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SPELEOGENESIS AND LANDSCAPE DEVELOPMENT IN THE BURRINGTON AREA, SOMERSET

by

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ABSTRACT

The Burrington area of western Mendip is well known for its caves, and contains over 3.7 km of surveyed passage. The typical Burrington cave consists of a maze network of predominantly small phreatic tubes generally aligned along strike and developed at certain preferential elevations, linked by steeply descending vadose canyons. Many of these passages are partially sediment choked. The speleogenesis of these cave systems is governed largely by the geological structure, the rate of erosion of the Mercia Mudstone in the Vale of Wrington and locally modified by sediment influx off the northern slopes of Black Down. Several well-developed former water-tables, analogous to those seen in the caves on the southern side of Black Down can be identified at elevations of 166-160 m, 151 m, 140 m, 127 m, 115 m and 106 m AOD. A summary of the hydrology of the Burrington area is given and an estimate of the age of the caves calculated.

INTRODUCTION

Burrington Combe is located on the northern flank of the Mendip Hills, 20 km south of Bristol (Figure 1). The area is well known for its small, complex cave systems. The study area is the same as that considered by Tratman (1963) in his paper on the hydrogeology of the Burrington area. It encompasses the region on the northern side of Black Down extending from Rowberrow Warren in the west to Ellick Farm in the east, including Burrington Combe and the springs at Rickford and Langford. The caves in the extension of the Rickford catchment to the east, including Ubley Warren Pot and Lamb Leer (Crabtree, 1979) are outside the study area and have not been given detailed consideration. Grid references are all within Grid Square ST and elevations are given above Ordnance Datum (AOD). The major stream sinks, springs and caves in the Burrington area are tabulated in Tables 1-3.

The earliest known references to caves in this area date back to the 18th Century. Goatchurch Cavern was known to the pioneer antiquary John Strachey in the 1720s (Williams, 1987), and Aveline’s Hole was discovered in January 1797. The history of Aveline’s Hole is summarised by Schulting (2005). Through the 19th Century some of the caves were subject to unsystematic investigations by antiquaries, and, in the case of Aveline’s Hole, treasure and souvenir hunters. Systematic investigation did not begin until the early years of the 20th Century.

In 1912 the Bristol Speleological Research Society (BSRS) was formed with the intention of bringing a somewhat more scientific intent to cave exploration (Williams, 2000). Two of their four recorded projects were undertaken in Burrington Combe; archaeological excavation in Aveline’s Hole and an attempt to clear out Plumley’s Hole, the vertical shaft uncovered by quarrying in 1875 where Joe Plumley met his death (Dougherty, *et al.*, 1994). Although the BSRS did not survive the First World War, both of these projects were continued for some years after the war by its successor body, the University of Bristol Spelaeological Society founded in 1919.

For most of the inter-war period, the majority of cave research carried out in this area was archaeological in nature, including the completion of the excavations in Aveline's Hole, the discovery of Read's Cavern and the excavation of its Iron Age deposits (Palmer, 1920, 1921; Langford, 1922, 1923; Jackson, 1923; Darbishire, 1923; Tratman, 1924, 1931, 1968). The survey of Read's Cavern has been documented by Stanton (1968) and the discovery of the Browne Stewart Series by Kenney (1968).

Some cave exploration was also carried out during the inter-war period, with the discovery and exploration of Sidcot Swallet in 1925 by boys from Sidcot School, with further extensions made in 1941 (Balch, 1948), together with the discovery of Drunkard's Hole in the early 1930s (Mullan, 2000), later extended in the early 1990's (Williams and Farrant, 1992), and East Twin Swallet in 1936 (Pearce, 1944). Rod's Pot was first entered in April 1944 (Pearce, 1946).

In the post-war period, a number of new caves have been discovered and extended in the study area. Bos Swallet was discovered in 1947 and extended in 1995 (Stanton, 1950; Boycott, *et al.*, 1998); Lionel's Hole, dug open in 1970 (Stanton, 1970) and extended 1978 (Moody, 1980); Bath Swallet, dug into in 1946, extended in 2001 and connected to Rod's Pot in 2007 (Stride, 1946; Newport, 2001, 2007); Spar Pot (Richards, 1975), opened in 1971 and later connected to East Twin Swallet and lastly Pierre's Pot which was dug into in 1983 (Moody, 1988).

Some explorers, in collaboration with others, have attempted to interpret the geology and geomorphology of the caves as well as describe their finds. Studies include that of Rod's Pot (Donovan, 1949), East Twin Swallet (Ineson, 1958), Lionel's Hole (Stanton, 1970), Drunkard's Hole (Williams and Farrant, 1992) and Bos Swallet (Boycott, *et al.*, 1998). The sedimentology of Goatchurch Cavern and Sidcot Swallet was described by Bull and Carpenter (1979). However, the most important study was Tratman's 1963 paper, which for the first time gave an overview of the Combe and the caves as a whole.

Since Tratman's review, over 1.5 km of passage has been discovered and this, coupled with advances in our knowledge of groundwater flow from tracer experiments, Quaternary landscape evolution and new compilations of survey data for all the Burrington caves, has necessitated the need for an updated review. The present account has been written for these reasons.

GEOLOGY OF THE BURRINGTON AREA

The Burrington area lies on the northern flank of the Black Down pericline, the westernmost of four en-echelon periclines that form the backbone of the Mendip hills. These are formed in Devonian and Carboniferous rocks which are superbly exposed in Burrington Combe and its tributary valleys (Green and Welch, 1965). The core of the pericline consists of Devonian reddish-brown sandstone, conglomerate and mudstone of the Portishead Formation, formerly known as the Old Red Sandstone. This is conformably overlain by a sequence of interbedded mudstone and limestone beds, which form the Avon Group ('Lower Limestone Shales') and mark the marine transgression which heralded the start of the Carboniferous Period.

Above the Avon Group is the Pembroke Limestone Group (informally known as the Carboniferous Limestone). This is a 680 m thick sequence of dominantly crinoidal and oolitic limestones with some mudstones, locally replaced by dolomite in the lower part. The basal part

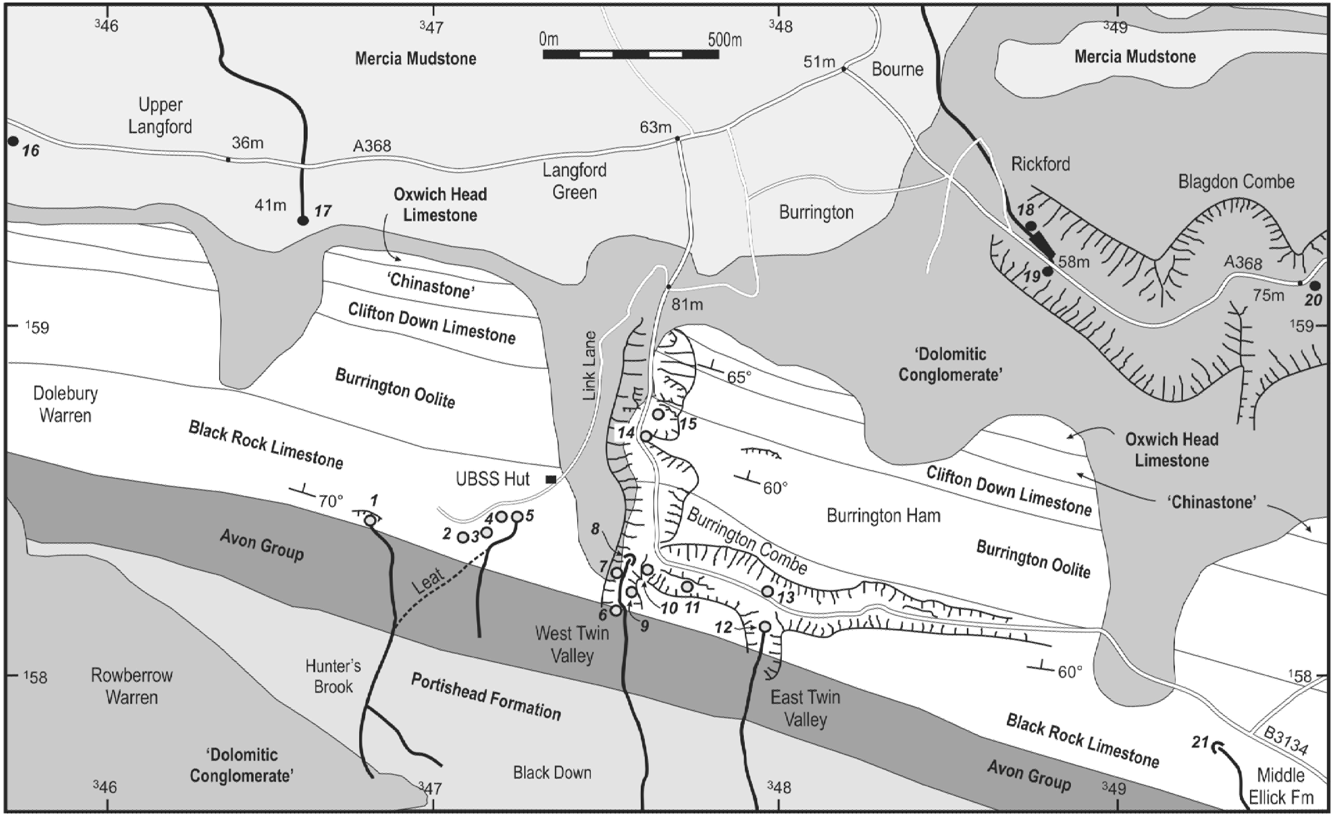

Figure 1. *Geology of the Burrington area, adapted from the British Geological Survey 1:50,000 scale digital geological data (Digmap), Sheet 280 (Wells). Spelaeological sites are numbered: 1. Read's Cavern, 2. Bos Swallet,3. Drunkards's Hole, 4. Rod's Pot, 5. Bath Swallet, 6. West Twin Brook Adit, 7. Sidcot Swallet, 8. Flange Swallet, 9. Goatchurch Cavern, 10. Pierre's Pot, 11. Tween-Twins Hole, 12. East Twin Swallet, 13. Lionel's Hole, 14. Aveline's Hole, 15. Plumley's Hole, 16. Saye's Lane Risings, 17. Langford Rising, 18. Gauge House Rising, 19. Rickford Rising, 20. The Squire's Well, 21. Ellick Farm Swallet.*

of the Pembroke Limestone Group is the Black Rock Limestone Sub-group, here around 270 m thick. This consists of a package of coarse, highly fossiliferous crinoidal packstones and wackestones with mud flasers and some interbedded chert. The basal part of the unit is transitional with the Avon Group and contains some interbedded mudstone horizons in the basal few metres. The limestone is regularly bedded with bedding partings, often with mudstone laminae developed every few metres. About half way up the Black Rock sequence is a 26 m thick zone of cherty limestones with abundant silicified fossils and chert bands; the 'Main Chert beds' of Green and Welch (1965). This cherty horizon crops out along the top of the main scarp face on the northern side of the Combe. The uppermost 20 m of the Black Rock Limestone is dolomitised, and this can be traced across Burrington Ham (Green and Welch, 1965). Nearly all the significant explored caves occur in the lower half of the Black Rock Limestone.

Above the Black Rock Limestone is the Clifton Down Sub-group. This consists of the Burrington Oolite Formation, and the Clifton Down Limestone Formation. The Clifton Down Sub-group has a total thickness of around 360 m in the Burrington area. The Burrington Oolite consists of 207 m of generally massive oolitic limestone (Figure 3) and crinoidal oolites with some thin dolomite beds, for example the prominent Rib Mudstone exposed in the quarry opposite the Rock of Ages. The beds are significantly thicker in the Burrington Oolite than in either the Black Rock Limestone or the overlying Clifton Down Limestone. The Burrington Oolite outcrop includes the prominent bluff in which Aveline's Hole is found, the Rock of Ages and the large quarry opposite (including Plumley's Hole). The overlying Clifton Down Limestone consists of 155 m of crinoidal packstones and wackestones with locally developed cherty horizons. It generally can be divided into three facies: dark grey to black calcite-mudstones ('chinastone limestones'); grey to black rather fine-grained limestones with sheets and masses of *Lithostrotion*; and alternations of calcite-mudstone, white oolite and dark splintery limestones with scattered *Lithostrotion.*

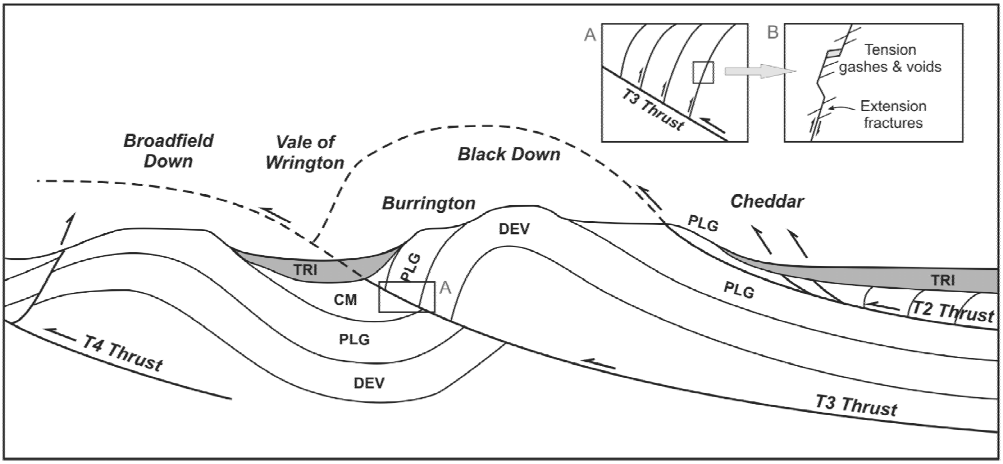

Figure 2. *North-south geological cross section from Cheddar to Broadfield Down, showing the role of thrusting in the development of the Black Down pericline (after Williams and Chapman, 1986). The generation of bedding plane (flexural) slip planes on the northern limb of the pericline and the role of asperities on the bedding surface is shown in insets A & B. TRI Triassic; CM Coal Measures; PLG Pembroke Limestone Group; DEV Devonian.*

At the top of the Pembroke Limestone Group is the Oxwich Head Limestone (formerly named the Hotwells Limestone). This only crops out in the quarry to the north of the Burrington Café and is not seen in any of the caves. The Oxwich Head Limestone mainly consists of fossiliferous, massive, grey, crinoidal and oolitic, bioclastic limestones with a total thickness of around 150 m. Only the basal beds of the Oxwich Head Limestone are exposed at Burrington Combe, comprising around 30 m of strata.

