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Abstract

The UK has a wide variety of hypogenic caves, including transverse maze caves, relict hydrothermal caves, gypsum mazes and hypogenic karst associated with water rising up deep thrust faults. While few of these are particularly extensive, they offer insights into the mechanisms of speleogenesis and mineralisation. The best developed hypogenic caves in the UK are in the Carboniferous limestones of northern England where at least nine network maze caves with plan lengths exceeding 1 km are known, almost all of which are accessible only via disused mine workings. In South Wales, relict hypogenic cave networks have been documented from cave systems surrounding the South Wales Coalfield. Hydrothermal cave systems are also known in the Bristol region in southern England, the Derbyshire Peak District and North Wales where they are associated with Pb–Zn mineralisation. In all three of these areas, active deep phreatic groundwater circulation is ongoing. Elsewhere in the UK, transverse artesian groundwater flow through Permo-Triassic gypsum in the Ripon area has led to the development of hypogenic cave systems and numerous sinkholes. This chapter documents for the first time all the known hypogenic cave systems found in the UK, discusses their modes of formation and outlines the potential for future discoveries.

Keywords

UK • Hypogene karst • Northern England • Maze caves

1 Introduction

The UK has many distinct karst regions, predominantly developed within limestones of Early Carboniferous age (Fig. 1), although significant karst also occurs in Devonian limestones in southwest England, Cambrian limestones in Scotland, and within Permian and Triassic evaporites in Northern England and the Midlands. Each has a distinctive

character and style of cave development. The vast majority of UK caves are epigenic, but significant hypogenic karst does occur, particularly associated with Pb–Zn mineralisation hosted in the Carboniferous limestones. Two main types of hypogenic caves occur in the UK: isolated phreatic vein cavities associated with deep phreatic dissolution along mineral veins; and maze caves associated with transverse rising artesian flow (Klimchouk 2000). The latter occurs in both limestones and Permian gypsum aquifers.

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2 Northern England

Northern England includes several significant karst areas, including the Yorkshire Dales and the Northern Pennines. The majority of cave systems occur in the Lower

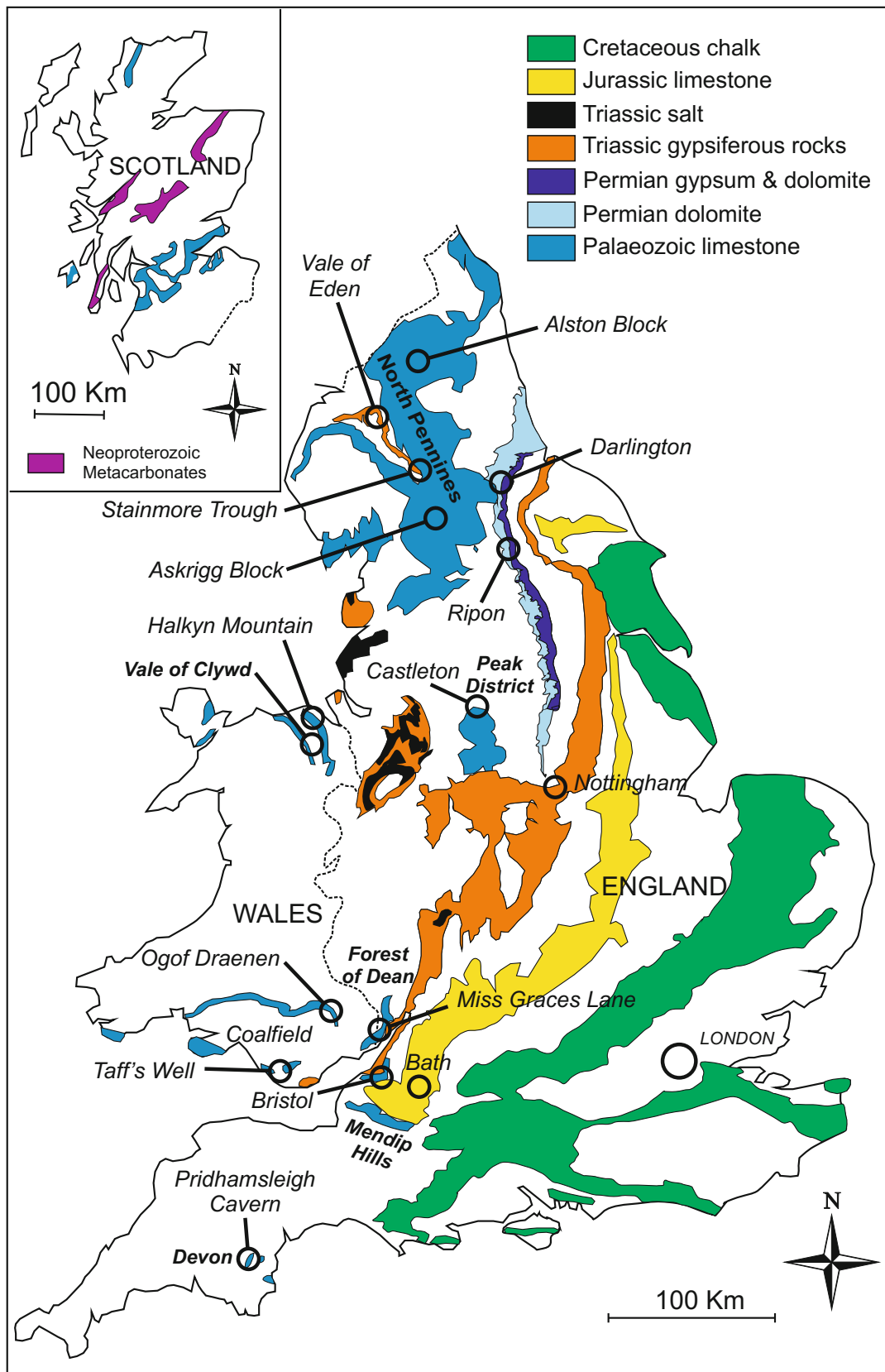


Fig. 1 Karst areas of the UK. The labelled *black circles* indicate features and areas of relevance mentioned in the text

Carboniferous Great Scar Limestone Group, but significant karstic development also occurs in the overlying Yoredale Group. Carbonate deposition was influenced by the development of structural highs and troughs including the Northumberland and Stainmore troughs, the Askrigg Block and the Alston Block (Fig. 2). Consequently, there are marked facies and thickness variations across the region (Aitkenhead et al. 2002). The principal carbonate unit, the Great Scar Limestone Group, is up to 800 m thick in the Stainmore Trough, thinning to 400 m on the Askrigg Block and 100 m thick on the Alston Block. Above, the 1200-m-thick Yoredale Group comprises a series of upward-coarsening cycles of marine limestone, shale and thin sandstone beds, commonly topped with coal. Of the many limestone units, the Great Limestone Formation is commonly the thickest (usually 20–25 m), but others including the Melmerby Scar Limestone and Middle Limestone formations can be significant.

The northern part of the Askrigg Block and the whole of the Alston Block are extensively mineralised, forming the Northern Pennine Orefield. Numerous mineral veins, primarily of galena, criss-cross the region and have been mined for centuries (Ryder and Harrison 2016). These veins are often several kilometres long, but mostly no more than a few metres wide and of limited vertical extent.

It is within the thin limestones of the Yoredale Group in the Northern Pennines that the UK's most significant hypogenic cave systems are found (Fig. 2). They are all maze caves, with evidence for transverse hypogenic speleogenesis (Klimchouk 2007, 2009) including a characteristic suite of dissolution features diagnostic of rising flows during development—'the morphological suite of rising flow'. These include floor slots (feeders for incoming water), wall channels, cupolas and ceiling slots (flow outlets).

