Cave Diving Group).

cascades break the gentle overall gradient, and some sections of tube remain flooded through shallow loops. The largest inlet appears to carry the water from Hammer Pot; a series of abandoned passages, partly choked with collapse and clastic sediments, lies between the two streamways and provides dry by-passes to the flooded sections.

Hammer Pot has a small streamway in its entrance series, joining a much larger passage at depth (Figure 2.31). From the entrance, tightly meandering, vadose canyons, mostly less than 0.5 m wide but about 5 m high, link wider shafts in the descent to a low bedding plane cave which emerges in the Out Fell Master Cave. The large stream in this rises from a deep flooded shaft, and can be followed downstream for 200 m to a waterfall into a chamber just before a sump, which probably drains into the Fountains Fell Master Cave (Figure 2.31).

Magnetometer Pot has a complex entrance series of canyons and shafts, which probably drain east to Hammer Pot, but also intersect an abandoned phreatic cave heading north-west (Figure 2.31). The old trunk passage as far as Caton Hall is up to 5 m in diameter, and there are numerous smaller side passages. Many of these are choked with sediment, but there are at least 20 sumps preventing progress along inlet and outlet passages. Although Magnetometer Pot is largely abandoned beyond its entrance series, the relict galleries transmit large flows in flood conditions.

The large stream in the lower passage of Hammer Pot appears to be the drainage from the many small sinks on Out Fell and Dick Close (Figure 2.28). Few of these can be followed beyond their short entrance shafts. Strangle Pot is the notable exception. It has two sections of phreatic passage, guided by joints along almost level shale beds, incised by small vadose trenches and broken by seven small shafts; these lead to the head of deep rifts which descend more than 70 m. The lower rift is a massive old feature with a vertical wall of boulders opposite the stream entry. Its impassably narrow outlet is about 15 m above the likely destination of the water, in Hammer Pot.

Resurgence caves

There are three separate risings within the Brants Gill catchment (Figure 2.28). All lie close to the base of the limestone, but regional dip and the

Figure 2.32 Fool's Paradise in Gingling Hole – a beautifully decorated phreatic tube and entrenched vadose canyon. (Photo: J.C. Cunningham.)

relief on the unconformity give them an altitude range of 21 m. Under normal flow conditions all water from the influent caves of Penyghent and Fountains Fell resurges at Brants Gill Head. The water emerges from narrow fissures between blocks in a large collapse zone, and it is significant that flood flows from Brants Gill Head never rise above about double the base flow. In flood conditions Douk Gill Head, 500 m to the south-east and 3 m higher in altitude, becomes active; normally dry, this produces flows of more than 0.5 m^3/s in wet weather. Narrow beddings and large dropped blocks prevent access to the extensive cave system which lies behind Douk Gill Head. Dub Cote Cave is the third resurgence, lying further south and updip. Normally this cave carries only a tiny stream, but it acts as a major resurgence under extreme flood conditions. Over 4000 m of passages have been mapped behind the sumps which guard the entrance (Figure 2.28). The main stream route along the north side of the system is largely flooded through active phreatic tubes. A second small stream flows in small vadose canyons through the main series to the south; this consists largely of abandoned phreatic tubes and bedding plane caves, all partly choked by clastic sediment.

Interpretation

The Brants Gill Head catchment contains a major karst drainage system linking numerous sinks with one permanent rising and two flood overflow risings. The hydrology is complex, with convergent and divergent conduits, together with numerous perched phreatic loops influenced by a variety of geological factors.

On the western side of Penyghent Hill, all the drainage from Hunt Pot, High Hull Pot and Little Hull Pot enters the lower reaches of Penyghent Pot, where it flows into an extensive series of passages developed on a single shale horizon about 22 m above the Brants Gill Head resurgence. Perched sumps between these influent caves and Penyghent Pot have been created by the drainage against the northerly dip. The Main Stream Passage of Penyghent Pot is the only long section of cave which can be followed below this shale horizon, to enter a phreatic loop down a flooded shaft and then probably largely up the dip of bedding caves to the resurgence. Continuations of the known passages on the higher level are all choked with sediment, and it is likely that the main water flows diverge to the various flood resurgences due to obstructions within passages on this shale horizon. Some of the Hull Pot water may also flow through Penyghent Pot, but the remainder takes a separate, unknown, route to Brants Gill Head. The ephemeral nature of karstic drainage routes was seen in 1986 when the Hunt Pot Inlet in Penyghent Pot suddenly dried up; the water found a new route through the Living Dead passages further to the west. Such individual events are likely to be related to the creation or removal of sediment blockages, as solutional modification of the limestone is a much slower process.

The hydrological relationships of the three risings clearly show that their distributary drainage is active only in flood conditions, and also provide fine examples of intermittent flow in karstic conduits. Douk Gill is clearly the overflow passage for Brants Gill Head, and must diverge from the base flow conduit downstream of the confluence of the Penyghent and Fountains Fell drainage. The relatively constant flow rate at Brants Gill Head is due to constriction of its conduit downstream of the divergence. Dub Cote Cave floods rarely but rapidly, and appears to be a higher overflow route that probably only extends off the Fountains Fell conduit.

The sinking streams of Fountains Fell all drain to Brants Gill Head, taking an underground route of up to 6 km rather than the shorter westerly course to the base of the limestone in Ribblesdale. Past and present drainage routes descend to depth in the limestone, and then head obliquely and gently downdip in a direction about 20° from the strike, to pass behind the high basement ridge exposed in Silverdale. The plan positions and levels of each of these routes were then controlled by the locations of the contemporary sinks and their rising. The older route lay from sinks on a shale cover margin west of its present position, through Magnetometer Pot and out to Dub Cote Cave, where the modern cave exit has been slightly truncated by surface lowering (Figure 2.28). The later route developed from new sinks, on a shale margin retreating towards the east, to a lower resurgence at Brants Gill Head in a deepened Ribblesdale. This created the main passages of Gingling Hole on a course again at a low stratigraphical level in the limestone, parallel to, 40 m below, and nearly 1 km further downdip to the north-east from the Magnetometer route.

On both phases of development of the Fountains Fell drainage routes, a deep vadose zone appears to have been established rapidly in the cavernous limestone. There are no known traces of abandoned caves on a graded profile associated with a sloping water table commensurate with an immature karst aquifer. The route from the Gingling Wet Sinks descends 160 m in its first 100 m of plan length, and then falls only 40 m in the following 5 km to the resurgence. Though the lower passages are phreatic, and the palaeo-water tables have not yet been recognized from the cave morphology, the steep initial profile of the conduit indicates largely vadose drainage to a deep water table. The abandoned passages in both Gingling and Magnetometer are largely at levels only a few metres above the active drains, and represent minor adjustments and rejuvenations as the cave matured towards a graded profile established by its resurgence level.

Though stratigraphical features have provided the greatest guides to cave inception, the joint patterns have exerted influence on the details of the cave morphology. The deep shafts of Gingling Hole and Dale Head Pot are all aligned on tectonic fractures, and rift passages have developed along the faults in Little Hull and Penyghent Pots, both with and against the dip. The entrances of Hull and Hunt Pots are classic examples of fault control, and the former has enlarged by the progressive solution and collapse of narrow limestone blocks between closely spaced fractures.

The sequence of development of the caves draining the northern sector of Penyghent Hill is not clear. Douk Gill Cave appears to be an older resurgence, now truncated by valley deepening and relegated to an overflow role. The extensive passage development at around the 283 m level in Penyghent Pot suggests that there may be an abandoned rising hidden beneath the soil profile at a level higher than Douk Gill; an old link to the Dub Cote Cave outlet could exist, but no evidence of it has been found. The influent caves contain various calcite and clastic sediments which indicate that the passages are old, and the caves appear to have developed through the interglacial stages of the Pleistocene. No sediments, from either the Penyghent or Fountains Fell caves have yet been dated, and further comment on the evolution of both the caves and the surface topography is therefore speculative.

Conclusion

The caves of the Brants Gill Head catchment form a large dendritic system of karstic conduits which gather water from widely scattered sinks, and drain to one or more resurgences depending on flow conditions. The known caves reveal the rerouting of floodwaters in a karst better than any other site in Britain. Many of the cave passages which must exist within this catchment are yet to be discovered, but it is clear that their morphology has been influenced by the stratigraphy and fracturing of the limestone and also by a ridge in the impermeable basement.

PIKEDAW CALAMINE CAVERNS

Highlights

Pikedaw Calamine Caverns is the larger of two accessible caves in the limestone of the Malham area with secondary minerals of base metals deposited on the cave walls.

Introduction

Pikedaw Calamine Caverns lie beneath the limestone plateau west of Malham Cove (Figure 2.33). An isolated segment of relict phreatic cave contains just over 1000 m of mapped passage, now only accessible via a 25 m mine shaft. The mining activity was reviewed by Simpson (1967), and the cave passages are described by Brook *et al.* (1991).

Description

The mine shaft from the surface enters through the roof of a chamber from which three passages radiate. A phreatic passage up to 10 m wide and 5m high extends over 200 m west and then south to end in a choke. South and east of the entrance shaft, large and small phreatic tunnels radiate and each extend about 100 m to chokes; there is also a small stream passage which can be followed to an upstream sump. All the large relict passages contain thick sand and mud deposits, some of which have been removed by miners. In some chambers there are thin green and blue wall coatings of secondary minerals of zinc, copper and lead. The abandoned tunnels are largely horizontal and lie about 250 m above the resurgence of Malham Cove Rising; the destination of the modern, underfit stream is unknown.

Interpretation

Pikedaw Calamine Caverns are the only abandoned, high-level, phreatic cave passages of any significant length known in the Malham area. Their great elevation above the present resurgence indicates that they are of considerable age; they long predate the evolution of Malham Cove and the other major features of the local karst. The phreatic tunnels appear to be fragments of major relict conduits, but there is no indication of where the sinks and resurgence were located; they were probably close to contemporary boundaries of the cover rocks which have since been stripped away.

Within the Yorkshire Pennines, the hydrated carbonates of zinc, copper and lead are only known in the Calamine Caverns and in the Grollit, a small cave 500 m to the north-east from which miners have also removed the mineralized sediment. The secondary mineralization may have been due to the redistribution by solution of metal ions from primary sulphides in hydrothermal veins, during the phreatic phase of the caves' history (Raistrick, 1938, 1954); this has implications for the potential generation of sulphuric acid, which could have played a significant role in the processes of karstic solution.

Conclusion

Pikedaw Calamine Caverns are a fragment of an ancient phreatic system which must relate to a former drainage and topography. They are distinguished by the coatings of secondary base metal carbonates on the walls of the ancient phreatic caves.

MALHAM COVE AND GORDALE SCAR

Highlights

Malham Cove and Gordale Scar are two of Britain's best known karst landforms. Malham Cove is a spectacular amphitheatre of limestone cliffs which in part represents a dry waterfall, while the neighbouring Gordale Scar is a fine gorge still carrying a small stream. The area is also renowned for its dry valleys, limestone pavements, tufa deposits and underground drainage patterns.

Introduction

The spectacular, concave, crescentic limestone cliff of Malham Cove and the impressive limestone gorge of Gordale Scar are located on the southern margins of the Yorkshire Dales karst plateau (Figure 2.33). Both are impressive examples of fluviokarstic landforms which demonstrate the intertwining of fluvial knick point retreat, glacial scour and meltwater excavation with karstic processes. The area has many other features of note including the fine Watlowes dry valley above Malham Cove, the stream sinks at the southern end of Malham Tarn, which feed to the Malham Cove and Aire Head risings, and the massive tufa deposits in Gordale Scar. Limestone pavements are prominent features of the plateau landscape, and those at the top of Malham Cove are especially well known for their fine morphology. The underground drainage of the area is a classic demonstration of the complex nature of limestone hydrology, with convergent and divergent flow patterns. The area contains some of Britain's finest glaciokarst, much of which is clearly related to the local geological structure.

The geomorphology of the area is summarized by Sweeting (1974) and Clayton (1981) and features in numerous textbooks. The denudation chronology of the area was deduced by Sweeting (1950), while regional denudation studies were carried out by Hudson (1933) and King (1969). Moisley (1955) describes many of the other karstic feature in the area while Pitty *et al*. (1986) discuss the formation of Malham Cove and Gordale Scar. A descriptive account of the geology of the Malham area is outlined by Arthurton *et al*. (1988), O'Connor (1964) and Shaw, J. (1983). The hydrogeology of the area was investigated by dye tracing (Smith and Atkinson, 1977) and by stable isotope analysis (Brown *et al*., 1986). The Malham area has been the focus for limestone surface solution studies, such as those of Sweeting (1966) and Trudgill (1985b), while its many glacial features were studied by Clark (1967). The tufa deposits of Gordale Scar were discussed by Pentecost (1981).

