16 The Mendip Hills—A Landscape Shaped by Exhumation and Karstification

Andrew R. Farrant

Abstract

The Mendip Hills, located in southwestern England, is a geologically diverse area that admirably demonstrates the strong interplay between geology, denudation and geomorphology. A thick sequence of Upper Palaeozoic sandstones and limestones were folded and thrusted into a series of en-echelon periclines that were denuded during the Triassic. A long history of successive marine transgressions during the Mesozoic led to the planation and eventual burial of the Palaeozoic strata. More recent uplift and erosion during the Quaternary have partially stripped this younger cover to reveal elements of the old Triassic landscape. Karstification of the thick Lower Carboniferous limestones has created a spectacular karst landscape with rocky gorges, dry valleys, sinking streams and caves, including the major tourist attractions of Cheddar Gorge and Wookey Hole. The complex geological history has created a region with an exceptional range of geology and geomorphology within a comparatively small area. This geodiversity has attracted the attention of numerous geologists, geomorphologists and naturalists over the past few centuries, making the region a classic area for study. For this reason, the Mendips host many Sites of Special Scientific Interest (SSSIs) and has been designated an Area of Outstanding Natural Beauty.

Keywords

Mendip Hills • Karst • Landscape evolution • Geomorphology

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16.1 Introduction

Situated at the boundary between the Palaeozoic uplands of western Britain and the undulating Mesozoic 'scarp and vale' landscapes of southern and eastern England, the Mendip Hills, located 25 km southwest of Bristol, have long been noted for their outstanding scenery and varied geology (Fig. 16.1). The exceptional geological diversity inspired many early naturalists and geologists including Charles Moore, and William Smith who created the world's earliest geological map in the area just north of the Mendips. Much of the region has been designated as an Area of Outstanding Natural Beauty (AONB). The region is also a karst landscape with extensive cave systems, sinking streams, dry valleys and gorges. Many of these caves host important archaeological deposits. The distinctive Mendip landscape stems from a complex interplay between the underlying geology, erosional processes, climate and time (Ford and Stanton 1968; Donovan 1969; Smith 1975, 1977; Waltham et al. 1997). This chapter aims to highlight the complementary roles of geology and weathering in creating the modern landscape, and to outline the geomorphological history of this fascinating region.

16.2 Setting and Location

The Mendip Hills form an elongated upland plateau extending almost 60 km from the Bristol Channel coast east to Frome (Fig. 16.1). The Hills rise up sharply from the surrounding lowlands, giving the region a well-defined geographical identity. This distinctiveness helped define the region and inspired many geologists and naturalists to study the region. In the central Mendips, the well-defined plateau surface at 250–280 m asl is incised by extensive networks of dry valleys and rocky gorges (Fig. 16.2). In the west, the plateau breaks up, the centre hollowed out to form the Lox Yeo valley, surrounded by isolated limestone ridges

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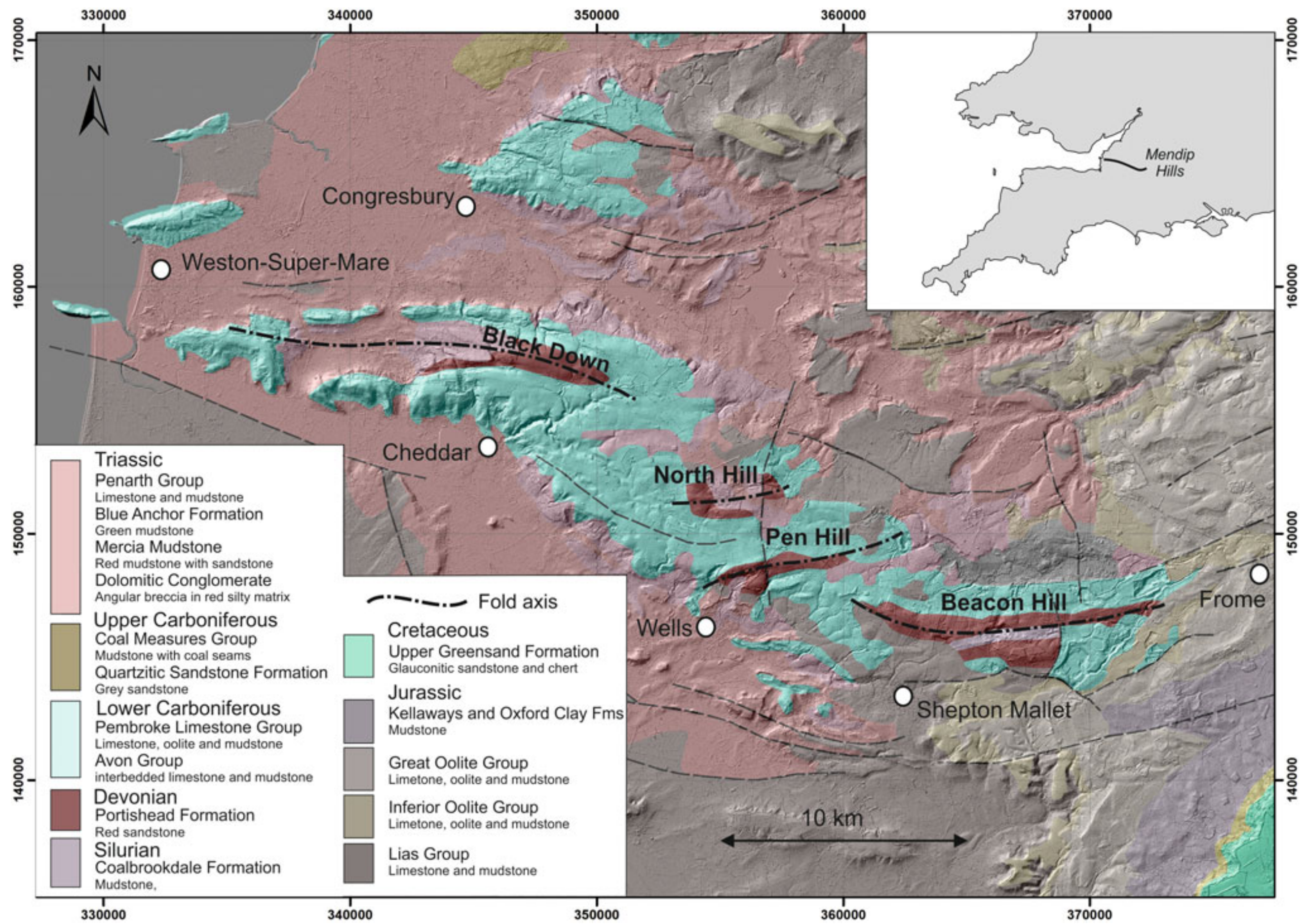

Fig. 16.1 Relief and geology of the Mendip Hills. Geology based upon 1:625,000 scale DigMap bedrock geological maps, with the permission of the British Geological Survey. The relief is derived from NEXTMap™ Britain elevation data from Intermap Technologies

(Fig. 16.3) before terminating in the finger of limestone at Brean Down extending out into the Bristol Channel. To the east, the plateau gradually descends, increasingly buried beneath younger rocks and losing its identity (Fig. 16.4).

16.3 Geology

The bulk of the Mendip Hills comprises Upper Palaeozoic strata folded into four en-echelon, east–west trending, asymmetric, northward verging and thrusted periclines. The core of the periclines exposes Devonian and Silurian rocks, surrounded by a thick succession of Carboniferous limestones and mudstones. The dips on the periclinal flanks are mostly between 20° and 70°; the steepest dips occur on the northern limbs (Fig. 16.5), which in places are overturned forming klippen structures. These Palaeozoic rocks are partially draped by a succession of more gently dipping Triassic to Cretaceous rocks.

The oldest rocks are Silurian volcanics and shallow marine mudstones exposed in the Beacon Hill pericline near Frome. These are overlain by Upper Devonian sandstones, the Portishead Formation, which also forms the core of the other periclinal structures. These sandstones pass up conformably into the Lower Carboniferous succession, which comprises about a kilometre of shallow marine Dinantian carbonates with a thin sequence of transitional calcareous shales (the Avon Group) at its base. These carbonates are overlain by Upper Carboniferous quarzitic sandstones and coal bearing mudstones (the 'Millstone Grit' and Coal Measures). These Upper Carboniferous rocks are preserved in the deep structural basins either side of the Mendips, largely concealed by younger Mesozoic rocks (Fig. 16.5). To the north of the Mendips, these were locally worked for coal.