Figure 3. *View of Burrington Combe, taken in 1909 by S.H. Reynolds. The steeply dipping massive Burrington Oolite forms the crag in the left hand side of the image, in which lies Aveline's Hole. The gully to the right of the image marks the contact with the more thinly bedded Black Rock Limestone which can be seen in the crag to the right.*
Photo is from the British Geological Survey photographic archive, Keyworth. Image No. P247359_S2

The flanks of the Mendip Hills are unconformably draped by the Triassic Mercia Mudstone Group strata. In this area, this group consists of a proximal breccia (the misnamed 'Dolomitic Conglomerate') and the more distal, finer grained Mercia Mudstone Formation which locally contains inter-bedded sandstone skerries (for example the Butcombe Sandstone Member). The breccias are mostly angular Carboniferous limestone and some Devonian sandstone clasts in a matrix of red silt. These were deposited either as slope (screes) or wadi fan deposits in an arid or seasonal climate on a highly irregular terrestrial erosion surface. These breccias fine to the north and south of the Mendips and interdigitate with the Mercia Mudstone, which are mostly reddish brown, wind-blown silts, mudstones and playa lake deposits. More importantly, the breccias are sufficiently carbonate-rich to host significant cave systems, the best example being the outer parts of Wookey Hole. The western flank of Burrington Combe cuts into a former Triassic valley or wadi, infilled with the 'Dolomitic Conglomerate', which can be seen in outcrops opposite the Burrington Combe café and along the minor road (Link Lane) leading up to the UBSS field headquarters.

The Palaeozoic rocks have been strongly affected by Variscan folding (Figure 2). The most intense deformation was along the Variscan Front which extends from South Wales, through the Mendips and eastwards towards Belgium (Kellaway and Hancock, 1983). This zone is a thin skinned, piggy-back foreland thrust belt with dominant northward transport (Williams and Chapman, 1986). Around Burrington, the Pembroke Limestone Group dips steeply on the northern limb of the Black Down pericline, the most westerly of a series of en-echelon, east-west trending periclines which make up the Mendip Hills. Although periclinal in general form, these folds are asymmetric and northerly verging with steep, southerly dipping axial surfaces. Their periclinal nature is due to thrust culminations at depth. On the northern side of the Black Down pericline, the strike is oriented east-southeast to west-northwest, with dips generally between 50° and 70° to the north-northeast. Some small, tight, anticlinal drag folding, parasitic on the larger Black Down pericline, have developed in the weaker, mudstone-rich basal part of the Black Rock Limestone Formation. One such fold is clearly seen in the Main Chamber of Read's Cavern.

There are no mapped faults in the area, but the anticlinal folding that developed during the Variscan orogeny has generated numerous bedding-parallel slip planes, which often have well-developed slickenfibres. These generally show movement slightly oblique to the dip, and sometimes display more than one period of displacement. The rock is well jointed with a conjugate joint set oriented northwest to southeast and northeast to southwest. The overlying Triassic deposits, unaffected by Variscan folding, are either horizontal or very gently dipping.

The Mendip region was later affected by Mesozoic tectonic extension. This extension created numerous fissures that are infilled with Late Triassic and Jurassic sediment (Wall and Jenkyns, 2004), particularly in eastern Mendip and around Charterhouse. The vast majority of the Mendip fissures are interpreted as having formed as a response of the Pembroke Limestone Group to pulses of tectonic extension during Ladinian–Norian/Rhaetian, late Hettangian–Pliensbachian and Bajocian times. Although no fissure fills have been identified in the Burrington area, the area would have still undergone extension with the dilation of the bedding plane and joint fractures. Subsequent basin inversion during the Tertiary (Chadwick, 1993) was concentrated in fundamental zones of weakness along the major basin bounding faults such as the Mere Fault and produced the asymmetrical folds and reverse faults which affected the Cretaceous rocks of the vales of Wardour and Warminster, leaving the Mendip area relatively unaffected.

HYDROLOGY

The hydrology of the Burrington drainage system is quite complex with five significant sinking streams (each with one or more discrete swallets) and two major resurgences, plus several other smaller springs. The sinking streams are from west to east: the Hunter's Brook, the Bath Swallet stream, the East and West Twin Brooks and the Ellick Farm stream. These streams rise on the Portishead Formation strata and sink on reaching the Black Rock Limestone. The catchment is drained by two major springs, one at Langford and one at Rickford, the latter also has several smaller satellite springs. All the springs occur within the Triassic strata, either wholly within the Dolomitic Conglomerate or close to the contact of the overlying Mercia Mudstone. The exception is the minor Saye's Lane rising which is the Mercia Mudstone.

The groundwater regime has been investigated by numerous tracer tests (Table 4), and a schematic diagram of the underground drainage network is shown in Figure 4. The earliest tracer tests were conducted by Bristol Waterworks in 1910, followed much later by Tratman in the early 1960's (Tratman, 1963). In the early 1970's the Mendip Karst Hydrology Project (MKHP) traced the major sinks and some cave streams using lycopodium, and the results are summarised by Drew *et al*., (1968). The western boundary of the catchment was delimited by Pottinger (1976a & b) who traced the Rowberrow valley stream sinking at Swan Inn Swallet [ST 4556 5786] and Rowberrow Swallet [ST 4553 5809] to Banwell Spring (Hobbs and Smart, 1989). This work was followed by tracer experiments using fluorescein and other fluorescent dyes by Crabtree as part of an undergraduate project in the Geography Department at the University of Bristol (Crabtree, 1979). Although there are no stream sinks east of Lower Ellick Farm, water from Lamb Leer Cavern [ST 5432 5506], almost 7 km to the south-east, was traced to Rickford in 1977 (Barrington and Stanton, 1977, p. 105). These tracer tests demonstrated that the Rickford catchment extends a significant distance to the east of Burrington area.

In addition, after the discovery of underground streamways in Pierre's Pot and Lionel's Hole, an attempt was made in March 1987 to trace their sources. Two separate tracer tests were made, each using three separate tracers. In the first test, Flourescein was poured into Flange Swallet (West Twin brook), Rhodamine WT into Ellick Farm Swallet and Tinopal CBS-X optical brightener into East Twin Brook Top Sink. Detectors were placed in Squires Well, Rickford and Langford Risings, at two points in the Pierre's Pot streamway (Western Inlet and Main Streamway Inlet), and one site in the Lionel's Hole streamway (West Low Level).

In the second test, Flourescein was used to test the small stream in the Water Chamber in Goatchurch Cavern, while Tinopal CBS-X optical brightener was used to trace the East Twin Brook and Rhodamine WT poured into Goon's Hole. Again, detectors were placed in the Rickford and Langford Risings, and in the Pierre's Pot streamway (both sites), plus three sites in the Lionel's Hole streamway (West Low Level, East Low Level and the Terminal Sump).

The samples were analysed by Peter Smart and Steve Hobbs at the University of Bristol, Department of Geography. The results from the first tracer test showed a moderate positive trace from Flange Swallet to the Pierre's Pot (Western Inlet) stream and a strong trace from Ellick Farm Swallet to Rickford. The second tracer test showed a moderate positive trace from the Goatchurch Cavern (Water Chamber) stream to the Western Inlet in Pierre's Pot and a strong visual trace from both East Twin Swallet and Goatchurch Cavern (Water Chamber) to the Main Streamway inlet in Pierre's Pot. In addition, there was a strong positive trace from Goon's Hole to the detectors in both West Low Level and East Low Level in Lionel's Hole. The rest of the results were either negative or possible positive traces (P.L. Smart *pers. comm*.). The Western Inlet in Pierre's Pot is just a small stream, and thus cannot be the main flow from Flange Swallet. It may be from the Water Chamber, or it may represents minor leakage from the Water Chamber – Main Inlet conduit and from Flange Swallet

In addition to delimiting the catchment and identifying swallet to resurgence links, quantitative tracer tests together with the detailed analysis of groundwater discharge, and chemistry (Tratman, 1963; Newson, 1972; Smith and Drew, 1975) have provided much data on the nature of groundwater flow in the Burrington area. The amount of water issuing from the combined resurgences is much greater than that sinking in the swallets. Around 90 to 95 per cent of the water resurging at Rickford and Langford is of percolation origin (Tratman, 1963), and much of the catchment is dominated by autogenic recharge, particularly to the east of the Burrington area. Water from as far afield as Lamb Leer Cavern has been traced to the Rickford

Risings, although probably via a separate tributary conduit system to that associated with the Burrington swallets.

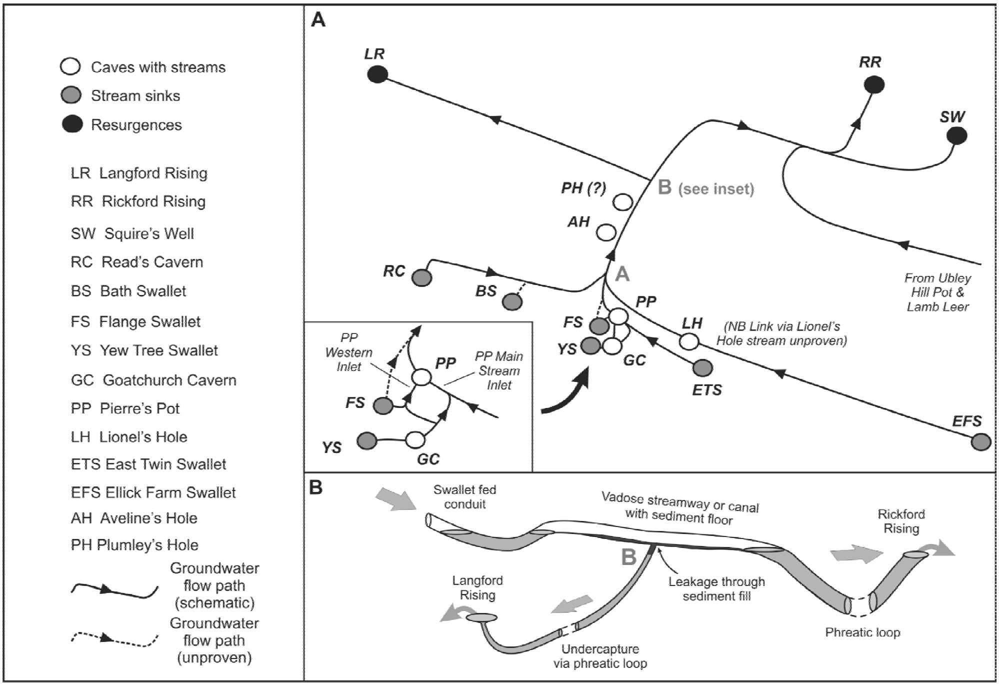

Figure 4. *A. Schematic model of the underground flow pattern as determined from tracer testing experiments and hydrological data. B. Possible mechanism for the capture of Rickford Risings by Langford Risings (T.C. Atkinson* pers. comm.*).*

Newson (1972) showed that both resurgences respond to rainfall by a reduction in total hardness (Ca^{++} content) coinciding with an increase in discharge. This effect is much more marked at Langford Rising than at Rickford. From this data, Newson suggested that both resurgences are fed by significant flood pulses from the swallets following rainfall, and that Langford has a higher fraction of swallet water compared to percolation water.

A reinterpretation of Crabtree's quantitative dye tracing experiments by Tim Atkinson (T.C Atkinson *pers. comm*. and unpublished data, January 2009), indicates that the relative proportion of tracer recovered at Rickford and Langford is the same irrespective of which swallet was traced, under any given flow conditions, but that the proportion of tracer recovered at Rickford increases as total discharge from the springs increases. This is best explained by supposing that conduit linking the master conduit to Langford (segment B → LR on Figure 4) is mostly waterfilled and discharges water that fluctuates less than the total discharge through the system. Similarly, the passage segment B → RR must have a discharge that fluctuates slightly more than the total discharge. If the head at B fluctuates by ΔH and discharge by ΔQ then this is equivalent to:

$\Delta Q \propto (\Delta H)^c$ (For the Langford distributary link $B \rightarrow LR$)
$\Delta Q \propto (\Delta H)^d$ (For the Rickford distributary link $B \rightarrow RR$)
Where $c < d$.

The simplest scenario in which this result could be achieved is for the Langford under-capture to branch off the main conduit at point B on Figure 4 in a vadose (or canal) section of the trunk conduit, and for this under-capture to be mostly water-filled. This capture could be by seepage through gravel on the passage floor for example, as shown on the inset in Figure 4 (Atkinson, *pers. comm*.). This type of situation is not unusual. Stanton (1974) describes a similar situation at Wookey Hole where a fissure in the wall of the main conduit carrying the River Axe through the Ninth Chamber has been traced to Glencot Spring, 1100 m away and 17 m lower. A similar distributary system was inferred for the underground drainage system in the Malham area of Yorkshire (Smith and Atkinson, 1977) using a combination of water tracing and flood pulse data. Other examples have been described from the Mammoth Cave area in the United States (Quinlan *et. al*., 1983).

The results from these tracer tests together with the hydrological evidence clearly indicates that the flow from all the Burrington stream sinks unite into a single, as yet unexplored conduit before diverging to flow to Rickford and Langford. In addition, tracer tests coupled with direct exploration in Lionel's Hole and Pierre's Pot suggests that at least two independent streamways flow approximately east to west along strike in the Burrington Combe area; one from East Twin Swallet to Pierre's Pot, and a second slightly lower, parallel streamway flowing through Lionel's Hole about 50 m to the north. The stream in Lionel's Hole may be derived Ellick Farm Swallet as the stream runs brown after heavy rain, but as yet there are no positive tracer tests to prove it. The West Twin water probably flows north-east, with some of the water sinking in Flange Swallet leaking into Pierre's Pot (Western Inlet) almost directly below. These streams must then unite to flow north towards the resurgences.

CAVE GEOMORPHOLOGY

Most of the known caves in the Burrington area occur at or close to the contact between the Avon Group mudstones and the overlying Black Rock Limestone (Figure 1). However, this is not always the case, and some caves, for example Rod's Pot and Bath Swallet, have been formed some distance away from the bedrock contact due to the presence of an impermeable blanket of Head (slope and solifluction deposits) which masks the underlying bedrock in this area. Trenching by the University of Bristol Geography Department (Tratman, 1963) demonstrated that these deposits are locally greater than 3 m thick.

The major caves are described from west to east and can be grouped into three distinct groups; the Read's Cavern to Bath Swallet group; the West Twin valley caves and the East Twin valley caves.

Read's to Bath Swallet group.

This group of caves comprises the swallets and caves between Rowberrow Warren and the West Twin Brook. Plan surveys of these caves are shown in Figures 5 and 6, and also Figure 7.