Description

The limestone geology at Malham is complicated by the major facies variations across the line of the Middle Craven Fault, which was active in Carboniferous times when it formed the boundary between a shallow submarine shelf to the north and a subsiding basin to the south. The central outcrop of massive limestone belongs to the Malham Formation, the upper part of the Great Scar Limestone; it is bounded by the North and Middle Craven Faults. The same beds form the higher ground north of the North Craven Fault, where erosion levels have reached just low enough to expose the basement of impermeable Silurian siltstones, on which most of Malham Tarn lies. A block of reef limestone, contemporaneous with the bedded Malham Formation, lies just south of the Middle Craven Fault and is overlain unconformably by the Upper Bowland Shales (Arthurton *et al*., 1988). Within the shale sequence, a thin basinal limestone crops out at Aire Head (Figure 2.33) and has a buried contact with the reef limestones to provide a routeway for the unseen, underground karst drainage. Glacial till is significant only on the lowland areas to the south, and there is an extensive glaciofluvial kame complex across the limestone plateau along the line of the North Craven Fault (Clayton, 1981). Malham Cove and Gordale Scar both lie about 500 m north of the Middle Craven Fault.

Malham Cove

The Cove is a massive, concave crescentic, vertical cliff cut into the Great Scar Limestone (Figure 2.34). Its rim is 80 m above the Malham Cove Rising, where water resurges at the foot of the cliff, and the curved walls extend over 100 m on each side of the resurgence. Above the Cove, the Watlowes dry valley extends up past Comb Scar, but loses most of its depth before its head zone on the plateau below Malham Tarn. The valley is entrenched up to 50 m deep into the massive horizontal limestone, more resistant bands of which form scars along the valley sides. Malham Tarn covers 62 ha, most of which is less than 3 m in depth, and owes its existence to the small inlier of impermeable Silurian rocks to the north of the North Craven Fault (Figure 2.33). Water from the Tarn flows out at its southern end and sinks shortly after crossing the fault onto the limestone; a number of choked fissures lie along the streambed, various of which are active at different times and stages. After exceptional rainfall, the sinks may overflow so that the dry waterfall at Comb Scar becomes temporarily active; the water then soaks away in the floor of Watlowes. On rare occasions, water gathered from seepage springs and direct rainfall in the lower Watlowes can cascade over the Cove. Continuous surface flow, from Tarn to Cove, is recorded in the past, but not in this century (Halliwell, 1979a). West of the Tarn, Smelt Mill Beck also sinks shortly after crossing the fault.

The hydrology of the Malham area is commonly regarded as a fine example of the unseen complexities of underground drainage in limestone. There are two major sinks: Water Sinks fed by the outflow of Malham Tarn, and the smaller Smelt Mill Beck sink to the west. There are two resurgences: Malham Cove Rising at the foot of the Cove, and Aire Head Rising south of Malham village. Dye tracing has proved that water from both sinks flows to both resurgences (O'Connor *et al*., 1974; Smith and Atkinson, 1977). Most of the water from Malham Tarn resurges at Aire Head, taking 13–24 hours, while a smaller amount resurges at Malham Cove, taking 24–29 hours to arrive. The waters of Smelt Mill Beck arrive at the Cove in 2–7 hours, and at Aire Head in 6–10 hours. Both the sinks and Aire head are choked by

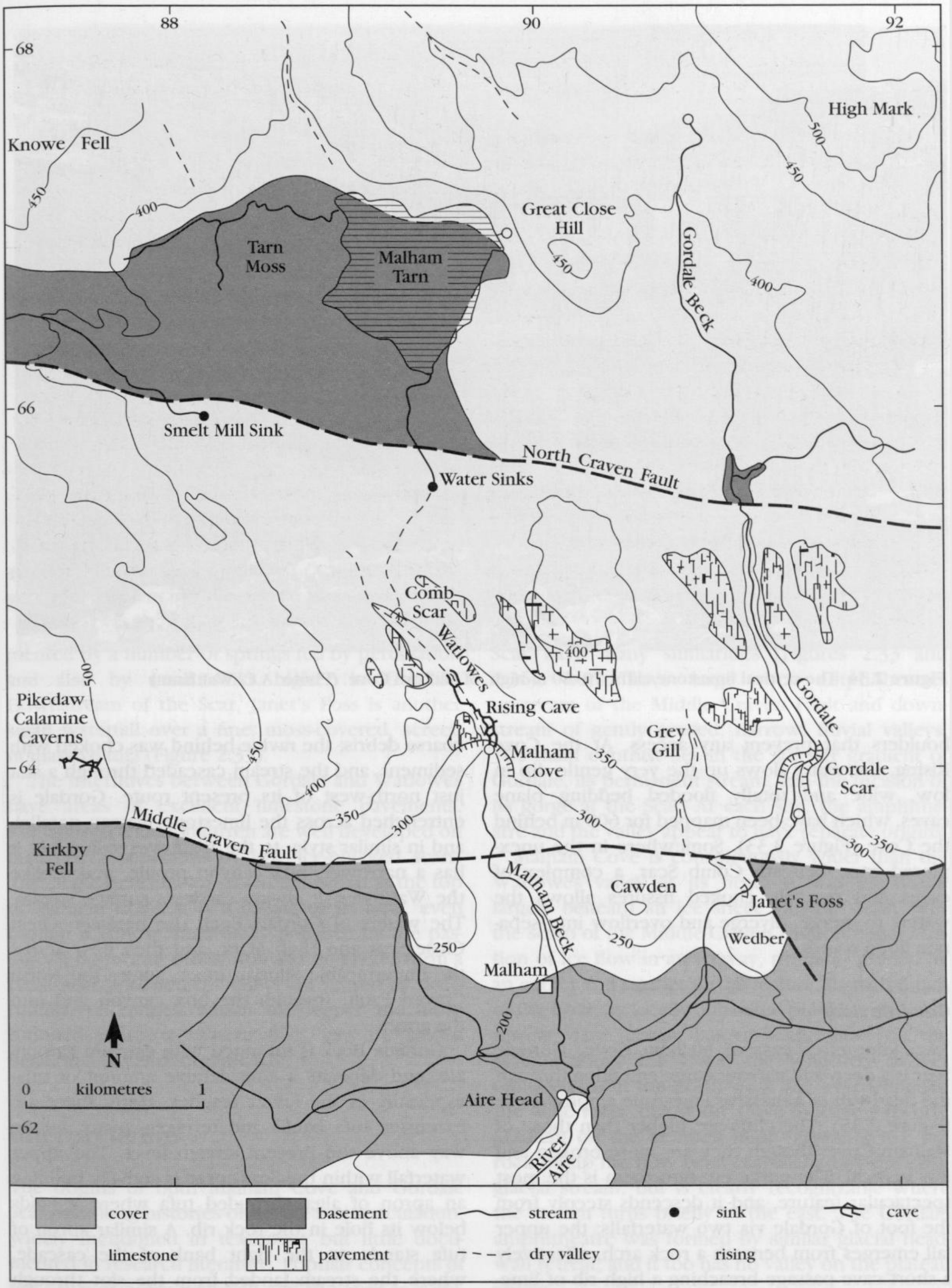


Figure 2.33 Geological map of the area around Malham Cove and Gordale Scar. The limestone at Aire Head is a thin basinal facies, distinct from the reef and shelf limestones north of Malham village. Cover rocks are Bowland Shales. Basement rocks are Silurian siltstones. There are many minor faults, mostly orientated NW–SE between the North and Middle Craven Faults. Only the main areas of well formed limestone pavement are marked.

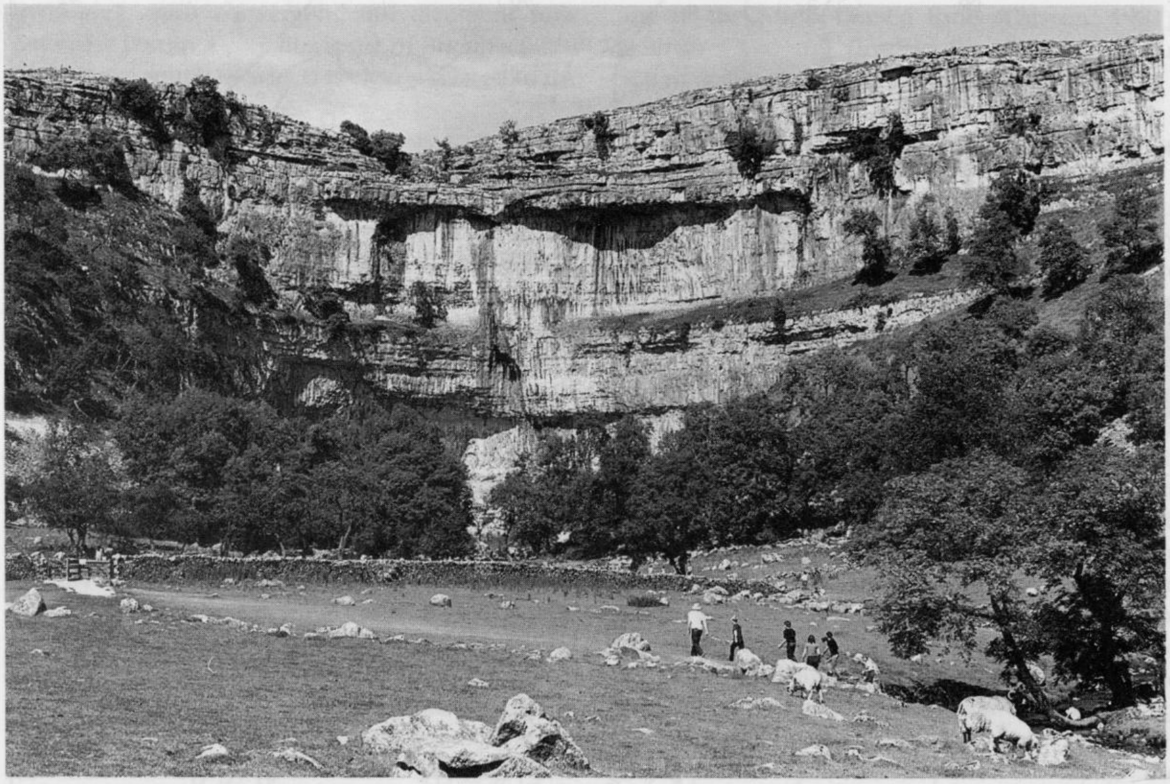


Figure 2.34 The vertical limestone cliffs, 70–80 m high, of Malham Cove. (Photo: A.C. Waltham.)

boulders that prevent any access. At the Cove Rising, the water flows up the very gentle dip in low, wide and totally flooded bedding plane caves, which have been mapped for 600 m behind the Cove (Figure 2.33). Somewhere in the unexplored zone beneath Comb Scar, a complex of caves and partially choked fissures allows the waters to merge, diverge and overflow into separate flood routes.

Gordale Scar

Two kilometres east of Malham Cove, Gordale Scar is a deep and narrow gorge emerging through the headwall of a massive limestone amphitheatre (Figure 2.35). The cliffs are higher than those of Malham Cove, though they are more broken and less vertical. The gorge cut into them is the most spectacular feature, and it descends steeply from the foot of Gordale via two waterfalls; the upper fall emerges from beneath a rock arch, effectively a short cave passage breaching a high rib of limestone bounded by minor faults. This route through the eyehole has only existed since 1730. Before then, the thin rock rib may have been intact, or the eyehole may have been blocked by coarse debris; the ravine behind was choked with sediment, and the stream cascaded through a slot just north-west of its present route. Gordale is entrenched across the limestone plateau parallel, and in similar style, to the Watlowes valley, but it has a narrower, box canyon profile, and, unlike the Watlowes, it always carries a surface stream. The waters of Gordale Beck rise between Great Close Scar and High Mark, and then flow across the impermeable Silurian inlier, across the North Craven Fault, through the box canyon and into the gorge.

Gordale Beck is saturated with calcium carbonate, and deposits a considerable amount of tufa, especially in the lower reaches. Here, there are extensive tufa banks and terraces, many a little way above the present stream level. The upper waterfall within the Scar gorge is actively building an apron of algae-shrouded tufa where it lands below its hole in the rock rib. A similar apron of tufa stands on the right bank of the cascade, where the stream landed from the slot through the rock rib until the change of course in 1730. The lower falls, formed over a partially re-eroded bed of strongly banded tufa, cascade onto a flatter gravel floored section, where the flow is aug-

Figure 2.35 The limestone cliffs of Gordale Scar. The tufa waterfalls are lost in the shadows in the meltwater gorge which opens into the glacially excavated amphitheatre. (Photo: A.C. Waltham.)

mented by a number of springs fed by percolation and also by small sinks higher in Gordale. Downstream of the Scar, Janet's Foss is another small waterfall over a fine, moss-covered, screen of massive tufa (Figure 2.33).

