Karst and Caves of Great Britain

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Chapter 7

Outlying karst areas in England

INTRODUCTION

England's karst landscapes are dominated by two rock types. By far the largest area of karst is provided by the Cretaceous Chalk (Figure 1.1), but this is a very distinctive karst type – almost totally lacking the bare rock outcrops and accessible cave systems which are characteristic of karst in the stronger limestones. Consequently, the Carboniferous limestones are more widely known for their karst landforms, even though they occupy a much smaller area in England. These strong limestones contain nearly all England's caves within the justifiably famous karst landscapes of the Pennine and Mendip Hills. There is an additional scatter of karst features on the same limestones in outlying outcrops, mainly in the west country.

Beyond the Chalk and the Carboniferous Limestone, karst landforms are developed on a lesser scale on a variety of carbonates and non-carbonates. Limestones range through most systems of the stratigraphic column, but their limited karst features are commonly regarded as poor relations of better developed sites on the Carboniferous and Chalk. Both gypsum and salt lie buried beneath the lowlands of England, but their surface expression in karst landscapes is virtually limited to the subsidence basins over the salt. The remaining, more obscure types of karst and pseudokarst are insignificant in Britain.

Karst on the outlying Carboniferous limestones

In the land areas each side of the Bristol Channel, the Dinantian limestones of the Lower Carboniferous form a scatter of outcrops which emerge through the cover of mainly Triassic mudstones. The largest of these forms the Mendip Hills, with the splendid caves and karst features already described in Chapter 5. Separate inliers further west form Brean Down and the islands of Steep Holm and Flat Holm, where solutional features are little more than details of the landscape (Simon *et al.*, 1961). An escarpment of the same Dinantian limestones forms the Clifton Downs, best known for their deep dissection by the Avon Gorge – a magnificent feature of superimposed drainage, inherited from the Triassic cover. The gorge has exposed many small fissures and solutional rifts in its walls, but there is minimal karstic expression on the Downs, which are high enough to receive no modern allogenic drainage. The hot springs at Bath lie over faults within Mesozoic cover rocks, but their source appears to be meteoric water which has drained through a syncline in the Carboniferous limestone deep enough to be geothermally heated (Kellaway, 1991). North of Bristol, there are facies changes within the Dinantian sequence, and karst features are very minor in the dolomites and thin limestones intercalated with clastic rocks.

North of the Bristol Channel, Dinantian limestones underlie the Forest of Dean basin. Their thickness is variable and they are partly cut out by the basal unconformity of the Westphalian, so that their main outcrop is round the western flank of the Forest and south across the Wye Valley to Chepstow (Figure 1.2). Within most outcrops on the English side of the border, the main karst features are formed in the Holkerian limestones, overlying less karstified dolomites. The main topographic features of the area are not karstic, but a series of small sinkholes feed an extensive cave system beneath a sandstone cover and draining to the Slaughter Rising in the bank of the River Wye.

Carboniferous outcrops in the Birmingham area lack any limestones as the region was a landmass in Dinantian times. Sedimentation in the Carboniferous basin north of this produced the thick sequence of carbonate, clastic and Coal Measure rocks which now form the Pennines and much of the rest of northern England. The karst and caves in the large Peak District inlier have been described in Chapter 4; the northern Pennines have even more extensive outcrops of Carboniferous limestone, which are also more varied in structure, and these are host to the many caves and karst landforms described in Chapters 2 and 3.

Outside the Pennines, the Dinantian rocks have large outcrops but very limited modern karst, though some of the Midland's inliers contain notable features of fossil karst (Simms, 1990). In northern Lancashire, the Clitheroe area lies on basinal facies of the Dinantian which are dominated by shale sequences; isolated outcrops of thinly bedded and reef limestones have almost no karstic expression. Similarly, the Dinantian sequences north of Weardale have only very thin carbonate units whose sinuous valley side outcrops are marked only by isolated scars and the shortest of underground drainage loops.

The Lake District has lost to erosion its Carboniferous cover, which originally included thick Dinantian limestones. These rocks now form an annular outcrop around much of the Lower Palaeozoic inlier, and the thicker limestone sequences remain in the south and east. Faulted blocks of limestone around the eastern arm of Morecambe Bay were scoured by Pleistocene ice, leaving some very fine pavements in addition to some small cave systems. Further extensive limestone pavements are formed on the Dinantian outcrops north of the Howgill Fells. Both these groups of sites (Figure 3.1) are described in Chapter 3 as they are so closely related to the Pennine karst. There are numerous small cave systems in the limestones all around the Lake District (Brook *et al*., 1994), and the geomorphology of those on the southern fringe, around Morecambe Bay, was described by Ashmead (1969, 1974a).

The limestones continue west round Morecambe Bay, across the Cartmel and Furness peninsulas. On Cartmel, Humphrey Head has more limestone pavements and a few short caves. Kirkhead Cavern, a phreatic rift modified by marine erosion and now left behind a raised beach, has been excavated to reveal cryoturbated Devensian clastics overlain by a Holocene cave earth with flints and other artefacts (Gresswell, 1958; King, 1974). The Roudsea Wood Cave is a joint-controlled network formed in the shallow phreas adjacent to a Devensian lake, in the same style as the Hale Moss caves east of the Bay (Ashmead, 1974a). The Dinantian limestones of the Furness peninsula are best known for their hematite orebodies, which have been valuable sources of iron. The ore bodies included veins and flats and also the unique sops. These were shaped like buried dolines over 100 m deep and up to 300 m across, with layered fills of sand over massive hematite over limestone rubble. More than 50 sops are known, mostly in the Holkerian Park Limestone west of Dalton. They appear to represent a style of interstratal palaeokarst where late Mesozoic saline waters leached iron from the overlying Triassic sandstones, invaded karstic fissures below, created and then filled larger solutional cavities in the limestone, and then promoted collapse of the cover by further solution (Rose and Dunham, 1977). Later erosion stripped the sandstone cover, and the sops were covered only by glacial till, until the hematite was mined; their sites are now marked by massive, flooded subsidence bowls. The Quaternary karst in Furness includes the relict phreatic chambers of Stainton Cavern, the abandoned resurgence cave in Henning Valley and many other small caves (Ashmead, 1974a).

Facies changes reduce the limestone to bands less than 20 m thick interbedded with clastic rocks in the Dinantian on the northern rim of the Lake District. The limestone outcrops are extensively blanketed by glacial till, and the few known caves include The Swilly Hole in the Asbian Fifth Limestone; this has over 800 m of relict rift passages invaded by a sinking stream in the entrance zone (Brook *et al*., 1994).

The chalk karst

The large areas of chalk karst across the south-eastern half of England are very distinctive in the styles of their landforms and their underground drainage. Both characteristics are a function of the mechanical properties of the chalk rock. It is a pure, white, weak, friable, poorly lithified, porous limestone. Its matrix is composed largely of crystals, fragments and skeletons of coccoliths; most particles are <0.002 mm across, and it is poorly recrystallized as it is largely low-magnesium calcite which was stable at low burial depths (Hancock, 1975, 1993). The rock is massive, with poorly defined bedding and few large fractures. Matrix porosity is generally >30%, but its permeability is low through the tiny pore spaces. The high bulk permeability of chalk is due to its networks of microfractures, many of which are enlarged by solution. The Chalk forms a single unit over 300 m thick in the Upper Cretaceous.

The distinctive landscape of chalk karst is a softly contoured grassy upland, often known as downland or downs. Though the chalk is weak, with a strength (UCS) of 5–30 mPa, it forms the high ground as the outcrops are surrounded by weaker clays and are little eroded by surface water. The low strength precludes scar formation, except in vertical sea cliffs, undercut by wave action faster than any surface degradation. Devensian ice covered little of the chalk, and earlier glaciations only reached to the Chilterns (Figure 1.2); glacial till masks only some of the eastern outcrop (Figure 7.1). The rounded landforms are the product of periglacial weathering. The top 10 m of most chalk outcrops have been so frost-shattered that they now form a rubble weak chalk or a thixotropic putty chalk (Higginbottom, 1966). Solifluction was widespread during the Devensian cold stages, and combe rock is a chalk head common on valley floors. Chalk outcrops were covered by woodland until the clearances between Mesolithic and

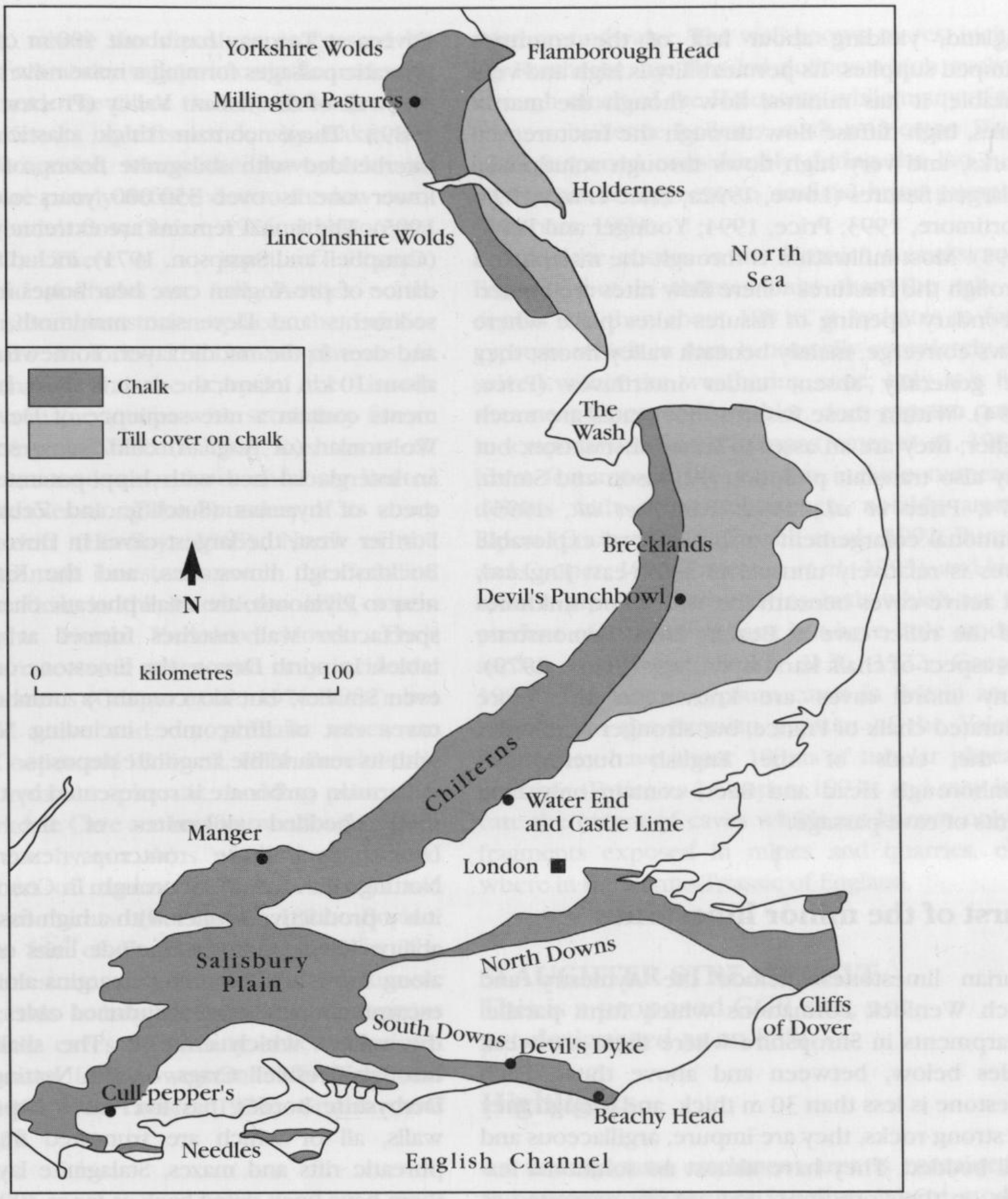

Figure 7.1 Outline map of the chalk karst of England, with locations documented in the text. Superficial deposits occur on many parts of the Chalk outcrop; only the large areas of glacial till are distinguished on this map, as they mask most topographic expression of the karst.

medieval times, and the subsequent sheep grazing has maintained the short turf of the modern downland.

Dry valleys are common on the chalk karst escarpments – largely the result of solifluction and snowmelt erosion during the Devensian. They form steep combes on the scarp faces and large dendritic systems on the dip slopes; the Manger, Devil's Dyke and Millington Pastures represent both these styles. Springs are common at their lower ends, and winter rises of the water table create many seasonal surface streams, known as bournes. Diffuse input of rainfall creates very few dolines on the main chalk karst. Along the margin of the Tertiary cover, on the very gentle dip slopes, allogenic drainage creates active sinkholes, deep subsidence dolines and the pipes which are largely clay-filled solutional fissures. The best of these features fringe, breach or underlie the feather-edge of the Tertiary cover in the London basin, but large dolines also punctuate the Quaternary cover in the East Anglian Brecklands and the Dorset Heaths.

The Chalk is the most important aquifer in

England, yielding about half of the country's pumped supplies. Its permeability is high and very variable; it has minimal flow though the matrix pores, high diffuse flow through the fracture networks, and very high flows through solutionally enlarged fissures (Lowe, 1992a; Price *et al.*, 1993; Mortimore, 1993; Price, 1994; Younger and Elliot, 1995). Most infiltration is through the matrix, and through the fractures where flow rates are higher. Secondary opening of fissures takes place where flows converge, mainly beneath valley floors; they are generally absent under interfluves (Price, 1994). Within these fissures, flow rates are much higher; they are an asset to water abstraction, but may also transmit pollution (Atkinson and Smith, 1974; Price *et al.*, 1992; Banks *et al.*, 1995). Solutional enlargement to the scale of explorable caves is relatively unusual in south-east England, but active caves beneath the Water End sinkholes and the relict cave at Beachy Head demonstrate this aspect of chalk karst hydrology (Reeve, 1979). Many more caves are known in the more indurated chalk of France, but stronger lithologies at the ends of the English outcrop, at Flamborough Head and Beer, contain only fragments of cave passage.

Karst of the minor limestones

Silurian limestones include the Aymestry and Much Wenlock Formations which form parallel escarpments in Shropshire where there are weak shales below, between and above them. Each limestone is less than 30 m thick, and though they are strong rocks, they are impure, argillaceous and well bedded. They have almost no solutional features on their outcrops, and are not exploited as aquifers.