Northwards directed crustal shortening during the Permian generated the en-echelon fold and thrust belt that forms the backbone of the Mendip Hills. This tectonic activity coupled with subaerial weathering in an arid climate during the Triassic created a rugged mountainous topography incised by many ravines, and surrounded by low relief basins eroded into the weaker Upper Carboniferous rocks. Outwash from the ravines generated alluvial fans,

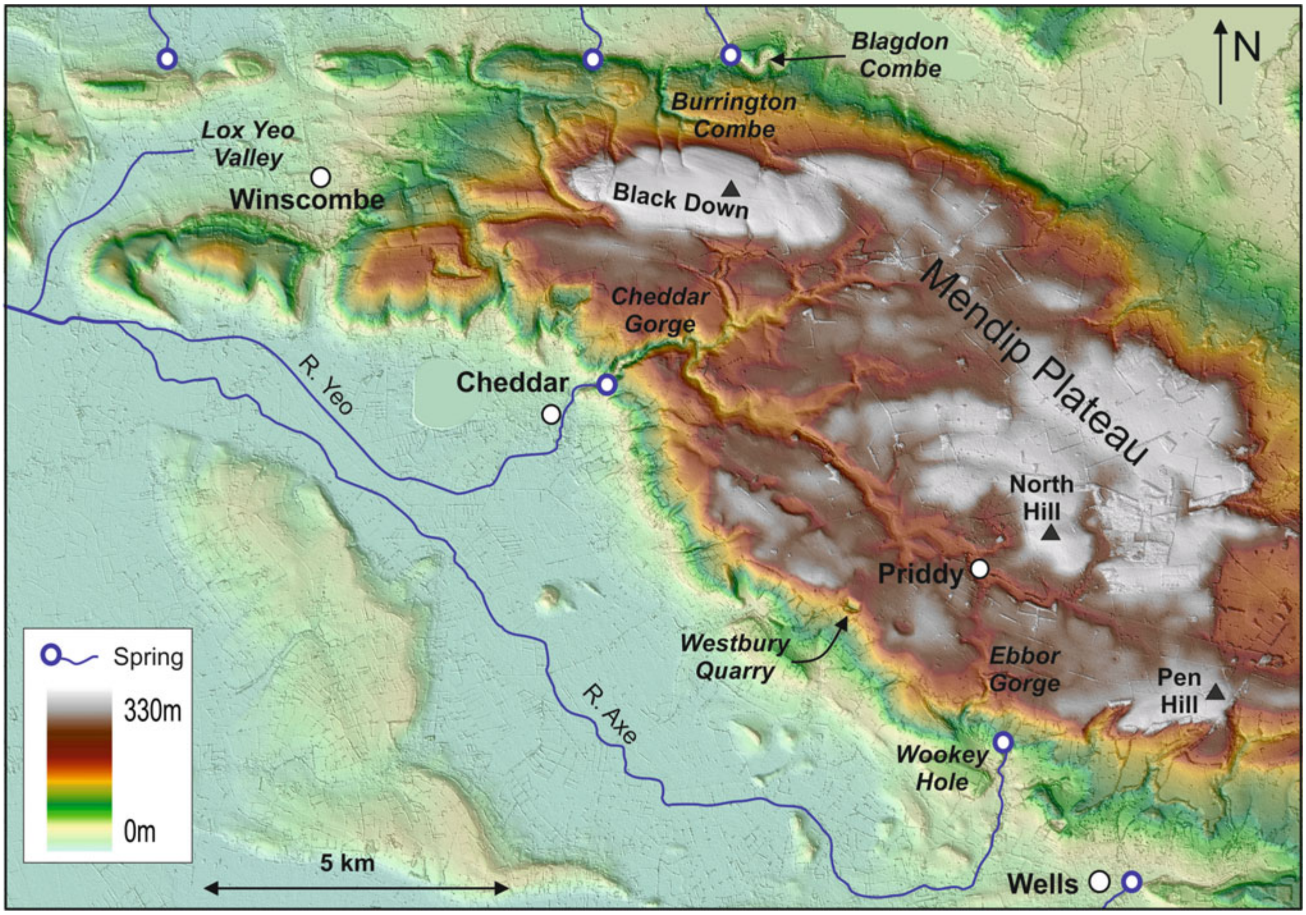

Fig. 16.2 Topography of the central Mendip Hills. Elevation data based on NEXTMap™ Britain elevation data from Intermap Technologies

comprising calcareous breccias known locally as the 'Dolomitic Conglomerate', which accumulated on the flanks of the mountain range and infilled the ravines. These conglomerates grade laterally into red mudstones, siltstones and sandstones that accumulated further out in the basins to the north and south. These sediments, part of the Triassic Mercia Mudstone Group, were mostly deposited in temporary lakes formed in part by flash floods or seasonal rains emptying out from confined upland regions.

During the later stages of the Triassic, regional extension and subsidence generated a marine transgression that encroached across the region (Fig. 16.6). The gradual flooding of the land by the sea continued into the Early Jurassic, transforming the rugged upland landscape into an archipelago of small islands. Near these ancient island shores, shell-rich Lower Jurassic limestone (Lias Group) was deposited, transitioning to thin, rhythmically alternating successions of limestone and mudstone deposited in deeper water offshore. The regional extension created numerous tectonic fissures in the Carboniferous limestones, subsequently infilled with terrestrial Triassic and marine Jurassic deposits as the Palaeozoic rocks were buried. These sedimentary dykes have yielded early mammal remains. Further marine transgressions in the Middle Jurassic encroached on the Mendip islands and resulted in the cutting of remarkably planar erosion surfaces across the Carboniferous limestone. This classic unconformity is spectacularly exposed in local quarries in the eastern Mendips (Fig. 16.7). Above this surface, the shallow-water limestones of the Inferior Oolite Group were intermittently deposited, capped by clay-rich sediments of the Fuller's Earth Formation. Continued subsidence led to the deposition of a thick Upper Jurassic sequence. A regional marine transgression during the Late Cretaceous removed much of the Jurassic succession, enabling the deposition of the Upper Cretaceous Upper Greensand Formation directly on the folded Silurian volcanic rocks around Beacon Hill. Renewed subsidence and sea-level rise led to the burial of the region by the Chalk Group. No Palaeogene or Neogene deposits are known; any sediments that were deposited have been subsequently eroded.

During the Quaternary, the Mendip Hills lay south of the maximum glacial limit, the nearest glacial deposits occurring around 15 km to the north near Clevedon. Some have

Fig. 16.3 Looking east from Crook Peak towards Cheddar along the upstanding limestone ridge that forms the southern limb of the Black Down pericline on the south side of the Lox Yeo valley (to the left of the image). The Mendip plateau surface can be seen in the distance. (Photo A. R. Farrant)

speculated that certain aspects of the geomorphology could be attributed to glaciation, notably a deeply incised dry valley at Blagdon Combe and an enigmatic gravel deposit near Bleadon (Findlay et al. 1972). However, there is no evidence of any glacial deposits or erratics on the Mendip plateau or in cave deposits. The valley at Blagdon Combe can be explained by superimposed drainage by the Congresbury Yeo (Barrington and Stanton 1977). Nonetheless, during cold climatic periods, the region would have experienced severe periglacial conditions, with permafrost and surface drainage in summer.

16.4 Main Features of Relief

The geomorphological character of the Mendips is determined primarily by the underlying geology. The Devonian sandstones that form the core of the Mendip periclines have a relatively small outcrop but form prominent rounded hills rising above the Mendip plateau, attaining a height of 325 m on Black Down. These uplands provide the catchment for many small streams. The surrounding Carboniferous limestones form the bulk of the Mendip plateau and give rise to a distinctive rugged karst topography, which is characterised by dry valleys, deep gorges, rocky outcrops and sinking streams. The softer Triassic Mercia Mudstone generally crops out in the lowlands surrounding the hills, such as Wrington Vale, although remnants still occur on the Mendip plateau. The harder Triassic conglomerates are also karstic. In the eastern Mendips, Lower to Middle Jurassic rocks, and in places Cretaceous strata, overstep onto the Palaeozoic rocks, creating a more subdued landscape.