The interfluves between Gordale and Watlowes have areas of excellent limestone pavements. Rundkarren and kluftkarren are well developed on many beds separated by low ice-plucked scars. The single best known pavement is that at the top of Malham Cove. It is a classic of its type, even though it is now unnaturally polished by the passage of boots and shoes. Kluftkarren grykes form a rectilinear grid, and the clints are scored by deep rundkarren runnels which are deeper and more rounded close to where they can be traced beneath a cover of organic soil.

Interpretation

The origins of both Malham Cove and Gordale Scar have long histories of debate and speculation, widely mentioned in textbooks but little documented in research literature. Popular concepts of the Cove as a dry waterfall and the Scar as a collapsed cave contain only fragments of the more complex histories of development (Clayton, 1981; Pitty *et al.*, 1986; Waltham and Davies, 1987).

The morphologies of Malham Cove and Gordale Scar have many similarities (Figures 2.33 and 2.36); both have large rock amphitheatres upstream of the Middle Craven Fault and downstream of gently graded, narrow, fluvial valleys. The main contrast lies in the steeper gradient of Gordale, its permanent stream, and the incision of its gorge at the Scar. At each site, the amphitheatre and the valley appear to have separate origins.

Malham Cove is conspicuously wider than the Watlowes valley at its head. It was excavated largely beneath an ice sheet moving south over the scarp of the Middle Craven Fault. A concentration of ice flow in an iceway, probably guided by an earlier and smaller fluvial feature, formed much of the Cove by locally enhanced plucking and wall retreat. The iceway has no expression on the plateau above the Cove; the Watlowes arrives obliquely from the north-west. Ice overdeepened the wide valley below the Cove to leave a reverse gradient on the bedrock floor (Figure 2.36); the rock hump has now been entrenched by the postglacial stream, but is clearly recognizable where the stream turns briefly to the east. The Gordale amphitheatre was formed by similar glacial headwall retreat, and it too has no valley on the plateau above.

Both the Watlowes valley and Gordale, above the Scar, are clearly fluvial features. Their excavation was largely by seasonal meltwater when ground ice reduced the permeability of the cav-

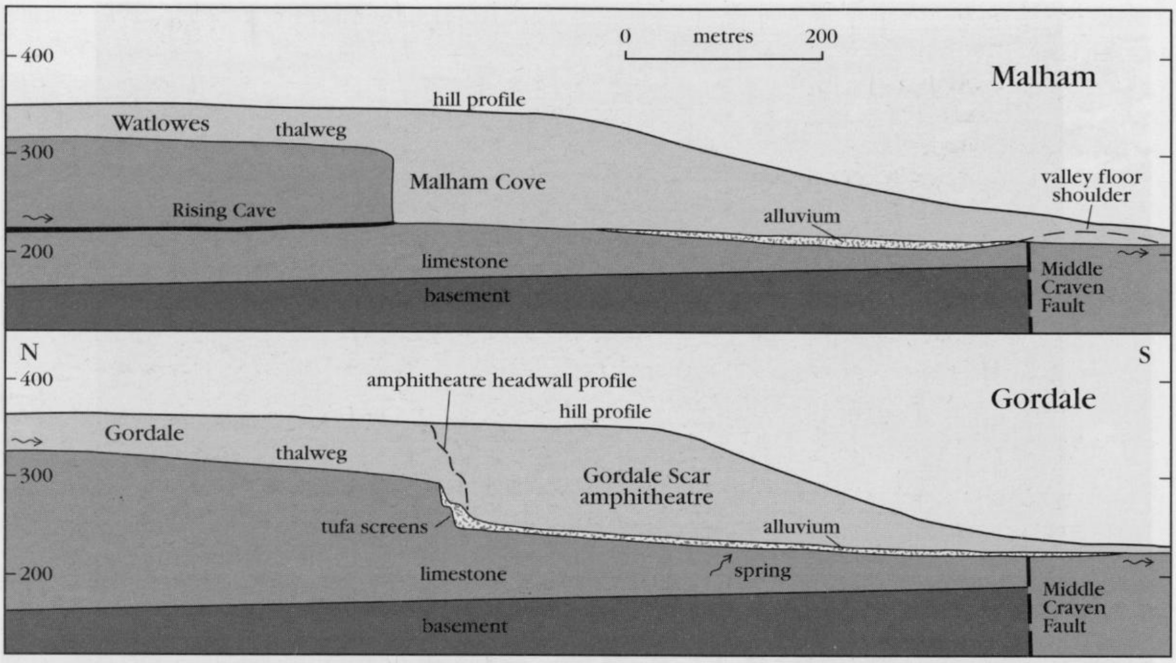


Figure 2.36 Long profiles through Malham Cove and Gordale Scar showing the prominent thalweg steps which have retreated from the Middle Craven Fault scarp.

ernous limestone. This took place subglacially at first, and then downstream of glacier snouts as the ice retreated; it is difficult to estimate the relative contributions of the subglacial and proglacial flow phases. Gordale is Britain's finest example of a meltwater channel cut into limestone under periglacial conditions, with a morphology closely comparable to modern examples in Arctic Canada (Smith, D.I., 1972); Watlowes is more degraded due to its more complete abandonment following underground capture of its drainage (Figure 2.37).

Pitty *et al.* (1986) suggested that Watlowes valley and the Cove were cut by repeated jökulhlaup outbursts of subglacial waters draining from the Malham Tarn basin; current groundwater temperatures and documented Devensian cooling indicate the likelihood of water ponding beneath a melting ice sheet in the Malham basin until it was released in the style of the jökulhlaup floods seen in Iceland today. They also suggested that these floods may have contributed to the scale of excavation at the site of a Cove waterfall. Alternatively, jökulhlaup events may have enhanced wall retreat at the Cove beneath an ice cover. In Holocene times, the steepness of the Cove cliffs has been maintained and assisted by spring sapping at the base, with associated undercutting and periodic collapse.

The meltwater incision of the Gordale Scar gorge may be ascribed to more rapid excavation along the line of minor faults, which are not present at Malham Cove. Solution of the limestone along and between fissures beneath the ravine bed created cavities which were subsequently exposed, and thereby accelerated downcutting in advance of wall retreat. One cave survives to form the eyehole above the top waterfall; cavern collapse is only a minor contributory feature in the gorge excavation by waterfall retreat. Pitty *et al.* (1986) point out that abrasive scour by sediment particles would have accelerated incision and knick point retreat at Gordale Scar, but was lacking in the Watlowes, where the Tarn basin was an effective sediment trap.

Grey Gill is a steep narrow limestone gorge in the slope between Malham and Gordale (Figure 2.33). It demonstrates the form of a gorge cut by meltwater into the fault scarp away from any larger, glacially excavated headscar.

The surface stream in Gordale is something of an enigma. Moisley (1955) surmised that carbonate precipitation may be more important here than solution, and drift deposits may have blocked former sinks. Springs at the foot of the Scar are fed largely by percolation water, and there are no cave passages comparable in size with those beneath the Watlowes. Moisley (1955) drew attention to a series of lacustrine deposits upstream of the Scar, through which the stream has cut leaving a series of terraces. He suggests that they were laid down in lakes held back by tufa dams or

Figure 2.37 Watlowes, the dry valley excavated by meltwater which leads down to the top of Malham Cove. (Photo: A.C. Waltham.)

moraine barriers. The unusually extensive tufa dams and screens of Gordale Scar were described by Pentecost (1981) as 'probably the best example of a tufa depositing stream in the British Isles'. The formation of tufa is aided by the presence of certain mosses and algae, which extract carbon dioxide and therefore cause precipitation from spring water saturated with calcite. This is aided by an increase in water turbulence, which is why many active tufa screens in Gordale are situated in the lower steeper section.

Dye-tracing in the Malham area has had a long history. The first unsuccessful attempts were made around 1870 (Tate, 1879) using a variety of crude tracers, and successful flood pulse traces were conducted in about 1879. Further traces in 1899, used both flood pulse methods and chemical tracers (Howarth *et al.*, 1900) to demonstrate the major links between Smelt Mill Beck and Malham Cove, and between Malham Tarn and the Aire Head Risings (Figure 2.33). A review of these early experiments is presented in Smith and Atkinson (1977), who then conducted rigorous dye-tracing experiments using *Lycopodium* spores, Rhodamine WT and flood pulse methods. These confirmed the underground links, and indicated that the two sinking streams joined before bifurcating to go to the two risings. The high velocity of underground flow suggested that a conduit drainage system existed, as opposed to a diffuse fissure network. Analysis of the flood pulses implied that most of the passage between Water Sinks and Aire Head is phreatic. Dye budgeting at varying discharges established that a greater proportion of the Tarn water emerges at the Cove risings under low flow than under high flow conditions; this suggests that a bottleneck in the cave system behind the Cove restricts the discharge at high flow thus diverting a greater percentage of the flood water to Aire Head. The waters of Malham Tarn also have a distinctive label in their stable oxygen isotope profile, which can be clearly identified in the Aire Head springwaters (Brown *et al.*, 1986).

The geochronology of the Malham area is poorly constrained. The broad relief was probably established during the late Tertiary, either by differential erosion or differential uplift across the Craven Fault system (Clayton, 1981). Both Clayton (1987) and Sweeting (1950) recognized erosion surfaces at 600 and 400 m, although in many places these erosion levels may be confused with stratimorphic surfaces (Waltham, 1970, 1990). Clayton (1981) advocated a Miocene age for his 600 m surface and an early Quaternary age for his 400 m surface. Glaciation has since modified the landscape, although when most of the valley incision took place is unclear. Short-term erosion rates of 0.1–0.6 m/ka were calculated for the Malham area by Trudgill (1985b) using limestone pill data; he showed that the composition of the soils and drift influences differential erosion, as the most rapid erosion occurs under acid soils. Many of the landforms seen today were probably formed during the Devensian glaciation (Clark, 1967; Clayton, 1981).

The valleys of Watlowes and Gordale were cut by meltwater, probably first beneath and then beyond the snout of a waning Devensian glacier (Waltham and Davies, 1987). The tufa deposits are all almost certainly Holocene in age (Pentecost, 1981).

Conclusions

The area bounded by the Middle and North Craven Faults of the Malham district has long been recognized to include some of the country's best developed glaciokarst landforms and shows a spectacular relationship to the regional geological structure. Malham Cove and Gordale Scar especially provide two excellent examples of glaciokarstic landforms, both formed in part by erosional retreat from a fault scarp. Malham Cove is a unique feature, partly an old waterfall, partly a glacial step, whose origins are complex and highly debated. Gordale Scar is a spectacular karst gorge entrenched between very high limestone cliffs. It was cut largely by meltwater; its active and fossil tufa deposits are the best exposed and among the most massive in Britain. The karst also contains many other impressive features, including the Watlowes dry valley and several expanses of well developed limestone pavement. The Malham drainage system is a classic example of the complexity of karstic hydrogeology.

HIGH MARK

Highlights

The dolines and closed basins of the High Mark plateau, east of Malham Tarn, are some of the best developed in Britain. The series of large closed basins, dolines and dry valleys constitute one of the country's finest examples of polygonal karst.

Introduction

The high ground of High Mark, between Littondale and Malham Tarn, forms a complex dissected plateau. Its surface is broken by closed depressions, dolines, rocky scars and shallow dry valleys. These include some of the largest closed basins in Britain. It constitutes an area of fine polygonal karst, and appears to be one of the most mature karst landscapes in Britain. It therefore has important implications for reconstructing the early evolution of this part of the Yorkshire Dales. The Great Scar Limestone reaches its maximum elevation in this area, which would have been one of the first areas of limestone to be exposed in the Yorkshire Dales, and it seems to have escaped the worst erosional effects of the Pleistocene glaciations.

The dolines of High Mark have been the subject of much discussion (Moisley, 1955; Clayton, 1966, 1981; O'Connor *et al.*, 1974; Sweeting, 1966, 1974). Trudgill (1985b) studied limestone solution rates in the area. The regional geology is documented by O'Connor (1964), Waltham (1974a), Shaw, J. (1983) and Arthurton *et al.* (1988).

Description

The dolines and closed basins of High Mark occupy the highest parts of the limestone outcrop a few kilometres north-east of Malham Tarn, at altitudes around 500 m. They are developed on a continuous succession of Carboniferous limestones; these are the Gordale Limestone from the upper part of the Great Scar, and the Hawes, Gayle and Hardraw Scar Limestones from the Wensleydale Group (Arthurton *et al.*, 1988). A very small outlier of Wensleydale Group shale and sandstone survives at the summit of Parson's Pulpit (Figure. 2.38).