Read's Cavern

Read's Cavern is located where the Hunter's Brook sinks underground at the edge of Rowberrow Warren (Figure 1). The stream sinks at the base of a large cliff of Black Rock Limestone and enters a sizable strike orientated chamber developed along the core of a small anticline before sinking amongst boulders. This anticline is well exposed in the roof of the main chamber. This chamber can also be entered via another entrance at the east end of the cliff. Various routes through boulders can be found, but much of the cave is unstable and adversely affected by collapse, primarily due to the locally intense folding in the weak mudstone-rich basal part of the Black Rock Limestone. For this reason, the cave has not been subjected to a detailed geomorphological investigation as little of the original wall morphology is intact. The deepest part of the cave is an active streamway that gently descends obliquely down-dip and reaches a depth of 109 m AOD. This point is only a short horizontal distance north of the entrance and emphasises the steeply dipping nature of the cave. This streamway must be at or close to the present base-level as seen in Pierre's Pot.

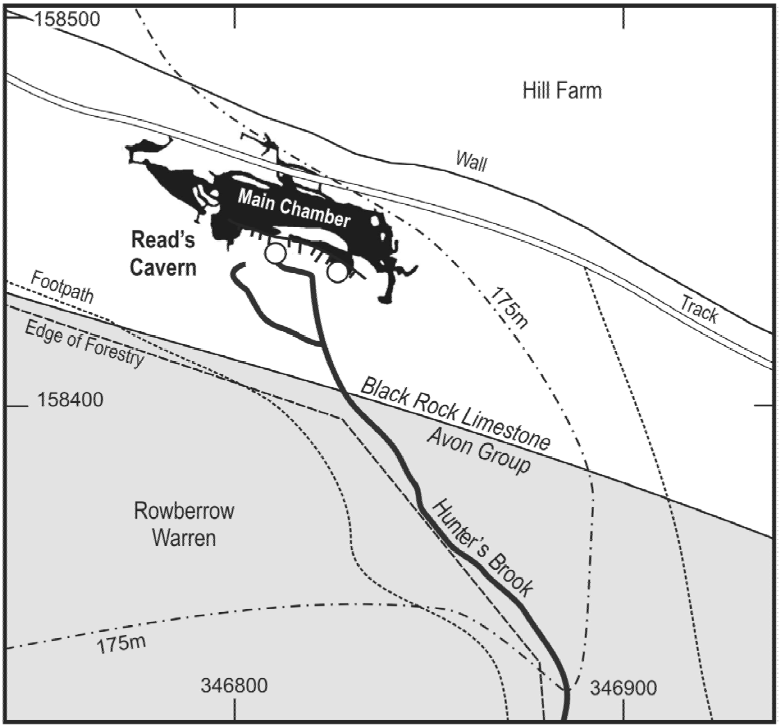

Figure 5. *Simplified survey of Read's Cavern. Adapted from a survey by W.I. Stanton, published by Wessex Cave Club (WCC).*

Bos Swallet

This cave (Figure 6) has been described by Boycott *et al.*, 1998, who also included a survey of the cave. Located in the base of a dry sinkhole, a small joint-guided vadose passage descends steeply down-dip before entering a small strike-orientated phreatic chamber (Disappointment Chamber) at an elevation of c. 166 m AOD. This probably represents a very small pre-existing phreatic conduit that has been intersected and enlarged by an invasive vadose streamway entering from the swallet. A tight vadose slot in the floor of Disappointment Chamber leads down an enlarged bedding plane to the head of a short fluted pitch, which enters a second small phreatic chamber at 148 m AOD. From here a small phreatic tube heads along the strike to the east to another short pitch and the final narrow descending vadose rift at 136 m

AOD. The cave has been abandoned by its formative stream and only a small drip-water trickle is seen in the current cave. The strike-aligned phreatic passages intersected in this cave are very small, and may well be impassable except where enlarged by later invasive vadose streamways, as has happened in Disappointment Chamber.

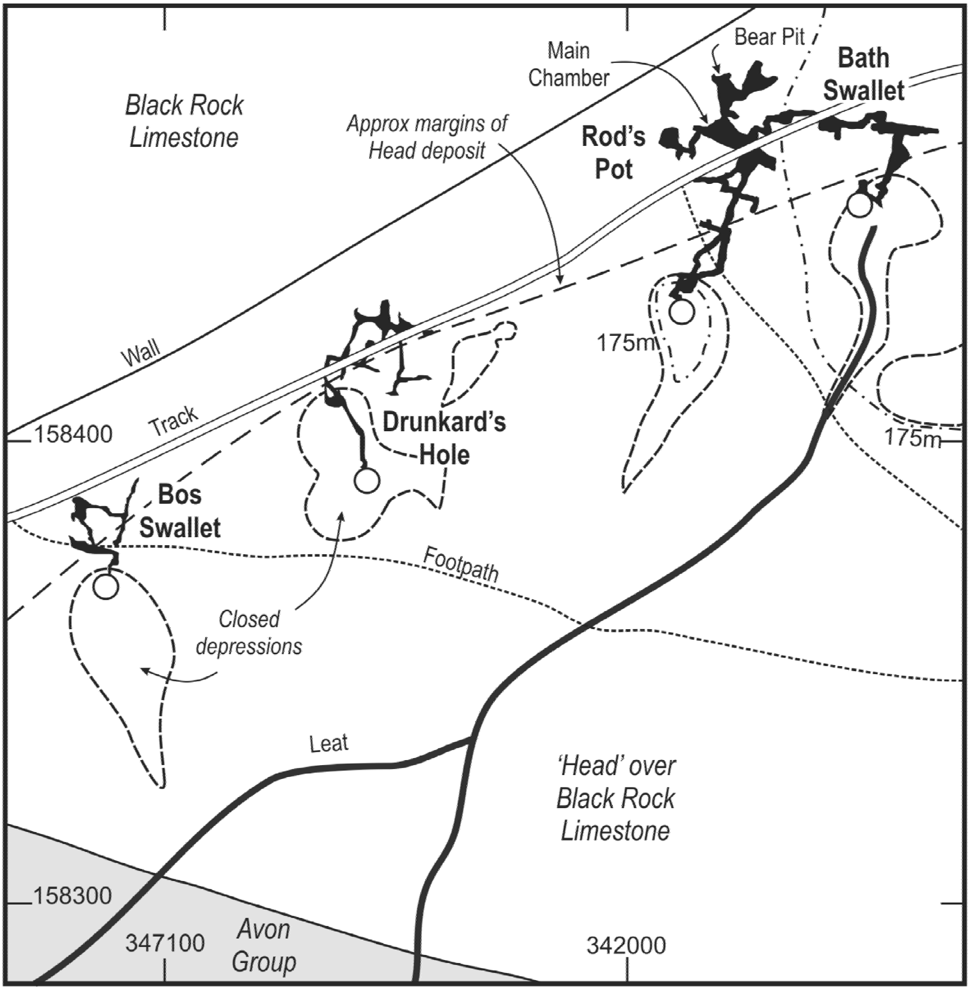

Figure 6. *Simplified survey of the Bos Swallet to Bath Swallet group of caves. Adapted from surveys by UBSS, WCC and Cheddar Caving Club.*

Drunkard's Hole

Located in a sinkhole adjacent to Bos Swallet, Drunkard's Hole is a short cave 127 m long and 48 m deep. It has been described by Williams and Farrant (1992) who also included a survey of the cave, though the north-point is 180° in error. The cave is very similar to Bos Swallet. A narrow, joint-aligned vadose trench descends steeply down-dip before turning into an eastward trending horizontal strike-oriented phreatic tube 0.75 m in diameter at 150 m AOD, which chokes after about 10 m. Part way along this tube, a second joint-guided, vadose rift descends further, initially via a 10 m pitch to another small strike-orientated, phreatic tube at 141 m AOD. Digging proves that this phreatic passage continues both to the east and the west (A. Sparrow, *pers. comm*.). To the east, this tube intersects several joint-guided dip-oriented vadose trenches running parallel to the entrance rift. These extend back towards the surface, but are either sediment filled or too narrow to follow. From this level, a third vadose canyon descends down-dip to the current end of the cave, a small north-ward trending phreatic tube at 127 m AOD which is sediment choked.

Rod's Pot

This is the largest, and best developed, of the four caves between Read's Cavern and the West Twin valley. The geology of Rod's Pot was described by Donovan (1949). It is developed in the lower half of the Black Rock Limestone, but cannot be far below the 'Main Chert beds' of Green and Welch (1965). The dip is 64° at 030° throughout most of the cave, but locally steeper near the entrance. The entrance is located in the base of a dry sinkhole with a prominent dry stream trench incised into the southern side of the depression. It is possible that a stream may have sunk here in recent times before the construction of a leat upstream. The first part of the cave consists of two joint-aligned, steeply descending vadose canyons developed down-dip along several bedding planes. These unite in a short section of phreatic passage at 150-152 m AOD. A couple of vadose shafts, aligned along the same joint as the entrance rift, descend around 12 m from this level to a small phreatic chamber at 140 m AOD choked with a sandstone fill. The phreatic tube continues northwards over the head of the pitches to the top of the Main Chamber. Just beyond the pitches, the passage intersects another phreatic passage that extends a short distance both to the east and the north-west. The passage floor is covered with large sandstone cobbles, and phreatic scallops in the roof suggest flow was to the west. This passage is interesting as it doglegs along strike and then along north-east trending joints, stratigraphically ascending the bedding to the north-west as it does so. Each short section of joint-aligned passage links one bedding plane with the next stratigraphically higher bedding plane.

The Main Chamber itself is a large, steeply sloping, bedding-guided chamber which descends down to a mass of boulders at 140-143 m AOD. The upper part of the chamber is roofed by a thick calcite vein aligned along the bedding (Donovan 1949), probably related to slippage along the bedding plane. In the lower part, the chamber roof is horizontal with a network of half tubes etched into the roof. These may result from the initial phreatic development of the cave, but are perhaps more likely to result from paragenetic modification of the cave following sediment influx (see below). Purple Passage trends eastwards from the Main Chamber at approximately this level. It links to the adjacent Bath Swallet via an excavated shaft.

From the base of the Main Chamber, an excavated phreatic passage extends westwards towards Drunkard's Hole at c. 140 m AOD, and leads to Hanging Rock Chamber. This steeply ascending chamber intersects the same horizontal phreatic passage seen at the top of the Main Chamber at 150 m AOD. These two phreatic passages almost certainly connect to the eastward trending phreatic passages seen in Drunkard's Hole at the same elevations (Figure 7). However, Drunkard's Hole lies around 100 m to the south-west, so if these passages do connect, there must be a significant section of joint orientated passage, or one or more phreatic loops. In the floor of the Main Chamber, another steeply descending enlarged vadose bedding plane drops to the Bear Pit, where it turns into a small, choked phreatic tube at c. 127 m AOD.

There is plenty of evidence of an extensive sandstone sediment fill, derived almost exclusively from the Portishead Formation, both in the entrance rifts where masses of sand and pebble rich sediment can be seen in the roof (Donovan, 1949), and in the passages leading off the Main Chamber. Much of this sediment has been flushed out by subsequent stream action, but pockets still remain.

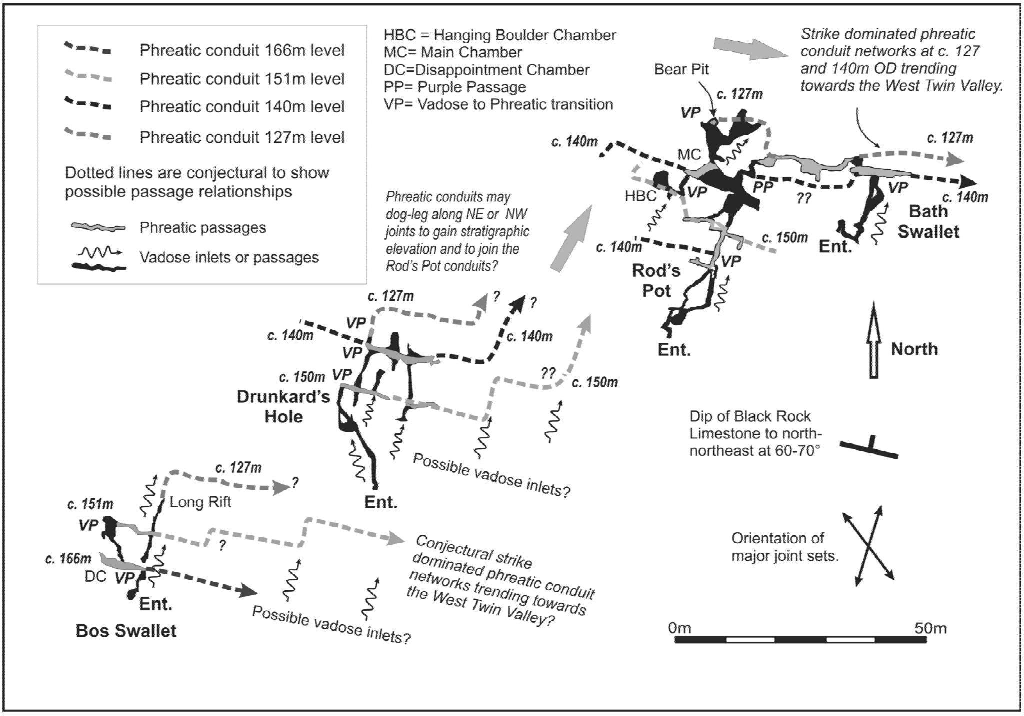

Figure 7. *Schematic evolution of the Bos Swallet-Drunkard's Hole-Rod's Pot-Bath Swallet system. Four distinct phreatic levels can be identified that represent distinct independent phreatic conduit systems. These are connected by invasive vadose inlets. Some of these inlets merely intersect pre-existing phreatic conduits; others directly fed, and are coeval with, the phreatic conduits. The connections between the caves are purely conjectural, but it is likely that these phreatic conduits drained approximately eastward, predominantly along strike. The observed location of the vadose to phreatic transitions for each of the levels is shown.*

Bath Swallet

Bath Swallet is an intermittently active stream sink in a large compound closed depression adjacent to Rod's Pot. The depression has undergone repeated subsidence. The cave entrance is at the base of the depression. Beneath the entrance series, the stream descends 20 m down a fine series of fluted vadose pots developed beneath a single prominent, steeply dipping bedding plane. At the base, it intersects a moderately large phreatic passage developed along strike at 140 m AOD. To the east the streamway extends for a few tens of metres before it disappears down another steeply descending bedding plane. This large section of passage occurs where the modern stream has intersected and enlarged a pre-existing relict phreatic passage. This relict passage can be seen to continue both to the west (where it probably links up with the phreatic development at the base of the Main Chamber in Rod's Pot) and to the east where it becomes choked. There is no evidence for phreatic passages at the 150 m level as seen in Rod's Pot which suggests Bath Swallet is a younger vadose invasion cave and was not an active swallet at the time when the 150 m level was active.