Devonian limestones form numerous small outcrops scattered through the structurally complex clastic sequences in both north and south Devon. All these Devonian rocks are lightly metamorphosed, and some of the limestones are commercially known as marbles, though their scale of recrystallization has not been enough to destroy their fossil shell structures. Surface karst landforms are insignificant in the fluvial landscapes, even on the largest outcrops forming much of the headlands on both sides of Tor Bay, but there are many notable caves. Berry Head has many small caves formed at the marine/freshwater interface during high interglacial sea levels of the Pleistocene (Proctor, 1988; Proctor and Smart, 1991). Kent's Cavern at Torquay has about 400 m of large, old, phreatic passages forming a maze now truncated in the wall of the Ilsham Valley (Proctor and Smart, 1989). These contain thick clastic sequences interbedded with stalagmite floors, of which the lower one is over 350 000 years old (Proctor, 1995). The faunal remains are extremely important (Campbell and Sampson, 1971), including an abundance of pre-Anglian cave bear bones in the lower sediments and Devensian mammoth, rhinoceros and deer in the middle layer. Tornewton Cave lies about 10 km inland; the cave is short, but the sediments contain a rare sequence of Devensian and Wolstonian (or Anglian) cold faunas separated by an interglacial bed with hippopotamus and hundreds of hyaenas (Sutcliffe and Zeuner, 1962). Further west, the largest caves in Devon lie in the Buckfastleigh limestones, and the Kitley Caves, near to Plymouth, are small phreatic chambers with spectacular wall notches formed at past water tables. In north Devon, the limestone outcrops are even smaller, but do contain a number of small caves east of Ilfracombe, including Napps Cave with its remarkable aragonite deposits.

Permian carbonate is represented by the impure, thinly bedded dolomites of the Magnesian Limestone, whose outcrop extends from Nottingham to Middlesborough. In County Durham it is a productive aquifer with a high fissure permeability. Karst landforms include lines of sinkholes along some of the outcrop margins along the low escarpment, and small abandoned caves in some of the valleys which cross it. The shallow gorge through Creswell Crags, on the Nottinghamshire/Derbyshire border, has five caves exposed in its walls, all of which are truncated fragments of phreatic rifts and mazes. Stalagmite layers within them have been dated back as far as 300 ka (Rowe, Atkinson and Ienkinson, 1989), and the clastic sediments have yielded important Devensian and earlier animal and human remains (Jenkinson, 1984, 1989). The site is best known as the type locality of the Cresswellian culture which occupied the cave in the late Devensian interstadial. Further north, the Knaresborough Gorge contains some large active tufa screens (Burgess and Cooper, 1993), and the tectonic fissures of Farnham Cave and Smeaton Pot contain limited features of solution and calcite redeposition (Lowe, 1978; Brook *et al.*, 1988).

Jurassic limestones have extensive outcrops in the scarplands across the heart of England (Downing, 1994). The Great and Inferior Oolites form the broad escarpment of the Cotswolds

(Figure 1.2), where the dip slope is crossed by numerous shallow dry valleys, mostly floored with Devensian head. The Great Oolite is the more productive aquifer; its high fissure density makes it a diffuse flow aquifer, where the flow catchment boundaries are poorly defined due to the low component of conduit flow (Smart, 1976; Atkinson and Smart, 1977). There is no input of allogenic drainage, and sinkholes are few. Further north, the Lincolnshire Limestone replaces the Inferior Oolite, where it forms the broad plateaus in Northamptonshire and the scarp of the Lincoln Ridge. It is a major aquifer with secondary fissure flow (Downing and Williams, 1969; Rushton *et al.*, 1982), but has no known caves and only limited areas of sinkholes along the boundary of its cover rocks and drift (Hindley, 1965). North of the Humber, the main limestones are in the Coralline Oolite Formation, in the Hambleton Hills, southwest of the North Yorkshire Moors. Their Windypits are tectonic caves with only incidental solutional features (Cooper *et al.*, 1976, 1982), but some small active and dry phreatic caves are recorded (Cooper and Halliwell, 1976, Brook *et al.*, 1988); the remnant, phreatic, bedding plane passages in Kirkdale Cave are best known for their role as Pleistocene hyaena dens which have yielded large numbers of mammalian bones of cold and warm environments (Buckland, 1822; Boylan, 1981). The Isle of Portland is capped by the Portland Limestone, near the top of the Jurassic succession; this is heavily fissured, and contains both tectonic caves and many relict solutional caves truncated in the western cliffs (Ford and Hooper, 1964; MacTavish, 1975; Graham and Ryder, 1983).

Salt and gypsum karst

Rock salt, which is almost pure halite, forms thick units in the Triassic Mercia Mudstones, beneath the Cheshire Plain (Figure 1.2) and in other smaller Triassic basins. In Cheshire, the Wilkesley and Northwich Halites are each sequences over 100 m thick consisting of salt interbedded with mudstone. Nowhere do they survive at outcrop, but they lie beneath thick covers of permeable drift where groundwater solution has left residual breccias of collapsed mudstone over their buried outcrops (Evans, 1970; Earp and Taylor, 1986). The landforms of the salt karst are restricted to subsidence hollows, formed where circulation of the brine has allowed continued solution by influxes of unsaturated groundwater. The well known meres, including Rostherne, are flooded dolines which evolved through much of the Holocene, while many of the linear subsidence hollows, such as Moston Flash, have deepened considerably during the last hundred years in response to artificial brine pumping (Waltham, 1989).

Anhydrite occurs in the Permian succession of England, but in thinner units than the salt. At depths less than about 100 m, it hydrates to form gypsum, which in turn is normally completely dissolved within the weathering zone; only at a few sites near Ripon, in Yorkshire, does gypsum occur in temporary surface outcrops (James *et al.*, 1981). Karst features on the gypsum include numerous dolines with active subsidence, notably around Ripon (Cooper, 1986; Powell *et al.*, 1992; Burgess and Cooper, 1993; Patterson *et al.*, 1995), and large breccia pipes in the overlying beds which are the product of interstratal karst but have little modern surface expression (Smith, D.B., 1972; Cooper, 1988). The largest gypsum caves in Britain are at Houtsay, in the Permian gypsum of the Vale of Eden: they have about 100 m of tubular phreatic passages (Ryder and Cooper, 1993), and may indicate the extent of caves which are known only as fragments exposed in mines and quarries, elsewhere in the Permo-Triassic of England.

SLAUGHTER STREAM CAVE

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

Highlights

An underground catchment area is contained in the plunging Worcester Syncline, where modern cave drainage converges on the axial zone and flows to the Slaughter Rising. Active and abandoned passages, within the Slaughter Stream Cave and adjacent caves, show strong stratigraphical and structural guidance of their origin and development. Palaeokarstic features, including conduits partially infilled by Triassic iron ores, and abandoned caverns containing mammalian bones, provide evidence of a long and complex history of cave development.

Introduction

The Slaughter Rising lies on the eastern bank of the River Wye, south of Symonds Yat (Figure 7.2),

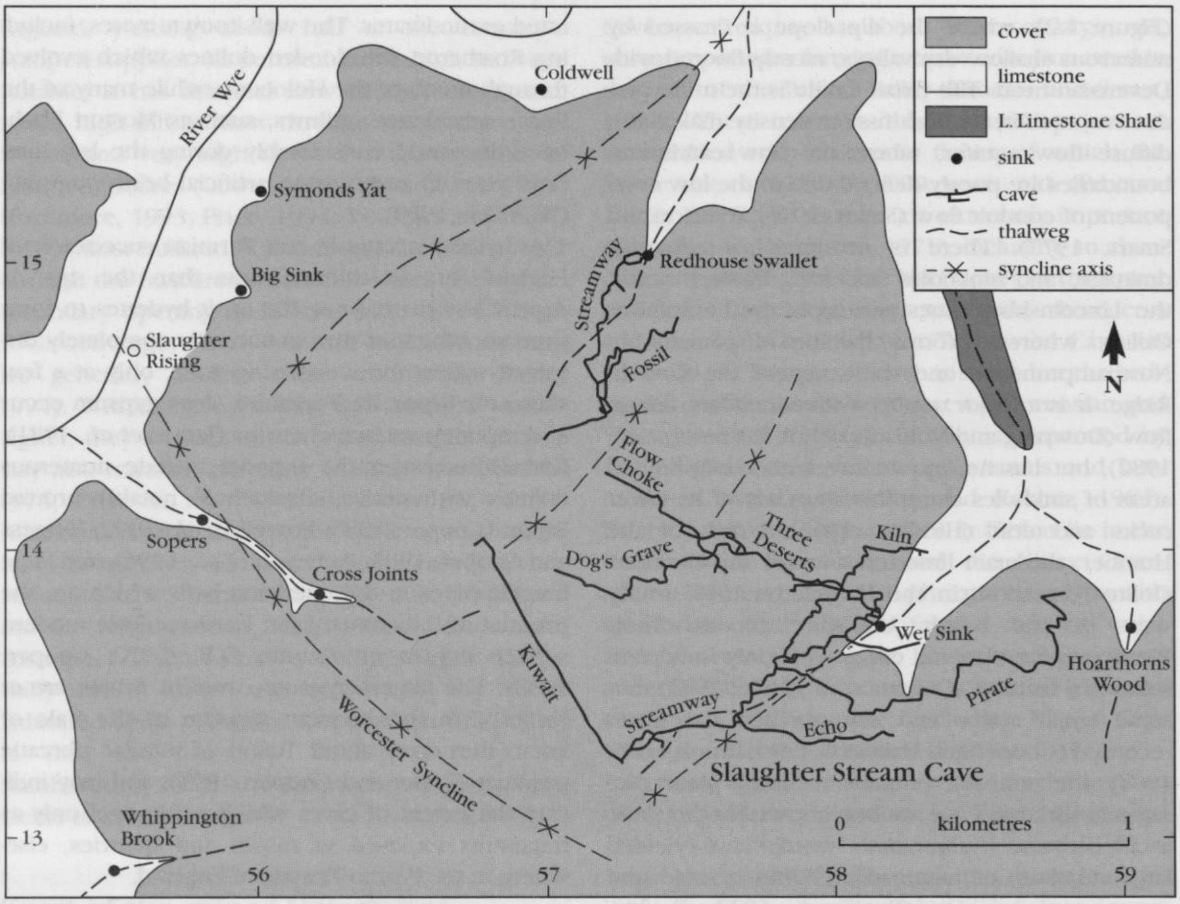

Figure 7.2 Outline map of the caves in the catchment of the Slaughter Rising. The cover rocks are the Drybrook Sandstone and the Upper Coal Measures. All the sinks marked on the map have been dye traced to the Slaughter Rising (from survey by Royal Forest of Dean Caving Club).

and gathers allogenic input from sinkholes as far apart as Coldwell Swallet, Whippington Brook Swallet and Hoarthorns Wood Swallet (Figure 7.2). It is the resurgence for nearly all the underground drainage which gathers in the Worcester Syncline, an arm to the north-west off the Forest of Dean basinal structure. Most of the feeder swallets have developed where water runs off the cap of Holkerian Drybrook Sandstone, and down through fissures in the Arundian Whitehead Limestone and the Chadian Crease Limestone, each about 25 m thick. The main cave passages are developed in the underlying Courceyan Lower Dolomite, which is about 70 m thick. Coldwell Swallet lies in the Crease Limestone as the Whitehead is overstepped by the Coal Measures. The Slaughter Stream Cave is the most extensive cave known within the catchment. Its 12 km of mapped passage are only a small part of the total network behind the Slaughter Rising; cave passages on both flanks of the Worcester Syncline include high-level remnants and the active drains, all forming parts of an ancient system which is still evolving.

The catchment of the Slaughter Rising was defined by a series of dye tests carried out by the local caving clubs (Standing, 1967; Solari, 1974; Lowe 1989a). Subsequently the cave passages were explored beneath Wet Sink (now known as Slaughter Stream Cave) and Redhouse Swallet (Clark, 1991; Taylor, 1993). Stratigraphical control of the cave geomorphology demonstrates the important role of inception horizons (Lowe, 1992b, 1993) and also the links with the palaeokarst and hematite deposits widespread in the Forest of Dean limestones (Trotter, 1942; Welch and Trotter, 1960).

Description

The only access to the Slaughter Stream Cave (Figure 7.2), most of which lies under the impermeable cover, is through immature fissures beneath Wet Sink, into a series of shafts and narrow rifts which meets the Main Stream Passage 52 m below the entrance. Downstream the passage is generally 2 m wide and up to 4 m high, but the stream is lost into flooded passages south of an overflow route through unmodified, partly sand-filled, solutional tubes. There are two inlet passages from the east; both are series of narrow canyons and rifts, of which Pirate Passage reaches over 1800 m. The stream is rejoined beyond its flooded section, and Echo Passage is another inlet with water emerging from a choked sump. The lower streamway is up to 15 m high, with walls in heavily corroded rock. A canyon develops in the floor of a wider phreatic roof passage, until the stream is again lost into flooded bedding planes. A primitive bedding passage at roof level continues above the sump, and turns north-east into Kuwait Passage. This long rift is 2 m wide, with black walls and white calcite formations, but becomes narrower after 1000 m, where a small streamway is met, and the current end of the cave is a static sump.

Upstream from the entrance series, Zurree Aven leads up into extensive upper passages. Abandoned passages lead into the Chunnel, which continues 10 m wide and 6 m high westward into a complex of rifts and chokes. Kiln Passage is an inlet with about 500 m of twisting canyon, ending near the surface excavation of Kiln Hole. The Three Deserts Series continues to the west and into Dog's Grave Passage. At low level, an abandoned streamway leads to a high rift with large crystals on its walls. The upper passage continues as a large tunnel to Helictite Rift, well decorated with helictites and dripstone of white calcite; this continues over a stream which is covered by a calcite crust. A short, choked passage leads over white calcite flakes into the Snow Garden, a high, narrow streamway with a white calcite floor. Flow Choke Passage is a series of abandoned rifts north-west from the Three Deserts into a major abandoned streamway, 10 m high, continuing in a straight line to a choke cemented by calcite flowstone.

The 12 km of mapped passages in the Slaughter Stream Cave cover a vertical range of 99 m. They include a magnificent active vadose streamway cut beneath a primitive phreatic route, as well as several, abandoned drains modified by vadose trenches. Abandoned passages contain thick beds of sand and silt, with sedimentary structures including ripple marks, and parts of Kuwait Passage and Helictite Rift contain very fine calcite formations. The cave contains an unusual number of mammalian bones, which have fallen or been washed in, or have been relocated by stream activity. The streamway contains bones of a hippopotamus, at least 125 000 years old. The Graveyard in the high levels near the Chunnel contains bones of domesticated species, and possibly human remains, and an auroch bone (2000–3000 years old) was found in a nearby passage. The skeleton of a dog in Dog's Grave Passage, and associated tracks in a nearby oxbow passage, present a mystery with regard to the animal's route into the system.

North-west of Wet Sink, a major stream is swallowed in a blind valley near Redhouse Lane, where over 2000 m of cave is now known in Redhouse Swallet (Figure 7.2). A series of narrow rifts, originally choked with sediment and boulders, drops about 30 m into the main stream passage. Downstream, this passage is of varied morphology, with deep canals, high rifts, collapse zones and abandoned loops over flooded sections; it ends in a choke over a flooded rift. The Fossil Series has a small inlet stream and several large chambers, including Bowen Chamber with its thick clastic deposits, and Missed Chamber.

Interpretation

The caves of the Slaughter catchment demonstrate the role of inception horizons, where chemical contrasts within the carbonate sequence have created specific stratigraphic horizons favourable to solution and cave development. These inception horizons are features of the host rocks, and the cave inception may be traced back to a limited scale of cavity opening soon after the limestones were formed, long before the caves were greatly enlarged by drainage beneath more modern landscapes (Lowe, 1992, 1993).