The complex dissected plateau of High Mark includes over 20 large closed depressions. Most lie in two clusters: a group of 11 on Parson's Pulpit and Clapham High Mark, and another group of 9 on Proctor High Mark (Figure 2.38). Dendritic dry valleys lie between and around these clusters, but within them the entire land surface consists of basins, and forms two areas of polygonal karst. Within the depressions there are numerous small dolines and shakeholes in the cover soils and drift.

The area is devoid of surface drainage except after heavy rain, when temporary lakes may form in some of the outlying depressions around Middle House Farm (Clayton, 1981). The largest depression, south of Parson's Pulpit, is 800 m across and almost 100 m deep (Figure 2.39). Most of the depressions are saucer shaped, though some have deeper profiles with low scars on their steeper sides. Most of the dolines lie in undisturbed strata, though some west of Parson's Pulpit have more linear shapes dictated by small faults. They have varying amounts of fill whose depth is unknown, and none has exposed bedrock in its

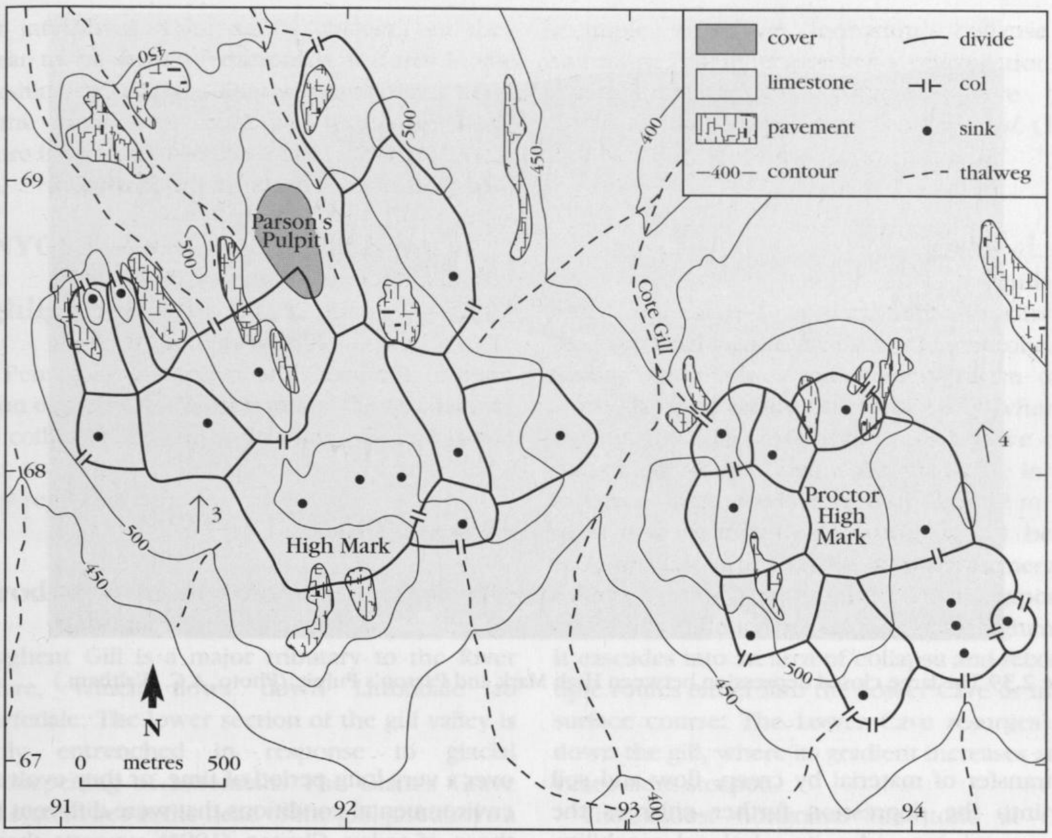


Figure 2.38 Outline geomorphological map of the polygonal karst developed on the limestone crests around High Mark.

floor. The fill includes clastic debris from the eroded cover of Wensleydale Group rocks, remnants of old soil horizons, glacial till, and ponded silts and clays deposited in periglacial lakes. The latter are comparable with sediments in the closed basins of Brimble Pit and Cross Swallet in the Mendip Hills.

The watersheds and cols separating the basins are, in general, poorly defined across ridges of gentle relief. Some of the depression rims are broken by low cols, some of which lie at the heads of shallow dry valleys down the outer slopes. On the east side of Proctor High Mark, two depressions form a more linear feature emphasized by the line of three low points in the southern basin (Figure 2.38); these appear to represent the dissected remains of a once continuous dry valley, which continues southwards outside the polygonal karst. The intervening ridges are generally mantled with thin soils, though patches of limestone pavement are distributed through the polygonal karst independent of the depression relief patterns (Figure 2.38). Some small shafts and hollows are the remains of lead mining about 200 years ago.

Interpretation

The dolines are solutional forms which appear to have developed over a long period of time, since the impermeable cover became thin enough to allow extensive solution to commence in the underlying limestone. The absence of any collapse features and marginal faults refutes any suggestion that the depressions were collapse features. Clayton (1966, 1981) proposed that they are a result of limestone solution, intensified by a layer of sediment holding water and generating carbon dioxide. He suggested that the high rainfall, low evaporation, acidic soils and peaty sediment created an 'acid sponge'. Solution of the limestone in the floors of the depressions occurs more rapidly than it does under the thin soils of the interfluves, thus continuing to deepen the depressions. Limestone pill experiments by Trudgill (1985b) support this hypothesis. A depression is self-perpetuating, once this 'acid sponge' effect is initiated within it. The inward sloping sides of the depression ensure a continued supply of water and reduce solution on the interfluves. In addi-

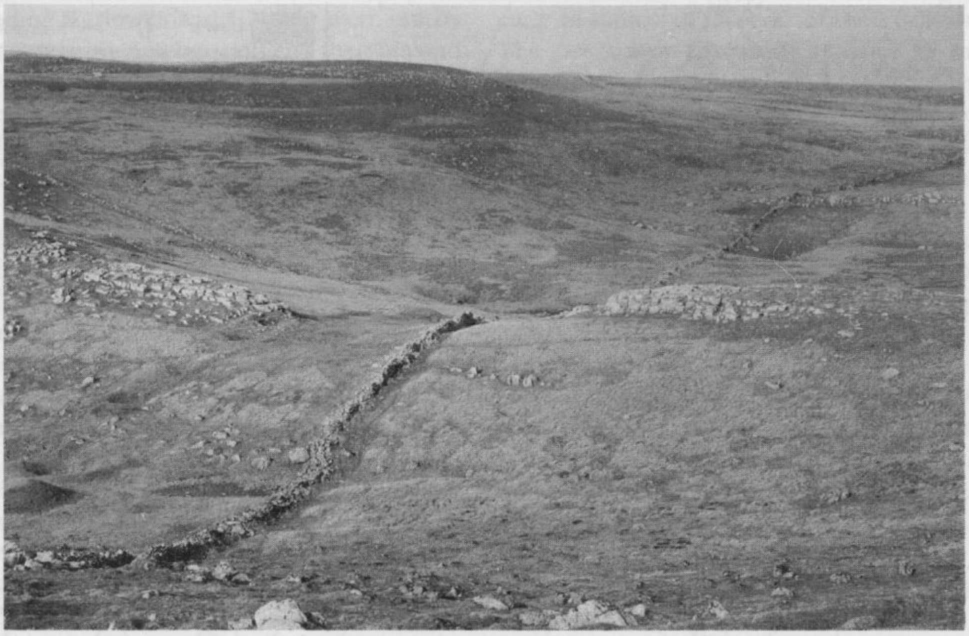


Figure 2.39 The large closed depression between High Mark and Parson's Pulpit. (Photo: A.C. Waltham.)

tion, transfer of material by creep, flow and soil wash into the depression further enlarges the 'acid sponge', increasing its solutional capability. As a basin enlarges and deepens, small limestone scars form around the rim, which then retreat as free-faces, widening the basin further.

The chronology of these features' development is difficult to constrain. Size and depth may indicate the relative age of dolines, but modifications by glaciation and meltwater erosion make these data of limited value. Current estimates of limestone solution rates in the area suggest that these depressions may predate the Pleistocene glaciations (Sweeting, 1966; Clayton, 1981; Trudgill, 1985b), and Sweeting speculated that the marginal plains around the high limestone masses are also very old erosional features. They are located where the Great Scar Limestone of the Yorkshire Dales reaches its greatest elevation and was probably exposed earliest, and the karst subsequently attained the greatest maturity. Although the age evidence is circumstantial, Clayton (1981) maintains that other hypotheses are hard to erect; he argues that the form of the depressions is unlike those such as the Malham Tarn basin produced by glacial erosion, and that areas such as Ingleborough have been eroded by ice and have no comparable features.

The age of the depressions is also relevant to their unusually large sizes. Either they formed over a very long period of time, or they evolved in environmental conditions that were different from those of today. Clayton (1981) suggests that the warmer climate of the Late Tertiary was more favourable for the formation of large dolines and polygonal karst; similar conditions could also date from the earlier Pleistocene interglacials. A pre-Devensian age is undeniable, and it appears that glaciations only caused minimal modification, by ice or meltwater, to the karst depressions. They lie away from the zones of powerful glacial scour, as the main ice flow from the north was obliquely deflected into the Littondale iceway to the east (Figure 2.1). It is significant that these areas of polygonal karst occur on the only limestones in the Yorkshire Dales which form a topographic summit area.

Conclusions

The high limestone plateau of High Mark features an unusual range of karst landforms, including dry valleys, rocky scars and dolines, with some of Britain's largest closed basins. The area provides a rare example of polygonal karst. The closed depressions were formed by solutional processes operating on the limestone underneath a blanket of wet acidic soil, which accentuates erosion in the centre of the basin compared to the higher drier interfluves. Their age is unclear, but they appear to be some of the oldest features in the Yorkshire Dales karst. The polygonal karst housing the depressions constitutes one of the most mature limestone landscapes in Britain.

PENYGHENT GILL

Highlights

The Penyghent Gill valley contains the finest illustration of cavern unroofing and collapse in Britain. The collapsed cave system shows clear relationships to both the geological structure and the valley rejuvenation.

Introduction

Penyghent Gill is a major tributary to the River Skirfare, which flows down Littondale to Wharfedale. The lower section of the gill valley is deeply entrenched in response to glacial overdeepening of Littondale. The Giant's Grave cave system lies at the head of the gill, just above a major knickpoint. This cave system contains over 700 m of passages, all at shallow depths beneath the valley floor. At its lower end there is an extensive area of collapse where the structure of the subsided limestone blocks is clearly recognizable on the surface. Although the site is a spectacular example of cave formation, collapse and unroofing, all in response to rejuvenation, it is poorly documented. The caves are briefly described by Long (1974) and Brook *et al.* (1988).

Description

Streams draining from the Blishmire peat bogs sink into caves formed within the Girvanella Nodular Band of the Hawes Limestone. The Giant's Grave caves have nearly 700 m of passages, broken by unroofed sections where the stream flows in daylight. The Main Cave carries the stream along a single bedding plane in a passage mostly about 1 m high and 2–12 m wide, with braided channels looping round bedrock columns (Figure 2.40). The stream emerges to daylight where the bedding plane is exposed at the head of the incised section of Penyghent Gill. It cascades into an area of collapse and feeds multiple routes either into the Lower Cave or into the surface course. The Lower Cave resurges lower down the gill, where its gradient increases and the valley sides steepen.

The almost horizontal limestone at Giant's Grave has two major bedding planes, about 2 m apart, on each of which there are small areas of well dissected limestone pavement (Figure 2.40). The Main Cave and the lower pavement are formed on the lower bedding plane. The zone of collapse is about 50 m across, and involves the

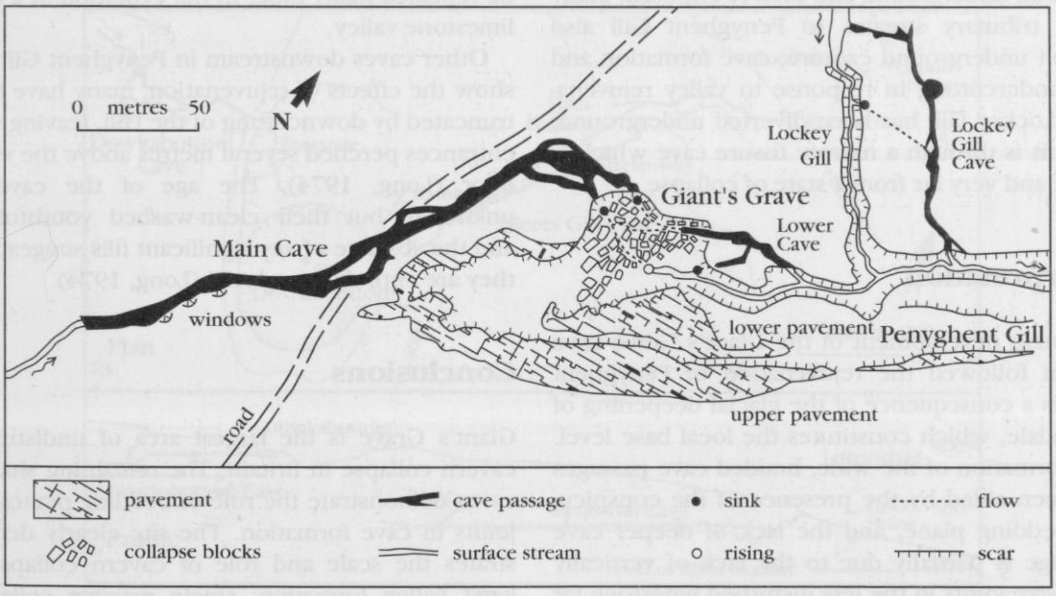


Figure 2.40 Geomorphological map of the collapse area and associated caves at Giant's Grave at the head of Penyghent Gill.