16.4.1 The Mendip Plateau

Perhaps the most perplexing landscape feature of the Mendip Hills is the remarkably level plateau at an elevation of about 250 m asl. This extends over much of central Mendip, from Shipham in the west to Beacon Hill in the east, cutting across both the steeply dipping Carboniferous limestones and the Mesozoic cover. The Devonian sandstone inliers of

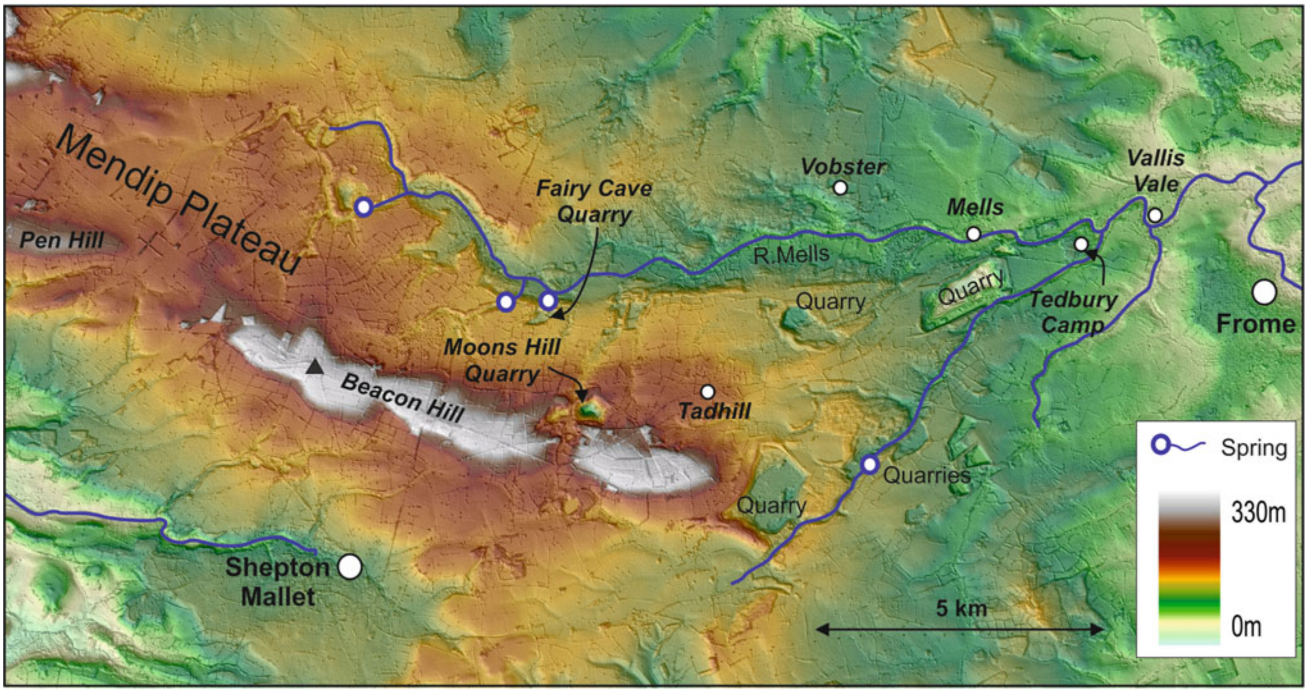

Fig. 16.4 Topography of the eastern Mendip Hills. Elevation data based on NEXTMap™ Britain elevation data from Intermap Technologies

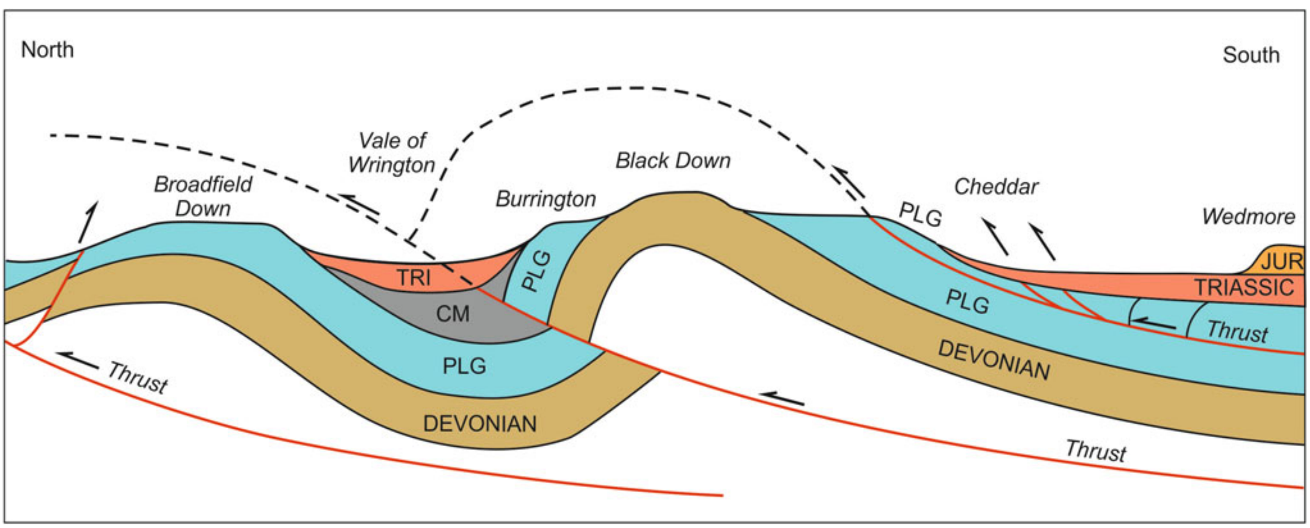

Fig. 16.5 Simplified north-south cross section showing the geological structure of the Mendip Hills. *PLG* Pembroke Limestone Group (Lower Carboniferous), *CM* Coal Measures (Upper Carboniferous); *TRI* Triassic (Mercia Mudstone Group); *JUR* Jurassic

Black Down, North Hill, Pen Hill and Beacon Hill form distinctive ridges rising above this plateau. The origin of this plateau has been a matter of some controversy for many years. As Donovan (1969) and others have noted it is neither an exhumed Triassic feature, nor is it wholly Jurassic, since the Jurassic cover is not horizontal. Green and Welch (1965) regarded it as having a late Tertiary origin, whilst Ford and Stanton (1968) advocated a Pliocene age. Donovan suggested that mid-Cretaceous erosion might have been partly responsible, while Barrington and Stanton (1977), using solutional lowering estimates provided by Atkinson (1971), argued for an age of around a million years. The presence of Upper Triassic–Lower Jurassic marine sediments (Penarth and Lias groups) preserved as fissure fill deposits hosted within the Carboniferous limestones (Wall and Jenkyns 2004), and outliers of Lower–Middle Jurassic rocks across much of the plateau, suggest that the initial marine planation occurred in the Late Triassic and Early Jurassic. The