Maze caves have been known about in the Northern Pennines for many years, nearly all having been originally discovered by nineteenth-century lead miners (Sopwith 1833; Bramall 1921; Gill 1993). Nine maze caves with a plan length of >1 km are presently known. Only one opens directly to the surface, eight being accessed from old mine workings, two of which are currently inaccessible. All are located in the limestones of the Yoredale Group, three in the Alston Block (the Silverband Mine Caves, Knock Fell Caverns and Hudgill Burn Mine Caverns) and six in the Askrigg Block (Grassington Moor Cavern, Windegg Mine Caverns and two separate mazes in each of Devis Hole Mine and Faggegill Mine). Most of these caves have many features in common not only with each other but also with hypogenic mine caves in Sardinia (De Waele et al. 2013). All are unrelated to the modern landscape. All are now dry, with no known links to existing watercourses. All are located in the top or middle of broadly horizontal sections of a Yoredale Group limestone; eight are in the Great Limestone

Formation, and one (Grassington Moor Cavern) is in the Middle Limestone Formation. All cave floors are covered with sediment, generally preventing observation of the bedrock base of the cave passages. All of the limestone locations are sandwiched between layers of sandstone and shale, typically with the sandstone as a base to the limestone and shale as a cap (except where erosion has removed the younger overlying strata). The predominant passage profiles in all the caves are tall vertical rifts and circular tubes. All mazes display network (rectilinear) passage outlines with high passage densities although these parameters differ dramatically from maze to maze. Most of the cave passages are dominated by NNW–SSE or N–S orientations, with WSW–ENE also an important direction. All of the caves are intersected by or adjacent to mineral veins, which mostly contain galena and in some cases sphalerite (Harrison 2016).

2.1 The Alston Block

The longest and most northerly of the Pennine maze caves is Hudgill Burn Mine Caverns (Fig. 3) near Alston in Cumbria (Dale et al. 2015). Discovered by nineteenth-century lead miners, it was not fully explored until 2014. It comprises a horizontal phreatic network developed within the Great Limestone Formation, here sandwiched between beds of sandstone and shale, with a surveyed plan length of 13.24 km enclosed within an area of 34,000 m². In plan view, the cave has a reticulate geometry with most passages aligned on and parallel to four major joint sets, within an area about 500 m long and 220 m wide at the northern end, decreasing to 70 m in the middle of the system and widening slightly to about 90 m wide to the south-east. The system shows many of the characteristics of transverse hypogenic speleogenesis, having no apparent relationship to the present landscape and a high passage density. It is two-dimensional comprising only one storey, lies on an essentially planar surface and displays rising flow features. Passage dimensions are locally up to 5 m high and 2–3 m wide with rift, V-shaped (triangular), circular and arched morphologies present, although a thick layer of sediment in the lower parts of the passages commonly obscures the true passage morphology and dimensions (Fig. 4).

Many of the passages have a distinctive 'sooty' black and brown deposit on all passage walls and ceilings; this is a zinc-rich birnessite-type phylломanganate. The source of the zinc is probably sphalerite, originally present as a primary mineral and has undergone subsequent oxidation to smithsonite, convertible to soluble cations capable of sorption into birnessite-type minerals.

Most hypogene maze caves in the Northern Pennines are thought to have developed through sulphuric acid speleogenesis, the acid being derived from the alteration of primary

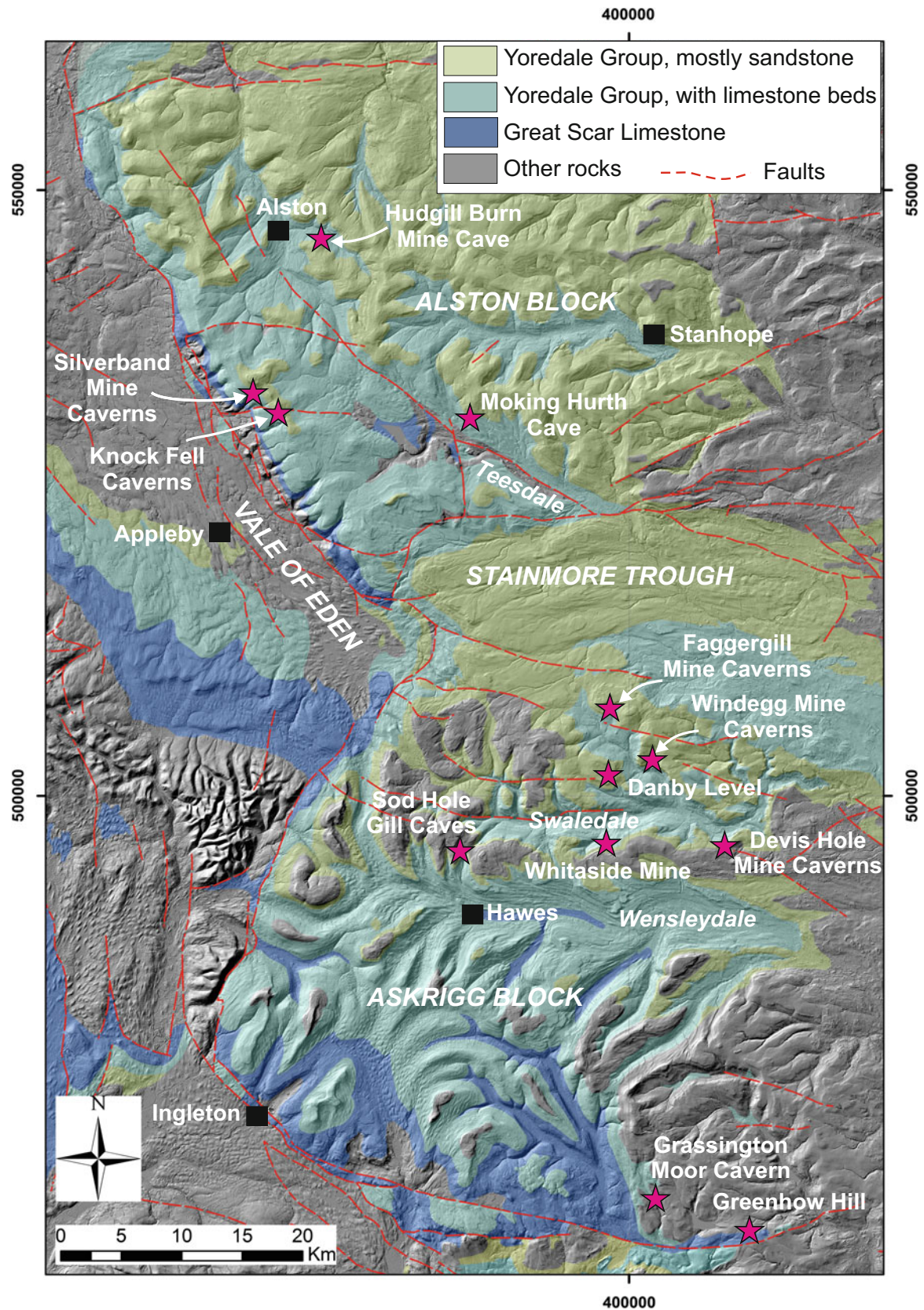


Fig. 2 Location of maze caves in the Northern Pennines (after Harrison 2016). Geology is based on the British Geological Survey 1:625,000 scale digital geological map. Topography is ©NEXTMap Britain DTM

Fig. 3 Outline plans of some Pennine maze caves including Hudgill Burn Mine Cave, the central maze in Devis Hole Mine, Windegg Mine Cavern and Faggersgill (from Harrison 2016). Red lines indicate mineral veins