Figure 2.41 The foundered blocks of limestone in the collapse area at Giant's Grave, Penyghent Gill. (Photo: A.C. Waltham.)

beds immediately beneath both bedding planes. The limestone has been undercut by the Main Cave and its downstream, unroofed extension, and also by flow along a third, lower bedding plane which now floors the collapse zone between the Main and Lower Caves. A mass of jumbled tilted blocks constitute the collapse zone (Figure 2.41); minor bedding planes have been etched into the walls of the detached blocks, whose original relationships to each other can still be recognized.

At Giant's Grave the surface drainage has been captured underground and then re-exposed. Many other tributary streams to Penyghent Gill also exhibit underground capture, cave formation and cliff undercutting in response to valley rejuvenation. Lockey Gill has been diverted underground, but this is through a narrow fissure cave which is stable and very far from a state of collapse.

Interpretation

The main development of the Giant's Grave cave system followed the rejuvenation of Penyghent Gill, as a consequence of the glacial deepening of Littondale, which constitutes the local base level. The formation of the wide, braided cave passages has been aided by the presence of the conspicuous bedding plane, and the lack of deeper cave drainage is partially due to the lack of vertically extensive joints in the less disturbed limestone far from the Craven Faults; single joints rarely extend through more than one bed of limestone (Waltham, 1974b). Following the rejuvenation of Penyghent Gill, numerous tributary streams sank into joint fissures in response to the increased hydraulic gradients, but they then followed shallow, nearly horizontal courses perched on the bedding planes. As the limestone above the shallow caves is further thinned by surface lowering, the wide roof spans progressively collapse, creating the masses of subsided blocks, of which Giant's Grave is the best example. This process clearly contributes to the karstic development and entrenchment of the valley, and the process may be repeated many times in the evolution of a deep limestone valley.

Other caves downstream in Penyghent Gill also show the effects of rejuvenation; many have been truncated by downcutting of the Gill, leaving their entrances perched several metres above the valley floor (Long, 1974). The age of the caves is unknown, but their clean-washed youthfulness and the absence of any significant fills suggest that they are entirely postglacial (Long, 1974).

Conclusions

Giant's Grave is the largest area of undisturbed cavern collapse in Britain. The remaining shallow caves demonstrate the role of bedding planes and joints in cave formation. The site clearly demonstrates the scale and role of cavern collapse in karst valley formation; single massive collapses instantly creating valleys or gorges are not involved. The very small scale of the Giant's Grave collapse stands in marked contrast to the larger karst valleys of Cheddar Gorge, Trow Gill and the Winnats Pass; these sites are not collapsed caverns, but cave collapse has played a role in their progressive excavation.

SLEETS GILL CAVE

Highlights

Sleets Gill Cave and the adjacent Dowkabottom Cave constitute fragments of an ancient, deep phreatic cave system truncated by surface lowering and now exposed out of equilibrium with the present geomorphology. The sediments within both caves contain clasts derived from strata no longer surviving at outcrop. Sleets Gill Cave contains the finest examples in Britain of both abandoned and intermittently active phreatic lifts.

Introduction

Sleets Gill Cave and Dowkabottom Cave lie on the western side of Littondale, just above its confluence with Wharfedale (Figure 2.1). The plateau above the caves is developed largely on the Great Scar Limestone, with only two very small outliers of Yoredale facies shales surviving within the catchment. The water from both caves resurges under normal flow conditions at Moss Beck Rising, 1 km east of the Sleets Gill entrance. The caves have remained largely undocumented. Sleets Gill Cave was described by Monico (1989b), and all the caves were described briefly by Long (1974) and Brook *et al.* (1988); Long (1992) made further comment on the unusual hydrology and flooding regimes.

Description

Sleets Gill Cave (Figure 2.42) is entered through a 3 m wide arch at the head of a normally dry stream bed, 60 m above the floor of Littondale. The entrance passage is an inclined tube descending to a depth of 24 m, where it levels out into the Main Gallery, a 4 m diameter phreatic tube which can be followed for 370 m to a choke. An immature active streamway lies below and just south of the old phreatic conduit, and provides access beneath the choke into a continuation of the large, relict phreatic tunnel. The Ramp is a large phreatic tube ascending over 60 m at an angle of 35° to a calcited boulder choke.

The choked ends of Sleets Gill Cave lie more than 100 m below Dowkabottom, a large, shallow closed depression cut in the limestone just below the main plateau level. Low rock scars line most of its perimeter, but its floor is grass on a thick soil. Behind the western wall of the depression, Dowkabottom Cave is another fragment of largely abandoned phreatic conduit, accessible through a

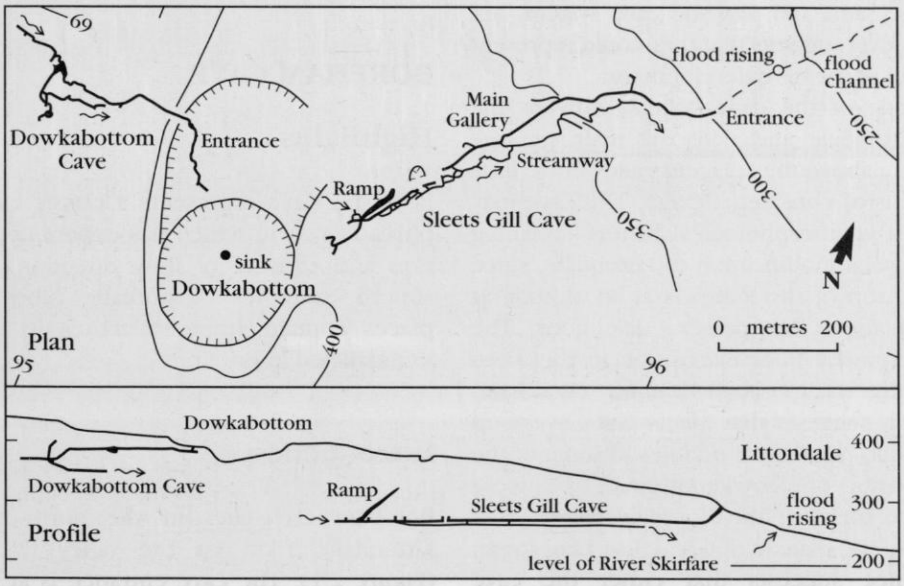


Figure 2.42 Outline map and profile of Sleets Gill Cave and its associated karstic features (from surveys by University of Leeds Speleological Association and others).

rift in the flat floor of an outer, higher basin (Figure 2.42). Most of its passages are large phreatic tunnels, rectangular in section due to block fall; one section is developed along a fault as a narrow rift 20 m high. This cave contains more extensive sediment deposits than does Sleets Gill Cave, and they include calcite flowstones and clastics with pebbles of Yoredale sandstone.

Interpretation

The Sleets Gill entrance passage and the Ramp both carried water upwards and are spectacular examples of relict phreatic lifts. They both ascend at an angle of 35°, cutting through the horizontal limestone with no visible sign of structural control. Their locations appear to have been guided purely by hydraulic factors where water was escaping from deep contemporary phreatic zones towards resurgences in the floor of Littondale when this was at much higher levels early in the Pleistocene. There is no evidence of the relative ages, except that the Ramp's position further into the hill suggests that it is the older, whose flow was subsequently captured by a new lower route along the Main Gallery. The entrance passage is truncated by the modern hillside, and the Ramp is choked at its upper end, so that it is unclear whether the inclined passages were the lower sections of deep vauclusian risings, or were merely phreatic lifts midway along deep karstic conduits. The passages of Dowkabottom Cave appear to be upstream fragments of the same old phreatic cave system, but their higher level suggests that they could represent earlier phases of the cave development.

The altitude of the cave system, now in the flanks of Littondale and with the main passage perched 65 m above the adjacent valley floor, indicates that it is of considerable age. The cave may encompass a geomorphological history spanning the entire glacial modification of Littondale, since the phreatic top of the Ramp is at an altitude at least 130 m above the present dale floor. The mean rate of valley floor excavation in the western Yorkshire Dales is 0.12 m/ka (Waltham, 1986), which suggests that Sleets Gill Cave is at least 1.1 Ma old. Sandstone pebbles in some of the clastic deposits of Dowkabottom Cave were derived from rocks of the Yoredale facies, now stripped from the plateau of Great Scar Limestone; their presence suggests that either the cave formed when the Yoredale cover was more extensive, or the Yoredale material was derived from a partial cover of glacial debris, subsequently largely eroded away. The sediment and speleothem sequence within these caves constitute a stratigraphical record of the evolution of Littondale, yet to be elucidated in full.

The present hydrology is complex, with percolation water derived largely from distant autogenic sources draining via immature caves to a resurgence near the valley floor. Response to heavy rainfall is delayed, but the outlets from Sleets Gill Cave, to both the permanent Moss Beck resurgence and also a flood rising below the entrance (Figure 2.42) appear to be constricted. Flood waters back up in the cave's large tunnels, find various fissure outlets to the rocky channel of Sleets Gill Beck, and in high flood create a temporary vauclusian rising when they overflow the lip at the cave entrance.

Conclusion

The two caves are fragments of a very old system which once carried deep phreatic flow from a large limestone plateau towards Littondale prior to its glacial entrenchment. Sleets Gill Cave contains Britain's finest examples of steeply inclined phreatic tubes, which may have fed ancient vauclusian risings. An immature modern phreas, fed by autogenic input and draining to a valley floor resurgence, lies alongside the larger abandoned passages, and the ancient phreatic conduits may still be utilized during periods of high flow.

BOREHAM CAVE

Highlights

Boreham Cave represents a classic example of a phreatic system which has experienced rejuvenation and reversal of flow direction. It contains superb examples of phreatic tubes, which in places contain straw stalactites in a profusion unparalleled in Britain.

Introduction

Boreham Cave lies in the north-east side of Littondale, 1 km up the valley from Arncliffe (Figure 2.1). The cave entrance is at valley floor level, with the passages extending to the east and north under Old Cote Moor. The slopes and floor of Littondale are cut into Great Scar Limestone, dipping very gently to the north-east. Boreham Cave represents the longest cave system yet explored on the northern side of the dale, with active and abandoned phreatic passages extending for a total length of 3100 m. The cave passages are described by Brook *et al.* (1988) and Yeadon (1975), and the latter includes discussion of the local karst hydrology.

Description

From the entrance more than 500 m of low-level passage extends north-east, before swinging round to the north for a further 1000 m (Figure 2.43). Most of this passage consists of a phreatic tube about 2 m in diameter. It is developed largely at one stratigraphical level, and long sections are permanently flooded, with water flowing slowly to the north, then down a shaft to a lower flooded passage. One half-flooded chamber in the low-level tunnel provides access to 1500 m of high-level caves extending mainly to the east. The main passage is a relict phreatic tube up to 4 m in diameter, which is joined by several small inlet passages,

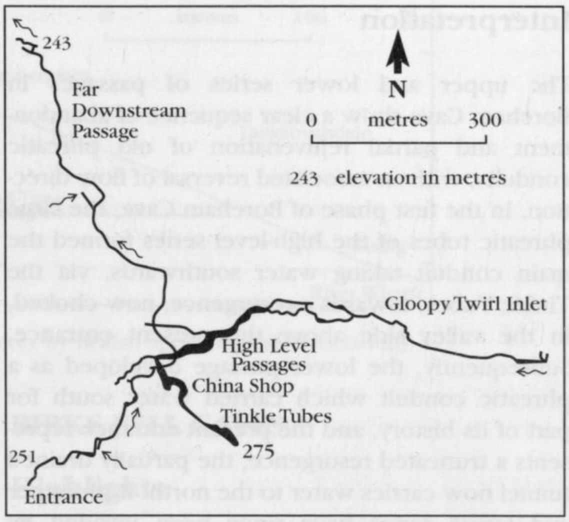


Figure 2.43 Outline map of Boreham Cave (from survey by Cave Diving Group).

both active and abandoned. Some sections of the high-levels contain thousands of closely packed calcite straws each up to 3 m long, with the finest display in the China Shop (Figure 2.44). There are thick sediment banks in some of the passages, all of which terminate in boulder chokes.