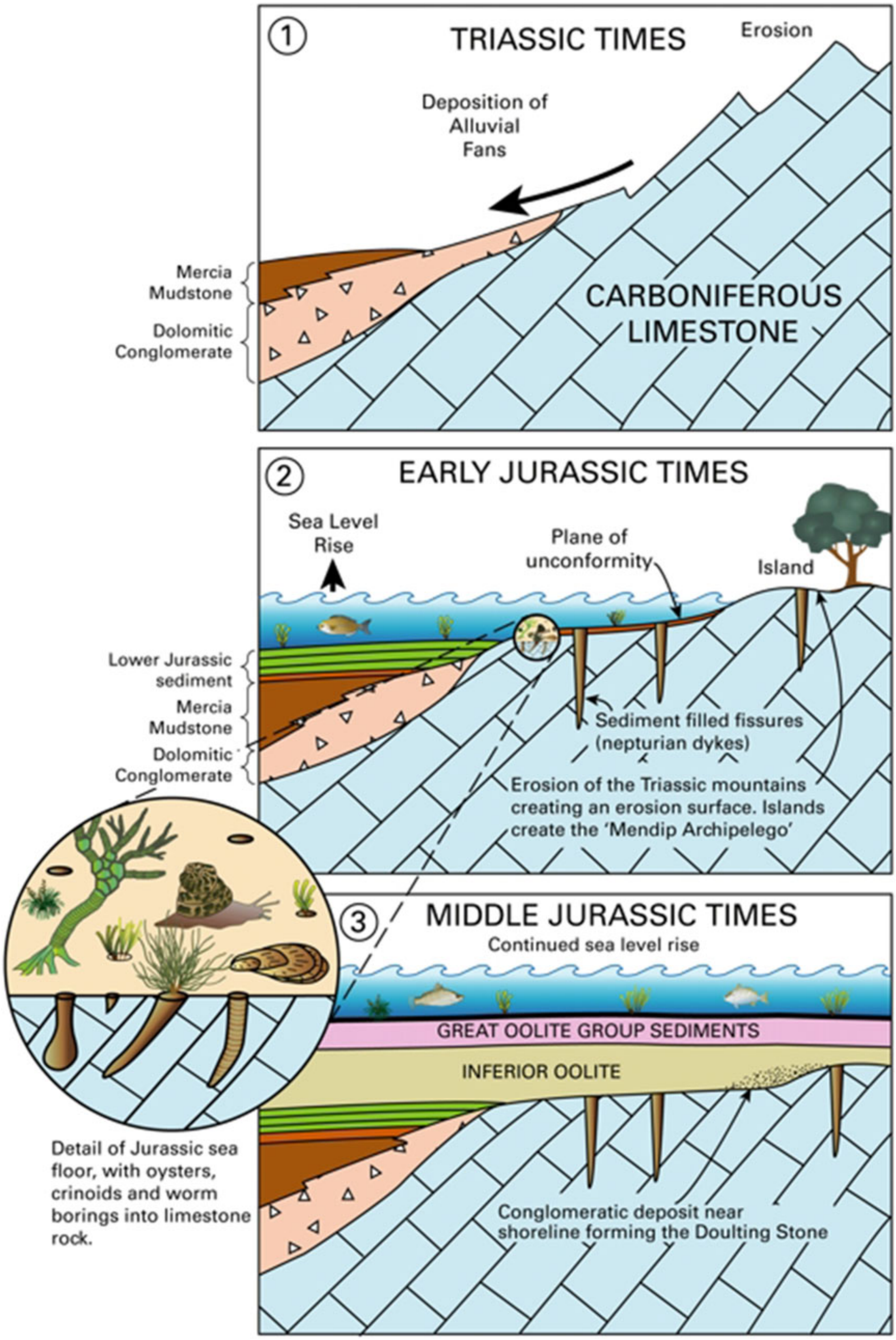

Fig. 16.6 Geological evolution of the Mendips from the Late Triassic to the Middle Jurassic

Fig. 16.7 The De la Beche unconformity between the Middle Jurassic Inferior Oolite and Lower Carboniferous limestone, Vallis Vale, near Frome. (Photo A. R. Farrant)

spectacular Middle Jurassic Inferior Oolite unconformity exposed at Vallis Vale (De la Beche 1846), resting on dipping Carboniferous limestones suggest several phases of Jurassic planation (Fig. 16.8). The recent discovery of Cretaceous Upper Greensand deposits resting on Silurian volcanic rocks at Tadhill (Farrant et al. 2014), and the evidence of Upper Greensand derived sediments preserved in a karstic void at Westbury-sub-Mendip (Andrews 1990; Adams 2017) suggests that the Albian transgression cut across both Jurassic and exposed Palaeozoic rocks alike (Fig. 16.8). Subsequent erosion of much of softer cover rocks during the Quaternary has delicately uncovered the previously planated Palaeozoic surface. Subsequent dissolution lowering of the Carboniferous limestones has produced the distinctive plateau surface seen today.

Ford and Stanton (1968) identified several erosional benches along the southern flank of the Mendips. These were attributed to still-stands formed in response to an intermittently falling sea level, but they are more likely to be stratimorphic in origin. Many of them occur where softer Triassic and Jurassic clays and mudstones have been stripped off underlying harder rocks (Stanton 1985), or are benches formed by outcrops of harder Triassic conglomerate.

16.4.2 Dry Valleys and Gorges

The plateau surface is incised by a network of dry valleys, the larger ones debouching out onto the surrounding lowlands via spectacular rocky gorges. The most spectacular of these is Cheddar Gorge (Fig. 16.9) entrenched up to 120 m deep (Trudgill 1977) into the plateau, but smaller examples occur at Ebbor Gorge and Burrington Combe. Some of these valleys, notably in the western Mendips, follow earlier filled-in Triassic valleys where erosion has picked out the softer Mercia Mudstone. However, not all the valleys follow existing Triassic lines, and across most of central Mendip, most valleys are incised into the Carboniferous limestones. These dry valleys and gorges have long been a source of debate. Early ideas included earthquake rifting and cavern collapse (Dawkins 1862; Callaway 1902; Stride and Stride 1949), the latter a myth still perpetuated in some modern geological texts. The immense disparity between the volume of the Gorge and that of even the largest Mendip caves, the lack of collapse debris, the truncation of existing cave passages, the meandering nature of the valley network and the occurrence of marked knick points suggest a fluvial origin. Moreover, most cave streams descend rapidly at first before levelling out at depth; by contrast, the steepest section of Cheddar Gorge is near its mouth. Cavern collapse can only have played trivial role in gorge formation. The commonly accepted view is that the dry valleys and gorges were incised during the Quaternary by surface drainage during periglacial periods, when underground drainage was restricted (Reynolds 1927; Smith 1975; Ford and Stanton 1968). Cheddar Gorge is the largest because it drained the bulk of the Mendip plateau and it had the greatest potential vertical range. Ebbor Gorge and Burrington Combe have smaller catchments and less vertical relief. Only one gorge, that immediately downstream of Wookey Hole, may be partially ascribed to cavern collapse.

The material washed out of these valley networks during cold phases form large low-angle alluvial fans composed largely of gravel. These fans (marked as ‘head’ on most geological maps) extend out onto the surrounding lowlands. The fan emanating from Burrington Combe has been attributed to two distinct cold periods (Findlay and Catt 2006), one before the Ipswichian Interglacial (Marine Oxygen Isotope Stage 5e) and one during the Late Devensian (MIS 2). A gravel deposit at Wookey Station near Wells is believed to be the remains of a coarse-grained alluvial fan

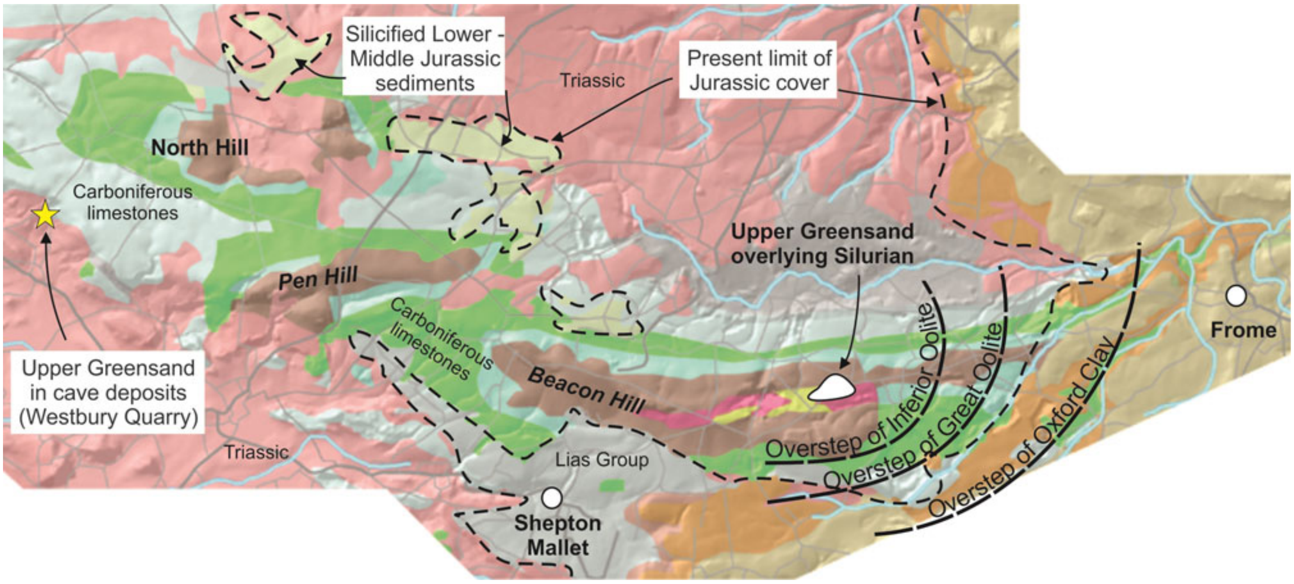

Fig. 16.8 Extent of the Jurassic and Cretaceous subcrop beneath the Albian unconformity across the eastern and central Mendip Hills. Geology based upon 1:625,000 scale DigMap bedrock geological maps, with the permission of the British Geological Survey

Fig. 16.9 View of Cheddar Gorge looking west over Cheddar. (Photo A. R. Farrant)

deposited by a low-sinuosity single thread stream (Macklin and Hunt 1988). Apart from a few exceptions in the extreme east, all the valleys cut into the limestone are now dry except under extreme flood conditions such as July 1968 (Hanwell and Newson 1970), thanks to the development of underground drainage and extensive cave systems.