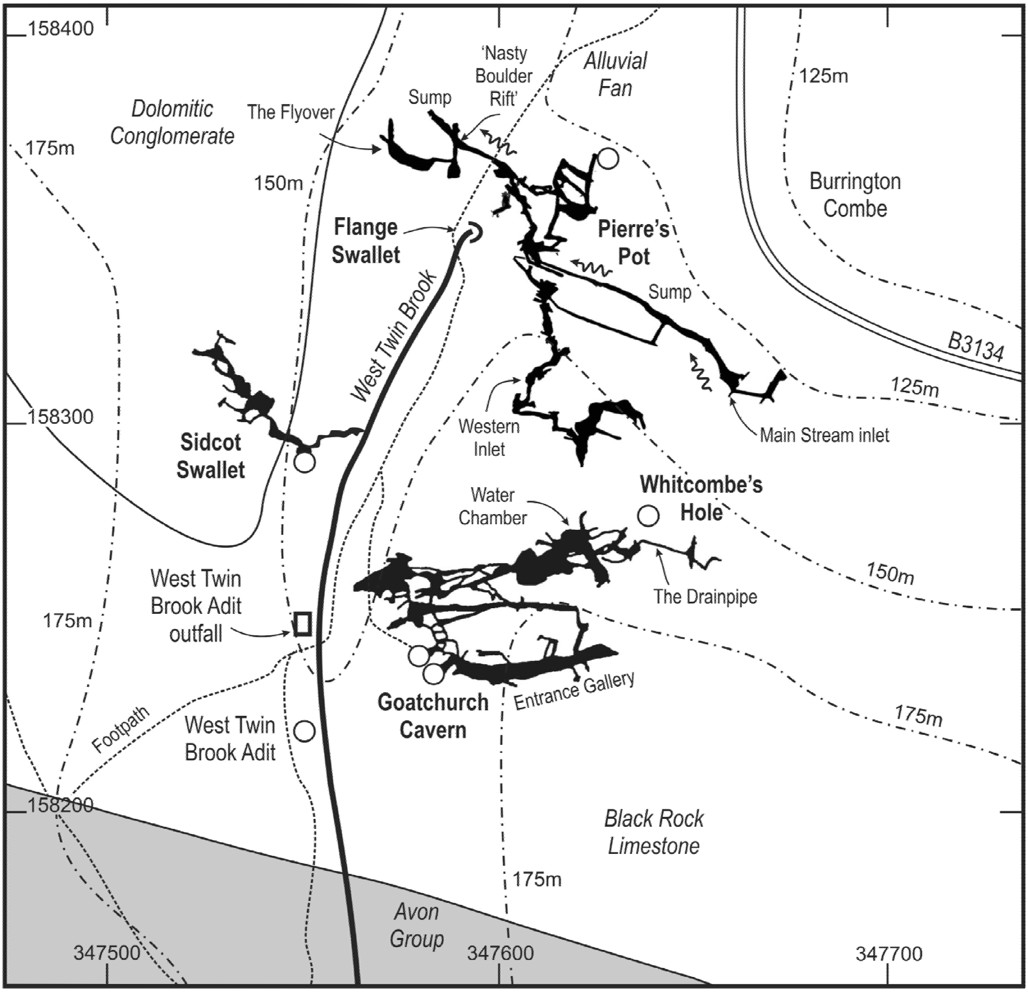

Figure 8. *Simplified survey of Sidcot Swallet, Goatchurch Cavern and Pierre's Pot. Adapted from surveys published by UBSS and Mendip Caving Group.*

Several ways on down the formative bedding planes have been dug for up to 15 m to intersect another series of small-bore phreatic passages at around 131 m AOD. This lower level is known to connect with the Bear Pit in Rod's Pot as a flood pulse in the eastern part of the passage caused water to back up there (A. Sparrow *pers. comm.*). An up-dip climb back up to the 140 m level is the link to Purple Passage in Rod's Pot. This low-level connection passage is either a phreatic loop along a single bedding plane or two independent phreatic passages linked via two vadose dip-orientated shafts. The sediment filled nature of this passage, coupled with good phreatic anastomotic features and parasitic half tubes etched in the ceiling suggests it may have undergone localised paragenetic modification.

All four caves (Bos Swallet, Drunkard's Hole, Rod's Pot and Bath Swallet) are genetically linked (Figure 7). They were all formed by one or more small streams or trickles which drained the northern flank of Black Down. Rather than sink along the Avon Group – limestone contact, a blanket of solifuction and slope-wash deposits derived from the Portishead Formation at least 3 m thick (Tratman, 1963) keeps water on the surface until it reaches the line of the track. Here the water has sunk at many different points over time. However, these rivulets were diverted in the 18th or 19th Century following the construction of the leat that leads from the Hunter's Brook towards the cottages at the top of track known as Link Lane, and all the water now sinks in Bath Swallet (Boycott *et al.*, 1998). The well-incised dry valley leading into the entrance sinkhole at Rod's Pot suggests that this sink was active until relatively recently. Similarly, ApSimon (1997) suggests that a small, but significant stream sank in Bos Swallet in Beaker times (Middle Bronze Age). The highly ephemeral nature of this stream suggests it is not fed by a significant groundwater source, and relies mostly on surface runoff and groundwater in the superficial deposits.

Each cave consists of a series of dip-orientated joint-aligned vadose passages which descend steeply down-dip and then either intersect, or turn into, a horizontal network of phreatic strike passages that generally trend approximately east-west. This process of cave formation has occurred several times, with each new phase of cave development adjusted to a new, lower water-table. This has created a stacked series of phreatic conduit networks, each linked by vadose inlets. This phreatic network was fed by each of the sinks (depending whether it was a functioning swallet at the time), thus creating an integrated system of passages. Some of the vadose inlets are younger than the relict phreatic passages and merely cut across them (for example, the rifts in Drunkard's Hole). Others utilise them for a short distance, sometimes enlarging them, such as the streamway at the base of the entrance pitch in Bath Swallet.

Although the caves are probably linked, the connections may well be sediment choked except where more recent streams have flushed out the sediment fill. However, each cave is at a different stratigraphic level, so if they are all connected by a single linear 'main drain', at each former phreatic level, then there must be significant north-east trending joint-aligned passage segments in order to 'join the dots'. It is perhaps more likely that at each former water-table level there is a dendritic network of roughly east-west trending predominantly strike-aligned phreatic conduits with regular doglegs along north-east or north-west trending joints which gradually coalesce to the east or north-east, each cave contributing one or more tributaries to the main conduit. The conduits do appear to get larger in an eastward direction. If the modern drainage system in Pierre's Pot and Lionel's Hole is analogous, it would suggest that each tier of relict passages generally trended east or northeastward towards Burrington Combe, each initially focussed on a northward-draining 'main drain' leading to a former resurgence, probably at or close to the foot of Burrington Combe. One such resurgence may have been Aveline's Hole.

The present groundwater drainage from Read's Cavern must flow east to join the main conduit flowing towards Rickford. As such it is likely to be similar to the phreatic palaeo-conduits in the Bos Swallet to Bath Swallet series of caves, probably flowing along a strike-dominated conduit with the Bath Swallet water entering as a down-dip tributary part way along at the modern day water-table.

The West Twin valley caves.

The second group of caves is centred on the West Twin valley. The plan survey of these caves is shown in Figure 8.

Goatchurch Cavern

At well over a kilometre in length, Goatchurch Cavern is by far the longest cave in the Burrington area. It constitutes a complex network of generally phreatic and paragenetic or floodwater maze passages developed in a narrow band of the Black Rock Limestone less than 20 m thick (Figure 9). In its simplest form, it consists of a series of strike-aligned phreatic conduits developed along no less than five distinct levels. These are connected by a multitude of vadose canyons which have often utilised, enlarged, modified and in some cases almost obliterated the existing phreatic conduits. Collapse and sediment infill complicate the picture still further.

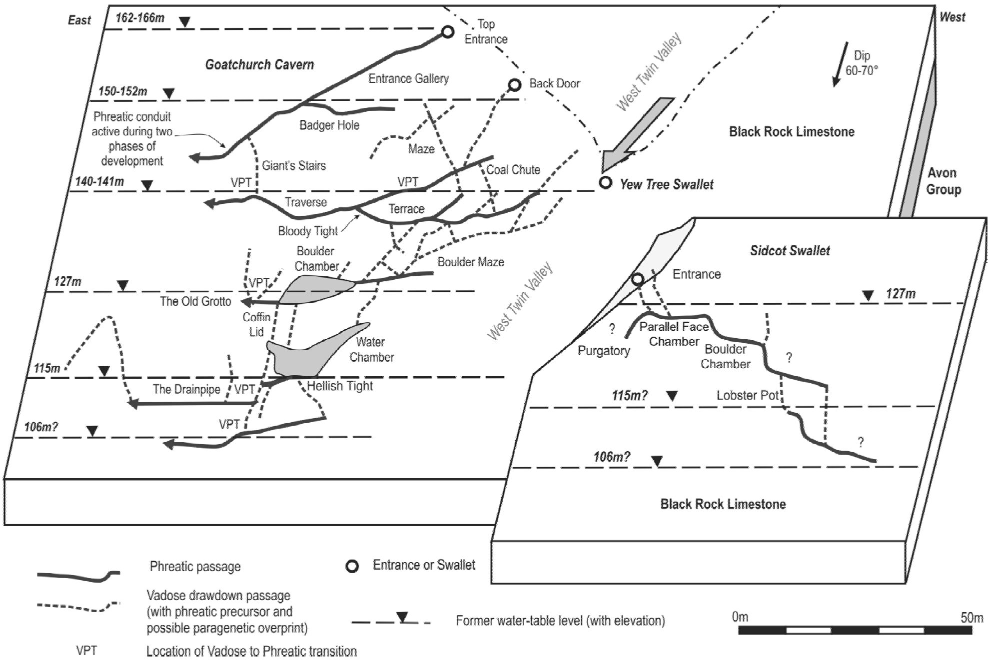

Figure 9. *Simplified block elevation survey of Goatchurch Cavern and Sidcot Swallet viewed looking south showing the main genetic elements that make up the cave systems. The observed location of the vadose to phreatic transitions for each of the levels is shown as are the former water-table levels so defined.*

The large Entrance Gallery is a strike-aligned phreatic tube which gently slopes down eastwards aslant the dip to a flowstone choke at 146 m AOD. It represents the descending limb of a single phreatic loop developed below a water-table at or above c. 162-166 m AOD. This passage should continue and eventually regain the 162-166 m level. The low passage, Badger Hole, entering part way along may be a later phreatic conduit developed when the water-table dropped to c. 150-152 m AOD which utilised the deeper part of the original Entrance Gallery phreatic loop.

From the Entrance Gallery, two down-dip passages descend steeply to the north. The largest of these is the Giant's Stairs, a dip orientated bedding plane tube with a paragenetic parasitic half-tube incised into the roof above which is traceable back up into the Entrance Gallery (Figure 10). The floor of this passage is a vadose canyon. This intersects a bedding-oriented strike-aligned phreatic conduit (the Traverse) at c 141-143 m AOD, which links to the Back Door. The Back Door is a similar down-dip tube to the Giant's Stairs, and probably once drained from the Entrance Gallery, but has been truncated by hillside retreat. The downstream end of the Traverse is the small, sediment choked passage that leads off east-wards from the base of the Giant's Stairs. The upstream end is indistinct, but some of the tubes that lead off the Traverse, such as 'Bloody Tight' (Figure 11) and the roof tubes above the Terrace may be phreatic risers feeding water obliquely along strike and up-dip into the Traverse from the large chamber at the foot of the Coal Chute that once served as a major inlet to the cave.

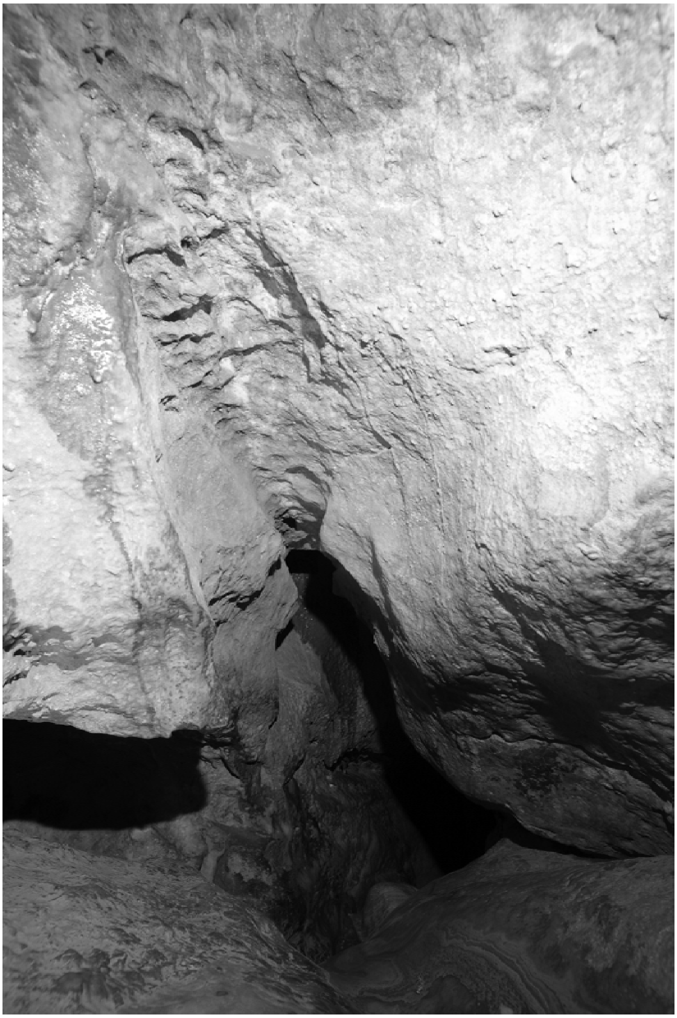

Figure 10. *Paragenetic half tube incised into the roof above the Giant's Stairs, Goatchurch Cavern. This tube, and another one adjacent, can be followed a short distance along the wall of the Entrance Gallery phreatic tube. They were incised when the lower part of the descending limb of the Entrance Gallery phreatic loop was at least partially choked with sediment.*

Photo: Andrew Atkinson.

The phreatic tubes that developed at or just below the 141-143 m level often have later vadose canyons incised into their floors which fed water via a multitude of routes obliquely down-dip to the Boulder Chamber area following a drop in the water-table. The large sediment choke that occurs at the western end of the Boulder Maze may be another inlet at this level, utilising the upstream part of the existing 141-143 m conduit. The Boulder Chamber is much affected by collapse, but a phreatic passage appears to lead along strike at or just below this level, ending in a sediment choke at c. 125-127 m AOD in the Old Grotto adjacent to the Coffin Lid. The sediment here appears to be mass-movement deposits that have run-in via a choked vadose bedding passage from the base of the Giant's Stairs which lies a short distance above and directly up-dip.