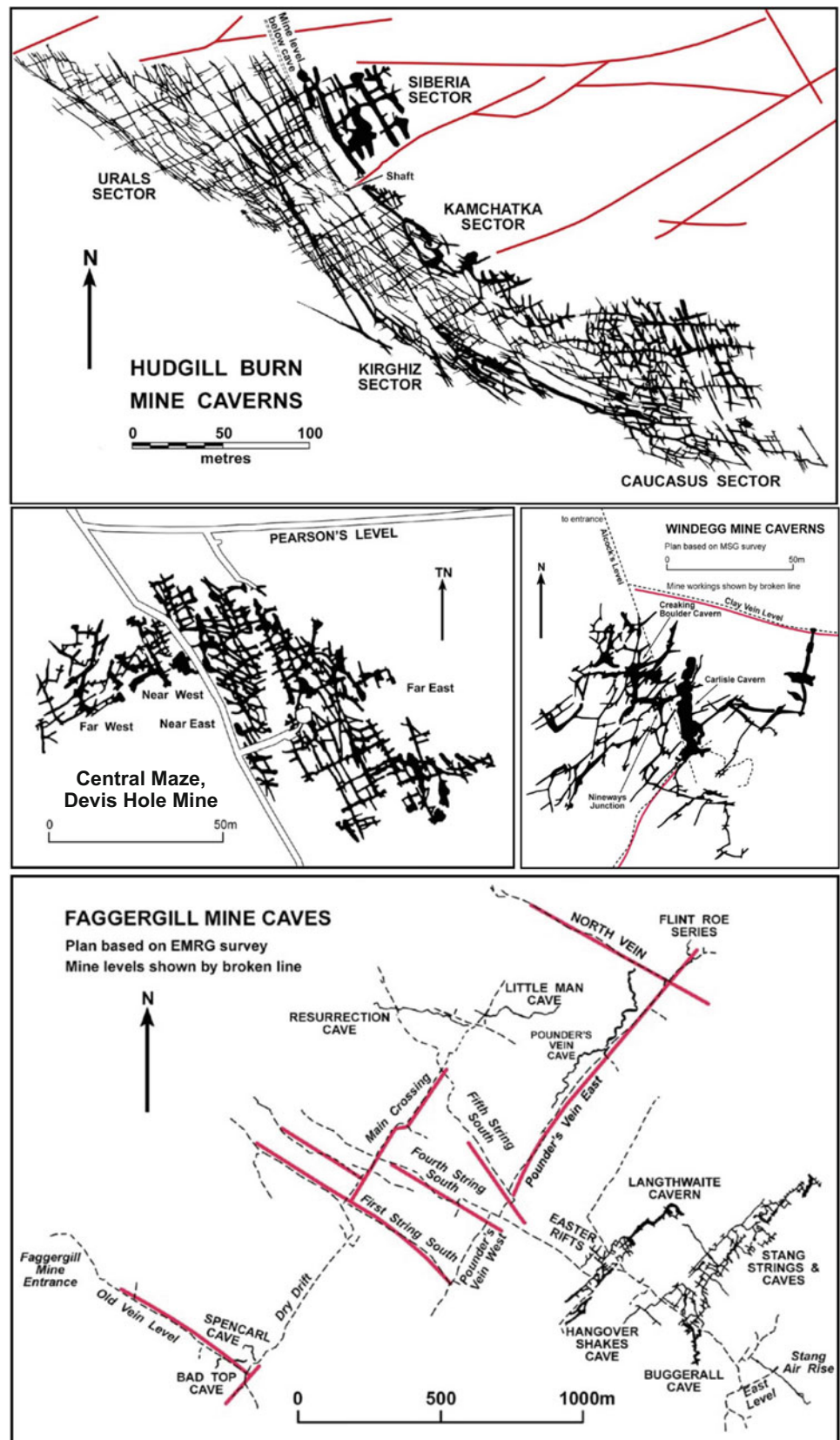




Fig. 4 A complex junction of passages in Hudgill Burn Mine Caverns (Photograph J Dale)

sulphide minerals to carbonates, releasing hydrogen sulphide which then reacted with oxygenated groundwater to form sulphuric acid (Dale et al. 2015). Hudgill Burn Mine Caverns lies within a complex zone of epigenetic mineral veins that were originally rich in galena (lead sulphide, PbS) although much of the ore extracted from the mine was in the form of cerussite (lead carbonate, PbCO_3). Disseminated stratiform Pb–Zn mineralisation also occurs at multiple elevations within the Great Limestone a few kilometres east of Hudgill Burn Mine. The alteration of sphalerite to birnessite-type phyllosilicate would have also generated acidic metabolic by-products, again assisting further dissolution (Dale et al. 2015). Speleogenesis occurred after mineralisation which commenced in the late Carboniferous and continued into the Permian. The caves were drained during Pliocene–Early Quaternary uplift of Northern England.

The second large maze cave in the Alston Block is Knock Fell Caverns. This cave, at 760 m above sea level, is one of the highest caves in England and is situated about 15 km south of Hudgill Burn Mine Caverns. It was

discovered in 1979 at the bottom of a sinkhole in a bench of the Great Limestone. Exploration uncovered a highly rectilinear system totalling 4.5 km in an area about 320 m long and 120 m broad with a high areal extent and passage density. The cave is the only maze in the Northern Pennines not reached through a mine level and was entered at its eastern edge where overlying sandstone and shale had been eroded. The cave is characterised by many narrow rifts and triangular passages, some with narrow outlet channels in the roof. Speleogenetic features associated with the morphologic suite of rising flow (Klimchouk 2007) are easily recognisable including cupolas, inlet feeders and outlet tubes despite a substantial overprint of water table and vadose features. About 3 m below some passages at the northern end of the system, a discrete lower series has been entered, which, although much smaller, has a much higher passage density. The cave is very close to the Knock Ore Gill Vein (Sutcliffe 1985; Smith and Murphy 2011). A similar speleogenetic mechanism to Hudgill Burn Mine Caverns is proposed.

A third maze cave is known from the Silverband Mines, about 2 km north of Knock Fell Caverns, again within the Great Limestone Formation. This cave, presently inaccessible, is much modified by mining (Myers 1967). Most of the cave is in two sections, separated by a small fault such that the two cave sections have a difference in level of some 3–4 m. The evidence suggests the Silverband Mine Caverns is a typical transverse hypogenic maze with a total length >1 km, but with a much lower passage density and areal extent than Hudgill Burn Mine Caverns.

Three other smaller hypogenic caves, all isolated from any present surface water features, are known in the Alston Block. Two are close to Silverband Mine Caverns on Great Dun Fell: Silverband Pot is a phreatic cross-rift system, subsequently modified by vadose infiltration, and Silver Jubilee Pot is another short phreatic system with several blind shafts in the floor. Both of these pots are capped by shale. Another system with rectilinear characteristics, again isolated from any existing significant water course, is Moking Hurth and the connected Moking Pot in Upper Teesdale, with a total length of 550 m. All three of these smaller caves are in limestone interbedded with sandstone and shale.

2.2 The Askrigg Block

The Askrigg Block is noted for several maze caves, all originally discovered and in places modified by lead miners. Faggersgill Old Level in Arkengarthdale intersected several areas of natural cave in the Great Limestone Formation (Fig. 3). All of these natural passages were probably originally phreatic, and two sections show maze or network characteristics: the Easter Rifts Maze and the Stang Strings Maze, respectively, about 2.4 and 6.3 km long (Harrison and Ryder 2016).