16.4.3 Sinkholes

The limestone surface is pockmarked by many closed depressions and hollows of various origins, especially across parts of the central Mendip plateau. Many of the natural depressions are aligned along dry valley floors, where their frequency is inversely proportional to thalweg gradient (Ford and Stanton 1968). These are typically suffusion or dropout sinkholes (Culshaw and Waltham 1987), developed in superficial deposits (Fig. 16.10) that have accumulated on the floor of the valley, on the plateau surface, or in the floor of larger closed depressions. Sinkholes and blind valleys are commonly associated with stream sinks around the Devonian sandstone inliers of Black Down, North Hill, Pen Hill and Beacon Hill. Many of these are associated with major cave systems. Sinkholes are also common around the margins of less permeable Triassic or Jurassic strata where they overlie the Carboniferous limestones. Most are solution sinkholes, often associated with minor stream sinks, and many are likely to have small vadose cave systems below. Some of the larger examples are caprock sinkholes, formed by upward collapse of a void at depth. These can propagate up through several tens of metres of overlying strata. The best example is Wurt Pit, near Harptree (Waltham et al. 1997), a 15 m deep sinkhole almost 100 m across formed by collapse and subsidence of the impermeable silicified cherts of the Harptree Formation (Smith 1975; Barrington and Stanton 1977). In some instances, traversable cave systems occur within the overlying Triassic and Jurassic rocks such as Red Quar Swallet and Wigmore Swallet. These are formed by upwards stoping of a void, or washing out of the softer rocks by influent streams descending into the limestones below.

Some buried sinkholes occur out on the limestone outcrop away from any impermeable rock outcrops. One example, Templeton Pot near Priddy was discovered when a small depression less than a metre deep appeared in a farmer's field. Excavations using a mechanical digger revealed a sediment-filled shaft, which was progressively excavated to a depth of over 82 m. Another site, Nod's Pot, just north of Cheddar comprised a 24 m deep shaft excavated through a compact unconsolidated breccia composed of angular limestone fragments without encountering solid rock. Many, if not most of the natural closed surface depressions are probably formed by dissolution, suffosion of overlying material and partial collapse into open voids below.

Also on the plateau are eighteen larger internally draining karst basins up to 15 m deep and 1.2 km^2 in extent (Fig. 16.11). Most are concentrated along a belt on the southern edge of the central Mendip Plateau between Cheddar and Wells (Ford and Stanton 1968; Barrington and Stanton 1977). They are often associated with major thrust faults in the underlying limestone. The best developed is Bag Pit near Westbury-sub-Mendip, a large closed depression 10 m deep, over 1000 m long and 400 m wide. The floor of the basin is covered in a thick layer of horizontally stratified loessic silty clay, pitted with small suffusion sinkholes. The basin is bounded by very gently graded slopes, dividing it from neighbouring depressions and valleys. At Brimble Pit, two small steeply descending vadose caves have been excavated the floor of the depression, one of which is developed on a major thrust fault. A kilometre to the southeast is another smaller depression, Cross Swallet. This is similar in depth, but is smaller in area being only 400 m in diameter, again partially infilled with horizontally laminated yellow-brown silty clay over 7 m thick. Near Cheddar, a small surface collapse in a closed depression at Vurley was excavated to reveal a cave system that has been extended to 88 m depth. The upper part of the cave is predominantly a boulder collapse, with a steep descending vadose system below. Ford and Stanton (1968) argued that the basins were formed by solutional activity during warm phases in the Pleistocene, and were sealed by permafrost during the ensuing cold periods and occupied by meltwater lakes in summer. The associated caves are vadose shaft systems formed during interglacial periods taking runoff from the clay deposits.

Not all of the depressions are natural features; many are related to quarrying or lead, zinc and ochre mining. These old mine workings, which date back as far as Roman times are characterised by a pockmarked hummocky topography known locally as 'gruffy ground'. They can generally be distinguished from their natural counterparts by their irregular rough-hewn nature and association with linear mineral veins (Stanton and Clarke 1984).

16.5 Caves

16.5.1 Cave Distribution and Morphology

The Mendip Hills are well known for its cave systems. Over 1300 caves with >60 km of explored passages are known. Much of the pioneering work on cave geomorphology was undertaken in these caves by Derek Ford and others in the

Fig. 16.10 Subsidence (dropout) sinkhole in Quaternary loessic deposits above GB Cave, near Cheddar. (Photo A. R. Farrant)

1960s. These include some of the best-studied caves in Britain such as Swildon's Hole, GB Cave and St Cuthbert's Swallet.

Most of the larger cave systems occur either where streams sink underground (known locally as 'swallets'), or where the water emerges as large springs around the flanks of the Mendips. This is well demonstrated in the Cheddar catchment (Fig. 16.12), where nearly all the major known caves are associated with sinks or springs. The swallet caves occur where streams draining the impermeable Devonian sandstone uplands of Black Down, North Hill, Pen Hill and Beacon Hill sink into the surrounding Carboniferous limestones. The local geological structure and lithology, in particular the dipping nature of the limestone, give the caves a distinctive morphology. Unlike the Peak District or the Yorkshire Dales, the dipping nature of the limestone means that the water draining the sandstone inliers sinks into the base of the limestone sequence, and then rises stratigraphically up through the limestone to resurge at the top of the succession where the limestone dips beneath younger strata (Fig. 16.13).

The swallet caves are characterised by steeply descending, joint-guided vadose stream passages that descend down-dip to the local saturation level, often more than 150 m below the surface. The caves typically comprise a coalescing influent network of tall narrow vadose canyons. Once at the water table, the passage morphology changes character to a more rounded phreatic form, the gradient lessens and the streamway is punctuated by numerous water-filled 'sumps', creating a characteristic looping profile. The passage orientation often changes to a more strike-aligned system. This is demonstrated very clearly in Swildon's Hole near Priddy (Fig. 16.14) which drains to Wookey Hole. These phreatic loops generally get longer and deeper towards the resurgence. In dip-aligned conduits, the descending limb is often developed on a bedding plane, sometimes reaching depths in excess of 90 m (Wookey Hole), before ascending joint-guided risers to regain a higher stratigraphical level, until it reaches the level of the resurgence. Where flow is along strike, the passage will generally be developed at or close to the water table, occasionally meandering obliquely up and down the guiding bedding plane. This structural guidance can be seen admirably in the active conduit in Gough's Cave, Cheddar (Fig. 16.15).

Most cave passages are typically aligned along either joints or bedding planes, or more commonly forming where they intersect. Up to 83% of the passages in Manor Farm Swallet are joint guided (Smart and Stanton 1974). Faulting generally has relatively little influence, but can be locally important where they are aligned with the hydraulic gradient, for example in Reservoir Hole, where many of the passages are along strike-slip faults or their associated Riedel shears (Farrant et al. 2016), or in the development of vadose shafts such as Rhino Rift (Stanton 1972). These joint-guided passage networks have been extensively modified by vadose erosion, sedimentation and collapse. Where the dip is greater than around 45°, strike aligned, conduits predominate.