Though exploiting fissures locally, the main drain and its tributaries in the Slaughter Stream Cave are cut beneath a bedding-guided solutional conduit, segments of which survive unmodified where drainage is captured by fault-guided short-circuits. Drainage in both the Slaughter and Redhouse cave systems initially flows away from the rising, maintaining a constant horizon and following local hydraulic gradients south-westwards into the trough of the Worcester Syncline (Figure 7.2). Stratigraphical guidance was crucial to underground conduit growth, but fracture guidance was important locally, where joints facilitate minor conduit sidestepping within the same horizon. Faults may be involved in offsetting and linking zones of stratigraphical guidance, but it is unconfirmed whether the major linear rifts, including Kuwait Passage, follow fault planes.

Superimposed across the Worcester Syncline is a series of gentle, asymmetrical folds whose axes plunge towards the main fold trough (Figure 7.2). These minor folds have fundamentally influenced the direction of past and present underground drainage. The modern drainage collects in the main syncline and then escapes by upward leakage through fissures to the impenetrable Slaughter Rising. It is unknown if the main cave conduits behind the rising are deep in the Lower Dolomite, at the stratigraphic level of the Slaughter Stream Cave; alternatively, they may lie in the Crease or Whitehead Limestones downstream of phreatic lifts from the known caves.

The earliest speleogenesis in the area probably predated the downcutting of the Wye, by many millions of years. A pre-Triassic maturity is likely, and inception activity commencing during the Carboniferous is a realistic possibility. The relationships of abandoned high-level passages to the active drains and to nearby relict cave fragments are yet to be elucidated, but the abandoned high-levels, of Flow Choke and Dog's Grave Passages, may once have carried drainage away from the River Wye, eastwards into the groundwater reservoir of the Forest of Dean basin. If this was so, these drains must have been conceived before the Wye incised its valley and captured the karst drainage during the late Tertiary. Whether the trunk passages in the main caves were contemporary with the passage segments truncated in the sides of the Wye Valley is unknown. The clastic sediments could provide the evidence; these may reflect a temporary engulfment of part of the proto-Wye during incision, or may have been deposited in pre-existing tunnels cut before the incision. It has been suggested that the Wye Valley relict caves formed before iron ore emplacement in the Triassic period, and some clastic sediment may be of late Triassic age (Lowe, 1993). Large chambers in Symonds Yat and Cross Joints Swallets were formed by solution of the Crease Limestone and collapse of the overlying beds. These resemble the voids in the local iron ore mines, where high-grade ore was removed from the host bedrock (Lowe, 1989, 1993).

Existing phreatic conduits, and any less well developed parallel or tributary routes of the same age, were drained following uplift, and then carried underfit vadose streams. After uplift, phreatic flow continued at lower levels, along fissures and inception routes that were conceived and partially developed before the uplift. Development of these lower routes was by the underflow which they carried along their own favoured hydraulic gradients, which need not have mirrored the hydraulic gradient favoured by simultaneous flow at higher levels. In the Slaughter Stream Cave, deep underflow continued, probably augmented by fissure leakage from underfit streams in the overlying primary conduits. As the Wye cut through the Worcester Syncline, favourable inception horizons in the aquifer were exposed first on the northern and southern fold flanks, and later in the fold core. With the breaching of each stratigraphic horizon in the fold core, a potential spring site was exposed and offered hydraulic gradients more advantageous than those towards more distant outlets.

Whether the high-level routes were imprinted within their guiding horizons before or after the minor fold ripples formed across the limbs of the Worcester Syncline is unknown. However, after downcutting and rejuvenation, these minor synclinal troughs offered a means of turning vadose drainage away from its regional, eastward trend and towards the advantageous westward route along the Worcester Syncline. In the Slaughter Stream Cave the roofs of the Main Streamway and its tributaries are at a constant horizon, close to the axis and across the limbs of a minor syncline. Redhouse Swallet lies in another syncline, and more parallel independent drains may exist in the other synclines where the drainage direction changes beneath abandoned high-level passages.

The presence within Slaughter Stream Cave of bones, animal tracks and ancient man-made detritus indicates that other surface connections have existed in the past. Some detritus, and bones of butchered domesticated species, may have been 'tipped' into shafts or active collapses at the surface, eventually to enter the cave. Other debris, of wild and domesticated species, might have been washed in, though this would have required sinks far more open than those which were excavated to give the modern access. Other bones, and local guano deposits, indicate that bats and small rodents have occupied the caves, but how they entered the caves is unknown. Most intriguing are the tracks and skeleton found in Dog's Grave Passage, which lies far beneath the impermeable cover remote from any sinkhole sites. It is difficult to imagine how the animal gained access, either uninjured or sufficiently uninjured to move around until its eventual death.

Conclusions

The underground catchment of the Slaughter Rising is a karst of synclinally folded carbonates whose stratigraphy and structure have guided the inception and development of a long and complex cave system. Among the known cave passages and chambers, there are elements which were well developed before late Triassic times. Underground drainage directions have changed radically during this long history, largely in response to the deepening of the Wye Valley, but possibly due partly to the earlier effects of tectonic deformation. Traces of animals preserved in the caves indicate that their recent history includes further significant changes.

BUCKFASTLEIGH CAVES

Highlights

The Buckfastleigh caves are the most extensive in England which are developed in pre-Carboniferous limestones.

Introduction

A series of caves lie in separate outcrops of structurally complex, Middle Devonian limestone in the valleys of the River Dart south-east of Dartmoor in Devon (Figure 1.2). The largest of the caves are beneath Church Hill on the outskirts of Buckfastleigh, but significant other caves are at Pridhamsleigh and further west in the Dean Valley. Many of the cave passages and aspects of their geomorphology have been described by Hooper (1956, 1960), Vowler (1980) and Neill (1988).

Description

The Devonian limestones occur mainly as a series of reefs within clastic formations; they now have very dispersed outcrops, due to the reef distribution and the subsequent folding, faulting and thrusting. Regional metamorphism has left them in a slate sequence; the carbonates are known locally as marbles, but the limited recrystallization has not destroyed their many fossils. In places the limestones contain interbedded volcanic ash and are cut by small lamprophyre dykes.

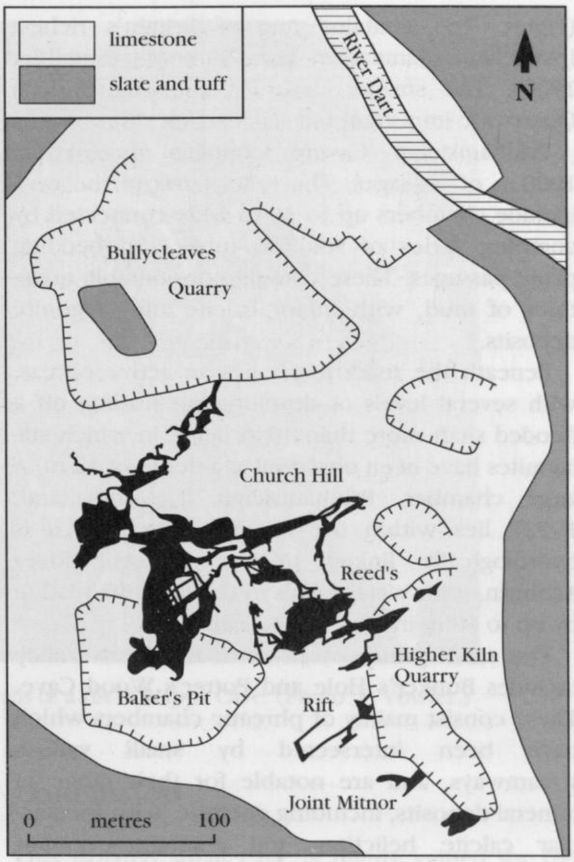

Figure 7.3 Outline map of the caves of Buckfastleigh (from surveys by Devon Speleological Society).

The most extensive caves lie in Church Hill, Buckfastleigh, which is a small limestone outlier partly underlain by thrust planes. The system of Reed's Cave and Baker's Pit extends through most of the hill to entrances in quarries on opposite flanks (Figure 7.3). Though contained, within an area of less than 4 ha, the caves have been surveyed to a total length of more than 3000 m, as they form an intricate maze on several levels – though some of the length is within complex collapse areas. Most passages are small in cross-section, except where they open out into chambers which survive between the zones of collapse. Some of these chambers contain small, well-preserved calcite and aragonite deposits. Several other small caves within the hill are not connected to the main system, but contain important calcite and clastic deposits. Joint Mitnor Cave

(Figure 7.3) contains one of Britain's richest Ipswichian mammalian bone deposits (Sutcliffe, 1960). The smaller caves in the Higher Kiln Quarry are important bat sanctuaries.

Pridhamsleigh Cavern contains more than 1000 m of passages. The relict parts of the cave include chambers up to 30 m wide connected by complex series of solution tubes and bedding plane passages. These contain considerable quantities of mud, with minor calcite and aragonite deposits.

Beneath the relict levels lies an active phreas, with several levels of development leading off a flooded shaft more than 40 m deep, in which stalagmites have been observed at a depth of 12 m. A large chamber, Pridhamsleigh II (Mulholland, 1992), lies within the flooded zone, which is hydrologically linked to the adjacent River Ashburn, with water levels in the cave fluctuating by up to 10 m in response to rainfall.

The small group of caves in the Dean Valley includes Bunker's Hole and Potter's Wood Cave. These consist mainly of phreatic chambers which have been intersected by small vadose streamways, and are notable for their range of mineral deposits, including goethite, with spectacular calcite helictites and aragonite crystals growths.

Interpretation

The caves of South Devon are largely phreatic in origin, and their morphology exhibits significant influence by faulting and vein mineralization within the limestone. There has been only limited vadose modification. The multi-level sequence of active and abandoned caves may be correlated with phases of valley incision and terrace formation in the Dart Valley, through at least the later parts of the Pleistocene. The speleothems 12 m below the present water surface in Pridamsleigh Cavern indicate that valley floor aggradation has caused a rise in the water table subsequent to the valley incision which had earlier drained most of the caves. The sediment and speleothem sequences within the caves may enable a more detailed chronology to be constructed through this interval, while the submerged speleothems may provide valuable data on sea-level fluctuations during this time.

The bone deposits of Joint Mitnor Cave contain remains of elephant, hippopotamus, lion, hyaena, deer and fox within an assemblage richer in species than any other Ipswichian deposit in Britain. The fauna is indicative of a warm environment when the bones accumulated as a pit-fall deposit, forming a debris cone beneath a shaft which was open to the surface.

Conclusion

The small and complex cave systems are the longest which are developed in the Devonian limestones. They show multi-level development related to downcutting and then aggradation in the adjacent valleys of the River Dart during the Pleistocene. One cave contains an unequalled interglacial assemblage of mammal bones, and the secondary carbonate mineralization is notable for including aragonite.

NAPPS CAVE

Highlights

This cave has only a short length of relict passages, but these contain some of the finest aragonite speleothems in Britain.

Introduction

Napps Cave was exposed at the turn of the century in a quarry into the eastern slopes of Napps Hill, west of Combe Martin on the north coast of Devon (Figure 1.2). The cave is a small remnant system of abandoned passages developed in a dipping band of limestone less than 20 m thick within the Middle Devonian Ilfracombe Beds. The cave is rarely visited as its aragonite is very fragile, and is briefly recorded only by Vowler (1980, 1981).

Description

Napps Cave consists of several elongate chambers connected by small rifts. Access to the cave is via one of these rifts where it has been intercepted by a quarry face, and about 200 m of passages have been explored. The walls of most of the rifts in the cave are decorated with anthodites – spectacular clusters of radiating aragonite crystals up to 70 mm in length (Figure 7.4).; these vary from pure white to browns and greys due to iron stain-

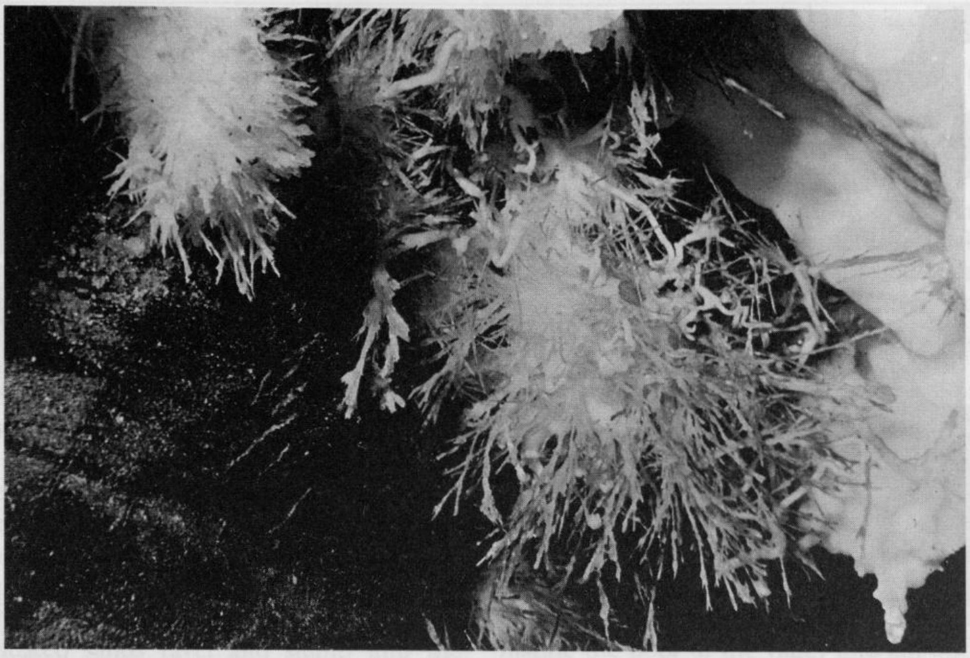

Figure 7.4 Clusters of delicate aragonite needles on the walls of a rift in Napps Cave. (Photo: F. Vowler.)

ing. Floor deposits include layered stalagmite of both aragonite and calcite, overlying thick clay, and there are various dripstone features including stalactites and very delicate helictites.

Interpretation

The morphology of Napps Cave is that of a short network of broad tubular passages connected by narrow rifts. The whole cave is a phreatic remnant, parts of which have developed along the steeply dipping boundaries between the limestone and adjacent mudstone.

Cave anthodites are generally the product of deposition by slowly moving film water which is lost to evaporation. This makes them distinct from dripstone which is deposited due to loss of carbon dioxide. Aragonite is the common mineral of anthodites, and generally precipitates in place of calcite where the carbonate is high in strontium; this situation is more common in thin limestones within clastic sequences. The precise controls on aragonite deposition and anthodite growth are unknown, but the environment of Napps Cave appears to fit the general case.

Although this cave is very small, the aragonite formations which it contains are the largest and most spectacular in Britain. The controls on their development await detailed research.

Conclusion

This isolated small cave is highly valued for the aragonite crystal formations, which are the largest and finest in Britain.