Both the Coffin Lid and the rift below are joint-guided vadose passages which unite in the Water Chamber, which is a large strike orientated chamber at c. 115 m AOD. A series of small strike-aligned phreatic tubes lead off from this area, including the Long Crawl, the Drain-pipe and Hellish Tight. Scalloping in these tubes indicate eastward flow. Locally well-developed phreatic pendants and anastamoses suggest passage development here occurred under paragenetic or floodwater conditions, although the sediment fill has long since been removed. The small stream in the Water Chamber has been traced from Yew Tree Swallet (Figure 12), a choked sink almost opposite Sidcot Swallet blocked by spoil from the West Twin Brook Adit upstream. It is clearly a misfit stream and is beginning to incise a small vadose canyon into the chamber floor.

In summary, Goatchurch Cavern is a stacked series of strike-oriented phreatic passages linked by a network of down-dip vadose inlets developed on at least five discrete former base-levels. This passage network has locally undergone paragenetic modification to create a complex phreatic/paragenetic maze along strike and down-dip, developed in just a few beds of steeply dipping Black Rock Limestone. It is clear that the cave has undergone several episodes of cave formation, partial sediment aggradation and localised paragenetic cave development, followed by sediment flushing under vadose conditions.

Sidcot Swallet

Sidcot Swallet is a small, relict, swallet cave now abandoned by the West Twin Brook (Figure 8). Stratigraphically it lies around 20 m higher in the Black Rock Limestone than the adjacent Goatchurch Cavern. From the entrance, the cave generally trends north-westwards along the strike as a series of closely-spaced solutionally enlarged bedding planes interspersed with several dip-oriented joint passages. The cave appears for the most part to comprise phreatic bedding planes and joints. The absence of any significant stream-laid allochthonous sediment fill is notable (Bull and Carpenter, 1979). There are no clearly defined former water-tables. However, as both Purgatory and Parallel Face Chamber exhibit phreatic features, the water-table was probably at or above c. 127 m AOD when the cave was formed. The avens in the Boulder Chamber also both close down at around 127-129 m AOD. However, much of the original passage morphology is obscured by flowstone and collapse. It is possible that a second water-table exists at the base of the Lobster Pot at c. 115 m AOD but the evidence for this is poor. The basal phreatic passages are at c. 106 m AOD and are thus at or just above the level of the streamway in Pierre's Pot, 80 m to the northeast. The cave probably functioned as an independent tributary to the Burrington master conduit rather than being a truncated part of Goatchurch Cavern. The lack of sedimentation in Sidcot Swallet may be due to complete choking of the swallet preventing sediment ingress, or subsequent flushing of the sediment.

Purgatory Passage trends in a north-easterly direction and is probably joint-aligned. The end dig is directly below the West Twin valley floor between Sidcot Swallet and Flange Swallet. It is possible that this part of the cave is genetically distinct from the rest of the cave, and probably connects with Pierre's Pot on the opposite side of the valley.

Pierre's Pot

The upper part of Pierre's Pot is another abandoned phreatic remnant which probably once functioned as a high-level relict cave system at or just below the 127 m former water-table. The survey is shown by Mullan (1998). The lower series is genetically distinct and is entered via a rather fortuitous and extremely tight vadose rift into an active streamway which is the downstream continuation of the East Twin streamway. This lower series consists of a partially relict conduit graded to a former water-table at around 105-106 m AOD. This emerges from the Main Stream Inlet sump as a horizontal, strike-aligned passage, then trends north-westwards along a joint and descends via a phreatic loop to c. 98 m AOD before ascending back up to c. 106 m AOD via a joint aligned riser (the Nasty Boulder Rift) and The Flyover. The modern stream has subsequently found a slightly lower, rather immature route through the Main Stream Inlet sump (at c. 101 m AOD) and on down to the downstream sump at 96 m AOD, utilising the lower part of the former phreatic loop. The lower end of the streamway is at approximately the same level as the stream seen in Lionel's Hole. Close to the squeeze down from the upper series, the streamway is joined by a tributary passage which can be followed up past the Western Inlet to a choke. The upper part of this tributary is at 113-118 m AOD and may represent an earlier phase of cave development.

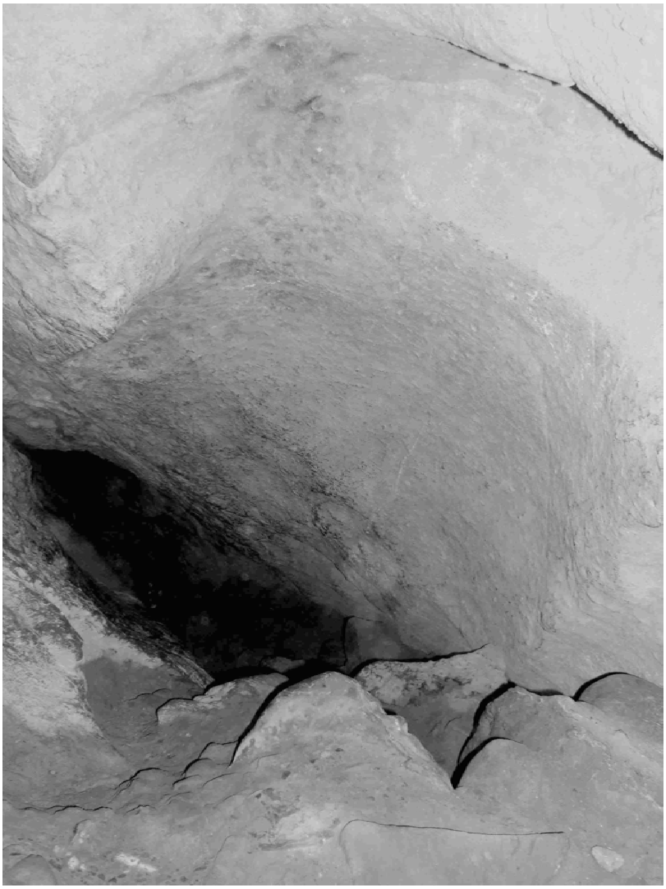

Figure 11. *'Bloody Tight', a well-developed, strike-aligned phreatic tube that developed just below the former water-table at 141 m AOD. It once transmitted water up into the Traverse.*

Photo: Chris Binding.

All three caves are likely to be linked underground, although how the caves relate to each other is at present unclear. The passages in Goatchurch Cavern generally trend east (but probably turn north a short distance beyond the present end of the cave), while Sidcot Swallet appears to have been formed by water flowing west, as is the case with Pierre's Pot. The relationship between these caves would repay a more detailed investigation.

The East Twin valley caves.

The third group of caves is centred on the East Twin brook. A plan survey of these caves is shown in Figure 13.

East Twin Swallet-Spar Pot.

East Twin Swallet is the modern stream sink for the East Twin stream, although it has sunk at several places between the present sink and the B3134 road in recent years. Water sinking at [ST 4796 5819] reappears in the lower part of the second chamber (Osbourne, 1999). Water was also observed to sink in a hollow behind the lay-by at the foot of the valley. From the entrance, the stream descends east a short distance along the strike, and pops out into a large pre-existing joint-guided and formerly sediment choked passage. Much of the passage roof and walls here consists of a sandstone-rich cobble fill, which chokes the passage upstream. The stream turns sharply north and descends steeply down a joint guided passage, reaching a wet weather sump/dig at or below 116 m AOD. The stream reappears at 101 m AOD in the Main Stream Inlet sump in Pierre's Pot 300 m to the west-north-west. This section of passage may well be a relatively recent, immature capture of the stream along strike.

Figure 12. *Yew Tree Swallet. This photo was taken in 1919 before the West Twin Brook Adit was completed. The site is now buried under spoil.*
Photo is from the F.W. Reader collection, British Geological Survey photographic archive, Keyworth. Image No. P249847_S2

Part way down the streamway is the low phreatic tube at 127 m AOD which connects East Twin Swallet to Spar Pot (the entrance of which is now blocked). Here a small strike-orientated phreatic tube with some good paragenetic phreatic pendants over a coarse, poorly sorted sandy gravel fill with cobbles of sandstone crosses the passage, but is choked either end. A vadose rift in the floor descends steeply before intersecting another phreatic tube at c. 115 m AOD. From here the cave trends predominantly along the strike, running parallel to, but around 50 m to the south of Lionel's Hole.

Lionel's Hole

Lionel's Hole is one of the most complex caves in Burrington. Much of the cave is developed along the strike, either on steeply inclined bedding planes, or along parallel, but southerly dipping bed-normal joints (Figure 15). Extensive collapse, coupled with multiple vadose inlets, has created a very complex maze, particularly in the Labyrinth.

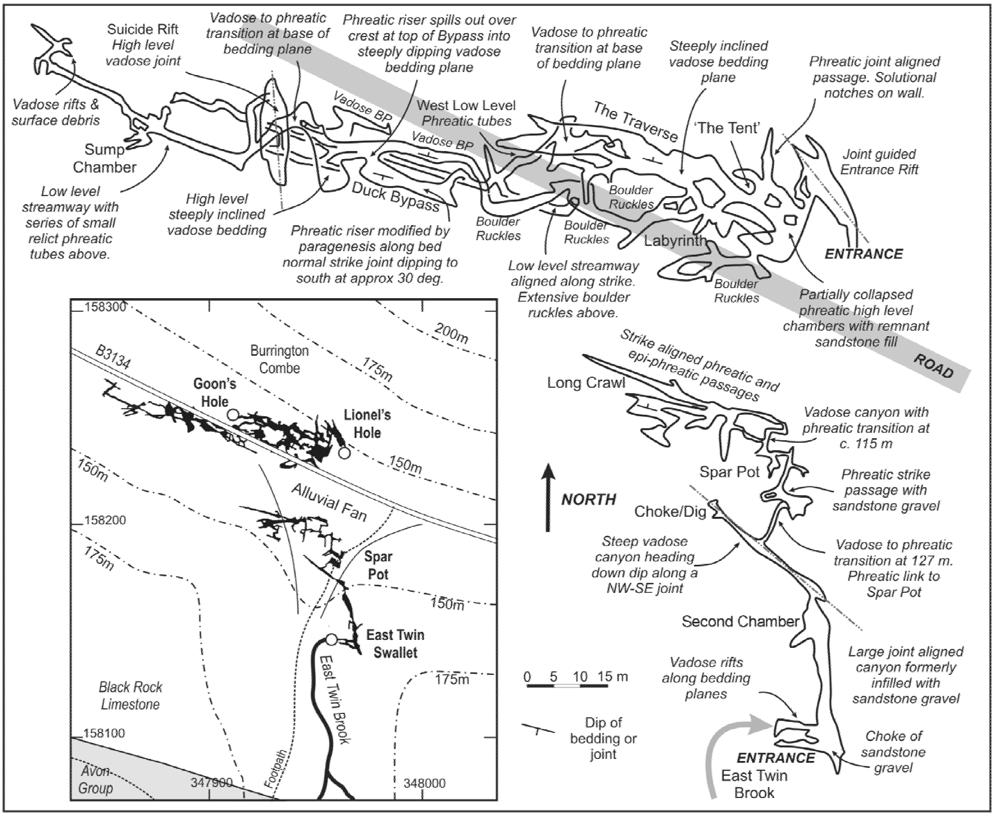

Figure 13. *Survey of East Twin Swallet, Spar Pot and Lionel's Hole. Adapted from surveys published by UBSS and WCC.*

The cave essentially consists of a low level, strike aligned, active streamway above which is a series of high level phreatic chambers and bedding plane rifts much affected by collapse. The joint orientated vadose entrance passage drops steeply down to a cross rift which enters a series of high-level phreatic chambers and passages (Boulder Chamber and The Tent) much modified by collapse. These phreatic chambers were formed when the water-table was at or above c. 126 m AOD. At the Tent, a phreatic joint-aligned passage trends north and displays some well-developed horizontal notches etched into the passage walls, indicating former sediment fill levels. At The Tent are some well-developed phreatic tubes developed both along strike and along the joints. These are lost at the start of the Traverse, which is a well-developed vadose bedding plane enlarged by percolation inlets from above. The lower end of the Traverse exhibits some phreatic features around 4 m above the base at c. 106 m AOD. A route along a small phreatic tube at the base of the Traverse (West Low Level) and a short duck leads to a two metre descent to the streamway, itself a phreatic tube at around 100 m AOD. This leads to a second duck which can be bypassed. This bypass ascends from the stream obliquely along a bed-normal joint dipping at c. 30-40° to the south up to c. 110 m AOD. This passage is characterised by some good phreatic pendants and copious coarse sandstone fill, both suggestive of paragenetic modification of the passage on the rising limb of a shallow phreatic loop. Some of the sandstone cobbles at the crest of the loop are 10-15 cm in diameter. This riser spills over into another inclined vadose bedding plane with some excellent small scale trenches which descends steeply to a phreatic tube at c. 105 m AOD. This tube leads to a second phreatic tube about 3-4 m lower, just above the modern streamway, itself a partially drained phreatic tube. The development of three distinct phreatic tubes suggests that the cave developed at three closely spaced levels between 92 and 105 m AOD. From here to the end of the known cave, the morphology of the cave changes to a vadose bedding-orientated rift which leads to a joint-aligned cross rift, and a second bedding-orientated vadose rift. To the south-east this ascends steeply to tree roots and surface debris.

The Labyrinth is an area of massive collapse caused by undermining of the well fractured limestone by the modern streamway. This process is aided by the dissolutional power of numerous vadose percolation inlets entering from above. The large amount of sandstone debris in the Boulder Chamber – Labyrinth area suggests that this part of the cave was close to a possible former sink or flood swallet for the East Twin stream. This is perhaps unsurprising given that the cave entrance just above is located close to the floor of Burrington Combe, directly opposite the foot of the small alluvial cone that issues from the East Twin valley. This proximity to the mouth of the East Twin valley and thus susceptibility to the floods that issue from it may also explain the coarse sandstone fill deposited on the rising limb of the phreatic loop that comprises the bypass to the second duck. Similarly large clasts of sandstone can be observed in the sediment fill in East Twin Swallet (Figure 14).

Spar Pot and Lionel’s Hole are almost certainly linked. A smoke test conducted by Alison Moody and Caremn Smith in June 2002 established that smoke from Spar Pot could be detected in the Boulder Chamber in Lionel’s Hole, and particularly in Junction Chamber. There is also likely to be a link with the nearby Goon’s Hole [ST 4791 5825], a small phreatic cave a short distance down-valley from Lionel’s Hole which ends in a narrow draughting rift.

Other Caves.

Aveline’s Hole

Aveline’s Hole is the obvious large entrance adjacent to the road on the bend a short distance up from the ‘Rock of Ages’ at the foot of Burrington Combe. The entrance is at an elevation of 100 m AOD. It comprises a single large phreatic passage in massive Burrington Oolite that descends steeply down for around 10 m before ascending slightly and closing down in a mud choke. A small side passage at the lowest point leads to a dig. The cave is phreatic throughout and parts of the walls have well developed outward flowing phreatic scallops. This strongly suggests that Aveline’s Hole was once a significant resurgence. Tratman (1963) also considered the cave to be a former resurgence. It is possible that the cave is merely a passage truncated by incision of the valley, but there is little evidence of any passage continuing on the opposite side of the Combe.