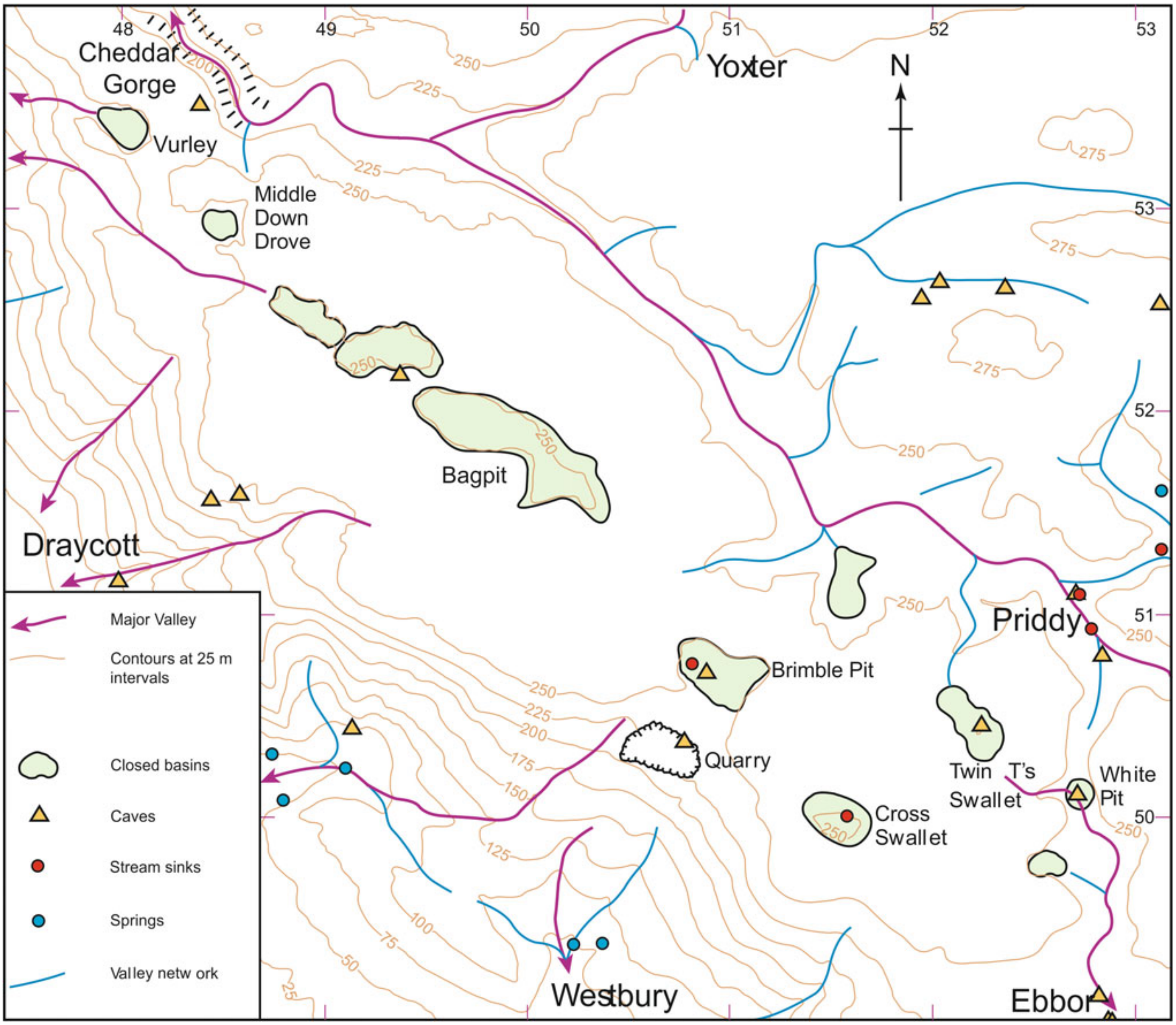

Fig. 16.11 Closed karstic basins on the southern flank of the Mendip plateau

16.5.2 Cave Evolution

Cave systems continue to evolve in tandem with changes in the surface landscape, driven by uplift and surface erosion. As the level of the resurgence is lowered by valley incision, new, more efficient conduits will develop graded to new lower base levels, leading to the gradual abandonment of former conduits. Thus, over time, given continued uplift and erosion, a vertically-stacked sequence of cave levels is formed, analogous to a staircase of river terraces. Each tier of cave development corresponds to a former resurgence level, with the oldest at the highest elevation. This is evident in the Cheddar catchment where a suite of abandoned passages occurs above the present active conduit (Farrant 1991). A drop in base level at the resurgence propagates back up to the swallet caves (GB Cave, Longwood Swallet, Manor Farm Swallet and Charterhouse Cave), where abandoned phreatic passages representing former water-table levels can be found spanning a range of elevations (Waltham et al. 1997). Similarly, as the location of stream sinks changes over time, some influent vadose passages can become relict. The result is a complex network of influent passages that converge into a streamway, above which are a complex series of relict passages. The largest passages tend to develop where successive phases of cave development have followed the same route. The large passage known as 'The Gorge' in GB Cave near Cheddar is the best example of this.

These relict passages provide evidence for the evolution not just of the cave systems, but also the surface landscape. The elevation of former base levels can be identified where

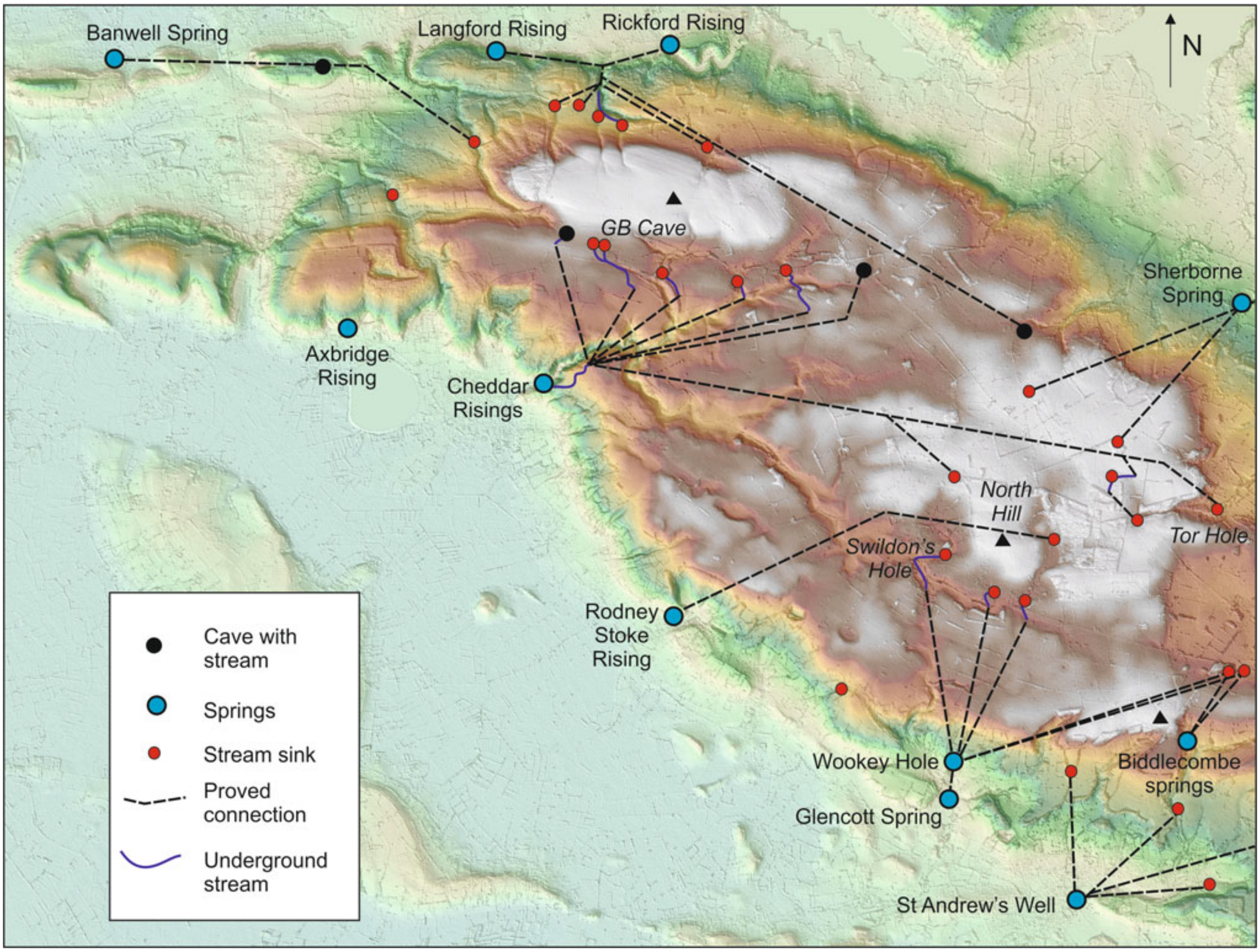

Fig. 16.12 Hydrology of the central Mendip Hills, showing the major stream sinks and springs, known underground streams, and proven hydrological links from tracer tests. Elevation data based on NEXTMap™ Britain elevation data from Intermap Technologies

relict passages change from a vadose to a phreatic morphology, or by the concordant elevation of phreatic loop crests and aven terminations. In the Cheddar catchment, a suite of former levels can be identified in the swallet caves. The highest occurs at 238 m OD, with lower levels at 138, 120, 93, 77–75, 65 and 40 m OD, the latter being at or close to the present water-table level. These levels also correspond to those seen at the resurgence in Cheddar (Farrant 1995), indicating that base level lowering at the resurgence is the ultimate control for cave development. In the Wookey Hole catchment, phreatic levels at 168–183, 140–146, 127, 109 m and below 100 m can be identified in some of the swallet caves. The lower levels correspond to former resurgence levels seen in Wookey Hole, the elevation of which is linked to erosional lowering on the Somerset Levels to the south (Fig. 16.10). Similar levels can be found in the caves around Burrington Combe on the north side of Black Down (Farrant et al. 2008).

