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 mud-stones. 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 southeastern 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 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 recrysollintion 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 Ienlcinson, 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).

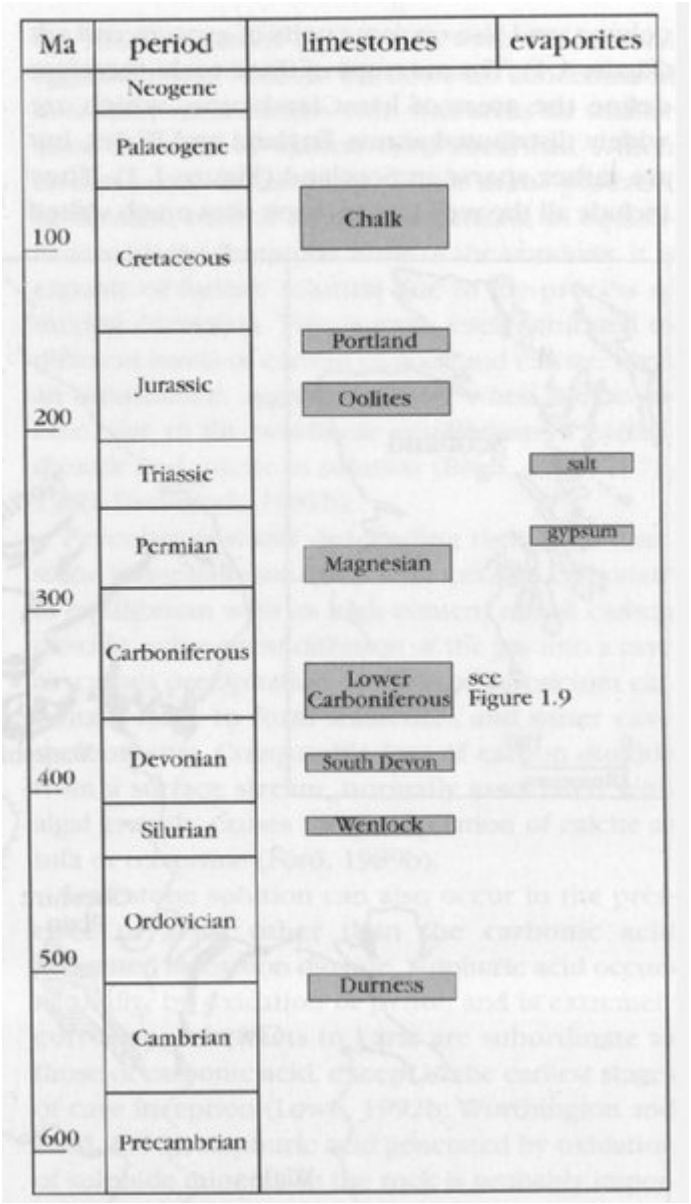
Jurassic limestones have extensive outcrops in the scarplands across the heart of England (Downing, 1994). The Great and Inferior Oolites form the broad escarpment of the Cotswolds (Figure 1.2), where the dip slope is crossed by numerous shallow dry valleys, mostly floored with Devensian head. The Great 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