The Stang Strings maze, with characteristic mud-covered floors, has a low passage density and areal extent, but nevertheless displays many of the features expected for hypogenic mazes including passage profiles with rising flow characteristics. It comprises essentially a reticular maze of passages, commonly widening into small largely linear caverns. The maze is separated from the nearby Easter Rifts Maze, some 150 m farther west by a small fault. The Easter Rifts maze also has a low areal coverage and passage density but differs from the Stang Strings Maze in comprising two large caverns that are joined by a network of tight rift passages. The phreatic Langthwaite Cavern in the north-east of the system is 300 m long and up to 15 m high and is one of the largest chambers yet discovered in a Northern Pennine maze cave. To the south of the system is Hangover Shakes Cave, another large cavern about 110 m long.

A few kilometres to the south-east of the Faggersgill Mine Caves, an extensive series of natural caverns occurs in the Great Limestone Formation in Windegg Old Level (Fig. 3). Rediscovered in the early 1970s (Ryder 1975), the cave system comprises about 1100 m of reticular passages. Many of the passages have been enlarged by collapse, resulting in some quite sizeable chambers, and several intersect or are aligned with mineral veins. Like the maze caves described above, the system shows all the hallmarks of having resulted from a transverse hypogenic speleogenetic process. Four kilometres further south is Danby Level, another nineteenth-century lead mine which intersects a complex network of tall, narrow rifts commonly 3–4 m high and 0.3–0.4 m wide, over 200 m in plan length and clearly showing hypogenic morphologies.

At the foot of Arkengarthdale is Devis Hole Mine, which contains three maze cave networks (Harrison 2006). Near the mine entrance is the Central Maze which consists of 1.62 km of passages, crammed into an area of about 120 by 45 m (Fig. 3). The passages, all floored with thick mud deposits, are generally small and narrow. Passage cross sections are commonly rift-shaped or tubular (Fig. 5), narrowing downwards, typical of hypogenic speleogenesis (Ryder 1975). Some 80 m further south, Wellington Vein, a natural passage much modified by mining activity, intersects a small natural network cave system, the Occidental Series, 490 m of primarily rift-shaped passages. About 300 m beyond Wellington Vein is the Southern Maze, essentially a single phreatic system totalling about 3.6 km in length. In part modified by miners, this mud-floored system has a relatively low passage density and areal coverage, but has many characteristic rising flow features, including high rift passages with narrow ceiling slots (Harrison 2006, 2012a, b).

A few kilometres to the west of the Devis Hole Mine Caves and also in the Great Limestone Formation, two more phreatic caves have been discovered, accessed only from mine levels. These are the caves in the Smithy Level of Whitaside Mine, 6.5 km west of Devis Hole Mine, and Summer Lodge East Level, 2 km farther west. The caves, probably segments of larger systems, are, respectively, 200 and 140 m in length and have typical tube-shaped passage profiles (Harrison 2012a).

Further south in Wensleydale, a group of eight caves including Sod Hole Gill Caves and Shivery Gill Pot may be isolated remnants of a single large phreatic network system (Ryder 1975). The caves may have developed as closely grouped clusters, a common characteristic of transverse hypogenic speleogenesis (Klimchouk 2013). The caves are entered by short vertical or sloping shafts in a line of shake-holes on an outcrop of the Great Limestone Formation. The joint-guided passages exhibit a rectilinear network structure and commonly have tubular or rift-shaped profiles with large

Fig. 5 A rift passage in the Southern Maze of Devis Hole Mine, a typical profile for maze cave passages in the region (Photograph J Dale)



amounts of clay infill blocking many of the passages. The overlying sandstone has been eroded away, and the cave system is undergoing breakdown and fragmentation.

Another possible hypogenic maze cave, now inaccessible, is documented in old mining records below Grassington Moor in Upper Wharfedale. Miners discovered and surveyed a cave 412 m long in the Middle Limestone Formation, with numerous small side passages that were not explored or surveyed (Brook and Murphy 2016). The cave is now inaccessible following collapse of the mine shafts and was known as Grassington Moor Cavern or the Lost Cavern of

Grassington Moor. Further east, sediment-filled karstic cavities known locally as ‘gulfs’ or ‘gulphs’ were encountered by miners between Nidderdale and Wharfedale around Greenhow Hill. These are thought to have formed as deep phreatic hypogenic cavities along mineral veins (Murphy and Everett 2013).

More as yet undiscovered hypogenic caves are likely to exist in the Northern Pennines. The presence of interbedded limestone, shale and sandstone adjacent to or intersecting mineral veins containing sulphide minerals are conducive to hypogenic cave formation. These will almost certainly be

remote from present surface features and in most cases probably only accessible from mine workings unless the covering rocks have been eroded away (as at Knock Fell Caverns), or where a modern valley happens to intersect them.

3 The Peak District

The Peak District, situated at the southern end of the Pennines, comprises a broad anticlinal structure cored by 1500 m of Lower Carboniferous limestones, locally interbedded with basaltic lava and ash deposits. It is flanked by Upper Carboniferous mudstones, fluvial and coal-bearing siliciclastics. The Peak Limestone Group is extensively mineralised, especially in the northern part of the outcrop where galena, fluorite, barite and calcite have been mined. The region is host to many cave systems including the 18-km-long Peak–Speedwell Cave system near Castleton (Waltham et al. 1997).

Evidence for active deep groundwater flow comes from the presence of several thermal springs, although none has yet been associated with known caves. Ten thermal springs grouped in seven centres are recognised in the area (Fig. 6), the best known being the Buxton and Matlock Bath springs with water temperatures of 27.5 and 20 °C, respectively, compared with ambient groundwater temperatures of about 9 °C. Isotope studies suggest these thermal waters were more than 15 years old and originate from local meteoric waters that have circulated to considerable depths. Radio-carbon dating showed that at least some of the thermal waters had bulk ages of up to several thousand years, although locally some of the springs, such as those at Buxton, also have a minor modern recharge component (Gunn et al. 2006; Abesser and Smedley 2008). There are significant differences between the water chemistry at the different thermal centres, but separate springs within each centre are of the same chemical type. This supports the idea that each centre originates from a separate flow cell with chemical differences reflecting variations in flow characteristics (Abesser and Smedley 2008). While most thermal waters are believed to originate within the Carboniferous Limestone sequence, isotope evidence suggests some of the springs, notably those at Buxton, have interacted with non-limestone lithologies (Gunn et al. 2006; Brassington 2007).

Evidence for deep hypogenic speleogenesis occurs in the northern part of the limestone outcrop around Castleton. Here a number of large, commonly isolated, phreatic dissolution cavities on mineral veins ('rakes'), faults and fractures have been identified (Fig. 7). These tall phreatic caverns are known from many of the ore fields, but are especially common in the Peak District. They occur either as

vertical open shafts where intersected by surface lowering, or are accessed via cave systems or old mine workings. More than 50 such vein cavities have been described (Ford 2000), including several entered from the Peak–Speedwell Cave system including the 160-m-deep Titan, the UK's deepest known shaft. The upstream limit of the Speedwell Cavern streamway, Main Rising, is a vein cavity where divers have descended to a depth of 74 m. Surface shafts include the 70-m-deep Eldon Hole and Bull Pit.