Tween-Twins Hole

Tween-Twins Hole, as the name suggests, is located on the southern side of the Combe between the East and West Twin valleys. It comprises a short length of largely excavated, almost totally sediment filled, relict phreatic passage running parallel to the steep valley side and intersecting the surface at several points. The sediment is mostly coarse sand, silt and mud, large derived from the Portishead Formation. The cave was formed when the water-table was at or above c. 140 m AOD.

Plumley's Hole

Plumley's Hole is located in an alcove in the quarry opposite the 'Rock of Ages' at the foot of Burrington Combe, at an elevation of 100 m AOD. Now blocked, it was opened by quarrying in 1874 and was estimated to be around 20 m deep by Balch (Dougherty *et al.*, 1994), with some reports mentioning a running stream.

Foxes Hole and other minor sites

Foxes Hole is located on the northern face of Burrington Combe a short distance up the valley from Lionel's Hole. It consists of two phreatic chambers developed when the water-table was at or above 172 m AOD. Tratman (1963) noted much reddish yellow silt in the cave. Its relationship to the rest of the Burrington caves is unclear. The neighbouring Trat's Crack [ST 4820 5820] is a rift passage descending steeply down dip which ends in a perched sump. Milliar's Quarry Cave [ST 4775 896], near Burrington village is a similar steeply descending tube ending in a choke.

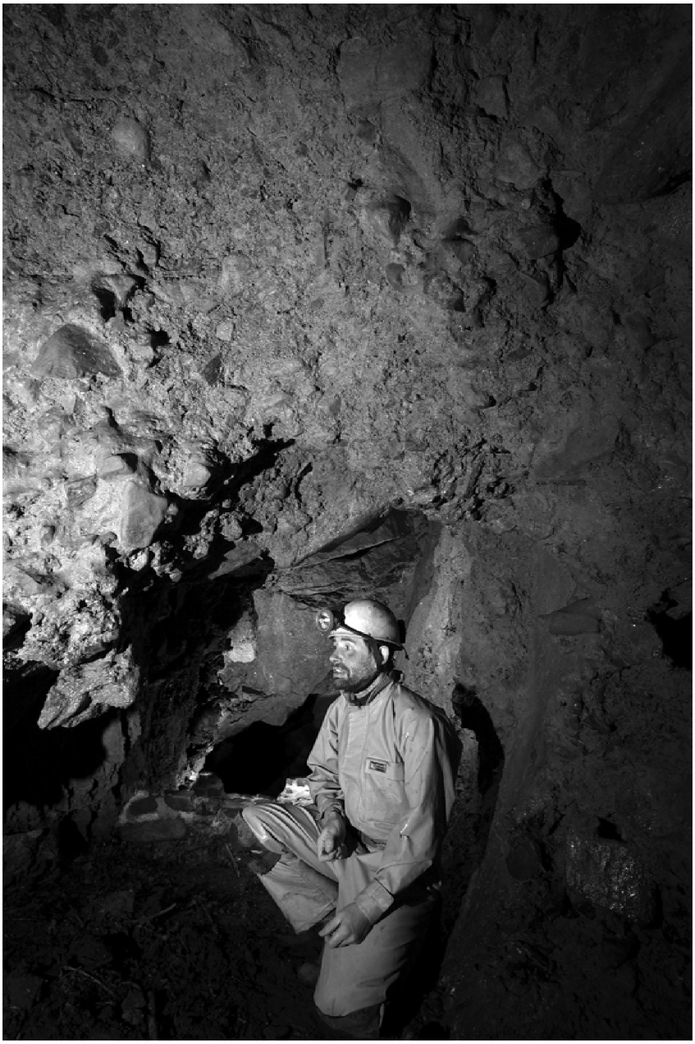

Figure 14. *First Chamber, East Twin Swallet. This passage was nearly completely infilled with a coarse, poorly sorted allogenic sediment fill comprised almost entirely of Devonian sandstone debris until it was flushed out by the stream in the 1940s.*

Photo: Andrew Atkinson.

Several other minor caves exist, mostly phreatic remnants, but none are significant in terms of their geomorphology. They are documented in Barrington and Stanton, (1977).

Speleogenesis.

The morphology of the Burrington caves is quite different from those on the southern flank of the Black Down pericline. The caves in Burrington are typically steeply inclined, tightly knit, complex three-dimensional maze caves with a dominant phreatic form. They are generally developed along relatively few bedding planes, with a significant strike component. In contrast, the caves along the southern side of Black Down are lower gradient, dominantly vadose, joint orientated systems.

Role of structure

This difference in character owes much to the contrasting geomorphological and geological situation. Nearly all the major known Burrington caves are developed in the steeply dipping basal part of the Black Rock Limestone. This well bedded sequence of crinoidal limestones has some significant bedding parallel discontinuities and generally closely-spaced bedding planes, particularly in the more mudstone-rich lower part of the succession. The location of the area on the steep, locally overturned, northern limb of the Black Down pericline has caused many of the bedding planes to slip in a reverse sense in order to accommodate tightening of the Black Down pericline as it was thrusted up over the T3 ramp (Williams and Chapman, 1986) during folding (Figure 2).

During bedding plane slip under a Variscan compressional regime (when σ_{max} was orientated approximately south to north, and σ_{min} vertical), any asperities on the original bedding plane surface would have rode over each other, creating tension gashes and conjugate pinnate joints, particularly in zones of increased compression or extension. These gashes and conjugate joints are often infilled with vein calcite. In the interbedded mudstone limestones sequence in the basal part of the Black Rock Limestone, much of the strain was taken up along weaker shale partings within the rock sequence, creating crush breccias of muddy limestone along the bedding partings. Many of the slipped bedding places are marked by calcite-filled slickenfibres or calcite veins. Good examples of these can be seen in Rod's Pot (Donovan, 1949).

During subsequent post-tectonic relaxation and Mesozoic extension, the stress field was changed to an extensional regime (i.e. σ_{max} was vertical and σ_{min} approx north-south). Much of the extension in the Mendip area was taken up in the formation of vertical fissures, subsequently infilled with sediment (Wall and Jenkyns, 2004), but some reactivation of the bedding plane faults in a normal sense may have occurred, as well as relaxing previously locked compressional fractures. This phase of extension may also have enabled groundwater flow to penetrate along the irregular openings aligned along the strike of the fracture plane, opening up many of the laterally extensive bedding planes to early groundwater flow and conduit inception (Figure 15).

Thus in the Burrington area, bedding plane slip and dilation of bedding plane apertures has made permeability much higher along strike than across the dip. This has enabled conduits to develop along strike on bedding partings in preference to the northwest-southeast trending joints or looping up and down dip in the Ford and Ewers model (Ford and Ewers, 1978) based on caves elsewhere on Mendip.

The steep dip also favours very steeply inclined vadose passages which rapidly descend to the contemporary water-table; the effect is to concertina the vadose passage component into a narrow zone close to the stream sink. The overall result is a series of predominantly phreatic conduits aligned along bedding planes, often along the strike or slightly oblique to the strike, linked or fed by joint-aligned vadose passages descending steeply down-dip. A good example of this type of development occurs in Drunkard's Hole (Williams and Farrant, 1992) for example.

It should be noted that where strike-aligned passages are horizontal., the passage trend will be the same as the strike, i.e. generally east-southeast to west-northwest. However, when the passage is descending obliquely down-dip, but along the strike, then the trend in plan view will either be more east-west if the passage is descending to the east, in the case of the Goatchurch Entrance passage, or more northwest–southeast if the passage is descending to the west as in Sidcot Swallet.

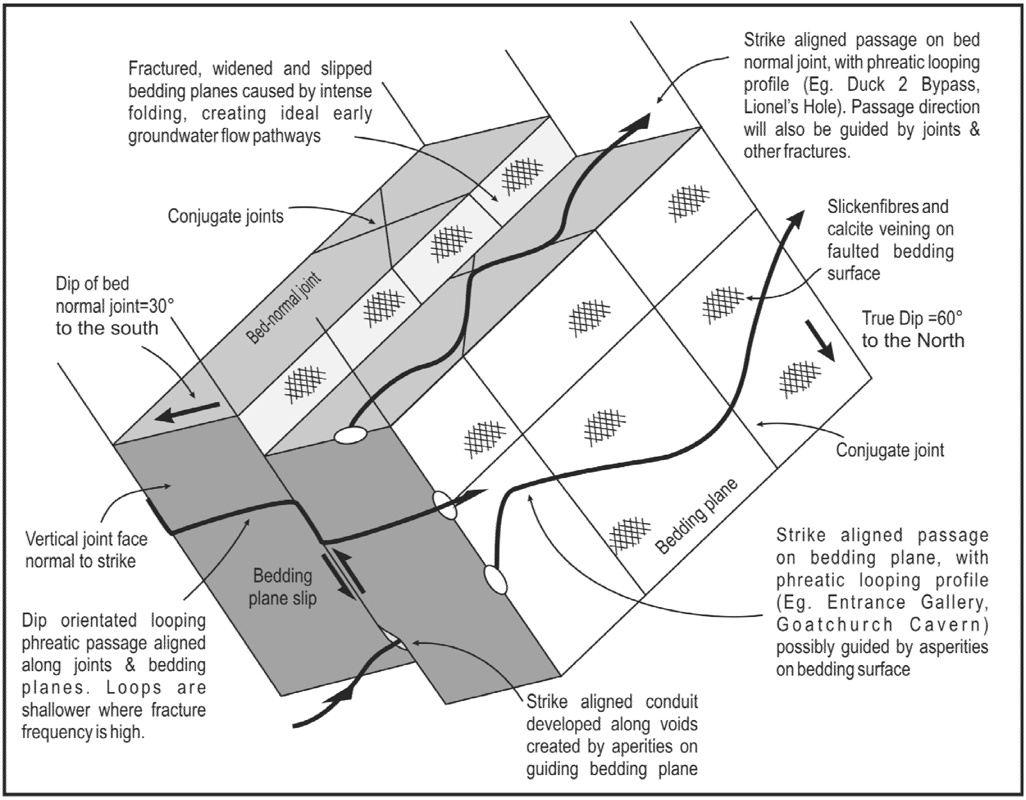

Figure 15. *Idealised block diagram of steeply dipping limestone beds showing the types of geological structures that influence speleogenesis in the Burrington area.*

This bedding control is clearly seen in the Bos Swallet to Bath Swallet series of caves, and particularly in Goatchurch Cavern, where the cave passages are often developed along the strike rather than perpendicular to the dip. Goatchurch Cavern has developed entirely within a few beds of limestone around 20 m thick, principally along just a few bedding planes, yet extends over 100 m along the strike. Lionel's Hole has a similar, strike-aligned morphology, being developed along a series of parallel bedding-planes and fractures. In addition to bedding planes, the bed-normal joints are often utilised. This is particularly apparent in Lionel's Hole where these joints have been enlarged to form southward dipping, strike-aligned conduits (Figures 13 and 15).

This model of strike dominated flow is supported by independent hydrological evidence. Tracer testing results indicate significant east-southeast to west-northwest flow patterns (Figure 4). The water sinking in East Twin Swallet has been traced to Pierre's Pot in the West Twin valley, almost directly below Flange Swallet. Similarly, the flow from Ellick Farm Swallet has been traced to both Langford and Rickford Risings (possibly via Lionel's Hole but this is as yet unproven) and Lamb Leer Cavern to Rickford Rising. In addition, the capture of flow from the former resurgence at Aveline's Hole, first to Squire's Well, then Rickford Rising and finally much more recently by Langford Rising have all taken place along strike, over distances of up to two kilometres.

The dominance of strike orientated cave development has enabled a high degree of flow convergence within the lower part of the Black Rock Limestone, as demonstrated by the quantitative dye tracing experiments performed by Crabtree (1979). This convergence may have been enhanced by the presence of significant chert and dolomite horizons within the middle and upper parts of the Black Rock Limestone. In a steeply dipping setting such as the Burrington area, these less soluble beds may act as a relatively impermeable barrier impeding direct flow to the north.

However, to reach the resurgences at Langford and Rickford, the conduits must pass stratigraphically up through these chert and dolomite-rich beds in the Black Rock Limestone, as well as the rest of the Carboniferous limestone sequence, and then up into the Triassic 'Dolomitic Conglomerate'. They must do this either via a series of northward trending phreatic loops, or by utilising the north-west to south-east or north-east to south-west orientated conjugate fracture sets within the limestone sequence. The north-east trending joint set will be favoured as they are normal to the strike, especially in a vadose environment where passages often follow the bedding plane-joint intersection. The route of the present day streamway from the end of Pierre's Pot probably follows a north-easterly trend along one or more of the conjugate joints, passing back under the Combe and close to Aveline's Hole (a possible former resurgence) and Plumley's Hole. Plumley's Hole, although now blocked, was estimated to be around 20 m deep by Balch (Dougherty *et al*., 1994), with some reports mentioning a running stream. If this depth estimate is correct, then the base of the cave cannot be that far above the present day water-table. This cave remains one of the most interesting sites in the Combe, located as it is half way between the sinks and the resurgences and would repay renewed excavation.

An alternative scenario is that the main north-draining conduit may have developed at the base of the Triassic Dolomitic Conglomerate infilled palaeo-valley that forms the western side of the Combe. Here Triassic erosion has incised a deep incision through the limestone sequence, which has been subsequently infilled with beds of limestone-rich breccia. These generally horizontal or gently dipping Triassic deposits are known to host significant cave systems (for example the outer parts of Wookey Hole). Water draining through the Pembroke Limestone Group along strike may have entered the base of this palaeo-valley and then flowed along the gentle north-ward dipping bedding planes. The depth of this palaeo-valley is not known with any certainty, but its eastern flank is exposed down to 100 m AOD opposite Aveline's Hole. The downstream end of Pierre's Pot trends towards this Triassic valley, along the northwest-southeast joint set. However, there is currently little evidence for this model, and the former resurgence at Aveline's Hole suggests groundwater flow was predominantly within the Pembroke Limestone Group in the past.

Given the relatively high frequency of both joint fractures and bedding plane partings within the Black Rock Limestone on the northern limb of the pericline, it is probable that the majority of phreatic conduits in the Burrington area will be correspond to State 3 cave of Ford (2000), or possibly water-table caves (State 4). Unlike the caves on the southern side of Black Down, very few deep phreatic loops are known; the largest occurs in the Goatchurch entrance passage (amplitude >17 m) and is aligned along the strike as opposed to down-dip. The more massively bedded limestones of the Burrington Oolite Formation may favour deeper phreatic loops, but as yet no significant caves in the Burrington Oolite have be found to test this theory. Part of one such loop is seen in Aveline's Hole (>13 m). Again, it is a strike-aligned passage.