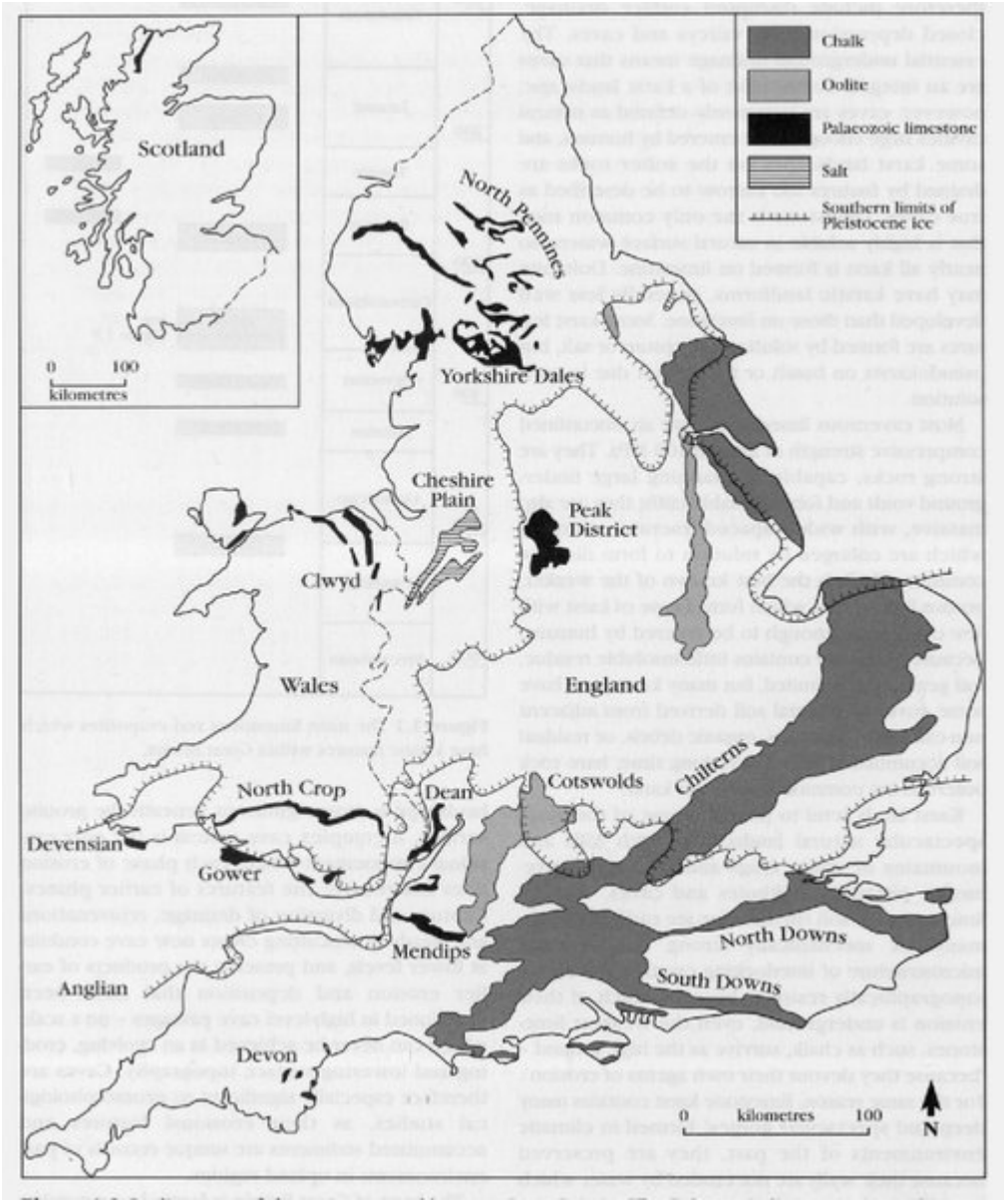
Rock salt, which is almost pure halite, forms thick units in the Triassic Mercia Mudstones, beneath the Cheshire Plain (Figure 1.2) and in other smaller Triassic basins. In Cheshire, the Wilkesley and Northwich Halites are each sequences over 100 m thick consisting of salt interbedded with mudstone. 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 unsatu rated 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 Penman 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.