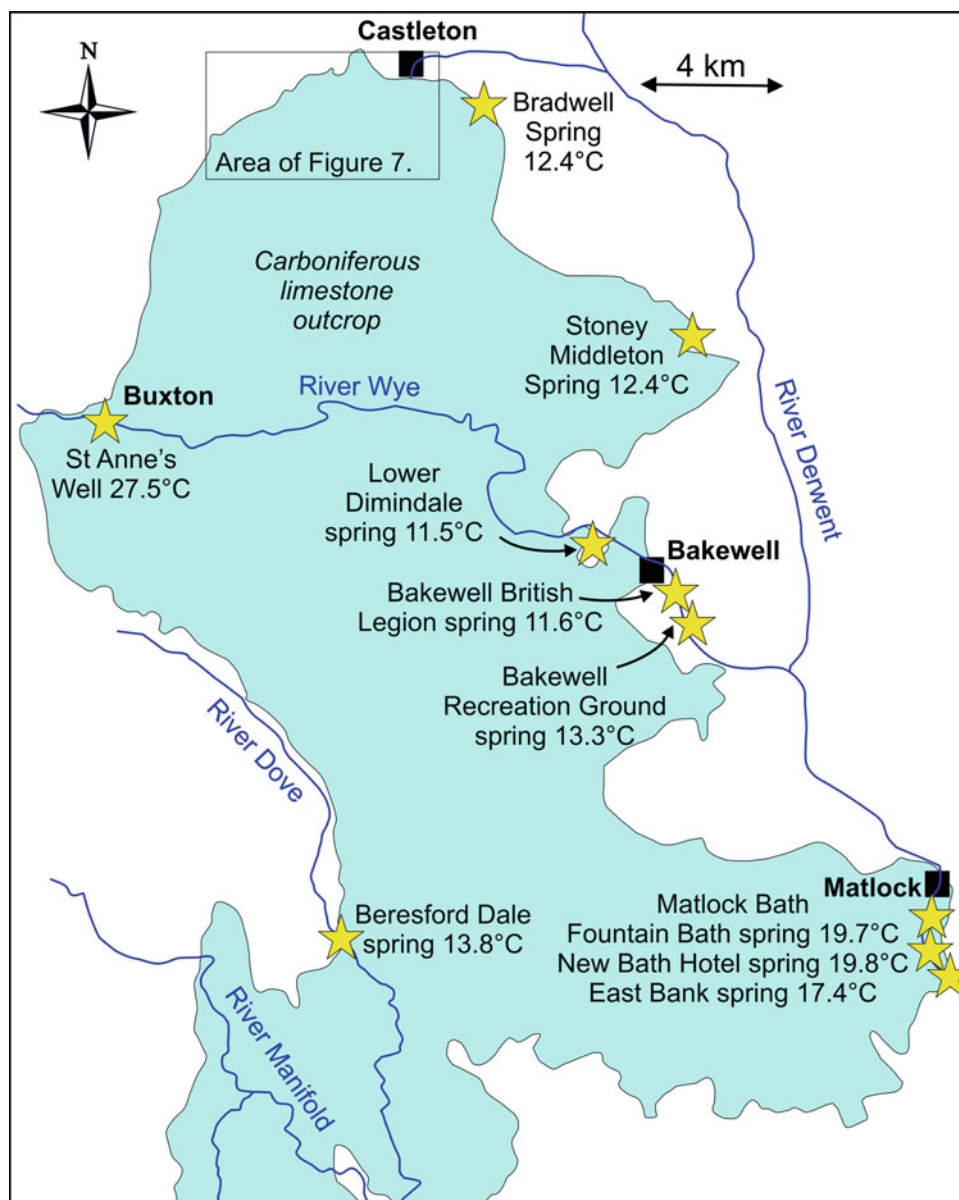
The development of the vein cavities was initiated in late Carboniferous times as mineralising fluids rising from adjacent sedimentary basins at temperatures between 70 and 120 °C emplaced a network of mineral veins in the limestone (Ford 2000). Following uplift and unroofing of the limestone in mid- to late Cenozoic times, circulation of groundwater was initiated. The relatively open vein and fracture network provided laterally extensive vertically oriented inception routes for deep phreatic groundwater flow (Ford 1995). With no effective base to the limestone, the slow circulation could have gone to virtually any depth, only to rise again at the resurgence points. Evidence from Peak Cavern suggests these vein cavities have a vertical range of several hundred metres. Slow dissolution would pick out any weakness in veins and slowly enlarge them so that an undulating phreatic drainage system could be developed (Ford 2000). These early cavities provided inception routes for subsequent groundwater movement through the limestone massif, thereby stimulating later phreatic and vadose development of the Peak–Speedwell cave system. The modern conduits still locally utilise these early cavities.

4 Wales and the Forest of Dean

The Carboniferous limestones of South Wales and the Forest of Dean host some of Britain's longest cave systems, two of which, Ogof Draenen and Miss Grace's Lane Cave, contain significant hypogene maze networks. Ogof Draenen is located on the northern margin of the South Wales coal basin (Fig. 1) where gently dipping Lower Carboniferous limestones are overlain by a thick sequence of Upper Carboniferous siliciclastics. Some deep artesian groundwater flow occurs beneath the coalfield emerging on the southern flank at Taff's Well near Cardiff with an average temperature of 21.6 ± 0.5 °C (Farr and Bottrell 2013).

In Ogof Draenen, two major maze networks occur within a larger branch-work cave system: the Squirrel Rifts maze and the Snowball-Hexamine Highways maze (Farrant and Simms 2011). They are typified by high narrow phreatic rift passages, with numerous junctions and blind passages, developed on several levels and generally do not display any clear dissolutional flow markings or scalloping. They occur at different stratigraphical levels, sandwiched between other

Fig. 6 Thermal springs in the Derbyshire Peak District



non-porous, but permeable, cavernous carbonate lithologies. These maze networks appear to have developed through hypogenic speleogenesis driven by the oxidation of metallic sulphides within the limestone and the overlying coal-bearing strata (Ball and Jones 1990). Locally abundant gypsum flowers, needles and anthodites are present.

In the Forest of Dean, Miss Grace's Lane Cave near Chepstow is a 4-km-long phreatic joint-guided rectilinear maze developed within Lower Carboniferous limestones. Little is known about its speleogenesis, but its interstratal setting beneath the Drybrook Sandstone may be significant. Perched over 150 m above the River Wye, it is now totally relict. No other hypogenic cave systems are known, but several mineralised palaeokarstic cave systems of possible Triassic age have been discovered by miners extracting iron

ore including Clearwell Caverns and Wigpool Iron-ore Mine (Bowen 2009).

In North Wales, limestone outcrops surrounding the Vale of Clwyd host many cave systems (Appleton 1989; Ebbs 2000). This area is extensively mineralised, and many of the caves were discovered by miners searching for lead. By the late 1600s, the driving of adits became necessary to drain the mine workings. In 1818, the 8-km-long Halkyn or Deep Level Tunnel was driven, followed by the Milwr Tunnel in 1897 (Fig. 8). This extended 16 km from the coast at Bagillt to Cadole near Mold (Ebbs 2008).

These tunnels and mines intersected several natural caves at depth, all phreatic and most now thought to be the result of hypogenic speleogenesis. Thirteen natural caves or groups of caves have been intersected in 42 km of mine passages.