Figure 2.44 Delicate straw stalactites hang down into standing water in the old phreatic tube of the China Shop in Boreham Cave. (Photo: T.G. Yeadon.)

Interpretation

The upper and lower series of passages in Boreham Cave show a clear sequence of abandonment and partial rejuvenation of old phreatic conduits, with an associated reversal of flow direction. In the first phase of Boreham Cave, the large phreatic tubes of the high-level series formed the main conduit taking water southwards, via the Tinkle Tubes, towards a resurgence, now choked, in the valley side above the present entrance. Subsequently, the lower passage developed as a phreatic conduit which carried water south for part of its history, and the present entrance represents a truncated resurgence; the partially drained tunnel now carries water to the north. Both upper and lower series have since been invaded by vadose inlet streams and the percolation water responsible for the spectacular straw stalactites. Invading waters in the upper level have cut a vadose trench in part of the old phreatic passage, and have cut down to intercept the flooded lower passages.

Passages in the lower series are still largely flooded, and water in the first section, from the entrance to the junction with the high-level series, is virtually static, being largely ponded percolation water. North of the junction, water draining in from the high-level series flows very slowly to the north, into a vadose canyon which ends at a waterfall shaft down to a lower flooded level; this probably drains to the Litton Risings, 850 m to the south-west. The flooded passages represent a perched phreas in progress of being drained as the downstream vadose canyon cuts back into them. The two levels of passages, both close to the floor of Littondale, contain in their morphology, their fluvioglacial sediment and their calcite speleothem contents an important, but as yet unstudied, record of the Devensian glaciation of the eastern Dales.

Conclusion

Boreham Cave is notable for its phreatic tubes, both active and relict, which follow the bedding at two levels in the limestone close to the level of the modern valley floor. The abandoned high-level passages contain the most beautiful assemblages of straw stalactites found in a British cave; their preservation from accidental damage will be ensured by the natural access restrictions imposed by the flooded passages in the lower series.

STRANS GILL POT

Highlights

Within Strans Gill Pot a series of fault-guided vadose shafts descends to a large, well developed, old phreatic tube. This tunnel has thick mud banks, a spectacular display of calcite straws, and a deep, vadose, floor trench incised in response to rejuvenation. In only a short length of passage, Strans Gill has all the classic features of a multi-phase Dales cave.

Introduction

Strans Gill is a shallow ravine cut into the northern side of Langstrothdale, north-west of Buckden (Figure 2.1). Below the slopes of Yoredale shale, the stream sinks on a narrow stratimorphic bench at the top of the limestone, and under normal flow conditions the gill is dry down its steeper, lower course. A single rift in the streambed gives access to Strans Gill Pot, which underlies the surface gill. The entrance to the pothole lies in the Hardraw Scar Limestone, which is contiguous with the underlying Great Scar Limestone where most of the cave passages are formed. The cave has been described by Long (1969), and more briefly by Brook *et al.* (1988) and Long (1974).

Description

Beneath the entrance fissure of Strans Gill Pot a series of short and very constricted rifts lead to a large shaft 50 m deep developed on a north–south tear fault (Figure 2.45). The stream pours down to the boulder floor of a chamber aligned on the fault, and drains into a vadose canyon developed along the intersection of a horizontal shale bed and the vertical fault. This ends at a cascade into a chamber modified by collapse at the intersection of two faults, and lower rifts descend to a sump 105 m below the entrance. Three relict phreatic passages, formed at the levels of shale beds within the limestone, radiate from the collapse chamber. To the south, a narrow, vadose, floor slot descends the fault for 23 m to standing water, but a bedding cave above it enlarges into the Passage of Time – an elliptical phreatic tube, 10 m wide and 2–3 m high over broad mudbanks. This phreatic tunnel is notable for its magnificent array of calcite speleothems, including stalactites, sta-

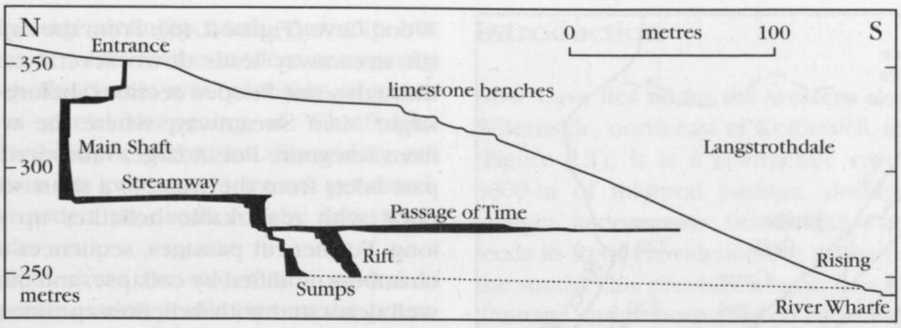


Figure 2.45 Long section through Strans Gill Pot (from survey by British Speleological Association).

lagmites, gour pools and straws up to 3 m long; some large individual calcite crystals are stained green. The ancient passage was truncated by glacial deepening of Langstrothdale, but the cave is choked to the roof with inwashed mud and sand, and surface sediments now bury the exit.

Interpretation

The vadose shafts of the Strans Gill Pot entrance series are in a fault zone, while the relict phreatic tubes are at the levels of shale beds, demonstrating the importance of these beds to cave inception within the limestone. It is notable that the vadose rifts and shafts, both above and below the Passage of Time, are all formed on the tectonic weaknesses in the limestone; in contrast, the large phreatic tunnel curves away from the fault line, while maintaining the stratigraphical level which was favourable to cave inception. Drainage of the lower levels of phreatic cave passages, and deposition of the abundant clastic sediments and calcite speleothems, were the consequences of rejuvenation in response to the adjacent deepening of Langstrothdale by Pleistocene glaciations. Sediments in the cave and around the partly inactive surface gill record the erosion and modification of the karst through past climatic changes, whose chronology has not yet been determined.

Conclusion

Strans Gill Pot is a textbook example of a cave system, with fault-controlled vadose rifts and shafts descending into abandoned phreatic passages. The Passage of Time contains an exceptional and very beautiful display of calcite decorations in a dramatic location.

BIRKS FELL CAVES

Highlights

Two remarkably linear, active, cave systems lie parallel to each other under the edge of Birks Fell, and are almost parallel to the adjacent, steep side of Wharfedale. They demonstrate the overriding influence of a dominant joint set, causing underground drainage to flow for a considerable distance against the dip of the limestone and parallel to the valley side.

Introduction

The caves are located under the eastern slopes of Birks Fell, overlooking Wharfedale south-west of Buckden (Figure 2.1). Both caves are developed in the Great Scar Limestone, with their sink entrances just below the mixed shale and limestone sequences of the Yoredale facies. The limestone dips very gently to the north and is broken by a fault and a major joint set, both trending north-west–south-east. Birks Fell Cave was described initially by Coe (1968), and the passages in all the caves are described by Brook *et al.* (1988).

Description

Birks Fell Cave is the eastern system, containing more than 3600 m of passages extending to a depth of 142 m (Figure 2.46). The entrance lies where a stream sinks through the Girvanella Nodular Band, the distinctive horizon of nodular algal limestone within the Hardraw Limestone, marking the top of the Great Scar facies. Narrow, joint-controlled rifts alternate with low, bedding-controlled sections in the entrance series. Beyond

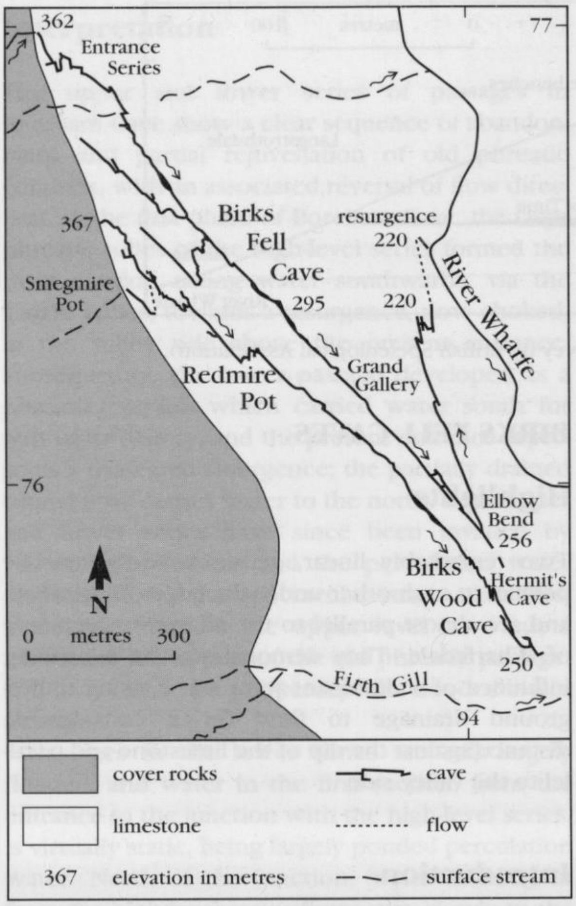


Figure 2.46 Outline map of the Birks Fell and Birks Wood Caves (from surveys by Craven Pothole Club and Cambridge University Caving Club).

two inlets draining from the west, the main passage heads south-east as a large rift developed along a fault. Beyond two avens, also with inlets draining from the west, the passage becomes larger and contains extensive collapse within its tall rifts; parts are well decorated with secondary calcite. Grand Gallery is a rift passage 20 m high leading to a series of high-level oxbow passages, decorated with stalactites and gour pools. The main streamway continues to Elbow Bend where the dry passage to the south-east ends in a choked rift 20 m from the end of Hermit's Cave (Figure 2.46). The active stream passage turns to the NNW, and a low passage draining downdip along a thick shale bed lies between two sections of rift passage. The final narrow rift ends at a sump only 120 m from the resurgence.

Parallel to Birks Fell Cave, and a short distance west into the hillside, a cave system with 1600 m of passage, developed over a depth of 117 m, links a sink at Redmire Pot to a resurgence at Birks Wood Cave (Figure 2.46). From the sink, a narrow rift streamway leads down several cascades and through some flooded sections, before joining the larger Main Streamway, where the water enters from Smegmire Pot. A large, vadose, rift continues past inlets from the west, to a short section decorated with remarkable helictites up to 300 mm long. Further rift passages, sequences of cascades, chambers modified by collapse, and more sections well decorated with helictites continue to a series of low bedding-plane passages with several flooded sections, which emerge at the resurgence exit of Birks Wood Cave.

Interpretation

The structural geology of the limestone has clearly influenced the development of both caves. The exceptionally linear form and the tall rift passages of Birks Fell Cave reflect the development along a fault for most of its length. The parallel Redmire/Birks Wood cave system, as well as Smegmire Pot and the two main inlets of Birks Fell Cave, have developed along the joints, and probably some minor faults, of a set parallel to the main fault. Both the Birks Fell caves have developed obliquely down their limestone fractures, with remarkably gentle gradients and only small shafts along their courses. This is in marked contrast to most of the fault or joint guided potholes in the Yorkshire Dales karst, which drop rapidly down vertical shafts to base level. The influence of a second joint set, trending NNW–SSE, can be seen in both caves, notably in the passage downstream of Elbow Bend in Birks Fell Cave (Figure 2.46).

Dominance of the fractures in guiding the initial drainage through the limestone is reflected in the fact that, over most of their length, the caves drain obliquely against the dip. The passages in Birks Wood Cave are developed largely along bedding/joint intersections; shallow phreatic loops are developed by ponding where the cave drains updip, and are interspersed with cascades where the streamway breaks through to lower stratigraphical levels. This contrasts with the type of phreatic loop prevalent in the Mendip caves at both Cheddar and Wookey, where the water flows downdip before ascending to stratigraphically higher levels up phreatic lifts developed along joints.

Hermit's Cave represents a former outlet for Birks Fell Cave, now lying 35 m above the valley floor. A later phase of Birks Fell Cave evolved with the lower passage draining north, downdip but still along major joints to the modern resurgence in the valley floor; this was probably a consequence of a glacial deepening of Wharfedale, wholly or partly in the Devensian. Secondary calcite deposits in the lower caves are not yet dated, but could provide a time-scale for the excavation of Wharfedale.

Though both caves are structurally guided in plan, their gently graded profiles ignore the potential influences of fractures and bedding, except on short sections of bedding cave. The uniformly graded profiles appear to have developed in a single phase along a hydraulically favourable, straight line path from the sinks to the contemporary resurgences in the slope north of Firth Gill. These paths would have been features of the steep water table in a youthful karst, and the conduits have retained their drainage roles, even though their upper parts are now effectively perched in the mature karst where the stable water table is close to the level of the nearby resurgences in the dale floor.