Former water-table levels.

Several former phreatic water-table levels may be identified in the Burrington caves (Figures 16, 17; Table 5). These can be distinguished in several ways (for examples see Ford and Williams, 1989). The most secure method is to determine where a passage changes from a vadose to phreatic form. This is clearly visible in many of the caves, particularly Goatchurch Cavern, East Twin Swallet, Drunkard's Hole, Rod's Pot and Bath Swallet. Another method is to compare the altitudes of phreatic loop crests as these define the water-table, although few examples of good phreatic loops are seen in the Burrington area. Similarly, phreatic avens will close down at the water-table. These former water-tables so defined (Table 5) can then be correlated between the caves, (roughly along strike) the high degree of correspondence indicating reasonable confidence in the phreatic levels identified. The concordant former water-table levels indicate external base-level control on the development of the systems, or at least on the main drain behind the resurgence, rather than internal local stratigraphical or structural controls. In the Burrington area, the base-level is the resurgence level, usually at the lowest outcrop of the carbonate aquifer, here either the Pembroke Limestone Group or the Dolomitic Conglomerate. This in turn is governed by the depth of incision of the Congresbury Yeo valley to the north, which is related to the stripping of the soft impermeable Mercia Mudstone that drapes the northern flank of the Mendip Hills. This continual erosion and base-level fall has created a vertically stacked tier of relict phreatic cave systems.

Each of these former water-table levels probably developed during interglacial or interstadial periods as renewed cave development adjusted to lower base-level elevations developed in response to active surface erosion and incision of the weak Triassic mudstones during periglacial episodes. The relatively small falls between each former base-level reflect the lesser relief in the Vale of Wrington compared to the southern side of Black Down (Waltham *et al.*, 1997).

The highest unequivocal former water-table level seen is that at 166-160 m AOD, although it is possible that still higher levels may occur in the topographically higher eastern part of the study area. This water-table is not very well defined and can only be seen in Disappointment Chamber in Bos Swallet and the upper entrance to Goatchurch Cavern, although the phreatic passages in Foxes Hole [ST 4823 5822] at 172 m AOD may be associated with this level. The second is at c. 148-150 m AOD and is seen in the Bos Swallet-Rod's Pot cave systems and possibly in Goatchurch. Again, it is not very well defined, consisting of mostly small, sediment choked phreatic tubes. The third former water-table level, at the 141-143 m AOD, is more extensive and can be seen in Goatchurch as well as the Bos Swallet to Bath Swallet series of caves. It is clearly identified by vadose to phreatic transitions in most of these caves. The phreatic passage exposed at Tween-Twins Hole [ST 4774 5827] at c 137-138 m AOD is probably part of this system, and suggests this level should be present in the East Twin

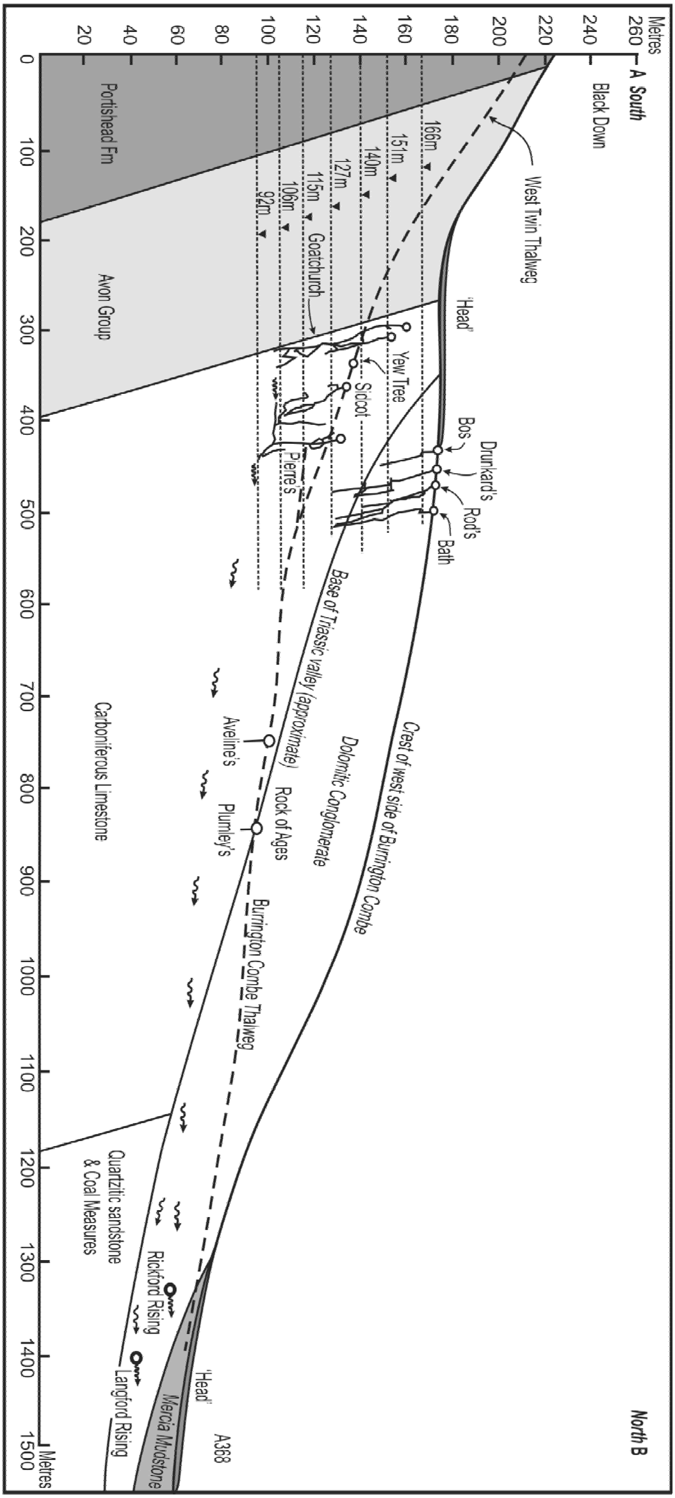

Figure 16. *North-South cross section (line A-B on Figure 18) along the western side of Burrington Combe and the West Twin Valley. The caves and resurgences are offset both east and west from the survey line. The depth of the Triassic fill within the palaeo-wadi is conjectural and may extend deeper than shown.*

valley caves too. It also corresponds with the knick-point in Burrington Combe just downstream from the entrance to Lionel's Hole, although to what extent this is actually a true knick-point is unclear. The break of slope in the valley floor here is more likely to be the downstream margin of the small alluvial fan at the foot of the East Twin valley. This extends across the Combe, creating a shallow closed contour feature in the Combe upstream. It is possible any floodwaters flowing down the Combe or water back-spilling up the Combe from the East Twin valley may have sank into Lionel's Hole hereabouts.

The most extensive and best developed phreatic former water-table level is that at ~127 m AOD. This is seen in all the caves with the exception of Bos Swallet and Bath Swallet, which are not deep enough to intersect it. This is clearly identified by vadose to phreatic transitions, for example the Bear Pit in Rod's Pot, and East Twin Swallet - Spar Pot. Below the 127 m level are a series of up to five very close spaced possible former water-table levels between 92 and 115 m AOD, identified in Goatchurch, Pierre's Pot, Lionel's Hole and East Twin Swallet. Their close spacing makes them more difficult to identify with certainty and some of them may be isolated phreatic passage segments or due to local perching, floodwater modification and sediment blockages rather than true base-level control. It also becomes difficult to distinguish between them given the potential errors in survey elevations. The best developed of these are at c. 115 m in Lionel's Hole and 106 m AOD seen in both Pierre's Pot and Lionel's Hole.

The modern day streamway in Pierre's Pot is presently graded to a level at or just below c. 96 m AOD (the downstream sump) whilst the stream in Lionel's Hole ends in a sump at 91 m AOD. The modern day resurgences are at 61 m and 40 m AOD. Assuming the sumps are at the water-table, the modern hydraulic gradient towards Rickford is currently between 0.023 (Lionel's Hole) and 0.025 (Pierre's Pot). However, this value is rather high compared to the gradient between Swildon's Sump Twelve and Wookey Hole (0.003) and the end of Reynolds Passage in Longwood Swallet and Cheddar (0.005) which suggests that the sumps in Pierre's Pot and Lionel's Hole may be perched rather like Sump One in Swildon's Hole. This also suggests that the hydraulic gradient is not uniform but gradually flattens out downstream. Consequently there must be a significant stretch of vadose passage downstream of the known explored limits.

As yet the only possible former resurgence cave known in the Burrington area is Aveline's Hole at c. 100 m AOD. Unlike Gough's Cave (Farrant, 1991) and Wookey Hole, Aveline's Hole only shows one phase of development. Using the modern hydraulic gradient as a proxy suggests this resurgence is probably related to the ~112-115 m water-table observed in Goatchurch Cavern. If this was the major resurgence location for the Burrington Combe area, other higher relict higher levels must exist unless Aveline's Hole represents an initial deep phreatic loop that has been reactivated during each successive phase of development. Clearly there has been a significant shift in resurgence location from within the Combe at Aveline's Hole to Rickford and Langford. This may be due to relatively recent stripping of the impermeable Mercia Mudstone around the base of the Combe, exposing the Dolomitic Conglomerate at lower elevations, and thus creating potential new resurgence locations. Structure contours on the base of the Mercia Mudstone are shown in Figure 18. The contact between the Dolomitic Conglomerate and the Mercia Mudstone currently crops out at c. 75-80 m AOD at the base of the Combe. In contrast it occurs at c. 50 m AOD at Langford Rising, and 45 m AOD at Bourne, downstream of Rickford. Rickford Rising lies at the lower end of Blagdon Combe, a deep high-level abandoned meander of the Congresbury Yeo (see Barrington and Stanton, 1977, p. 220). Here the Combe has been incised around 30 m below the base of the Mercia Mudstone. Extrapolation of the structure contours indicate the base of the Mercia Mudstone was at

c. 80-90 m AOD here. This valley is a classic example of a superimposed valley, similar to the present day Wadbury Valley in East Mendip through which the River Mells flows, and is not a glacial overflow valley. The incision of Blagdon Combe by the former Congresbury Yeo occurred relatively early exposing the Dolomitic Conglomerate at a low level. This enabled the springs to develop at Rickford (at c. 61 m AOD) rather than a spring at the foot of the Combe (at c. 75 m AOD), and capturing higher level springs further up the Combe such as Aveline's Hole. Similarly, more recent erosion has exposed the conglomerate at a still lower elevation at Upper Langford, creating a steeper hydraulic gradient and enabling Langford Rising (c. 40 m AOD) to develop through a thin cover of Mercia Mudstone. This is currently the lowest possible outlet for the karst drainage system east of Knowle Wood, Sandford [ST 439 594]. Thus the spring at Langford is probably in the process of capturing flow from Rickford. As shown earlier, the hydrological evidence from tracer tests also strongly supports this view.

The integrated former water-table levels throughout many of the caves in the Burrington area suggest that they have had a common resurgence or main drain throughout their development. It also indicates that a well-integrated karstic drainage system has developed at least seven times in response to erosion in the Vale of Wrington. The sink points have remained more or less the same but new phreatic segments have developed, each following the same general pattern of strike dominated flow close to the sinks, followed by northwards drainage. The steep dip facilitated phreatic capture rather than vadose incision as a response to base-level fall.

Although each conduit system was independent, some passages were active during one or more phases of cave development; either because the original phreatic conduit was deep enough to still be in the phreatic zone following base level fall, or due to localised paragenetic cave development following sediment influx. A good example of the former is the Entrance Gallery in Goatchurch. These passages are often significantly larger than might be expected for the size of catchment as they have been undergoing active dissolution for longer. Similarly, in many caves invasive vadose streamways have utilised and enlarged sections of relict phreatic passage, such as the horizontal passage in Bath Swallet at the base of the main pitch. The passage at the head of the pitches in Rod's Pot may be another example.

Effects of sediment influx.

The streams draining the steep north-facing slopes of Black Down transport a large amount of coarse fluvial sediment. This sediment transport is clearly demonstrated by the well-developed fans of coarse sandstone debris that have been deposited at the junction of both the East and West Twin valleys with Burrington Combe. A larger fan occurs at the foot of the Combe where over three metres of periglacial gravels and solifluction deposits have accumulated (Figure 10 in Findlay, 1965). Rapid localised sedimentation in the caves continues to occur today particularly during flood events as borne out by recent observations. During the early 1960's, the 10 m deep excavated shaft at Flange Swallet was often infilled with stream debris after winter storms and was completely infilled after the 1968 floods (Barrington and Stanton, 1977, p. 78). The sink became blocked again in the late 1990's, the stream overflowing as far as the road, and had to be re-excavated in 2001.