As well as the passage morphology, cave deposits including gravel and speleothems (stalagmites, stalactites and flowstones) yield evidence about how the caves developed and functioned over time. Similarly, these provide clues to surface processes and environments. Extensive accumulations of sediment occur in many caves, some of which are important archaeological sites, such as Westbury Quarry Cave (Bishop 1974, 1982) and Gough's Cave, Cheddar. These yield much information on the palaeoclimate and environment during the Pleistocene. Much of the allochthonous gravel seen in the swallet caves is probably surface material weathered during interglacial periods and then carried into the cave system during the following periglacial episode as the climate deteriorated and slopes became unstable. Comparatively little clastic material is being carried into the caves under present climatic conditions. Speleothem deposits are valuable palaeoclimatic archives. They tend to form during warmer and wetter

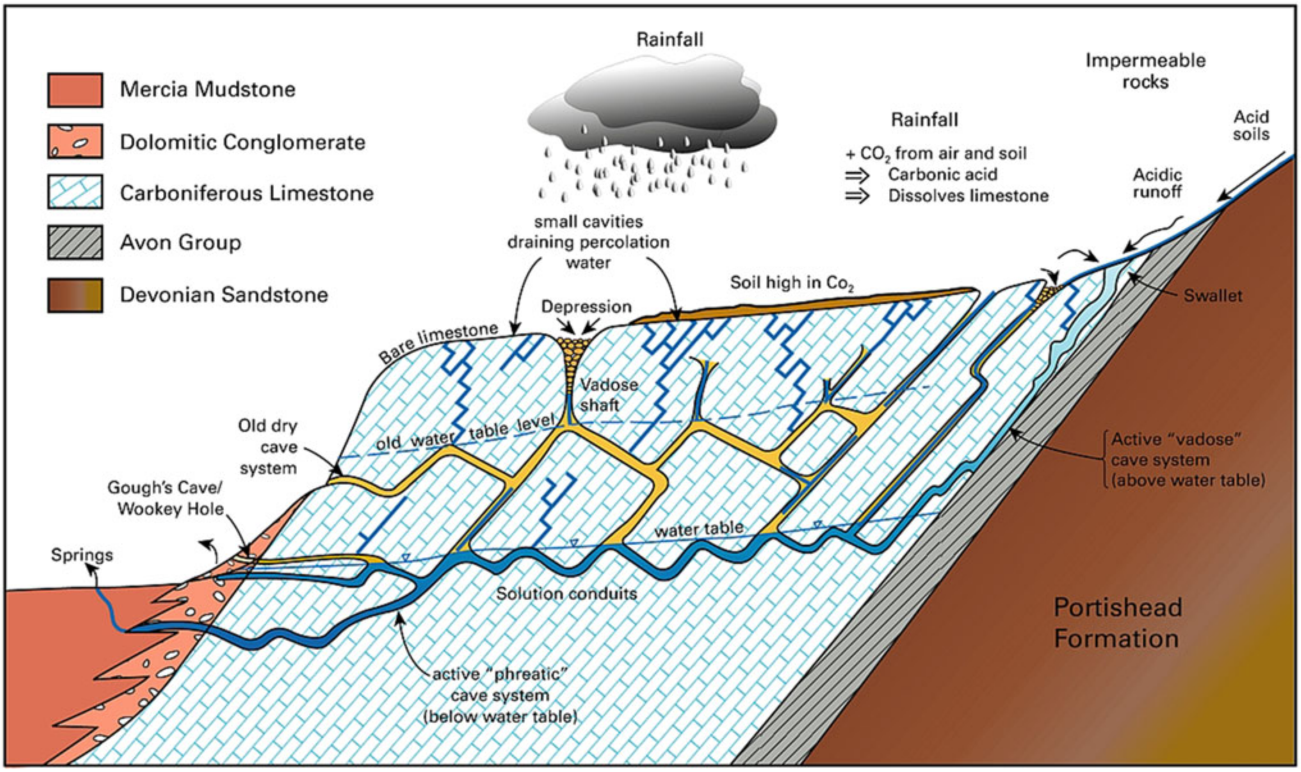

Fig. 16.13 Cross section through the Mendip Hills showing looping profile of cave systems and relationship to geology

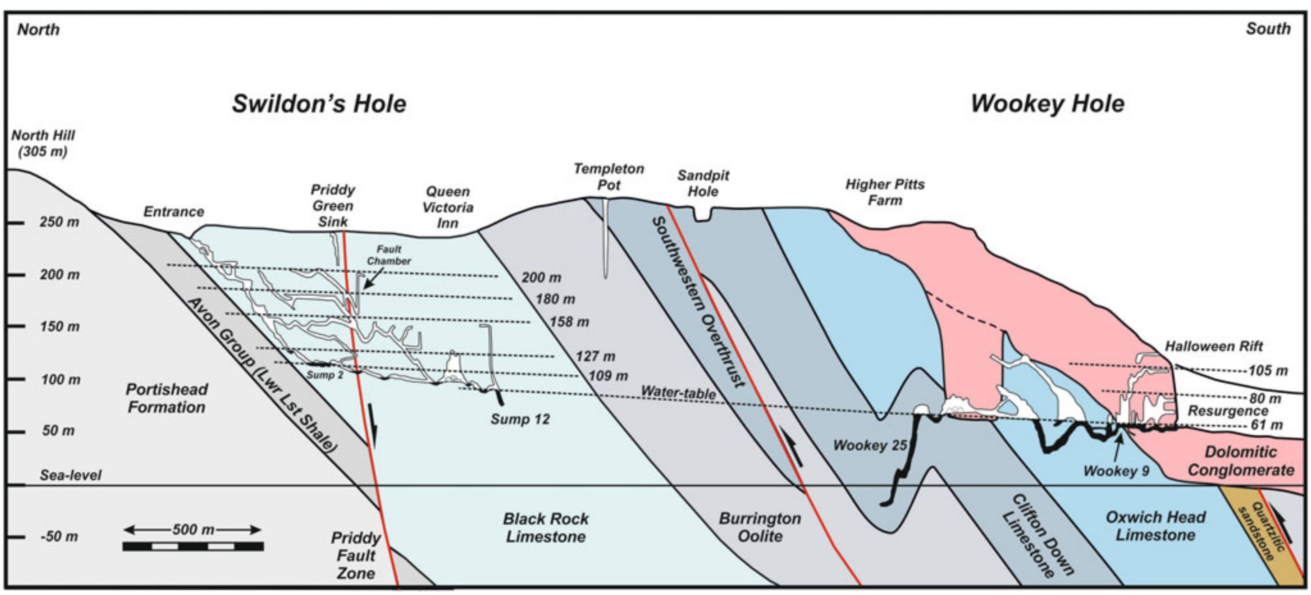

Fig. 16.14 Cross section through the southern flank of the Mendip Hills between Swildon's Hole and Wookey Hole, showing the various cave levels