The development of two adjacent, independent, parallel, linear caves along the hillside that they drain has had a distinctive and unusual influence on their hydrology. Much of the allogenic drainage from the shale cover is captured by the Birks Wood Cave, and the only inlets to enter Birks Fell Cave drain from sinks which lie beyond the northern limit of Redmire Pot. None enters the lower part of Birks Fell Cave.

Conclusion

The two parallel and adjacent caves of Birks Fell provide a classic example of the manner in which geological controls on underground drainage and cave development can override the prevailing surface drainage patterns. Both caves are excellent examples of rift development along joints and faults, and Redmire Pot is also notable for some exceptionally large calcite helictites.

DOW CAVE

Highlights

Dow Cave contains a remarkably linear joint-controlled inlet passage draining from sink to rising beneath a surface interfluve. The main passage intersects a massive choke of debris in a large interglacial shaft.

Introduction

Dow Cave lies under the western slopes of Great Whernside, north-east of Kettlewell, in Wharfedale (Figure 2.1). It is a resurgence cave with about 3000 m of mapped passage, dominated by the straight and narrow Dowbergill Passage, which feeds in from Providence Pot in the next valley to the south. This provides a small flow, but the main drainage enters from choked sinks in Caseker Gill, above the much shorter main passage.

The cave was initially described by Brindle (1954, 1955) and Powell (1954). Its geomorphology is briefly discussed by Long (1974), and the passages are described by Brook *et al.* (1988).

Description

The resurgence entrance to Dow Cave is over a large debris pile where roof collapse has retreated from its exposure in the flank of Caseker Gill. Behind the fallen blocks, the stream flows in a fine keyhole passage up to 4 m wide and 8 m high. Upstream the vadose slot diminishes and the phreatic tube emerges from a wide bedding-controlled cave. This can be followed for only a short distance beyond a large chamber 400 m from the entrance to a major collapse feature, the boulder choke of Hobson's Choice. Above are higher chambers roofed with ill-sorted limestone and sandstone blocks in a matrix of mud. A smaller upstream passage has several waterfalls in rifts up to 25 m high, before a final boulder choke from which the main stream emerges. Some of the old roof channels in this part of the cave are well decorated with speleothems.

The Dowbergill Passage inlet enters Dow Cave low in the south wall a short distance downstream of the Hobson's Choice choke. From its junction with Dow Cave it extends SSE in a remarkably straight line for more than 1300 m to an upstream sump. A series of small, muddy rifts and fragments of larger passages in Providence Pot, are entered through an excavated shaft in the streambed of Dowber Gill, and link into Dowbergill Passage 90 m downstream of the sump. Through much of its length, Dowbergill Passage is a vertical rift, 10–25 m high but rarely more than a metre wide (Figure 2.47). Wedged blocks create sections of false floor, high above the gently graded stream. There are very few roof inlets or speleothems, since the passage lies beneath the Yoredale shale outcrop.

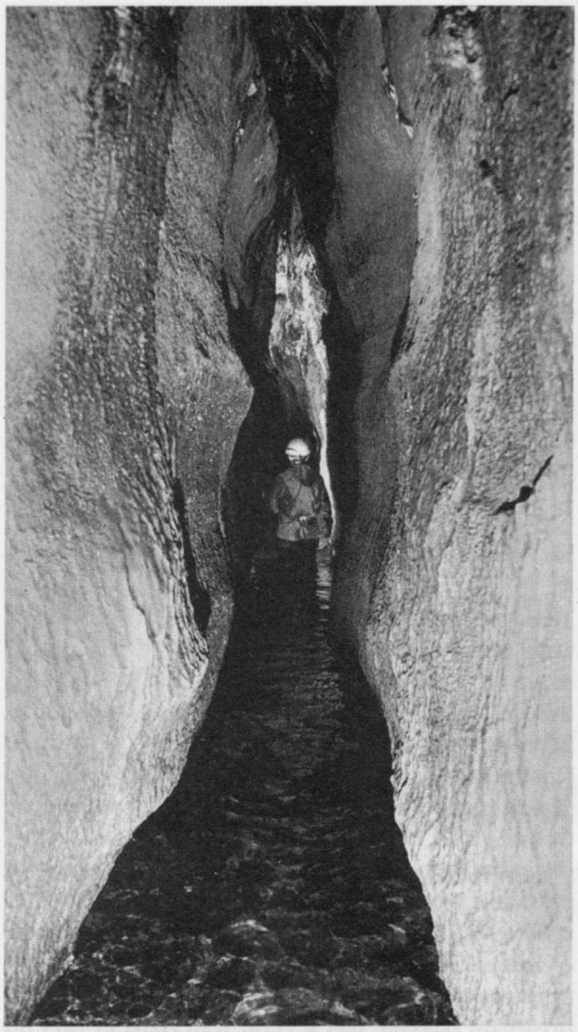


Figure 2.47 The tall, narrow rift of Dowber Gill Passage in Dow Cave (Photo: M.H. Long.)

Interpretation

The large main passages of Dow Cave represent part of a major, old, phreatic conduit, since modified by vadose entrenchment and truncated by valley downcutting. The mix of very large limestone and sandstone blocks in the Hobson's Choice choke suggests that it is a fill of both collapsed and inwashed material in a large pothole, extending to the surface and formed prior to the Devensian glaciation. This fill has since been partly removed from below by the Dow Cave stream.

The Dowbergill Passage inlet is almost dead straight, and is formed along a single major joint. It is a spectacular example of both control by a tectonic joint (Halliwell, 1979b), and a drainage route passing beneath a surface interfluve. Cave passages this straight over such a great distance are generally formed on faults, but Dowbergill Passage appears to be on a simple joint, with no visible sign of fault displacement. The phreatic origins of the rift cave are no longer discernible. Similarly, there is now no evidence of the extent of tectonic opening on the fissure, prior to its solutional enlargement; the site of the joint, parallel to the hillside, would have favoured opening by de-stressing, probably after a glacial retreat. Vadose incision along the fissure was probably very rapid, and has now produced a smoothed profile graded to the level of the Dow Cave streamway. This has been aided by capture of the drainage in Dowber Gill, where Providence Pot appears to be an old sink; this is now active only in flood, as most of the water joins Dowbergill Passage from sinks further up the gill.

Conclusion

The main passage of Dow Cave demonstrates the progressive destruction of a phreatic cave, by drainage, vadose entrenchment, truncation, collapse and choking by debris. It also provides unusually easy access to the base of a large, choked, interglacial sinkhole. Dowbergill Passage is a rift passage of unusual straightness and length, formed along a joint and capturing the drainage from an adjacent valley.

BLACK KELD CATCHMENT AREA

Highlights

Mossdale Caverns and Langcliffe Pot are the two most extensive cave systems developed in the Yoredale limestones. The known cave passages in Langcliffe Pot breach the sandstones and shales into a lower Yoredale limestone, and both caves drain through relatively impermeable beds into the underlying Great Scar Limestone.

Introduction

The two long cave systems lie beneath the southern slopes of the Conistone and Grassington Moors, east of Wharfedale; between them they drain a large part of the slopes of Great Whernside (Figure 2.1). Each cave system is accessible through its stream sink entrance, and can be followed only as far as flooded or choked passages well before their confluence. Both caves drain to the Black Keld resurgence, in the floor of Wharfedale. Most of the accessible cave passage lies within the Brigantian Middle Limestone, which is about 30 m thick, dipping very gently south-east. Shale and sandstone separate this from the underlying Simonstone Limestone, less than 20 m thick; this is underlain by another thin shale separating it from the Brigantian Hardraw Scar and Gayle Limestones which are locally contiguous with the Asbian Great Scar Limestone. The cave drainage traverses a total stratigraphic thickness of over 280 m, to reach the Black Keld resurgence low in the Great Scar Limestone. Namurian Grassington Grit lies unconformably over the Brigantian sequence, and rests directly on the Middle Limestone at Mossdale Scar.

Many of the cave passages were originally described by Leakey (1947), Grandison (1965) and Monico (1989a). Further descriptions of the caves are given by Brook *et al.* (1988), and the hydrology and geomorphology of the area have been discussed by Brook (1971a, 1974b).

Description

Mossdale Caverns

Mossdale Caverns are entered where Mossdale Beck flows into the largest sink in the area. Over 10.5 km of cave passages have been mapped (Figure 2.48), all developed at or near the base of the Middle Limestone. The beds dip south-east at 1–5°, so that the cave reaches a depth of about 60 m. The system has an unusual branching morphology with various outlets for its water. From the descent through the collapse zone near the entrance, the main streamway continues east, only 2 m high but up to 5 m wide, floored by the sandstone underlying the Middle Limestone. Two distributary passages, one perched 2 m above the base of the limestone, branch off the south side before becoming floored with sandstone, subdividing, narrowing and ultimately becoming too tight

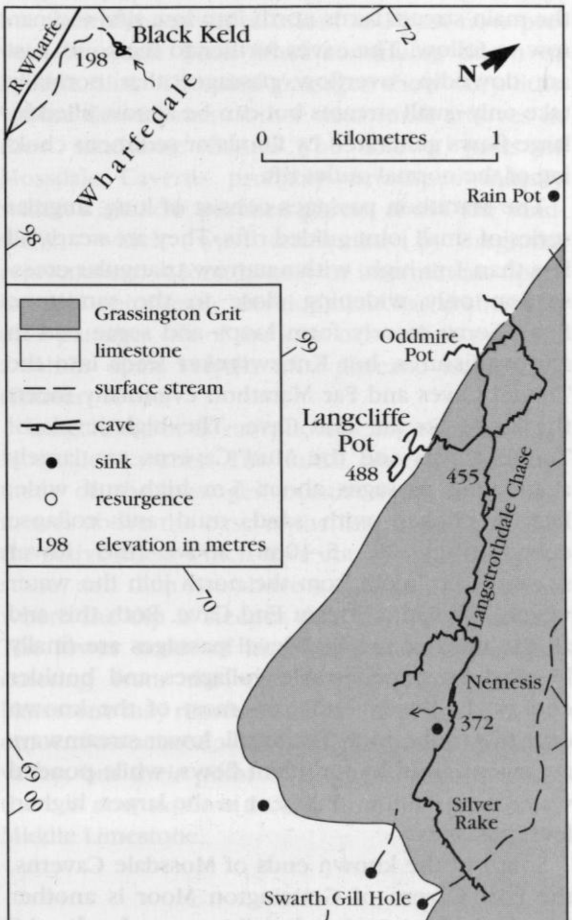


Figure 2.48 Outline map of Mossdale Caverns and Langcliffe Pot, which both drain to Black Keld. The limestone includes the Great Scar Limestone and the Yoredale facies limestones of the overlying Brigantian Wensleydale Group; the latter are separated by thin shales and sandstones that are not marked (from surveys by University of Leeds Speleological Association and others).

to follow. In a second area of branching passages, the main stream turns north into low rifts too narrow to follow. The caves further to the south-east are downdip, overflow passages that normally take only small streams but can be almost filled by large flows generated by floods or sediment choking of the normal outlet rift.

The Marathon passages consist of long, angular series of small joint guided rifts. They are nearly all less than 1 m high, with a narrow triangular cross-section only widening close to the sandstone floor. Some merely form loops and some end in narrow fissures, but Kneewrecker leads into the Tunnel Caves and Far Marathon eventually meets the larger Stream End Cave. The high levels of Tunnel Caves and the Mud Caverns are largely abandoned passages about 5 m high and wide, heavily choked with sand, mud and collapse debris; they lie 5–10 m above the lower streamways. Inlets from the north join the water which flows into Stream End Cave. Both this and all the ends of the high-level passages are finally blocked by impenetrable collapses and boulder chokes. In flood conditions most of the known cave fills to the roof. The small, lower streamways are swept clean by turbulent flows, while ponded water deposits fine sediment in the larger, higher-level passages.

South of the known ends of Mossdale Caverns, the Lost Cavern of Grassington Moor is another fragment of large, abandoned cave passage in the Middle Limestone. It was entered by miners at a depth of 55 m below the Old Turf Pits Shaft, early in the nineteenth century. They found a large dry tunnel, over 230 m long, up to 10 m high and of variable width. This and the larger side passages were mapped (Figure 2.48), but many other passages were left unrecorded, and all the caves have been inaccessible since the entrance shaft collapsed after the mining ceased (NCMRS, 1980).