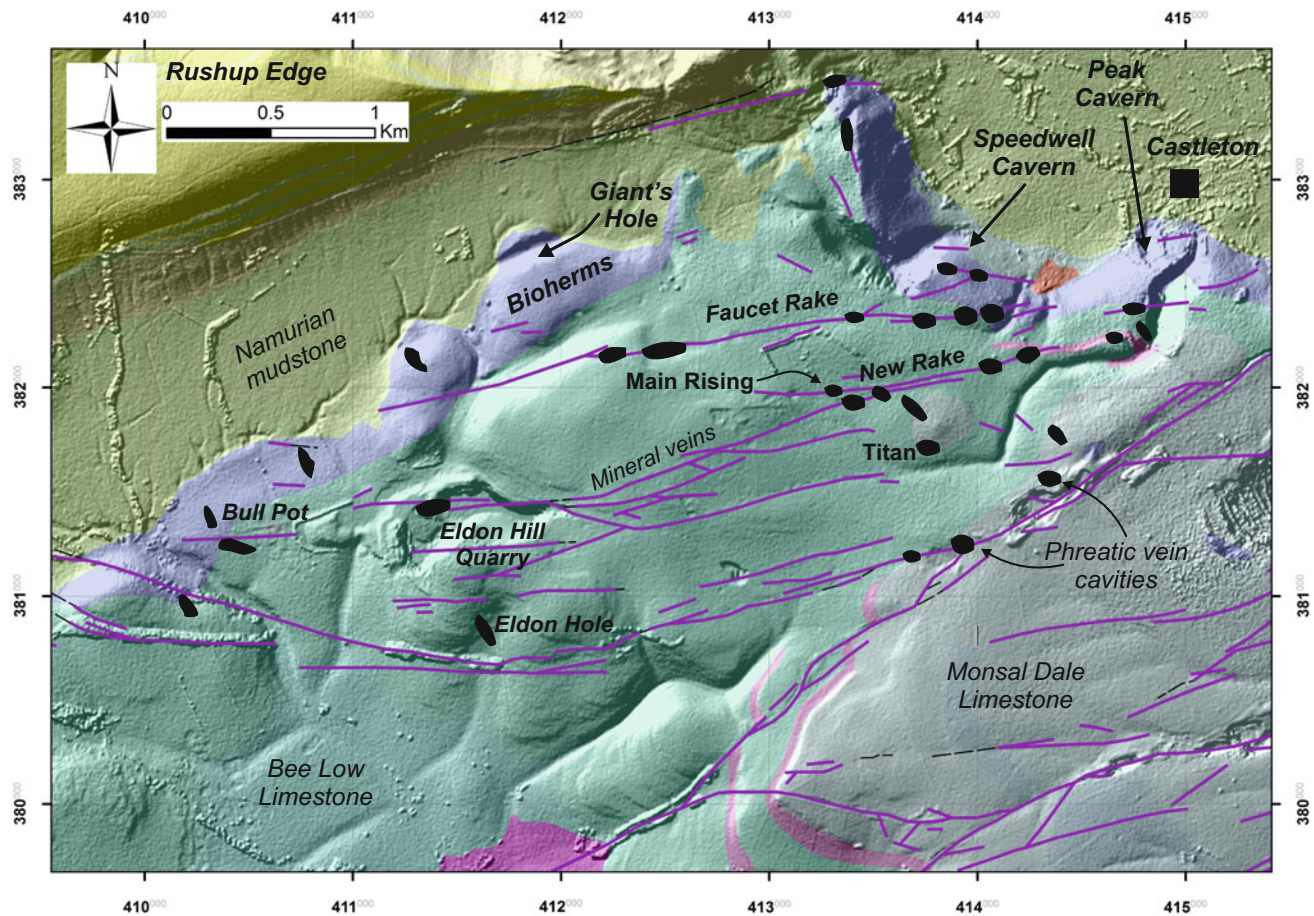


Fig. 7 Map of the known and probable vein cavities (black ellipses) in relation to the mineral veins near Castleton, Derbyshire (after Ford 2000). Geology is based on the British Geological Survey 1:50,000 scale digital geological map. Topography is ©NEXTMap Britain DTM

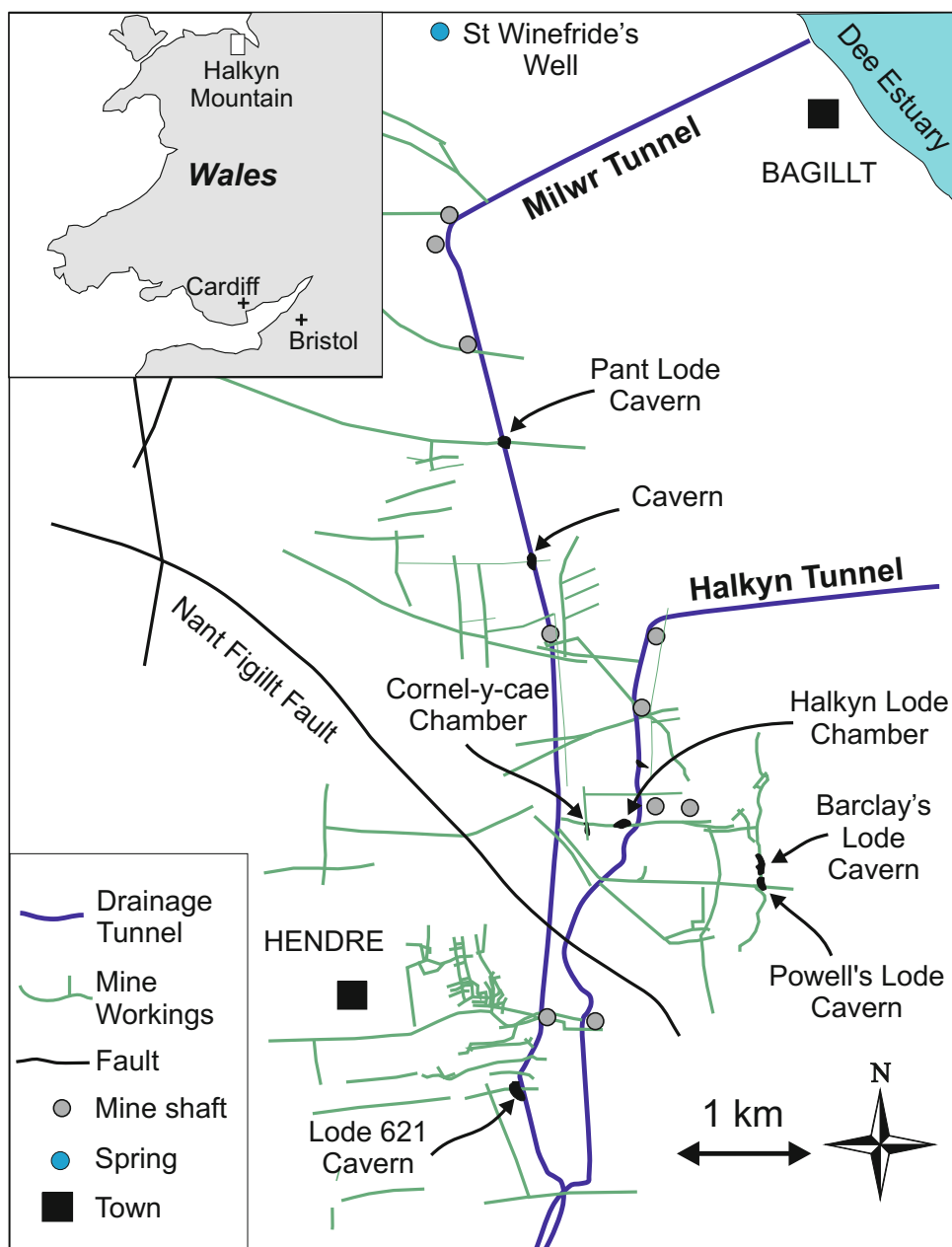
The largest is the Powell's Lode Cavern, first entered in 1931. The cavern is 70 m long, 20 m wide and about 20 m high (Fig. 9) and with a 20-m-diameter lake at its southern end which has been dived to a depth of 42 m (Fig. 10). A second lake was plumbed to a depth of around 60 m (c. 40 m below sea level) but was infilled with mining spoil. Mine plans show the cavern rising a further 50 m, giving an overall vertical extent of at least 110 m. Water resurges here at a rate of about 380 l/s, fed by a large conduit at a depth of at least 60 m below sea level. The water used to emerge at St. Winefride's Well at Holywell, over 8 km to the north, prior to the lowering of the water table by mining (Ebbs 2000). A passage was driven north from the lake on Barclays Lode through further natural chambers which extend continuously for 320 m until dipping below water level. A similar water-filled vein cavity was intersected on the Pant Lode during the construction of the Milwr Tunnel in 1917. The resulting flood disrupted work for many weeks and caused St Winefride's Well to dry up 11 h later. The water temperature emerging from the east side of the vein was about 9 °C, while that on the west was 13 °C. Other

chambers intersected by the miners include the Halkyn Lode Chamber, a large cave near the junction of the Halkyn Tunnel with Halkyn Lode, about 30 m long, 10 m wide and 38 m in height, now partially filled, and the nearby Cornely-Cae Chamber, 20 m in diameter and 20 m high. Lode 621 Chamber, another large natural chamber about 10 m in diameter and 20 m high, has good wall scalloping indicating a strong upward flow of water. These isolated phreatic caverns suggest there is an active deep-seated hypogenic cave system extending under Halkyn Mountain now partially intersected by mine workings.