CULL-PEPPER'S DISH

Highlights

The doline fields in the chalk karst of Dorset are noteworthy for their density, and Cull-pepper's Dish is the largest, most spectacular and best developed of the individual dolines. Nearly all the dolines lie in a covered karst where Tertiary and Quaternary sands overlie the chalk karst and their relationship to datable archaeological remains suggests a very short time-scale of evolution.

Introduction

The Dorset heathlands, along the northern edge of the western Hampshire Basin, are pock-marked with an impressive array of dolines. Over 370 are recorded on Puddletown Heath, and there are more than 100 on the smaller Southover Heath. Cull-pepper's Dish is the largest and most spectacular individual doline, and occurs on the Bryants

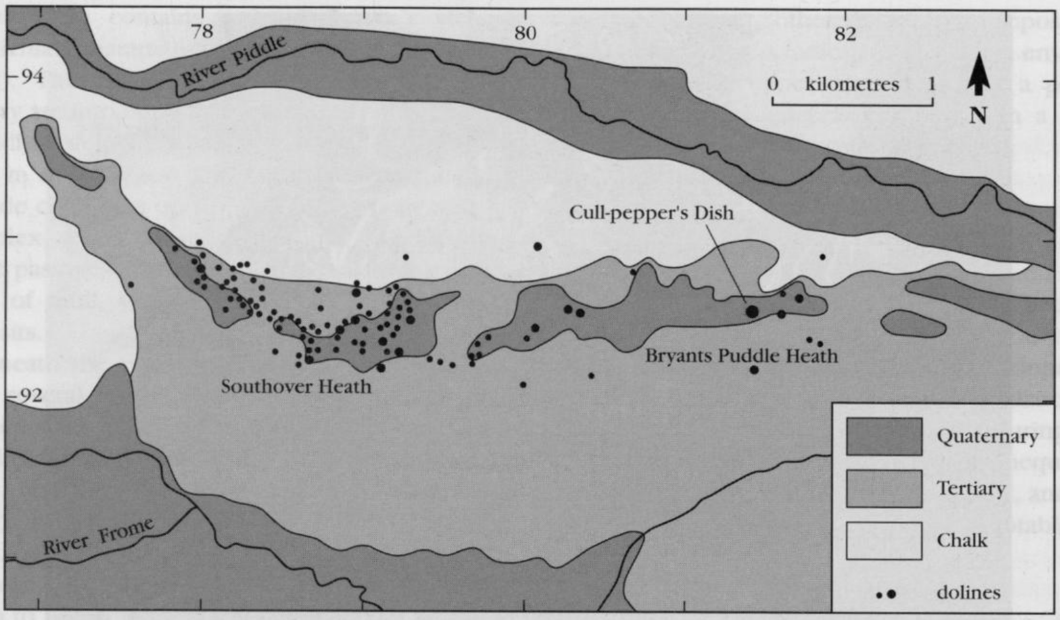

Figure 7.5 Geological map of Cull-pepper's Dish and the doline fields of the adjacent Dorset heaths on sediments overlying the chalk. The Tertiary rocks include the Reading, London and Bagshot Beds. The Quaternary rocks include plateau gravels along the central strip of heathland, and also alluvium in the valleys north and south (after Sperling *et al.*, 1977).

Puddle Heath, along with just a few other dolines of larger than average size (Figure 7.1).

The Dorset doline fields gained early mentions by Stevenson (1812), Mansel-Pleydell (1873), Fisher (1858, 1859) and Reid (1899), and the site geology is described by Wilson *et al.* (1958). The doline genesis was explained by Sperling *et al.* (1977), and again further considered by House (1991, 1992) and Goudie and Gardner (1985). These chalk karst dolines are comparable with some of those developed on the Carboniferous Limestone (Coleman and Balchin, 1959; Thomas, 1974).

Description

The doline fields of the Dorset heathlands reach densities of 99 km^{-2} on Southover Heath and 157 km^{-2} on Puddletown Heath, where the majority of the dolines are only about 10 m across. Cull-pepper's Dish, located in woodland on Bryants Puddle Heath, is the largest single doline in the area, and lies in a region of lower doline density (Figure 7.5). It is a conical depression, 21 m deep with a mean diameter of 86 m, slightly elliptical in plan, with uniformly graded sides sloping at about 30° (Sperling *et al.*, 1977). The whole depth of the visible doline is developed within the clastic sediments which survive over the chalk. These are the sands and gravels, with minor clay horizons, of the Eocene Reading Beds, overlain by a thin spread of Pleistocene plateau gravels. Beneath the Reading gravels, the Cretaceous Upper Chalk is a soft pure-white limestone over 100 m thick, which dips at less than 3° (Wilson *et al.*, 1958). Soils mask all the bedrock, except at a few exposures of unconsolidated sand. In the floor of the doline, a sinkhole is choked with soil between loose blocks of chalk; there is no evidence of any collapse structure.

Two other large dolines occur in the immediate vicinity, but Cull-pepper's Dish is the largest and least vegetated, and consequently the best exposed. They all lie in the heathlands at altitudes around 80 m, overlooking the chalk slope to the valley floor 50 m below. None of the dolines bears any relationship to the surface drainage pattern which is poorly developed on the very permeable sand.

Interpretation

The formation of the dolines was initially ascribed to the subsidence of the clastic material into pipes in the subjacent chalk, owing to the percolation of rainwater, which dissolved the chalk (Fisher, 1859). Reid (1899) further suggested that the moist climate and acidic peaty soils combined with the vertically extensive vadose zone to provide conditions favourable to doline development. It is notable that the doline fields lie along the ridge where groundwater can drain rapidly downwards to a deep water table within the chalk. The same location provides the required thickness of the sediment cover, where it thins enough to permit substantial through drainage.

Solution of the underlying chalk by highly acidic percolation water from the peaty heathlands may be locally concentrated by discontinuous clay-rich beds in the very variable Reading Beds. This creates small cavities and fissure networks in the Chalk. Collapse may occur when they reach a critical size, but is unlikely to be a significant process as there are no comparable collapse features in the exposed chalk to the north. With or without any collapse, the loose unconsolidated sands ravel and slump into the chalk voids, and are carried to depth by the vadose drainage. Most of the dolines are formed where the Reading Beds are capped by Quaternary gravels – which are even more permeable and prone to ravelling. At some sites, less concentrated recharge may cause solution and subsequent lowering at the interface between the chalk and the overlying material, producing more gradual surface lowering.

The age of the dolines is open to debate. They clearly postdate the Pleistocene gravels in which they are formed, but these deposits on the higher levels of the heaths are probably older than Ipswichian. New dolines continue to form, and small collapses have been recorded in recent years (Goudie and Gardner, 1985). Doline development within the last 4000 years has disturbed a Bronze Age burial site (House, 1992), but this is located west of Dorchester and correlations with Cull-pepper's Dish are tenuous.

Conclusions

Cull-pepper's Dish is the largest and most spectacular of the dolines developed on the covered chalk karst of Dorset. It provides an excellent example of a conical subsidence doline formed in unconsolidated sands and gravels of Tertiary and Quaternary age.

THE MANGER

Highlights

Incised into the escarpment of the Berkshire Downs, the Manger is one of the finest chalk dry valleys, or combes, in Britain. It is especially notable for the series of steep chutes which serrate its southern flank and for its well documented floor sediments and downslope alluvial fan.

Introduction

The Manger is one of many short dry valleys which etch the chalk escarpments of southern England. It is incised into the northern escarpment of the Berkshire Downs, overlooking the Vale of the White Horse (Figure 7.1). The Manger's importance lies in the sediments which mantle the floor of the valley and fan out into the Vale. These provide evidence for the geomorphic evolution of the valley, which is pertinent to the many other similar dry valleys in England's chalk downland. The debate over the origins of the chalk dry valleys has extended through many years (Smith, 1975b). The two main suppositions are that the valleys were cut by normal stream action which has since gone underground (Chandler, 1909; Fagg, 1923, 1954; Sparks and Lewis, 1957; Small, 1962, 1964), or that they were cut by runoff and solifluction processes under periglacial conditions (Reid, 1887, 1892; Bull, 1936, 1940; Kerney *et al.*, 1964; Sheail, 1971). The geomorphology of the Manger has been described by Arkell (1947), Beckinsale (1954), Paterson (1977) and Goudie and Gardner (1985).

Description

Overlooking the broad Vale of the White Horse, the chalk escarpment rises steeply for 100 m, and is scored by many short, steep, dry valleys. The Vale is developed largely on the Mesozoic Gault and Kimmeridge clays, which are separated from the chalk by a narrow band of Greensand cropping out at the foot of the scarp. The Lower and Middle Chalks form the bulk of the escarpment, with some of the Upper Chalk surviving along the crest; they dip 1–3° south.

The Manger combe is a rounded valley about 500 m long and 50 m deep, cut into the scarp-face

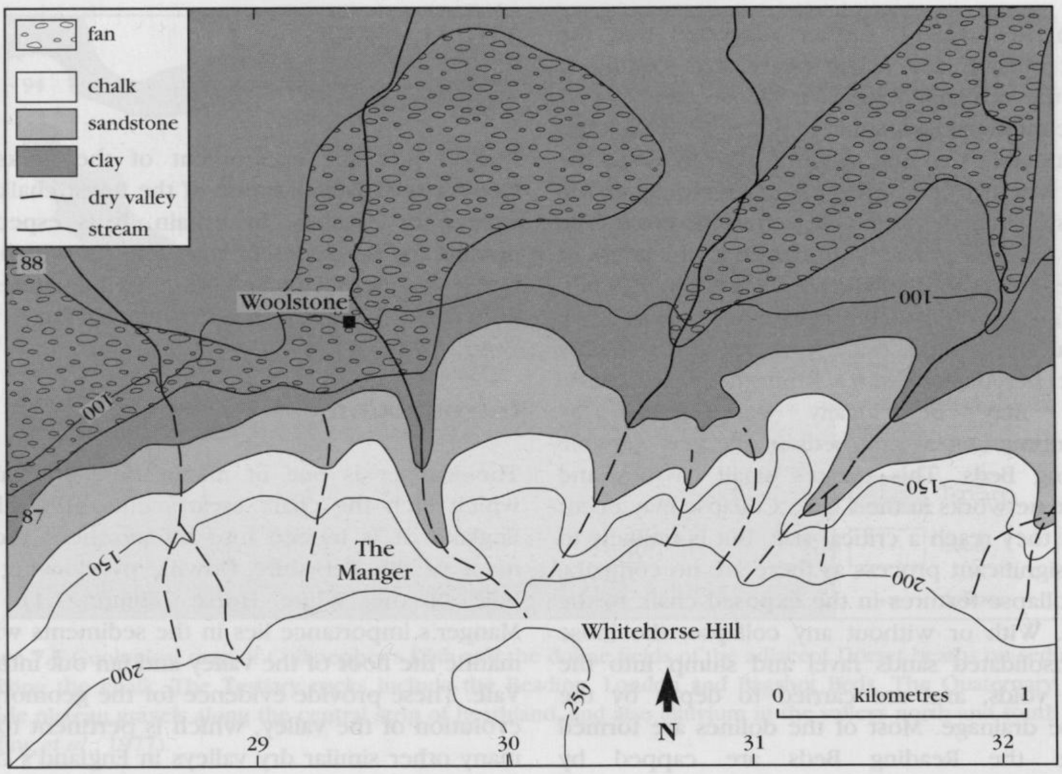

Figure 7.6 Geological map of the Berkshire Downs scarp face, with its dry valleys, or combes, including the Manger, and associated fan deposits.

below Whitehorse Hill (Figure 7.6). It is totally dry. Its floor gradient is up to 36° near the head of the combe, but this eases to less than 10° lower down. The long profile is a smooth graded slope, convex over the upper rim and concave on the lower slopes; the cross-valley profiles are generally symmetrical. On the southern slope of the combe, the left bank is corrugated by a series of ten much smaller combes or furrows (Figure 7.7). These are each about 120 m long and 40 m across, and are incised by about 5 m.

Both the geomorphology of the valley and the stratigraphy of the combe floor alluvium and fan deposits were investigated by Paterson (1977), using electrical resistivity surveys, field mapping, excavated trenches and over 800 augered boreholes. The floor of the valley is cut in the chalk until it breaks through to the underlying sandstone (Figure 7.8). Bedrock is covered by up to 5 m of white, angular, chalk rubble and silt; above this are up to 3 m of grey-brown, humic, chalk silts with occasional chalk and flint fragments, capped by a thin layer of topsoil (Paterson, 1977). These deposits can be traced the whole length of the combe, and the white chalk rubble alone extends into the gently graded fan of chalk detritus which reaches out over 2 km from the foot of the scarp face (Figure 7.6). A terrestrial molluscan fauna is preserved in a cryoturbated chalk debris in the equivalent fan below the combe to the west of the Manger (Paterson, 1971, 1976).

Interpretation

The origin of the Manger was ascribed to spring sapping when the water table was higher (Arkell, 1947), and the gullies on the south side were interpreted as old spring sites which represent former positions of the spring line. This concept is, however, incompatible with the large amount of sediment remaining within the Manger. Excavation by surface run-off and solifluction is indicated by depositional evidence from the banded gravels in the combe floor (Paterson, 1977). The Manger was carved out by an abundance of meltwater from annual snow banks on the summit of the escarpment. This was aided by seasonal solifluction on the valley sides, which led to major deposition on the valley floor, but the importance of meltwater transport is demonstrated by the large fans of well sorted chalk

Figure 7.7 The dry valley of the Manger seen from its head; the chalk of its south slope is scored by the series of furrows or small-scale combes, above the flatter valley floor veneered by solifluction debris. (Photo: A.C. Waltham.)

debris extending out onto the clay floor of the Vale.

The dry furrows, or small-scale combes, in the south slope of the main dry valley have been attributed by Paterson (1977) to the sites of former springs, which supplied water into the valley and provided the loci for intensive freeze–thaw action and other periglacial processes. Alternatively, they may be avalanche tracks (Goudie and Gardner, 1985), dating from Devensian periglacial environments. Avalanches can cause erosion of a weak bedrock such as frost-shattered chalk. The north-east aspect of the slope makes it a prime site for snowdrift accumulation in winds from the south-west; spring avalanches would scour the thawing, weakened, active layer within the chalk, and would repeatedly follow the same tracks.