Langcliffe Pot

Langcliffe Pot is very different from Mossdale Caverns, with five sinks draining to a single underground streamway, in a cave system over 9600 m long (Figure 2.48). Entrance shafts at two small stream sinks each drop about 25 m to the base of the Middle Limestone. Their outlet passages, and many tributaries, are little over 1 m high and wide; they are floored by sandstone, locally eroded through to the shale beneath. Individual segments of the passages are nearly all aligned on joints, but the overall cave pattern is of passages coalescing in the main streamway, which follows the very gentle dip to the south-east. Langstrothdale Chase carries the main stream in a square-cut canyon mostly 2 m wide and 5 m high, its floor rising stratigraphically until it is 4 m above the base of the limestone. In Boireau Falls Chamber the stream cuts down through 0.5 m of sandstone and 4 m of underlying shale to cascade down a 22 m shaft through the entire thickness of the Simonstone Limestone.

The stream then enters a vast zone of blockfall and collapse, estimated to have total dimensions of 100 m by 50 m and 40 m high. Beyond, the stream flows in the Hardraw Limestone but enters a perched phreas, preventing further exploration, before the Great Scar Limestone is entered. A large abandoned inlet passage enters from the south-east before the sump; this extends eastwards as a series of tall rifts along the Silver Rake mineral vein, eventually terminating in a choke.

Dye tests of the Swarth Gill sinks into the Middle Limestone almost above the Silver Rake passages were not conclusive, but suggested that the sinks do not drain into the known parts of Langcliffe Pot; the intervening sandstone and shale appear to be an effective aquiclude in the immediate area, but all the sinking water eventually flows to the Black Keld resurgence (Figure 2.48). The flooded passage at Black Keld has been followed upstream only to a choked area after 150 m. A short dry series reached from airbells has no open continuation.

Interpretation

The underground drainage system which feeds Black Keld is one of the largest and deepest in Britain, though only a small proportion of its cave passages are accessible at present. It is also unique, in that the cave drainage is constrained initially within the Yoredale limestones but then breaks through into the underlying Great Scar Limestone, and resurges about 160 m lower down from near the base of the carbonate succession. The caves therefore breach the intervening shales and sandstones which are normally hydrological barriers. Two of these aquiclude breaches are visible in Langcliffe Pot. The breakthrough from the Middle Limestone into the Simonstone Limestone occurs via a vadose canyon through undisturbed shales and sandstones which then leads to a vertical shaft in the underlying limestone. There is no known continuation of an older passage in the limestone above the breach; the initial route through the non-carbonates was probably via an open tectonic fissure or small fault. The vast area of collapse immediately below the Nemesis shaft may be located in a major zone of fractures which could have guided the initial drainage route through the shale and sandstone between the Simonstone and Hardraw Limestones. The choke now represents a type of interstratal karst, with major collapse of the beds above the limestone, though this has not yet worked through to create a surface depression. The Mossdale water must also pass through several shale and sandstone aquicludes before entering the Great Scar Limestone. This may occur along one of the faults in the area, which have throws sufficient to bring the Middle Limestone and Great Scar Limestone into juxtaposition. The extent to which the Mossdale cave stream backs up in flood conditions suggests that its drainage route into the Great Scar Limestone is via constricted or extensively choked passages.

The complex plans of both the Mossdale and Langcliffe caves are unusual for sites in the Yoredale limestones, which more typically have a single stream passage, as typified by Fairy Holes. Mossdale Caverns has the more complex system, partly due to multiple sink points along the Mossdale valley. Its divergent, branching pattern approaches that of phreatic maze caves such as Knock Fell Caverns, and may reflect development under conditions of frequent back-flooding caused by its restricted drainage outlet. Langstrothdale Chase and Marathon Passage are the longest stream passages in the upper limestone beds in the two caves; they are almost entirely developed on joints, but they are constrained to drain downdip to the south-east within the vadose zone, though the resurgence of Black Keld lies to the north-west.

Mossdale Caverns has an older series of large relict passages along its north-eastern sector through Tunnel Passage, Stream End Cave and the High Level Mud Caverns. This may have developed from sinks higher in Mossdale Beck which have been subsequently choked, probably by an input of glacial debris. The large passages below the modern sink in Mossdale Scar may constitute an old phase which has been reinvaded, and these now drain into the small, relatively immature passages on the base of the limestone. There are other abandoned and choked passages within the entrance complex and Western Passages. Abandoned sinks occur further down the valley, but floor deposits of alluvium and peat now prevent Mossdale Beck from continuing down to Bycliffe Sink. The cave passages show very little vadose development other than small grooves in their sandstone floors. The known parts of Mossdale Caverns probably developed initially within a shallow perched phreas above the sandstone, which was unaffected by regional rejuvenation. A long history of intermittent flooding and epiphreatic development has etched the cave passages out of the joint network to produce a rather open version of a phreatic maze cave (Palmer, 1975).

Langcliffe Pot is morphologically simpler than Mossdale Caverns. The initial phreatic development of the passages occurred up to several metres above the base of the limestone. It is only the active inlets which have cut down to the sandstone, and then rise above it further downstream where the dip is steeper than the cave gradient. The lower series of largely abandoned passages entering from the east in the Hardraw Scar Limestone may represent an earlier phase of development associated with old sinks in the Mossdale valley, but their point of origin is unknown and there is now no flow though from the sinks in the Middle Limestone.

Conclusion

The two influent caves perched high above their Black Keld resurgence are the longest known systems in the Yoredale limestones. They are unique in that they drain through shale and sandstone sequences into the Great Scar Limestone beneath; two of the hydrological breaches which have permitted this are already visible in Langcliffe Pot, as a cave canyon entrenched into the non-carbonates and a major collapse zone.

CONISTONE OLD PASTURE

Highlights

The area around Conistone Old Pasture, on the east side of Wharfedale near Conistone, contains two fine meltwater valleys, one with an excellent dry waterfall and the other a classic narrow gorge section. Between these two valleys is a superb expanse of well developed limestone pavement.

Introduction

The two dry valleys on Conistone Old Pasture are fine examples of channels incised by meltwater at the end of the last glaciation. They lie in the eastern flank of the glacial trough of Wharfedale, beneath a limestone bench which carries areas of well developed pavement. Conistone Dib provides a spectacular illustration of fluvial incision in a limestone area, and admirably demonstrates the role of jointing in determining the form of its gorge section. Dib Scar is an impressive dry waterfall that invokes debate on the role of cave undercutting in its formation. Although little has been written specifically about these sites, they are important examples of their representative landforms. The valleys are briefly described by Sweeting (1974) and Waltham (1984) and the pavements are referred to by Goldie (1976, 1981, 1993).

Description

The dry valley of Dib Scar lies south of Conistone village and the Old Pasture plateau (Figure 2.49). It is less than 1 km long, descending from a broad col out of a broad and shallow closed depression. It is entrenched up to 30 m into the strong Carboniferous Great Scar Limestone. Its main feature is Dib Scar, a fine dry waterfall that now forms an overhanging limestone cliff, 20 m high, at the head of a short gorge with vertical sides. Immediately east of its namesake village, Conistone Dib is a longer and larger dry valley. It is incised by up to 60 m as it descends 120 m through the Great Scar Limestone. The upper end of the valley has a broad grassy floor where it collects three short tributaries; its sides are scored by solifluction terracettes (Figure 2.50). Downstream it narrows into an impressive ravine, often referred to as the Gurling Trough. This is cut into two of the stronger limestone beds, with its form influenced by the joints. The walls pinch in to less than a metre apart at one point, and have fluvial potholes and old swirl pool sites on the bends. The gorge descends gradually until it widens to die out at the edge of Conistone village. The overhanging limestone cliff of Kilnsey Crag rises on the opposite side of Wharfedale; it is a glacially truncated spur, and its only karstic feature may be that its foot was undercut by lateral solution when a postglacial, moraine-dammed lake lapped against it.

The limestone plateau above the dry valleys lacks any surface drainage. It is a broad feature with disorganized low relief, with shallow, broken troughs aligned parallel to Wharfedale. Close to the dry valleys there are fine expanses of lime-

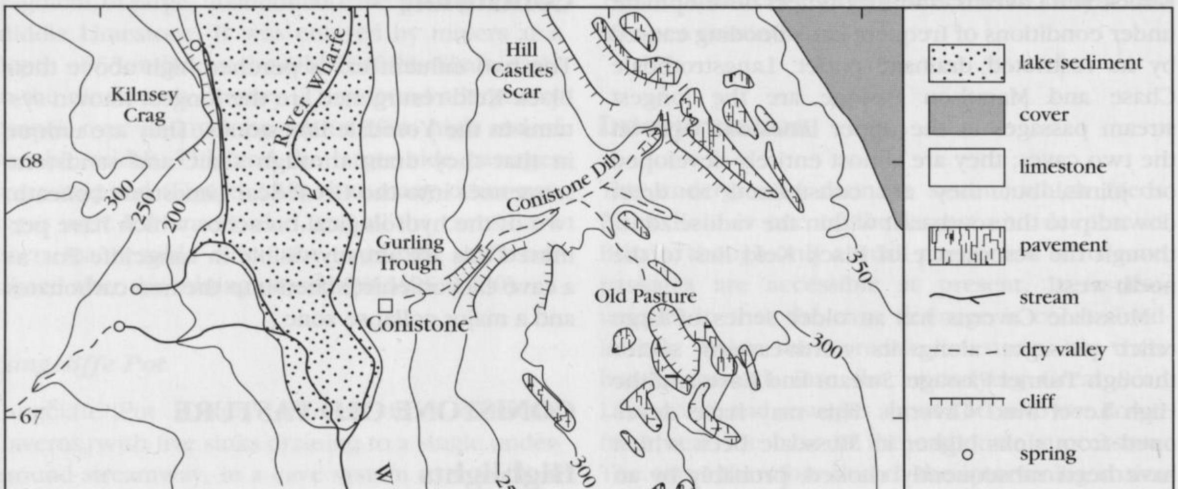


Figure 2.49 Outline map of the dry valleys, scars and limestone pavements of Conistone Old Pasture. Cover rocks are the shales and limestones of the Yoredale facies, above the Great Scar Limestone.

Figure 2.50 The dry valley of Conistone Dib, seen from the limestone scars with Wharfedale in the distance. (Photo: A.C. Waltham.)

stone pavement and small rocky scars in the stronger and more massive beds. Above Hill Castles Scar the pavements are horizontal with blocky clints less than 1 m by 2 m on average, and shallow grikes with a mean depth of 0.7 m (Goldie, 1976). Solution runnels are mainly smooth rundkarren, and there is great variety in morphological detail with excellent kamenitzas and small-scale rippling and pitting. Nearer to Dib Scar, the limestone slabs dip as much as 15°, and longer solution runnels are orientated down their slopes.

Interpretation

The fluvial gorges have been interpreted as glacial meltwater channels active when underground drainage was impeded by permafrost and glacial debris (Sweeting, 1974; Waltham, 1984). The dry gorge at Dib Scar is a classic example of gorge formation by waterfall retreat. It was incised at the tail end of the Devensian glaciation by meltwater flowing down a channel from the fells above, perhaps from or under the snout of a retreating glacier. At the location of Dib Scar this flow crossed a resistant bed of limestone, whose face retreated beneath the sediment-laden water to form the tapering gorge seen today. The waterfall was subsequently left dry by the climatic amelioration when underground drainage resumed. Cliff undercutting and cavern formation may have played minor roles in the development of the waterfall, but modern weathering and frost action are degrading its form.

Conistone Dib was a second meltwater channel, which once carried a large stream. This may have been fed from a retreating glacier lobe on the plateau above, but its source could have been related to ice margin meltwater flows which may have excavated the linear depressions parallel to Wharfedale on the limestone plateau (Raistrick, 1931). The upper gorge section occurs where the meltwaters incised through the stronger limestone beds of Hill Castles Scar, and the Gurling Trough gorge is cut into the same strong beds of limestone as is Dib Scar. The whole feature was probably incised very rapidly at the end of the Devensian glaciation, and was abandoned by the resumption of underground drainage in the more temperate Holocene climate.

The limestone pavements are restricted to the ice scoured bench less than 400 m wide along the rim of the Wharfedale glaciated trough. They occur on the outcrops of the more massive beds of limestone, away from the meltwater channels which score the bench and the slopes below. The rundkarren are well developed, but clint sizes are restricted by the closely spaced rock joints. The shallow grike depths suggest that the top layer of clint blocks may have been extensively removed (Goldie, 1981), perhaps during construction of the many early Celtic settlements on this bench.

Conclusions

The dry valleys of Conistone provide two excellent examples of fluvial erosion processes on a karst terrain. Dib Scar is a classic illustration of a tapering retreat gorge with a dry waterfall at its head, and is comparable to Malham Cove without the involvement of glacial excavation. The larger Conistone Dib, with its fine gorge section, is a superb demonstration of the role of fluvial erosion by glacial meltwater under periglacial conditions in a karst terrain. The well developed limestone pavements offer a wide variety of morphological detail and show clear response to structural control, valley and soil formation.