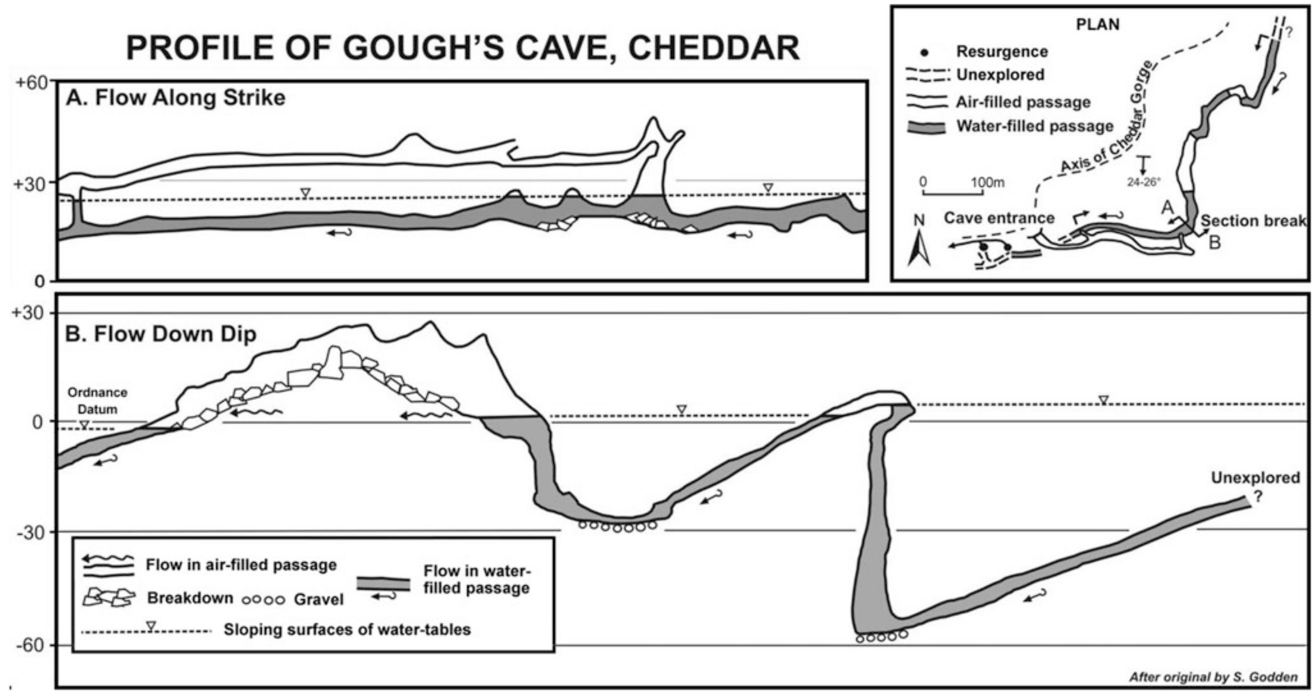

Fig. 16.15 Profile through Gough's Cave, Cheddar, showing geological influence on cave geomorphology between dip and strike orientated passages

climatic interludes (Baker et al. 1993) and isotopic analysis of speleothem deposits can provide clues on past climate (Fairchild and Baker 2012). As they can be precisely dated using uranium–thorium or uranium–lead methods, they can also be used to constrain the age of cave systems. Similarly, undisturbed clays can be dated using palaeomagnetic stratigraphy. Dating the base of the oldest speleothem or dating deposits provides a minimum age for a particular passage.

16.6 Landscape Evolution

16.6.1 Weathering and Exhumation

The evolution of the Mendip landscape has been widely debated over the years, but until recently with little quantitative evidence to back up the various theories.

One of the more widely accepted evolutionary models was proposed by Ford and Stanton (1968). They argued that the Mendips were initially submerged during an Early Pleistocene high sea level stand. As sea level fell during the Quaternary, a series of marine benches was incised into the southern flank of the Mendip Plateau. They suggested that the incision of the dry valleys and gorges and the development of cave levels were linked to the falling sea level. Since this model was proposed, our understanding of Quaternary palaeo-environments has been revolutionised, and a marine high stand model is no longer accepted.

The origins of the Mendip landscape can be traced back to the Permo-Triassic, when the region was subjected to prolonged subaerial weathering and denudation in a semi-arid desert climate. Much of the present topography has its origins in the weathering of the Palaeozoic rocks during this period. The Devonian and Upper Carboniferous sandstones are more susceptible to arid-zone weathering processes (Goudie 1989) than the indurated Lower Carboniferous limestones. Where they were exposed to subaerial weathering in the Permo-Triassic, the sandstones were preferentially eroded, leaving the limestones upstanding. This is particularly apparent in the western Mendips where the Devonian sandstone core of the Black Down pericline was removed, leaving prominent limestone ridges flanking either side of the Lox Yeo valley (Simms 2004). By the Late Triassic, the Mendips and other Carboniferous limestone outcrops in the Bristol area formed prominent uplands rising above eroded siliciclastic lowlands. At the end of the Triassic, these were subsequently buried, initially by the Mercia Mudstone Group sediments, and then marine Jurassic and Cretaceous deposits.

More recently, Quaternary uplift and erosion have peeled off this Mesozoic cover. Evidence from river terraces suggests that much of southern England has been uplifted by several hundred metres during the past 2–3 million years at rates of around 0.07–0.10 m ka^{-1} (Maddy et al. 2000). During much of this time, the climate was cold, leading to extensive periglacial weathering. Unlike arid desert weathering, the softer Mesozoic mudstones and limestones are more susceptible to erosion under periglacial conditions. This weathering led to large-scale differential erosion which, combined with uplift, removed much of the softer Mesozoic cover. This has gradually exhumed the old relict Triassic landscape beneath, which has subsequently been modified by modern erosion. The detail in which it has been uncovered is so good that the celebrated American geomorphologist Davis (1895) proposed the term 'mendip' to describe such an exhumed topography.

In the eastern Mendips, the older Palaeozoic rocks have only recently been exhumed and so the landscape is still comparatively immature. This is shown by the small size, number and immaturity of caves in this area, such as Thrupe Lane Swallet, the absence of well-defined karst features such as blind valleys and dolines and the lack of deeply incised dry valleys and gorges. Further west, the more mature karst landscape across much of the central Mendip plateau reflects the longer time the limestone has been exposed. Here the extensive cave systems attest to a long history of development spanning much of the last 1–1.2 million years. Across the western Mendips, the removal of the Mesozoic cover has laid bare the highly denuded Permo-Triassic landscape. Evidence of cave development associated with the removal of the Mesozoic cover is still present in relict phreatic cave systems beneath Banwell Hill and Axbridge Hill.

16.6.2 The Age of the Mendip Landscape

Quantitative estimates of the timing of cave passage development can now be obtained thanks to recent advances in geochronology, particularly uranium-series dating of speleothem deposits. Dating of cave sediments in the Cheddar catchment (Atkinson et al. 1978, 1984; Smart et al. 1988; Farrant 1995) demonstrates that the highest level phreatic passages (at c. 238 m O.D.) are at least 800,000 years old. The large cave exposed at Westbury-sub-Mendip (c. 246 m O.D.) was infilled with sediment earlier than 780 ka (Yassi 1983) and was abandoned and the roof had collapsed by the Cromerian interglacial about 500 ka (Bishop 1974, 1982; Andrews 1990). Dating of each of the former water-table levels observed in the caves suggest that Cheddar Gorge has been incising at an average rate of about 20 cm per thousand years over the last c. 400,000 years. If this rate is extrapolated back, assuming constant incision rates, it gives an age estimate of about 1.2 Ma for the plateau surface. When dissolutional lowering of the plateau surface is taken into consideration then an age of c. 1.5 Ma is obtained. This value is similar to that proposed by Barrington and Stanton (1977), who used solutional erosion rate data from Atkinson (1971) to calculate the length of time the limestone has been exposed, assuming that the summit of Black Down represents the elevation of the original limestone surface.

The Mendip landscape is still evolving. Natural events such as the floods of July 1968 can cause major changes, both on the surface and underground (Hanwell and Newson 1970). However, perhaps the biggest modern agent of 'geomorphological' change is quarrying and mineral abstraction. Already, these have removed large chunks of the eastern Mendip Hills and altered the hydrogeology.

16.7 Conclusions

Despite its relatively small geographical extent, the Mendip Hills host an amazing wealth of geological and geomorphological diversity. The region contains many well-known geomorphological features including major tourist attractions such as Cheddar Gorge and Wookey Hole, but also many other notable geological Sites of Special Scientific Interest and designated 'Local Geological Sites'. This geological diversity gives rise to a very distinctive landscape, and provides one of the finest examples of an exhumed landscape in Britain.

The limestone landscape hosts extensive and well-studied cave systems. The study of these cave systems has revealed a long complex history of development spanning much of the Quaternary. Dating of cave deposits provides a method of quantifying rates of erosion, valley incision and scarp retreat, and provides estimates for the age of the Mendip landscape. It appears that much of the modern Mendip landscape has developed over the last 1–1.5 Ma.

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