The volume of sediments in the alluvial fan represents about a quarter of the volume of the Manger valley. This implies that much of the material eroded is still present in the fans, and suggests a relatively recent origin for the deposits. The stratigraphy of the deposits, the nature of their

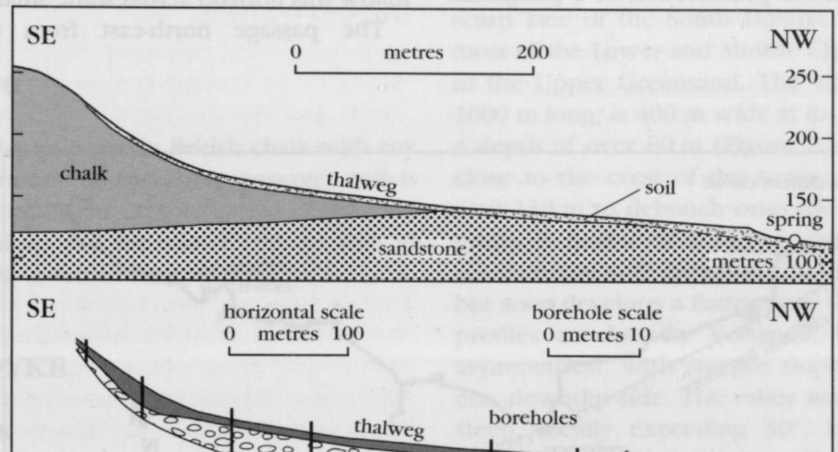

Figure 7.8 Long profiles of the floor deposits in the Manger. The upper profile is drawn to true horizontal and vertical scales. In the lower profile the soil thicknesses are increased by a factor of 8 (after Paterson, 1977).

molluscan faunas, the absence of deep leaching and chemical weathering, and their geomorphic relationship to the surrounding land, all indicate a Devensian age. Paterson (1976) assigned the molluscan assemblage to the Allerød Interstadial of the Late Devensian. He then dated the soliflucted chalky debris to the succeeding cold environment of the Loch Lomond Stadial (10.8–10.3 ka), and the brown chalk silts to hillwash following clearance and cultivation in the Holocene. Though there is no surviving evidence of pre-Devensian sediments, the scale of the Manger, compared to the volume of sediments, demonstrates that the valley was incised over several cold phases during the Pleistocene. In each of the intervening warmer stages, and in the Holocene, renewed underground drainage led to the combe becoming a temporarily inactive dry valley.

Conclusions

The Manger is a spectacular combe incised into the scarp face of the Berkshire Downs; it is a particularly fine example of this type of dry valley which is distinctive of England's chalk karst. The sediments preserved in the valley floor and in a fan extending out in the Vale to the north provide striking evidence of solifluction and periglacial excavation during the Devensian glaciation. The furrows preserved on the southern side may represent either an abandoned spring line or relict avalanche tracks. The dry combe is excellent evidence of the karstic preservation of a periglacial landform.

BEACHY HEAD CAVE

Highlights

Beachy Head Cave is the longest and best example in Britain of a phreatic conduit developed in chalk.

Introduction

Beachy Head Cave is entered from an opening close to the foot of the cliffs 400 m west of Beachy Head, East Sussex (Figure 7.1). The cave is formed in the lower beds of the Senonian Upper Chalk, which locally dips very gently to the west. It lies immediately above a tabular flint band 20 mm thick. There is no apparent relationship between passage orientation and surface topography. The cave was described by Reeve (1980), and cave development in chalk has been reviewed by Lowe (1992a).

Description

The opening to the cave is on a ledge 4 m above the base of the cliff, where marine erosion has caused cliff retreat to intersect a remnant phreatic cave passage (Figure 7.9). Most of the cave comprises a phreatic tube about a metre in diameter but there are a few phreatic domes and small avens. The cave is close to horizontal, as it follows the one bedding horizon, but it changes level to follow this horizon across some small faults.

The passage north-east from the entrance

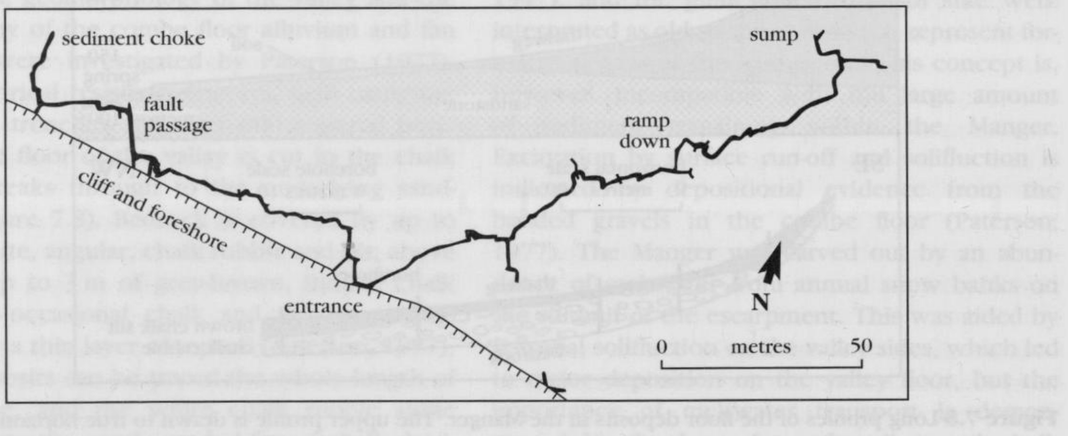

Figure 7.9 Outline map of Beachy Head Cave (from survey by Chelsea Speleological Society).

extends for about 180 m, obliquely away from the cliff face, to where a static sump has prevented further exploration. Several smaller passages branch off at various points and a small cluster of botryoidal stalactites is present near the end. The western passage extends almost parallel with the cliff face, for about 145 m to a clay choke. Daylight can be seen at several places where small branch passages open to the cliff face. One short stretch of passage is aligned on a fault, and has well-developed phreatic domes in the roof.

Interpretation

The development of Beachy Head Cave appears to have been entirely phreatic; there is no evidence of vadose modification. The thin tabular flint band which floors the passage appears to have played a fundamental role in cave development. It may have acted as an aquiclude which prevented downward migration of water, and initiating cave development immediately above; alternatively its chemical contrast may have created a favourable inception horizon. The cave is phreatic, and its altitude means that it predates at least 5 m of water-table lowering. It may be much older, and it now carries no drainage flow; it is unrelated to the present topography, but its depth of over 100 m below the South Downs surface renders this of little significance. Beachy Head Cave may represent a relict example of the type of passage that must extend below currently active sinks in chalk, such as those at Water End in Hertfordshire (Walsh and Ockenden, 1982).

Conclusion

The cave is the only one in British chalk with any significant amount of accessible passage, and is therefore an important demonstration of the existence of conduits and the role of conduit flow in the heavily exploited chalk aquifer.

DEVIL'S DYKE

Highlights

The Devil's Dyke is the largest, and perhaps the most famous, of the combes developed on the chalk karst of England's downlands. Its sheer size provides ample evidence of the effectiveness of the solifluction and other periglacial processes which operated during cold stages of the Pleistocene.

Introduction

Many short, steep-sided, dry valley, or combes, are cut into the scarp face of the Cretaceous Chalk escarpments of southern England. The Devil's Dyke, incised into the northern side of the South Downs, north of Hove (Figure 7.1), is probably the largest, most spectacular and most well known of all the chalk combes. Its unusually large size is partly due to its two stages of excavation, but it still provides an excellent example of the scale of periglacial activity in the chalk karst.

Debate over the origins of the Devil's Dyke and the many other chalk combes has been extensive. The main hypotheses have centred on either spring sapping and normal stream erosion in temperate climates (Chandler, 1909; Fagg, 1923, 1954; Sparks and Lewis, 1957; Small, 1962, 1964), or erosion under periglacial conditions by solifluction and surface run-off (Reid, 1887, 1892; Bull, 1936, 1940; Kerney *et al.*, 1964; Sheail, 1971). Specific studies of the Devil's Dyke include those by Martin (1920), Sherlock (1929), Wooldridge (1929), Bull (1936) and Small (1962, 1964).

Description

The Devil's Dyke is incised into the north-facing scarp face of the South Downs; it cuts through most of the Lower and Middle Chalk, and finishes in the Upper Greensand. The valley is just over 1000 m long, is 400 m wide at its rim and reaches a depth of over 80 m (Figure 7.10). Its head lies close to the crest of the scarp, and it descends over 130 m to debouch onto the clay vale to the north. It begins as a steeply descending, steep-sided combe with an initial gradient of about 25%, but soon develops a flatter floor. The valley cross-profiles are broadly V-shaped, but are slightly asymmetrical, with steeper slopes on the southern, downdip side. The valley walls are unusually steep, locally exceeding 30°, before flattening sharply to gentle convex profiles in their upper parts. A ribbon of soliflucted chalk debris, known as combe rock, follows the thalweg of the dry valley.

The combe heads north-east, until it swings to

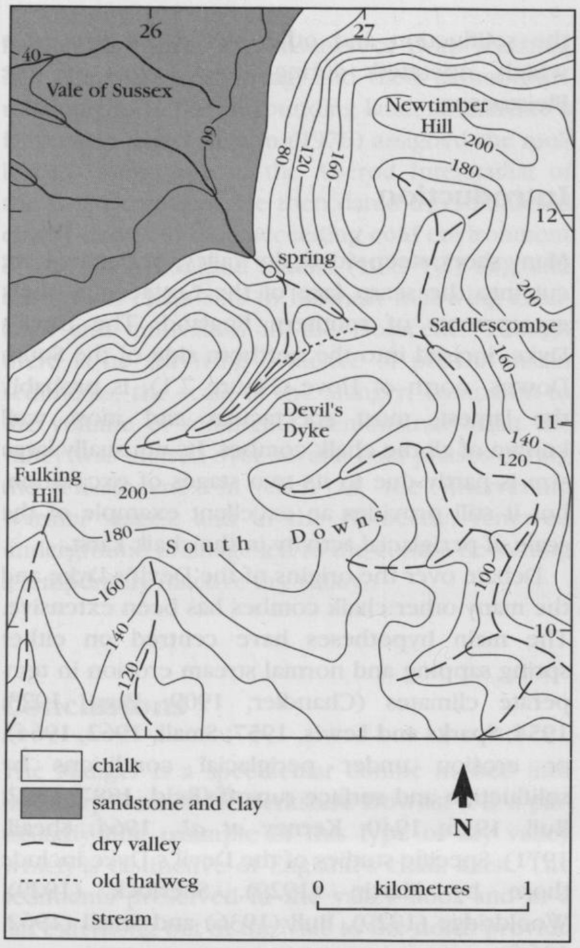

Figure 7.10 Topographic map of the Devil's Dyke and the Saddlescombe dry valleys on the South Downs.

the north, and flattens and widens considerably below a marked step. Lower down, the dry valley again steepens, and ends at the foot of the scarp above a powerful group of springs. A tributary valley on the south at its lower end is the only one to enter the combe; its head lies at a col over into a large dry valley system cut in the dip slope (Figure 7.10). Their is no trace of any related valley feature in the clay vale to the north.

Interpretation

Early claims that the Devil's Dyke was excavated by glaciers (Martin, 1920; Sherlock, 1929) were refuted by Wooldridge (1929) and Bull (1936) who proposed that it was incised by meltwater flowing from melting snow caps during periglacial periods. Fagg (1923, 1954) suggested that the chalk dry valleys were cut by normal stream action, and were then desiccated by scarp retreat when new springs caused a fall in the local water table.

Small (1962) suggested that the Devil's Dyke was originally the upper segment of Saddlescombe, which was captured by headward erosion in a scarp face valley. The sharp bend in the combe may be regarded as the elbow of capture, and the saddle on the small spur just to the east may be a remnant of the original valley floor (Figure 7.10). Following capture, the new steeper gradient caused the valley to become overdeepend. Small proposed that this was due in part to spring sapping and associated stream erosion, a mechanism which has also been put forward for the formation of several other chalk dry valleys such as the Manger in Oxfordshire (Arkell, 1947; Sparks and Lewis, 1957). He also noted the role of erosion by snowmelt run-off during periglacial episodes, and speculated that a former impermeable capping of clay-with-flints may have caused surface drainage under wetter conditions.

The chalk is very susceptible to frost shattering in its weathering profile, followed by erosion by surface run-off and solifluction processes, under periglacial conditions (Paterson, 1977). Valley excavation in the chalk thereby progressed during each cold stage of the Pleistocene, and became dormant when underground drainage resumed during each subsequent warm stage. About half the depth of the Devil's Dyke was cut when it was a high tributary of the Saddlescombe valley system on the dip slope. Probably very late in the Pleistocene, it was rejuvenated when it was captured by the scarp face valley, and periglacial processes were enhanced on the new, steeper slopes. Even though it appears to have a two-phase history, the Devil's Dyke represents an excellent example of the massive scale of periglacial activity on the chalk downlands.

Conclusions

The Devil's Dyke is the largest and most impressive of the many combes incised into Britain's chalk karst. Its origins are complex, with capture and rejuvenation creating its present overdeepened form. The dimensions of the valley have important implications for ideas on the scale and effectiveness of solifluction and meltwater run-off on the chalk downlands of England during periglacial stages of the Pleistocene.

WATER END SWALLOW HOLES

Highlights

The Water End swallow holes are some of the largest, best developed and most accessible swallow holes in the chalk karst of southern England. They admirably demonstrate the role of conduit flow within the Chalk aquifer.

Introduction

Mimmshall Brook has a catchment area of 45 km^2 draining the high ground to the south and west of Potters Bar (Figure 7.1). It drains an area of Tertiary London Clay and flows north onto the Cretaceous Chalk outcrop. For 3 km, the stream flows in a shallow valley floored by thin gravelly alluvium which rests on the chalk. At Water End, it drains underground through a series of sinkholes. Two other small streams drain into the same broad depression, and also sink into the chalk. In wet weather, the sinks cannot cope with the flow, and a lake develops; in extreme flood, this overflows into a surface course to the west to join the River Colne. The sinking water resurges between 7 and 15 km to the east at four springs along the River Lea.

The site has been described by Wooldridge and Kirkaldy (1937), Evans (1944), Waltham (1969), Ockenden (1972) and Reeve (1979). Kirkaldy (1950) included the area in his study of chalk solution in the Mimms Valley, and Walsh and Ockenden (1982) reviewed their detailed hydrological studies of the sinkhole complex.

Description

Water End lies at the edge of the London basin where the Tertiary outlier is eroded to expose the underlying chalk. Thin sandy Reading Beds are capped by London Clay, both of which are Eocene, and Pleistocene gravels form the higher ground around the valley; chalk is exposed along the floors of the main and tributary valleys (Figure 7.11). The chalk dips to the south at less than 0.5°. Glacial till is extensive to the north, and floors a shallow trough just north of Water End.