5 The Bristol District

Hypogene caves and thermal springs are known in the Bristol–Bath area of southern England (Fig. 11). The area is geologically complex, dominated by thrust and folded Devonian sandstones and Lower Carboniferous limestones. These Palaeozoic rocks were uplifted and exposed during the Triassic, subsequently buried by a thick Jurassic to

Fig. 8 Location of hypogenic cavities (in black) intersected by mine workings beneath Halkyn Mountain, North Wales



Palaeogene cover, and now partially exhumed by Quaternary uplift and erosion. Active thermal springs provide evidence for hypogenic cave development and deep groundwater circulation. Those at Bath are well known, but several other thermal springs occur at or close to the present level of the River Avon which flows east–west through the region. The thermal waters at Bath emerge under artesian head at 39–46 °C from three springs in the centre of the town with a combined flow of 16.7 l/s. They rise up from Carboniferous limestones at depth, emerging through a thin Triassic cover. The springs are thought to form the outlet of a regional

thermal aquifer within Lower Carboniferous limestones that descend to depths >2.7 km within the North Somerset coal basin (Atkinson and Davison 2002). Isotopic evidence (Edmunds et al. 2014) suggests the water has been heated to a maximum temperature in the range 64–96 °C, indicating a most probable maximum circulation depth of 3 km, and a residence time of between 1 and 12 ka. Thermal waters were also encountered in a borehole at Batheaston, a few kilometres east of Bath. In Bristol, thermal springs occur at Hotwells; at Jacobs Well in Clifton; and at several points in the intertidal zone along the Avon Gorge.



Fig. 9 Powell's Lode Cavern looking north, showing abandoned mid-twentieth-century mining equipment (*Photograph J Dale*)

The only known relict hypogene cave system is Pen Park Hole (Fig. 11) in north Bristol (Mullan 1993). This short cave, with a surveyed length of 112 m and a depth of 61 m, was discovered during quarrying around 1669. It consists of a short, fault-guided entrance series which opens out into a large chamber occupied by a lake whose surface fluctuates by up to 27 m. The cave is confined to a narrow zone of steeply dipping limestone no more than 20 m thick. The first recorded descent was on the 2nd July 1669. The cave was surveyed in September 1682 and published in January 1683 (Southwell 1683), making it one of the earliest published cave surveys in the world (Shaw 1979). It is perhaps noteworthy that it was the cave's hypogenic origin that led to the cave being surveyed at such an early date!

Evidence of hypogene speleogenesis includes the dendritic, upward-branching passage morphology aligned along the fault planes; deep, rounded cupolas; and highly corroded bedrock where steam has condensed above hot pools.

Several phases of mineralisation are evident. The first phase was the deposition of minor amounts of galena, followed by a 2- to 3-cm-thick crust of coarsely crystalline calcite up to 15 cm thick covering most of the floor, walls and roof of the cave (Fig. 12). A second phase of dissolution led to the etching of the calcite, followed by the deposition of a thin layer of limonite over the calcite throughout most of the cave. The cave appears to have been formed by hydrothermal waters rising up to emerge as thermal springs, similar to those seen in the region today, possibly during the early Pleistocene prior to the incision of the nearby Avon Gorge, although a Jurassic age cannot be ruled out. A similar, hot spring origin has recently been suggested for the main fissure at Cromhall Quarry, some 17 km to the north-east (Simms 1990).

No definitive hypogene caves are known from the Mendip Hills, although some of the lead and zinc mineralisation was undoubtedly accompanied by karstic development.



Fig. 10 The Lake, Powell's Lode Cavern (*Photograph J Dale*)

However, some isolated phreatic chambers and caves in the western Mendips may have a hypogenic origin. These include Axbridge Hill Cavern, Loxton Cavern and other nearby caves. These are associated with ochre (iron) workings and may be associated with hypogene karstic development at or just below the Triassic unconformity. Similarly, Pridhamsleigh Cave in Devon may be associated with deep groundwater flow in Devonian limestones rising up thrust planes.

6 Transverse Hypogenic Gypsum Karst of Northern England and the East Midlands

Transverse hypogenic karst associated with groundwater flow through interbedded dolomite and gypsum occurs within Permian and Triassic strata in parts of Northern England and

the Midlands. The main areas of gypsum karst are in the Permian outcrop east of the Pennines, particularly around Ripon and Darlington, where two gypsum- and anhydrite-rich mudstone units (the Edlington and Roxby formations) are sandwiched between dolomite aquifers (the Cadeby and Brotherton formations) (Fig. 13). This heavily karstified gypsum and dolomite succession crops out in a narrow belt approximately 140 km long and 3 km wide from Darlington through Ripon to Doncaster. It is characterised by active subsidence and abundant sinkholes, particularly around Ripon. The topography and easterly dip of the strata enables artesian water to flow up through the dolomite into the overlying gypsum sequences, emerging as sulphate-rich springs with temperatures between 9 and 12 °C (Cooper et al. 2013). It seems likely that there are extensive active transverse hypogene cave systems developing within the gypsum and anhydrite, especially in the Ripon area (Cooper et al. 2013). Although many sinkholes are present in the