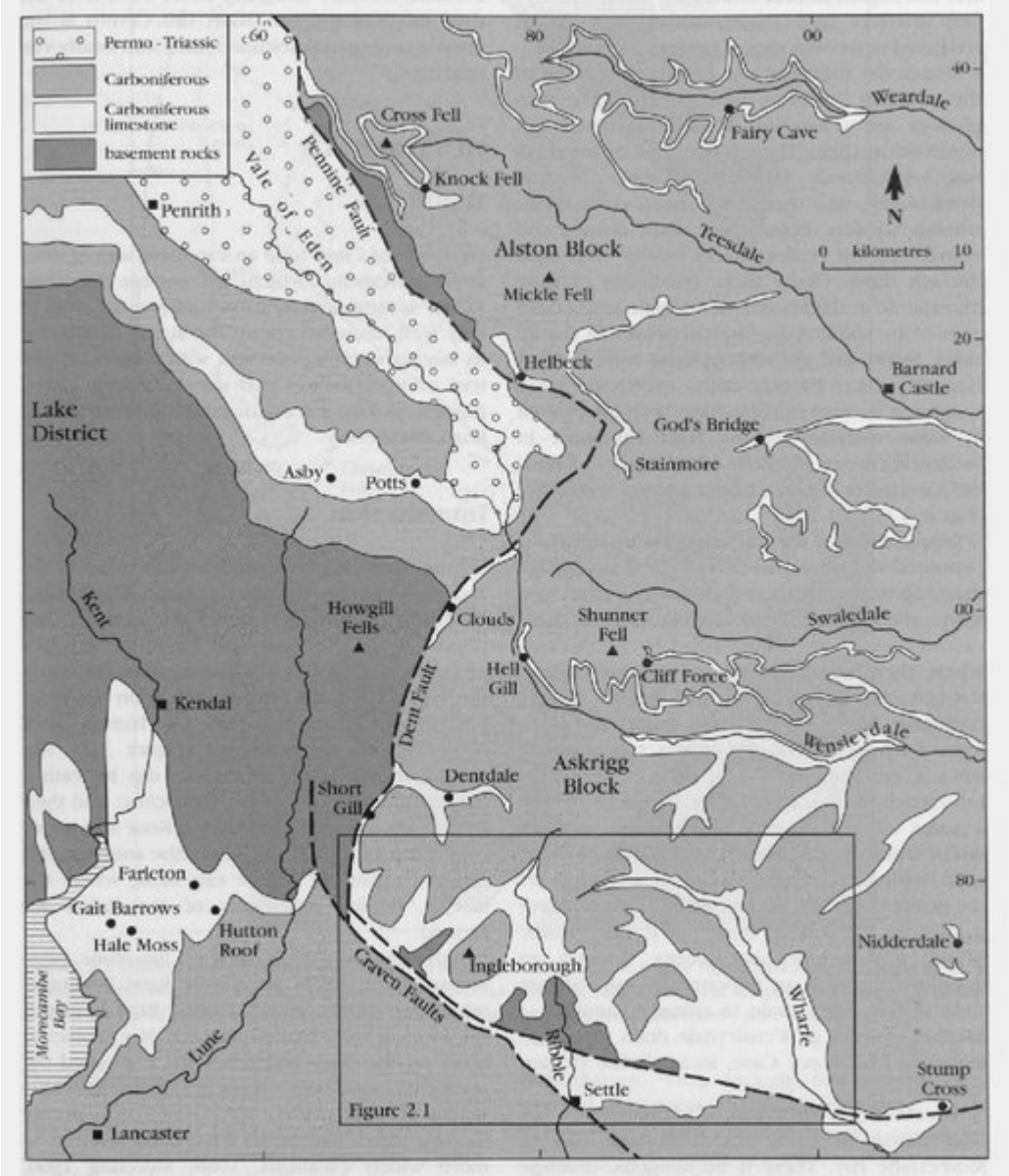
References



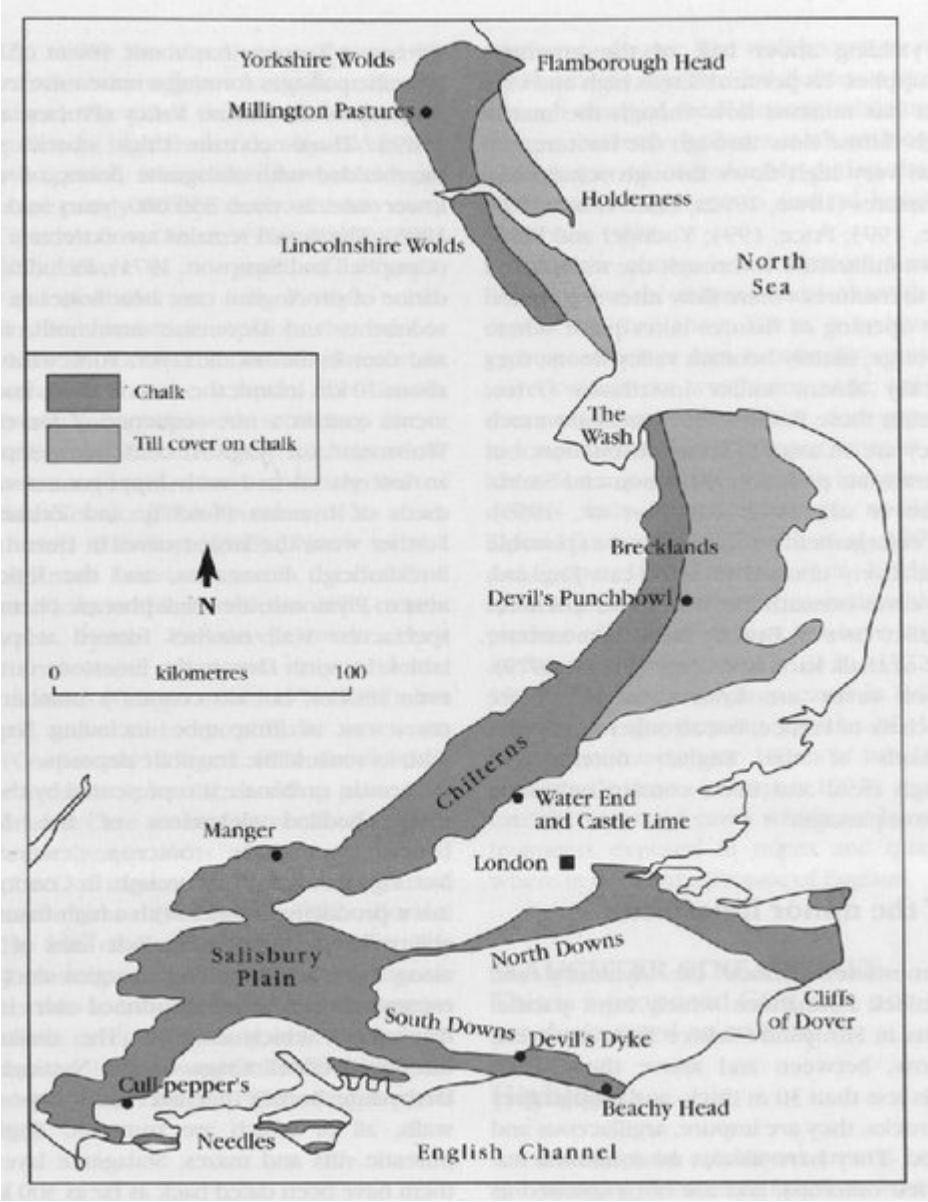
(Figure 1.1) The main limestones and evaporites which have karstic features within Great Britain.



(Figure 1.2) Outline map of the main areas of karst in Great Britain. The Palaeozoic limestones are of Lower Carboniferous age, except for the Devonian limestone in Devon, and the Cambrian–Ordovician limestone in Scotland.



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



(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.