The sinkhole complex at the end of Mimmshall Brook occupies a large blind valley up to 10 m deep. The main sinks are clustered within an area of 1 ha at the end of the Mimmshall Brook surface course; this zone normally has about 15 discrete

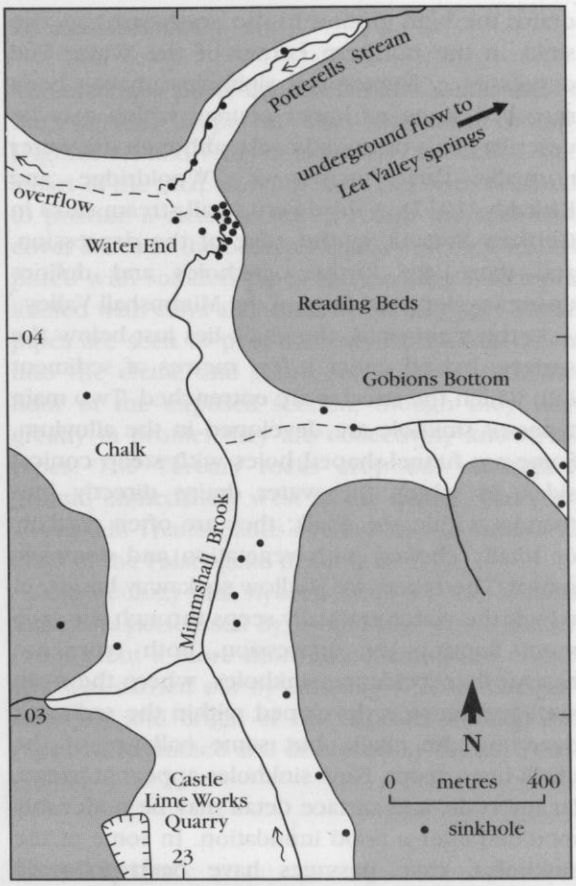

Figure 7.11 Geological map of the Mimmshall Valley with the Water End sinkholes and the Castle Lime Works Quarry.

sinks and depressions, but the number may change after a major flood (Figure 7.11). Under normal weather conditions most of the water sinks at a single point, but under progressively wetter conditions the main sink is overwhelmed and a series of other sinks in the valley are utilized. In flood, the combined discharge of the streams may exceed the capacity of the swallets; a lake then forms and expands to cover more than 2 ha before overflowing down the normally dry valley to the west, to join the River Colne (Figure 7.11). Average stream discharge is about 80 l s^{-1}, but the swallets have a capacity of about 1 m^3 s^{-1}, and this is exceeded in flood (Walsh and Ockenden, 1982). Fluorescein dye tracing proved that the water resurged at four springs spread out down 12 km of the Lea Valley (Morris and Fowler, 1937); these lie between 8 and 15 km from Water End, at elevations 20–45 m lower, and the flow-through rates averaged about 5500 m per day.

A second smaller stream, the Potterells Stream, drains the high ground to the north-east and also sinks in the northern corner of the Water End depression. Numerous sinkholes have been recorded along its lower course, which may be described as a degraded uvala, although the water normally flows across it (Wooldridge and Kirkaldy, 1937). A third very small stream sinks in Gobions Bottom, at the edge of the depression, and there are further sinkholes and dolines upstream along the floor of the Mimmshall Valley.

At the main sinks, the chalk lies just below the surface, buried under a few metres of sediment into which the streams are entrenched. Two main types of sinkhole are developed in the alluvium. Some are funnel-shaped holes with steep conical sides, in which the water drains directly into fissures within the chalk; they are often partially or totally choked with vegetation and domestic refuse. The others are shallow soakaway basins, in which the water gradually seeps through the sediment flooring the depression. Both types are essentially subsidence sinkholes, where the main surface feature is developed within the sediment overlying the chalk, but some collapse of the chalk does occur. New sinkholes appear at irregular intervals, and surface detail may be noticeably modified after a flood inundation. In some of the sinkholes, cave passages have been followed within the chalk for lengths of 10–20 m; they consist of narrow rifts with phreatic solutional enlargements and the water cascades along and down narrow floor fissures. Sediment chokes and flood risk have precluded further exploration.

Auger drilling across the sinkhole basin has revealed a layered sequence in the sediments (Walsh and Ockenden, 1982), which reach about 5 m in total thickness:

3. Dark-grey or black organic silts and clays, overlying light-brown silty clay, occasionally gravelly in part.
2. Greenish brown clay, overlying brown sands.
1. Brown silty clay with occasional chalk fragments, resting on chalk.

Interpretation

The initiation of the swallow hole complex appears to have been in the Pleistocene. The Radlett Mimms depression, in which the Mimmshall Brook is located, may have originated as part of a meander loop from a former course of the River Thames (Wooldridge and Kirkaldy, 1937). Subsequently, the underfit Mimmshall Brook was diverted by a plug of glacial till, which blocked the natural northerly continuation of the valley towards Hatfield, causing it to flow north-west to the River Colne. Since the last glaciation, a thin spread of gravels has been deposited over the valley floor.

The swallow holes appear to have formed after the gravels were deposited, as they cannot be shown to be older than the gravels (Walsh and Ockenden, 1982). Thus the sinkholes appear to be relatively recent features, formed over chalk fissures which were enlarged by solution over a very much longer period; new collapses occur at frequent intervals (Evans, 1944; Reeve, 1979; Walsh and Ockenden, 1982), usually after the basin has flooded.

The upper sediment layer (3) is interpreted as flood lake deposits, laid down during the last few decades or centuries (Walsh and Ockenden, 1982); the change from silty clay to organic clay is ascribed to geographical or vegetational changes in the drainage basin. The middle layer of sediment appears to be identical to the Reading Beds which crop out on the slopes to the east. The lowest clastic horizon (1) is a thin insoluble weathering residue of the chalk. Pollen analysis of the sediments (Walsh and Ockenden, 1982) indicates that they are postglacial. The Reading Beds (layer 2) lie under the basin at levels below the chalk on all sides, which suggests that they have been lowered by solution of the chalk on which they rest.

The nature of the cavity system under the swallow holes, and the pattern of underground drainage, remain conjectural. Dispersion of the dye from the single sink to the four widely spaced springs suggests that the water sinking in the swallow holes does not flow through a discrete cave system; the flow is probably mostly through a network of micro-fissures and a maze of larger fissures. The rapid flow rate suggests that there is a significantly large passage allowing vadose flow for at least part of the flow route, probably in the initial stages. The North Mimms Well, 500 m from Water End, has a very stable water table about 12 m below the sinkhole level, and recorded none of the dye injected at the sinks. This suggests that the chalk is honeycombed by a fissure system which allows free drainage from the sinks down to the regional water table, as seen in the short vadose sections of accessible cave. The large amount of clastic sediment which has been carried into the stream sinks during formation of the surface depressions is a further indication of the considerable size of the solutional cavities within the chalk.

Quantitative dye-tracing from the sinks under different stage conditions would provide further data on the nature of the underground drainage network beneath the swallow holes, and this would have implications for waste disposal and water management in Chalk areas.

Conclusions

The Water End swallow holes are the best and largest examples in Britain of permanent stream sinks developed in the chalk karst, and they clearly demonstrate the role of conduit flow within the Chalk aquifer.

CASTLE LIME WORKS QUARRY

Highlights

The preserved walls of this quarry provide the finest exposures in Britain through clay-filled pipes and fissures within the Chalk. The infills to these solution features are Tertiary sediments much older than the clay-with-flints commonly found on the Chalk outcrops.

Introduction

The old chalk pit of the Castle Lime Works lies in the western slope of the Mimmshall Valley (Figures 7.1 and 7.11). It is partially backfilled, but a part of the final working faces has been retained to provide a clean section through the sediment cover and into the bedrock chalk. The rockhead is pitted with solution pipes and cavities, which are infilled with clays and sands of Tertiary age. These pipes are seen to penetrate several metres down into the chalk, and some continue beneath the floor of the exposed section; though they vary greatly in profile, they are collectively known as pipes. The Tertiary rocks crop out on higher ground immediately west of the quarry, and consist of thin Thanet Sands overlain by the sands and clays of the Palaeogene Reading Beds.

The geology and hydrogeology of the Mimms Valley was discussed by Wooldridge and Kirkaldy (1937), but a more thorough examination of the site was carried out by Kirkaldy (1950). The petrography and origin of the deposits infilling the pipes were studied and discussed by Thorez *et al.* (1971).

Description

The solution pipes and cavities occur on the eastern face of the quarry, which stands nearly 5 m

Figure 7.12 A section of the preserved face in the Castle Lime Works Quarry exposing the extremely irregular upper surface of the chalk, broken by clay-filled pipes and broader depressions. (Photo: A.C. Waltham.)

high and is a preserved, permanent exposure (Figure 7.12); other faces of the quarry have been backfilled or are still active. The poorly bedded, horizontal Upper Chalk is exposed; it is irregularly fractured and has ill-defined bands of nodular flint. It is overlain by less than a metre of Quaternary reddish clay containing flints, and this supports a thin layer of topsoil.

A complex rockhead relief and infilled solution features have long been recognized during the progressive advance of the quarry faces. Though many individual features have since been lost to the quarrying, three main types of filled pipes can be recognized, all lying beneath 1–2 m overburden of stony clay soil (Thorez *et al.*, 1971):

1. Shallow basins up to 3 m deep and 30 m wide. These contain disturbed units of the flint-rich glauconitic Bullhead Bed, the basal member of the Palaeogene deposits, overlain by grey and brown pebbly sands with clay partings.
2. Steeply inclined or vertical cylindrical pipes, between 0.5 and 5.0 m wide; many were seen extending to depths greater than 12 m in parts of the quarry now destroyed. They are mostly infilled with grey and brown pebbly sand and are lined with dark-brown clay.
3. Horizontal seams of dark-brown clay and sand, up to 0.5 m thick, veining the chalk and occurring to 20 m below ground level; these include the 'sheet-pipes' described by Kirkaldy (1950).

The chalk surface along the preserved face is pitted with a series of these filled cavities; they vary considerably in shape, from shallow, rounded depressions, to steep-sided pipes up to a metre deep, and all are infilled with flint-bearing clay soils. Three larger pipes up to 3 m deep and wide are largely infilled with varieties of brown clays, reddish clays and sandy deposits derived from the overlying Tertiary rocks. Many of the pipes are lined with a dark-brown, very porous clay. The mineralogy and microstructures of these sediments were documented in detail by Thorez *et al.* (1971).

Interpretation

The pipes now exposed in the quarry formed as solutional voids or small caves in the chalk beneath the Tertiary cover rocks, causing the overlying sands and clays to slump into them. An early interpretation related the pipes to a group of fossil swallow holes, similar to the modern features at Water End (Kirkaldy, 1950). However, the quarry pipes are clearly subsurface solution features; structures within the Tertiary fills show that they have slumped and collapsed into them and were not the result of subaerial sedimentation in surface depressions.

The mineralogical composition of the infills supports this hypothesis, by showing that the pipe sediments are mainly a correct sequence of the Palaeogene cover rocks overlying the chalk (Thorez *et al.*, 1971); the clastic material does not have an inverted sequence which would evolve from erosion and redeposition. The lowest few metres of pebbly sand in the pipes relate to the Thanet Beds, which thin out beneath their cover 10 km south-east of the quarry. The higher sediments are typical of the Reading Beds which now outcrop on the hillside immediately west of the quarry. It appears that the chalk is initially dissolved beneath a cover of Thanet Sands and Reading Beds, which then slump into the underlying void. The relatively coherent Bullhead Bed at the base of the Palaeogene deposits was strong enough to support the upper sandier material until the cavities were enlarged sufficiently for collapse to occur. Disrupted Bullhead Bed material occurs up to 3 m below the original sub-Palaeogene surface.

The dark clay lining many of the pipes was deposited from suspension in the percolating groundwater, into the voids created by solution of the chalk. The clay material was derived from the overlying Palaeogene sediments, with only a small component derived from the insoluble chalk residue (Thorez *et al.*, 1971). The clays infilling the sheet pipes appear to have a similar origin. If the solution of the chalk and redeposition of the clay was concentrated near the water table, the sheet pipes may represent palaeo-water tables. It appears that solution of the chalk has been enhanced along the feather edge of the Tertiary cover rocks (Edmonds, 1983), where concentrated allogenic recharge enabled greater solutional activity to create the multiplicity of pipes and solutional basins.

The age of the solutional features is open to some debate, and may cover a considerable range. It appears that the larger pipes are a feature of early solution, possibly during the late Tertiary, and are only preserved beneath the Tertiary cover. Thanet and Bullhead material has been preserved within the pipes while it is missing from nearby undisturbed stratigraphic sequences; this indicates solutional lowering before deposition of the Reading Beds. However, Reading material is also slumped into the pipes beneath undisturbed Quaternary soils, indicating renewed solution and subsidence in the later Tertiary. Estimation of solution rates in pipes elsewhere on the Chalk suggests that they form in 5–10 ka (de Bruijn, 1983), but this does not indicate the absolute age of fossil features. The more widespread smaller pits, infilled with clay-with-flints, are probably of Quaternary age. Some of the material infilling the upper parts of the larger pipes is heterogeneous, suggesting that it was reworked by solifluction, and infilled surface depressions that overlay any collapse feature (Thorez *et al.*, 1971). Chalk solution and sediment collapse associated with the pipes continues today, away from the quarry, at numerous sites where subsidence is observed.

Conclusions

The solutional features exposed along the eastern rockhead of the Castle Lime Works Quarry are some of the best preserved examples of clay-filled pipes in the chalk karst of Britain. They demonstrate a significant component of chalk karst morphology and provide evidence of the role of subsurface solution of the carbonate rock. The processes of chalk solution and subsequent subsidence of the cover rocks are analogous to those in the interstratal karst doline fields of South Wales (see Chapter 6), and also to those which preserved the Brassington Formation in the Peak District sinkholes (see Chapter 4).

DEVIL'S PUNCHBOWL

Introduction

The Devil's Punchbowl is a fine subsidence doline. It is the deepest and most spectacular of the many dolines developed on the covered chalk karst of the Norfolk Breckland, just north of Thetford.

Introduction

The sandy heathlands of the Breckland in Norfolk (Figure 7.1) are pock-marked by dozens of small dolines or depressions, often partially filled with water. These depressions and meres are developed on a thick cover of boulder clay overlying the chalk. The Devil's Punchbowl is the clearest example of these depressions. Its morphology is especially interesting as it is intermediate between the conical collapse dolines and the larger shallower subsidence basins both of which are common in the Breckland. The origins of the Devil's Punchbowl and the many other pits and depressions in Norfolk were discussed by Clarke (1903), Marr (1913), Jones and Lewis (1941), Prince (1962, 1964) and Sparks *et al.* (1972), and were reviewed by Day and Goudie (1978) and Goudie and Gardner (1985).

Description

The dolines of East Anglia are particularly numerous north and east of Thetford, in the area of heaths known as the Breckland. The chalk is overlain by up to 30 m of Anglian (and possibly 'Wolstonian') till which is mainly of sandy composition; nowhere is rock exposed at the surface. Scattered across the plateau are many dolines, with their surface forms entirely developed within the glacial drift. Most of these are steep conical depressions, up to 20 m across, but there are also about ten larger, shallower, saucer-shaped depressions up to 150 m across and covering up to 12 ha. These normally contain small lakes or meres.

The Devil's Punchbowl is one of the finest of the Breckland dolines (Figure 7.13). It has the profile of a shallow inverted cone, 6 m deep with sides sloping at up to 18°; almost perfectly circular, the doline has a surface diameter of about 150 m and its lake covers an area of about 0.6 ha. The lake level fluctuates by 2–3 m with changes in the groundwater level, in the aquifer which is contiguous between the chalk and the permeable till; the fluctuations are not simply seasonal, as the Punchbowl may be dry for many years at a time and then contain water for several years. The position of the doline is independent of the local valleys and surface streams.