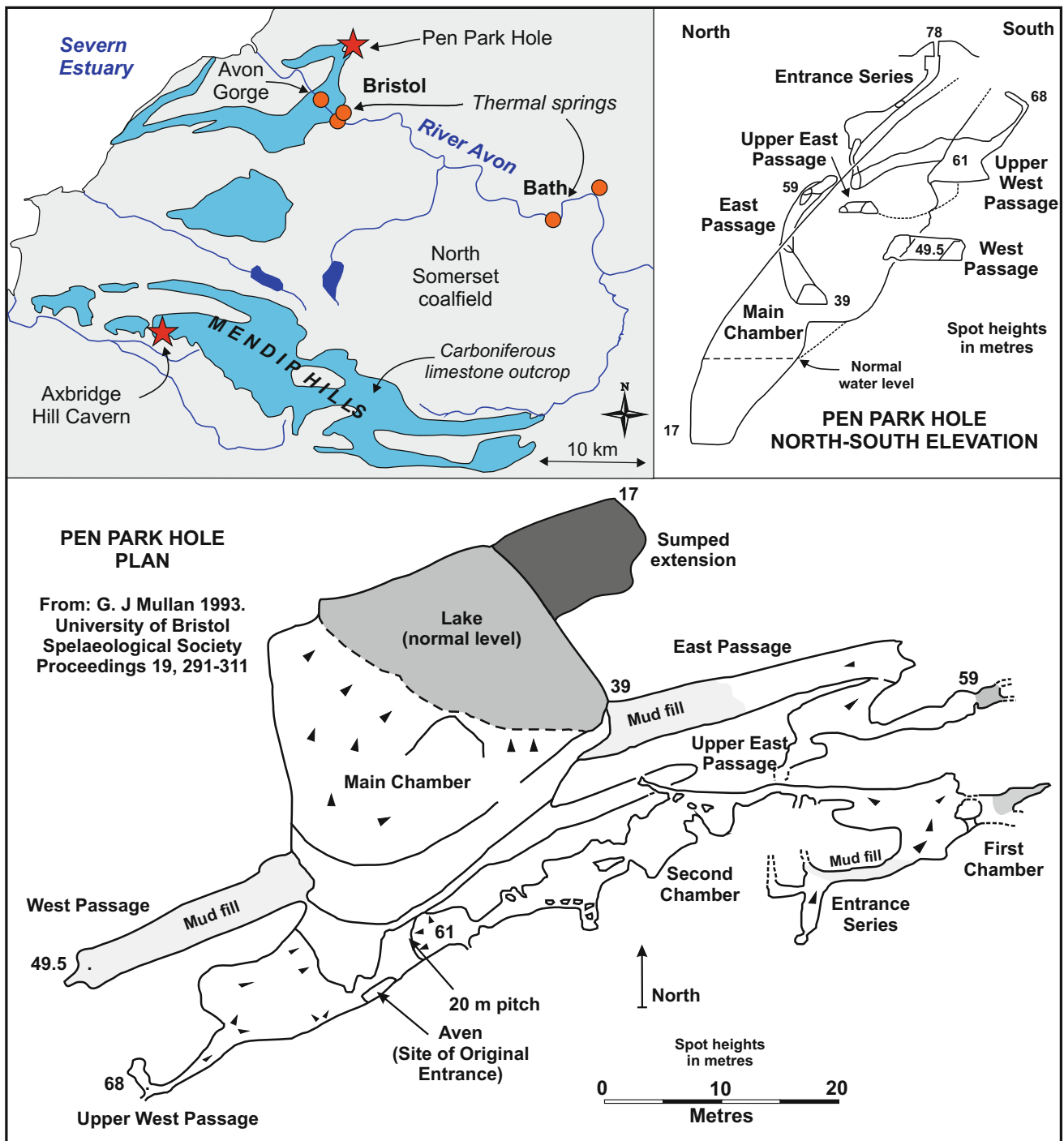


Fig. 11 Plan survey and section of Pen Park Hole, Bristol. *Inset map* Location of hypogenic caves and thermal springs in the Bristol-Bath area, including the Mendip Hills



Fig. 12 Hydrothermal calcite crust in the entrance series of Pen Park Hole. Crystals are 2–3 cm across (*Photograph A Farrant*)

region, some up to 20 m deep, no accessible hypogenic caves have yet been found. However, numerous karstic cavities including clay-filled cavities up to 20 m high have been discovered in boreholes (Waltham and Cooper 1998; Cooper and Waltham 1999).

Further south, fragments of caves have been observed within gypsum mines in the Triassic Mercia Mudstone Group south of Nottingham and Derby, but these are poorly recorded. It is possible that some of these may have a transverse hypogenic origin, fed by artesian water rising up sequence through dipping strata.

A smaller area of gypsum karst occurs in Permian strata in the Vale of Eden. Thin beds of gypsum are

present in the Eden Shales Formation. Four distinct evaporite beds exist, labelled A to D (Stone et al. 2010). In 1988, the Houtsay Quarry Cave was discovered in the 'B' Bed in a gypsum quarry at Kirkby Thore near Penrith (Ryder and Cooper 1993). The cave, which has now been quarried away, was a relict horizontal phreatic system with passage diameters between 1 and 4 m and averaging about 2 m and a total length of about 140 m. Scallopings suggested upward water movement, implying that the cave resulted from hypogenic transverse flow up through the system similar to that now occurring in the Ripon area. Similar features may be widespread in the gypsum belt of the Vale of Eden.

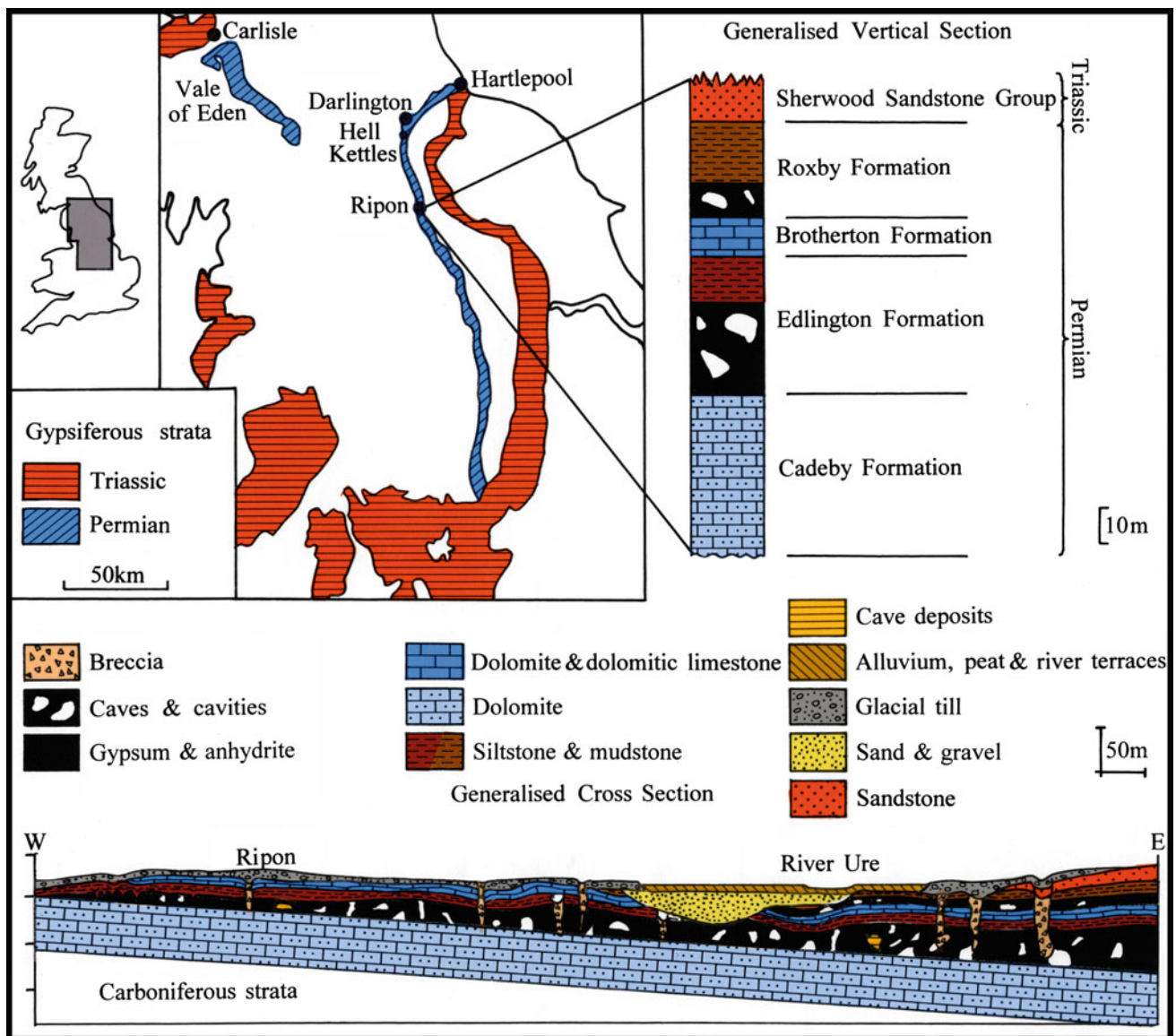


Fig. 13 Map of Northern England showing the outcrop of and generalised section through the Permian gypsiferous strata. *Inset* Cross section through the Permian sequence in the Ripon area, showing the development of gypsum karst (from Cooper 1998)

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