Interpretation

Jones and Lewis (1941) described the circular Breckland meres as swallow holes due to the solution of the chalk and, in some cases, the collapse of the surface into underground cavities. Acidic drainage from the peaty heathlands has percolated

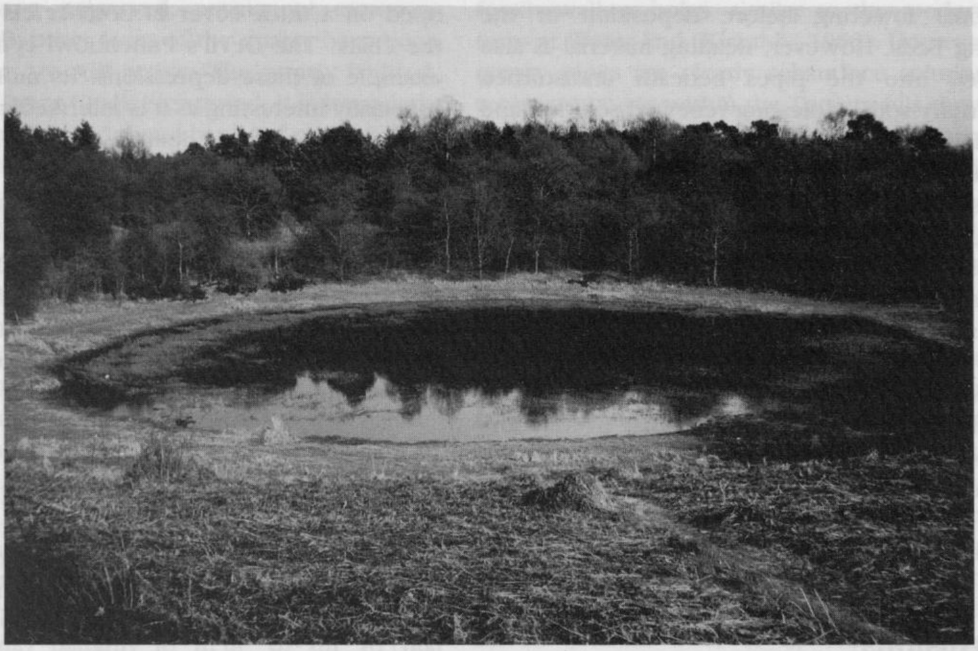

Figure 7.13 The Devil's Punchbowl doline with a lake on its floor in April 1982. (Photo: A.C. Waltham.)

through the glacial drift and dissolved the chalk below, causing subsequent settlement of the overlying glacial drift and subsidence on the surface. This mechanism characterizes the many forms of subsidence doline formed by ravelling and surface lowering in poorly consolidated clastic cover materials overlying cavernous carbonates. Analogies may be drawn with dolines in Dorset (Sperling *et al.*, 1977) and the widespread shakeholes in the till of the Yorkshire Dales karst.

The form of the Devil's Punchbowl appears to be intermediate between the small, steep conical collapses developed by ravelling into a single chalk fissure, and the larger shallow depressions formed by subsidence over a broader zone of rockhead solution; the Punchbowl may therefore provide the genetic link between the two styles of Breckland doline. The main group of Breckland meres, including the Devil's Punchbowl, all lie on a local dome, about 8 m high, in the water table (Day and Goudie, 1978), demonstrating the importance of downward seepage through their floors. This infiltration, and downwashing, is very slow, as the mere levels fluctuate with a time lag of some months behind the rainfall patterns. The age of the Breckland dolines is unknown, except that they postdate the glacial drift in which they are formed.

Alternative modes of origin for the many depressions in the Norfolk landscape include mineral workings, marl pits, and thaw sinks, besides the karstic landforms (Marr, 1913; Prince, 1962, 1964). No single explanation could account for the large numbers and uneven distribution, but the artificially excavated pits are recognizable by their small and irregular forms. The hypothesis of the thaw sinks has been applied to the Devil's Punchbowl and other Breckland meres (Prince, 1964; Sparks *et al.*, 1972). A pingo is formed by ice expansion within the shallow soil layers, and a soil cover may then slump off its domed surface so that a subsequent thaw leaves a depression: this cover sliding may leave marginal ramparts, but the Breckland meres have none of these features, which are recognized at other Norfolk sites.

Conclusions

The Devil's Punchbowl is the most spectacular of the many dolines developed in the covered chalk karst of the Breckland. Its origins have been strongly debated, but it is a fine example of a subsidence doline caused by subsurface solution of the chalk and subsequent settlement of the glacial drift cover. Its morphology suggests a genetic link between the large shallow basins containing meres and the smaller, steeper conical dolines, both of which are common in the Breckland.

MILLINGTON PASTURES

Highlights

The dry valley system of Millington Pastures may qualify as the finest dry valley system on the Chalk of Britain. With its deeply incised, dendritic form and well developed head deposits, it is an excellent representative of this important and ubiquitous karst landform.

Introduction

The Yorkshire Wolds form the crest of a wide chalk escarpment with a gentle dip to the east (Figure 7.1). Many dry valley networks are cut into both the scarp face and the dip slope. Millington Pastures is the finest and deepest of these, incised in the steep scarp face. It consists of a superb dendritic valley network with eight separate branches, all converging into Millington Bottom, east of Pocklington village. The thick head deposits in the valley floor are well preserved. The dry valleys of the Yorkshire Wolds have been poorly documented in comparison with the chalk valleys of southern Britain. Their origins have been discussed by Cole (1879, 1887), Mortimer (1885), Lewin (1969) and De Boer (1974), and many of the arguments put forward to explain the dry chalk valleys of southern England apply equally well.

Description

Millington Pastures has a dendritic system of eight converging dry valleys entrenched by up to 100 m

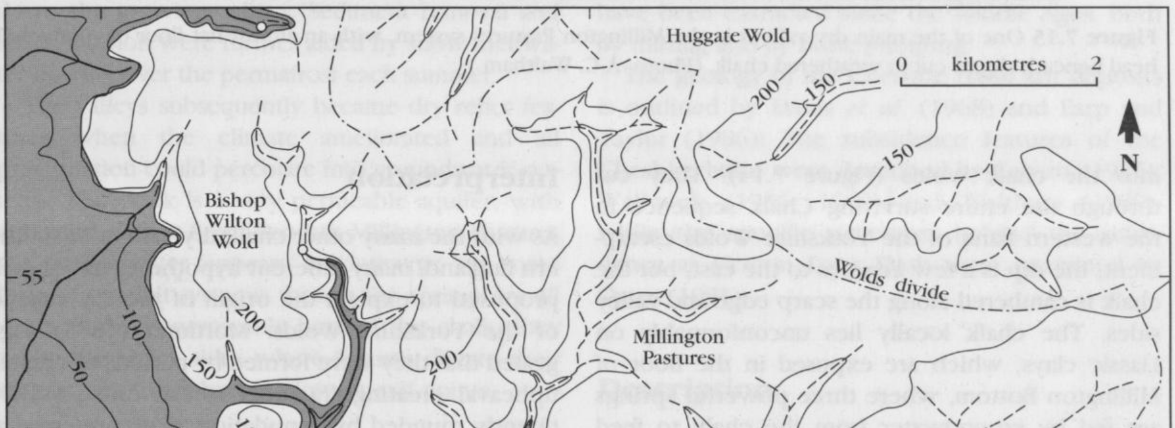

Figure 7.14 Outline map of the dry valley systems of Millington Pastures and its neighbours in the Yorkshire Wolds chalk escarpment. The chalk outcrop includes those of the impure, red Ferriby and Hunstanton Chalks, forming the lowest 25 m. Only the larger springs are marked.

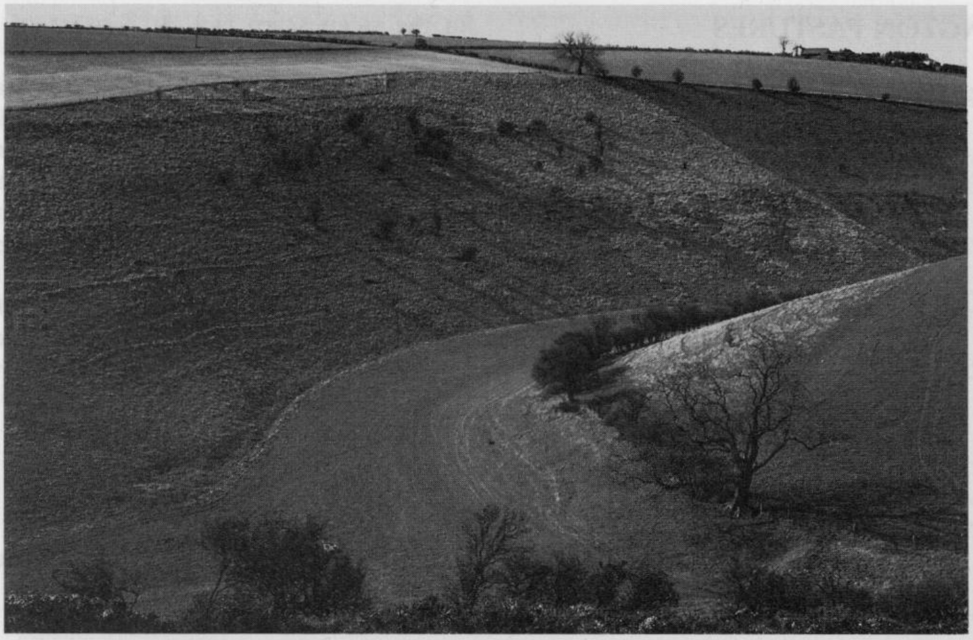

Figure 7.15 One of the main dry valleys in the Millington Pastures system, with an almost flat floor of soliflucted head beneath slopes cut in weathered chalk. (Photo: A.C. Waltham.)

into the chalk wolds (Figure 7.14). They cut through the entire surviving Chalk sequence in the western flank of the Yorkshire Wolds escarpment; the dip is a few degrees to the east, but the chalk is cambered along the scarp edge and valley sides. The chalk locally lies unconformably on Liassic clays, which are exposed in the floor of Millington Bottom, where three powerful springs are fed by groundwater from the chalk to feed Millington Beck. Upstream of the springs, which are all now capped, the valleys are completely dry except after extreme rainfall events (Cole, 1887). Several sections through weathered chalk and the overlying combe rock are exposed in old quarries and pits, but there are no natural chalk outcrops.

The valley floors are gently graded, but steepen rapidly up into their headwalls. Many of the valley sides have very uniform gradients for most of their height, with a short convex section at the top. The valley cross-sections show a flattening where the thicker head deposits occupy the valley floors (Figure 7.15). The dry valley systems of both Millington Pastures and Warter Wold are among the largest of the scarp face systems. Their headward retreat has been so extensive that they have shifted the topographic divide of the Wolds escarpment towards the dip slope (Figure 7.14); the trendline of high points along the interfluves passes through Coldwold.

Interpretation

As with the many other chalk dry valleys in southern England, many different hypotheses have been proposed to explain the origin of the dry valleys of the Yorkshire Wolds. Mortimer (1885) suggested that they were formed by periods of crustal upheaval creating fractures in the crust, subsequently rounded by denudation. Cole preferred a more realistic explanation (1879, 1887) after noting the effects of a prolonged sharp frost followed by a rapid thaw. He witnessed surface flow occurring in many normally dry valleys causing extensive erosion and commented that 'nothing could more plainly show what rapid denudation of the chalk dry valleys might be carried out under glacial conditions'. However, he still maintained that chemical denudation was the primary cause for their origin. Lewin (1969) provided a comprehensive review of the dry valleys of the Yorkshire Wolds. He noted that there were at least three generations of valley which can be identified: old wide valleys which continued as wind gaps through the interfluves; younger dendritic valleys such as Millington Pastures; and the Devensian glacial meltwater channels. He reviewed the several hypotheses for their origins: by meltwater erosion of frozen ground, by subsurface solution and collapse, and by dissection resulting from scarp retreat and climatic change. He concluded that the dendritic valleys such as Millington Pastures formed by headward erosion by surface streams and were later abandoned due to climate change. These valley systems are clearly distinct from the glacial meltwater channels which cross parts of the Wolds without gathering tributaries and commonly with neither upstream nor downstream continuations.

By analogy with similar valleys in the Chalk of southern England such as the Manger (Paterson, 1977), and the Devil's Dyke (Small, 1962), it is clear that the dry valleys were excavated by a combination of solifluction and subaerial fluvial action under periglacial conditions. Ice sheets covered the Wolds in the earlier Pleistocene glaciations, but they were not covered by Devensian ice. During a long period of Devensian periglacial conditions, extensive and recurrent solifluction flows moved frost-shattered and saturated chalk debris into and down the growing valleys. Sediment removal and valley incision were further aided by snow meltwater flowing over the permafrost each summer.

The valleys subsequently became dry relict features when the climate ameliorated and all precipitation could percolate into groundwater systems. The chalk is a very permeable aquifer, with extensive diffuse flow. Beneath Millington Pastures the groundwater appears to converge on some form of conduit systems; though the springs are all close to the impermeable base of the chalk, they are in the valley sides where fissures dictate their sites, and not simply at the lowest exit points.

Conclusions

The chalk of Millington Pastures is scored by a singularly well developed system of dry valleys. It is a particularly spectacular example of a dendritic, dry valley network, more compact and deeply incised than any other in the Chalk of Britain. Slope morphologies and solifluction deposits are clearly displayed, and small old quarries expose useful sections through the weathered chalk and head deposits.

MOSTON LONG FLASH

Highlights

Moston Long Flash is a lake lying in one of a pair of well developed linear subsidence depressions above the Triassic salt beds of Cheshire. These are two of the clearest examples of this landform, which characterizes the Cheshire salt karst, and they are still deepening by active subsidence.

Introduction

The lake of Moston Long Flash lies on the Cheshire Plain 4 km south of Middlewich (Figure 1.2), at a site underlain by the Triassic salt beds. Natural subsidence features on the salt include linear depressions a few metres deep and several kilometres long, cutting across both hills and valleys, and also broader areas of ground lowering. Moston Long Flash is an example of an actively subsiding linear depression; initially its development was slow and natural, but accelerated greatly within the last 70 years as a result of brine abstraction. The salt beds of the Cheshire basin have been extracted since the Middle Ages, both by mining and by brine pumping.

The geology of the Cheshire basin salt deposits is outlined by Evans ***et al.*** (1968) and Earp and Taylor (1986). The subsidence features of the Cheshire basin were described by Calvert (1915), Wallwork (1956, 1960) and Waltham (1989), while the specific processes behind the subsidence at Moston Long Flash were examined by Oates (1981).

Description

Moston Long Flash is developed on over 20 m of permeable glacial till and glaciofluvial drift, of Devensian age. The underlying Triassic Mercia Mudstone sequence includes the Wilkesley Halite, which is a formation over 100 m thick consisting of alternating beds of mudstone and halite: individual beds of almost pure halite are 0.5–20 m thick, and the whole formation contains about 50% soluble salt.

The flashes of the Cheshire karst are lakes which form rapidly in depressions which subside below the water table due to subsurface salt solution. Moston Long Flash is a recently formed lake within an active linear subsidence (Figure 7.16). The whole subsidence landform extends for over 3 km, and is about 200 m wide and 3–10 m deep. Its gently curving cross-profile, remarkably uniform along its length, is asymmetric; a gently graded slope lies opposite a steeper bank which is often scored by a series of small slip scars as the

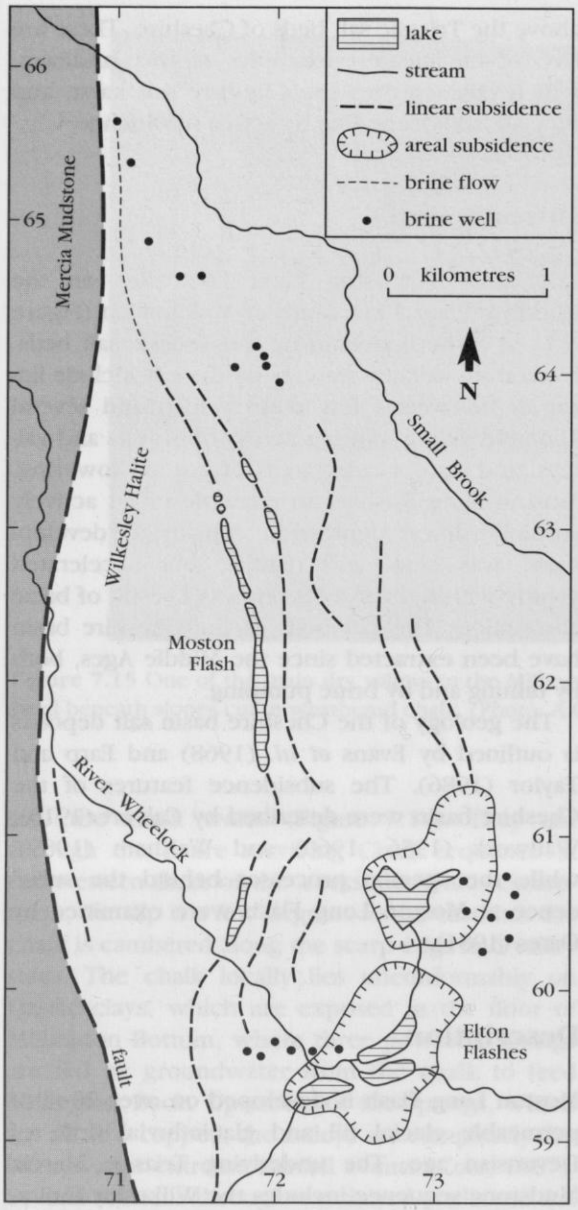

Figure 7.16 Outline map of Moston Flash and the adjacent linear and areal subsidences formed over the Wylkesley Halite. There is no solid outcrop as the entire area is covered by about 20 m of glacial till and glaciofluvial gravels. All the brine wells have now ceased pumping (after Oates, 1981, and Waltham, 1989).

depression subsides and enlarges in its direction. Some parts of the linear subsidence feature have the topographic appearance of a valley, but it is totally independent of the valleys of the area which have been formed by surface water erosion since the Devensian.

Subsidence has persisted over the last 70 years, often at rates in excess of 77 mm year^{-1} (Waltham, 1989); this was measured at a reference post on the edge of the depression, and subsidence rates were certainly higher in the centre of the flash. The lake first appeared in the 1920s, expanded first to the south and then extended to the north. Active subsidence continues to affect the adjacent farmland and farm buildings, and is clearly demonstrated by the repeated repairs to the road which crosses the flash (Figure 7.17). A second linear subsidence feature lies north-east of, and almost parallel to, the flash. It is smaller, less active and contains only a few small ponds where it crosses shallow valleys on the drift terrain. Subsidence rates in both features greatly reduced when brine abstraction stopped in 1978, but slow movement does continue today.

Interpretation

Where halite beds reach rockhead, the exposed salt is dissolved by groundwater flow at the base of the drift cover. The remaining insoluble mudstone beds collapse to create a permeable breccia zone, which may deepen to reach a thickness of over 50 m (Figure 7.18). Groundwater flows through the breccia, as a layer of saturated brine in contact with the halite, along the buried surface locally known as the wet rockhead. Solution is negligible where the impermeable halite is buried beneath impermeable mudstone, at the contact misleadingly known as the 'dry rockhead'. The brine is overlain by fresh water of lower density, and continued solution is dependent on an inflow of fresh water reaching the halite, usually after the brine has flowed out to natural brine springs or has been artificially pumped out (Calvert, 1915; Waltham, 1989).

The commonest type of subsidence feature is the linear trough of which Moston Long Flash is the prime example. These depressions are formed where solution of the underlying salt beds has been accentuated along zones of concentrated groundwater flow, locally known as brine streams, at the rockhead interface of the halite and breccia, usually 50–120 m below the surface. Slow natural subsidence does occur along these brine streams; but this is greatly accelerated where the saturated brine is artificially abstracted, so that unsaturated groundwater flows into contact with the halite. Wild brining is the process of pumping from boreholes sunk into the natural underground brine streams, and one of their effects has been that Cheshire's brine springs have all ceased to flow.

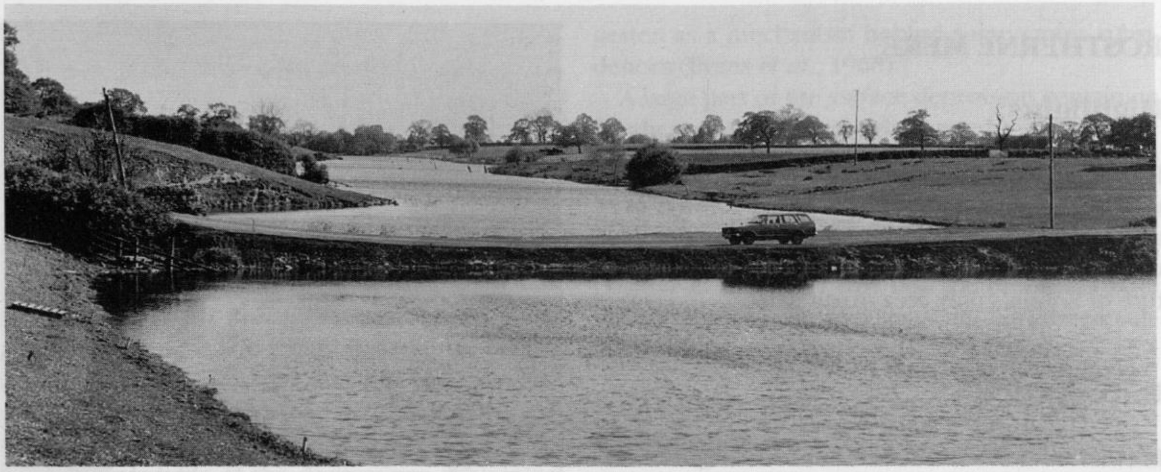

Figure 7.17 The linear subsidence of Moston Flash, looking south where the left face is steeper because it is retreating in the direction of dip as the depression enlarges. (Photo: A.C. Waltham.)

By correlation of the increasing volume of the subsiding depression with the volumes of pumped brine at nearby wells, Oates (1981) showed that the recent rapid subsidence of Moston Long Flash was due largely to brine pumping at a well 2 km to the north (Figure 7.16), and that the subsidence lagged about a year behind the pumping. The pumping draws fresh groundwater laterally through the surface drift and breccia, and solution and subsidence occur where it first meets the halite, far from the abstraction borehole. Saturated flow in a brine stream causes no subsidence. The linear subsidences are broadly aligned with the regional groundwater flow, but most appear to be located over the rockhead outcrops of individual beds of pure salt or along fracture zones. Moston Long Flash appears to follow the bedding until its brine stream turns parallel to a fault. The Elton Flashes are in areal subsidences, which are broad, less well defined depressions formed where fresh water is drawn into contact with the halite rockhead beneath surface streams and valleys (Figure 7.16).

The linear subsidence containing Moston Long Flash is almost certainly post-Devensian, formed after the salt rockhead was scoured by ice and then blanketed with drift. Subsidence has accelerated since the Middle Ages, and especially over the last 70 years, as a result of brine abstraction.

Conclusions

The active linear subsidences of Moston Long Flash and its smaller neighbour are excellent examples of the landforms developed by solution of underlying salt beds; they are characteristic of the Cheshire salt karst. Both features are clearly identifiable, and Moston is the largest active flash in the Cheshire Plain.

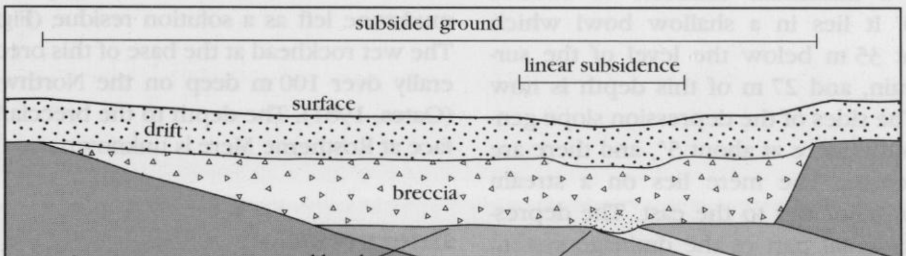

Figure 7.18 Diagrammatic section through the breccia of solutional residue at the rockhead in salt karst, with a brine stream flowing beneath an active linear subsidence like Moston Long Flash (from Waltham, 1989).

ROSTHERNE MERE

Highlights

Rostherne Mere lies in one of the finest and clearest examples of a subsidence basin formed over the Triassic salt beds of Cheshire. The meres of the Cheshire Plain are the most conspicuous feature of Britain's only area of salt karst.

Introduction

Rostherne Mere, north of Knutsford (Figure 1.2), is a lake within a roughly circular subsidence basin which was formed by solution of salt beds at depth. The buried salt is dissolved and removed where it is exposed to groundwater flow, causing regional and localized subsidence and collapse at the surface. Many depressions become lakes as they subside below the shallow water table of the plain. Lakes formed rapidly by accelerated subsidence in recent times are locally known as flashes – such as Moston Long Flash. The meres, including Rostherne, have a longer history of slow subsidence.

The subsidence features of the Cheshire salt karst have been described by Calvert (1915), Wallwork (1956), Reynolds (1979) and Waltham (1989), and the geology of the plain is outlined in Evans *et al.* (1968) and Earp and Taylor (1986). The bathymetry of Rostherne Mere was surveyed by Tattersall and Coward (1914) and redrawn by Pritchard (1961).

Description

Rostherne Mere is a lake with a surface area of 48.7 ha, and a maximum diameter of 1200 m (Figure 7.19). It lies in a shallow bowl which reaches about 35 m below the level of the surrounding terrain, and 27 m of this depth is now submerged. The sides of the depression slope gently down into the mere at about 5°, and there are no rock outcrops. The mere lies on a stream course which drains out to the east. The depression is an incidental part of the drainage system and is an isolated feature in the plain landscape of low relief, though other comparable meres occur nearby.

The mere depression is formed within the cover of Devensian glacial till and glaciofluvial sands. The drift overlies the Northwich Halite, a formation of

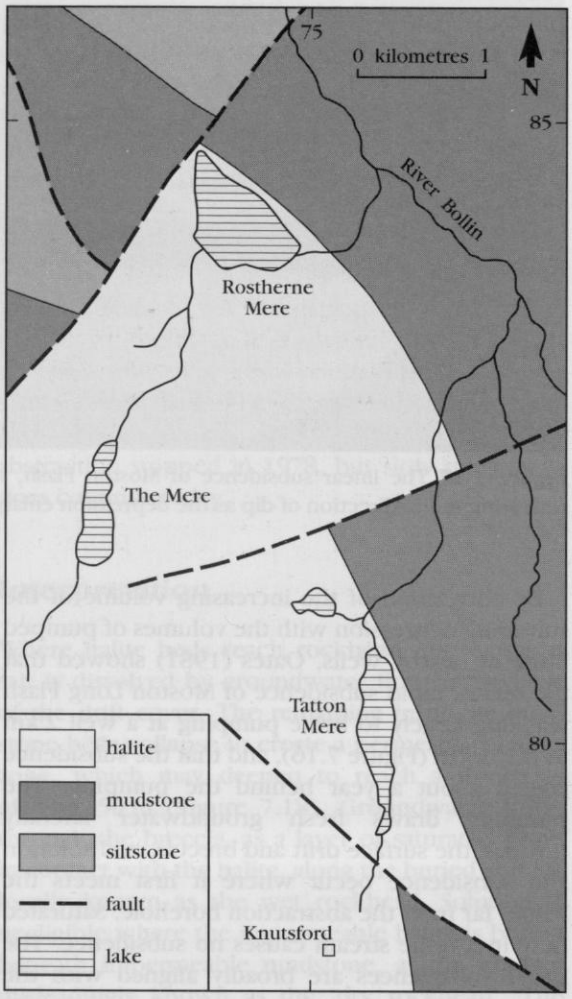

Figure 7.19 Solid geology map of the area around Rostherne Mere and the other adjacent subsidence depressions over the Northwich Halite, buried by a complete cover of glacial and glaciofluvial drift.

200 m of interbedded halite and mudstone within the Triassic Mercia Mudstone Group. On the halites the rockhead is covered by a breccia of mudstone left as a solution residue (Figure 7.18). The wet rockhead at the base of this breccia is generally over 100 m deep on the Northwich Halite (Oates, 1981). The depth to the breccia/drift interface at Rostherne Mere is unknown.

Interpretation

Both the halites and the mudstones are impermeable, and the only groundwater flow is in the permeable drift. Solution of the beds of halite therefore takes place where they meet the rockhead, causing collapse of the interbedded mudstones to create the residual breccia. The removal of the soluble salt by the groundwater flow, through both the drift and the breccia, caused the surface lowering and the formation of a subsidence basin, which subsequently flooded to form the mere. Continued solution of the rockhead halite relies on a supply of fresh water, but most of the rockhead on the halite is covered by a layer of dense, saturated brine, incapable of further solution. Both Rostherne and Tatton Meres overlie the Northwich Halite close to its buried edge, where groundwater flow off the adjacent rockhead of Mercia Mudstone first encounters the soluble salt (Figure 7.19).

The deep profile of the depressions containing Rostherne and some other meres is more than can be accounted for by differential solution and subsidence. The meres may be self-perpetuating in that, once formed in an incidental slight depression, they may gather surface water and act as supply points to the salt below. The same infiltration flow may cause some ravelling of the cover sediments into solution cavities beneath and around the deepening mere; this process was suggested as a mechanism behind some crater subsidences (Evans *et al.*, 1968).

A large part of the surface depression containing Rostherne Mere was clearly formed by subsidence which postdates the Devensian drift. Pritchard (1961) suggested that the subsidence may have been localized over an ice-excavated hollow; the known morphology and bathymetry provide no positive evidence for this, and the profiles of both the surface and the rockhead will have been substantially modified by postglacial solution.

Conclusions

Rostherne Mere occupies one of the prime examples of a subsidence basin developed over the Triassic Halites of the Cheshire Plain. Solution of the underlying salt beds, by natural groundwater circulation, has caused the surface subsidence. Its clear morphology makes it representative of these diagnostic features of the Cheshire salt karst, and it provides an excellent contrast with the linear subsidences such as Moston Long Flash.