In addition to the modern stream sediments, evidence of earlier periods of sediment accumulation is clearly seen in many of the caves, either as existing sediment fills or as small remnants of previously more extensive sediment fills preserved in alcoves or by in-situ cementation by speleothem calcite. In Goatchurch Cavern, pockets of coarse, poorly sorted, sandstone rich sediment can be seen in many places on passage walls or in the roof, particularly in the

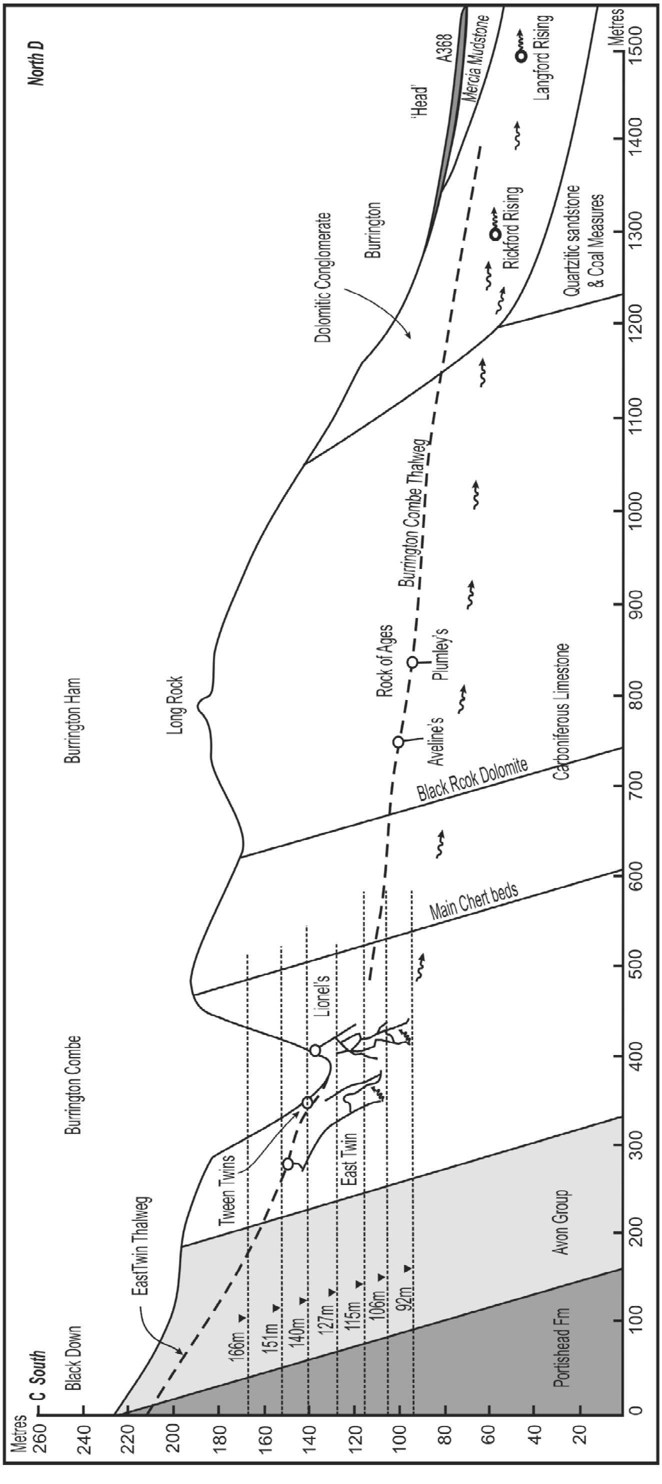

Figure 17. *North-South cross section (line C-D on Figure 18) across Burrington Ham and the East Twin Valley. The caves and resurgences are offset both east and west.*

Traverse and in the Dining Chamber, suggesting former extensive fills, although much has been removed by archaeologists, cavers and diggers. Over twelve tons of material was removed from the Traverse in Goatchurch during archaeological excavations (Bull and Carpenter, 1979). Yet elsewhere in the cave there is remarkably little evidence of a significant sediment fill until the Boulder Chamber is reached. Coarse sandstone cobbles are still evident deep within the cave, and can be seen on the floor of The Drainpipe. Evidence of former sediment fill levels can be observed in the Dining Chamber by small horizontal notches cut into the passage walls, formed by water flowing along the top of former sediment fills. Remnants of these coarse, poorly sorted fluvial sediments are still cemented on the wall by speleothem. Similar horizontal notches can be seen the phreatic passage between the Boulder Chamber and the Tent in Lionel's Hole. Sediment notches have also been identified in Shatter Cave, in a similar geomorphological situation on the northern side of the Beacon Hill pericline in eastern Mendip.

East Twin Swallet also contains an extensive sediment fill in the entrance passages, consisting of very coarse, poorly sorted sandstone rich cobble gravel (Figure 14). The rapid erosion of this fill has been clearly demonstrated in the years since the cave was first entered in 1936 (Ineson, 1958) and described by Tratman (1963). During the first exploration, the cave was almost entirely choked with sediment. A few years later, between 1934 and 1940, much of the sediment was flushed out by the stream and the rest of the streamway explored. The present dig at the end of the streamway often becomes sediment filled after a wet winter, necessitating various dams to hold the sediment back. Across the Combe, Lionel's Hole also contains a significant sediment fill, primarily due to its location at the foot of the alluvial fan at the mouth of the East Twin valley. Many large sandstone pebbles and cobbles can be seen the Boulder Chamber area, close to the entrance, although much of the fill has been affected by wholesale collapse of the cave hereabouts, so the original nature of the sediment is no longer apparent. Similar large sandstone clasts often over 20 cm across occur in the bypass to the Second Duck, derived from the erosion of a previously more extensive sediment fill. However, apart from near the entrance, there is little evidence of infiltrating stream debris from the floor of Burrington Combe above, although surface debris is visible at the end of the known cave. Other small caves nearby also have sediment fills; Tween-Twins Hole in particular is a phreatic passage completely filled sediment with sand and silt grade material derived largely from the Portishead Formation.

In Drunkard's Hole, many of the north-south orientated rift chambers contain thick fills of poorly sorted, coarse, sandstone-rich sandy gravels (Williams and Farrant, 1992). Similarly in Rod's Pot there is evidence for significant former sediment fills preserved as pockets of gravel in the roof of the entrance rifts (Donovan, 1949) and in the Main Chamber. Donovan (1949, p.74-75) states that sediment "probably once filled the cave more completely than it does now, and in the rifts of the first part of the cave masses of such debris may be seen overhead. Even small cracks are in many places packed with this material". The link into Bath Swallet via Purple Passage was almost totally filled with sandstone rich sediment prior to excavation. The only cave without evidence for a significant sediment fill in the Burrington area is Sidcot Swallet.

Most of the sediment seen in the caves is allogenic, derived from the Portishead Formation on Black Down. The north-facing aspect of Black Down is conducive to periglacial activity, frost shattering and solifluction during the glacial periods. This has generated locally thick blankets of fluvial, solifluction and mass-movement deposits collectively known as 'Head' that have accumulated along the gentler slopes of the Avon Group mudstone and out across the lower part of the Black Rock Limestone plateau, for example south of Bath Swallet.

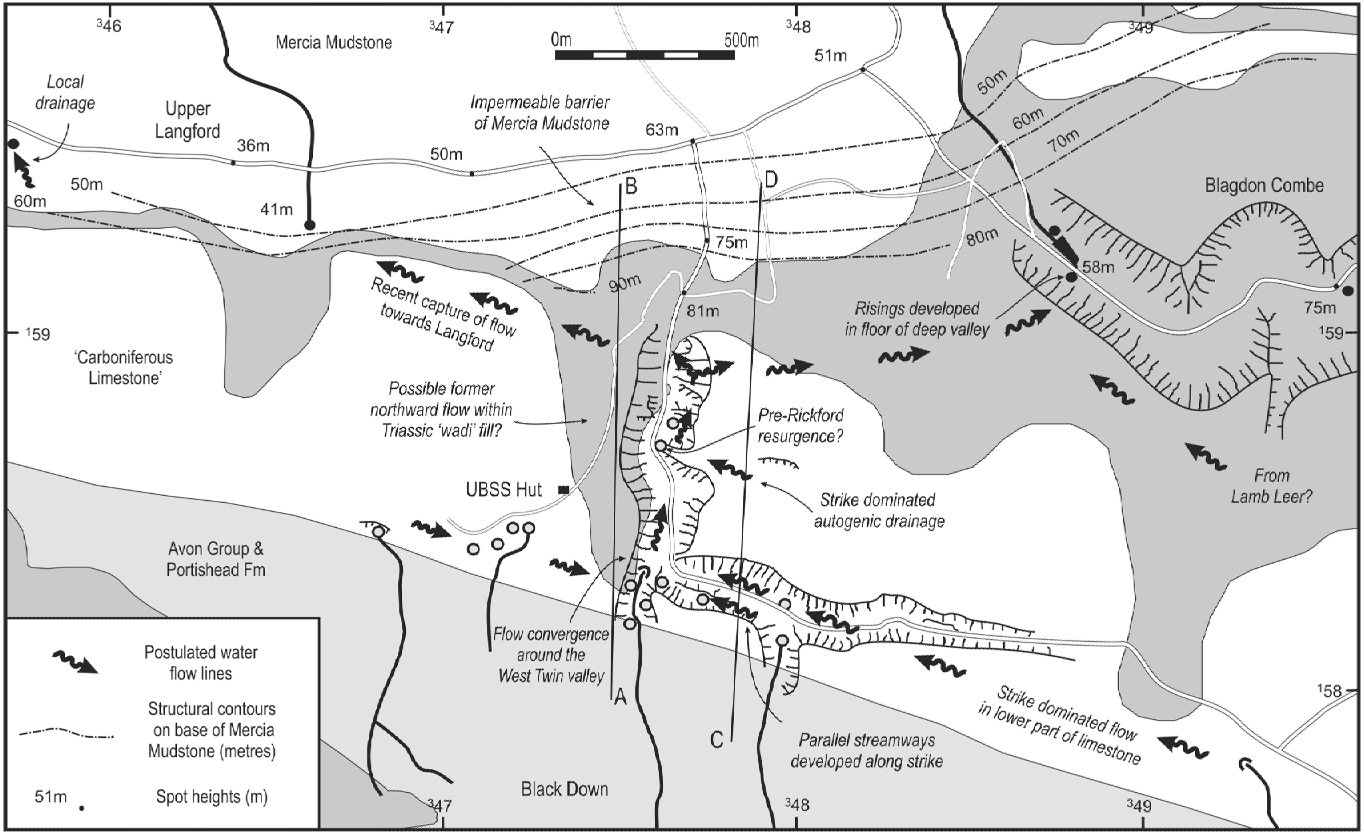

Figure 18. *Idealised flow paths for groundwater flow based on direct exploration, tracer tests, geological and geomorphological data. The structure contours for the base of the impermeable Mercia Mudstone that form the impermeable barrier at the foot of the Combe are shown. The caves and symbols are as for Figure 1. The cross-sections A-B and C-D are shown on Figures 16 and 17.*

This Head constitutes a poorly sorted, often chaotic mix of angular to sub-rounded coarse sandstone gravel with a silty, sandy matrix and is almost exclusively derived from the Portishead Formation. It is locally thick enough to impede underground drainage. The development of these deposits probably occurred during the onset of periglacial conditions at the start of a glacial or stadial period when the previous interglacial weathering products were mobilised. Over the last million years, there have been many periods when periglacial weathering and mass-movement processes would have been active. During each of these periglacial phases, the weathering products of the preceding warm phase would move down-slope by solifluction. It is likely that the main sediment influxes were relatively rapid, possibly mass-movement events triggered by summer melt-water floods. Sediment influxes are not solely restricted to periglacial periods. Heavy rainstorms such as that which occurred in 1968 can also trigger mass-movement events (Hanwell and Newson, 1970). However, much of the coarse grained sediment currently in transport is derived from reworking of older fluvial and solifluction deposits rather than active erosion of the bedrock.

These periglacial deposits are easily reworked by fluvial and gravitational processes into the caves, particularly during the climatic deterioration at the onset of periglacial conditions. The sediment input in the swallet caves here is likely to be greater than elsewhere on Mendip due to the large, and particularly steep drainage catchments on the northern side of the Black Down pericline. The coarsest deposits, particularly those derived by solifluction and mass-movement events are likely to accumulate close to the initial entry point, and are generally confined to areas vertically below the point of sediment influx. This is clearly seen in Goatchurch Cavern and particularly in the Bos Swallet to Bath Swallet series of caves. Here, multiple entrances and almost vertical cave systems have facilitated the injection of solifluction debris deep into the caves. These may then be reworked by fluvial processes deeper into the cave, as has happened in Lionel's Hole. Elsewhere, finer grained fluvial sediment accumulations often build up at the base of phreatic loops (for example in Aveline's Hole) or in long sections of horizontal passage.

In the current interglacial however, the dominant process is of sediment removal, although temporary sediment aggradations often occur on time scales of weeks to decades, such as in Flange Swallet. Perhaps the most celebrated Mendip example is the collapse of the sinkhole above the top end of the Gorge in GB Cave [ST 4759 5622] and the resulting sediment fill at lower end of the cave (Hanwell and Newson, 1970); although even here, much of the sediment has already been removed by stream action over the intervening decades. As seen in East Twin Swallet, this sediment removal can be a most efficacious process. In some of the caves, particularly Goatchurch and Aveline's Hole, the anthropogenic removal and redistribution of sediment both by archaeological and cave digs, and on caver's overalls, should not be underestimated.

Large amounts of sediment washed into steeply descending cave passages can affect cave development in several ways (Farrant, 2004). Depending on sediment calibre and stream power, some routes may get blocked by sediment input, either where passages narrow or where passage gradient and thus stream power slackens, for example at the local water-table. Backing up of a stream due to progressive infilling, particularly during floods can locally increase the hydraulic head in a phreatic environment. This stimulates the development of floodwater mazes and bypass tubes along suitable fractures. The Drainpipe and Hellish Tight in the lower parts of Goatchurch Cavern may be examples of such features.

As well as forming new passages, extensive sedimentation can also modify existing passages. In passages clogged with sediment, some water flow may occur through the sediment, but most flow (and hence dissolution) will be concentrated at the interface between the sediment and the passage wall or roof. This flow concentration generates parasitic conduits which develop over, round and along the sediment and cave wall interface. More generalised overprinting of vadose morphologies by phreatic dissolution can occur in such environments, but most of the characteristic paragenetic forms are for channelled phreatic flow along these parasitic routes. In the Burrington area, these typically occur as small, often meandering half-tubes developed at roof level (commonly orientated up or down bedding planes), and are often associated with well-developed anastamoses and phreatic pendants. These paragenetic features may form some considerable time after both the initial cave formation and the subsequent sediment infilling event, and under different hydrological conditions.

A good example of such a passage, complete with a coarse allogenic sediment fill occurs on the upstream, rising limb of a phreatic loop in the bypass to the Second Duck in Lionel's Hole (possibly caused by blockage of the duck itself). Here the abundant sandstone rich sediment fill has been partially washed out by later vadose inlets, revealing good paragenetic anastomoses and pendants developed by upwards dissolution of the roof in a phreatic environment. Small paragenetic half-tubes can be clearly seen in parts of Goatchurch, for example above the Giant's Stairs (Figure 10) and in the Water Chamber. Smaller networks of paragenetic parasitic tubes can be seen etched into the roof of the Main Chamber in Rod's Pot (see Donovan, 1949 for a photograph). These are not bedding plane features as they do not follow any structural or lithological discontinuity.

In vadose environments, sediment aggradation will prevent fluvial incision and the development of vadose trenches. Where aggradation is not sufficient to totally fill the passage and initiate paragenesis, water flowing over a sediment fill may incise laterally, eroding notches in the passage walls. Small examples of these notches can be seen in the Dining Chamber area of Goatchurch and near The Tent in Lionel's Hole. It is clear from the distinctive passage morphologies that paragenetic cave development and vadose alluvial aggradation has locally modified some of the caves in the Burrington area. The development of paragenetic/floodwater bypass tubes may have contributed to the maze aspect of some of the caves, particularly Goatchurch Cavern and Lionel's Hole, although not to any great extent. However, it is clear that many of the caves have had extensive sediment fills in the past.

THE AGE OF THE CAVES

As yet, no published Uranium series, palaeomagnetic or any other dates are available for the Burrington area. The only age data available is that of the archaeological deposits in Aveline's Hole, Bos Swallet, Read's Cavern and other sites, all of which significantly postdate the formation and development of the cave systems. Clearly the caves have developed over several glacial-interglacial cycles.

The current water-table observed in Lionel's Hole and Pierre's Pot is at around 91-96 m AOD. Rates of base-level lowering of approximately 0.2 m per thousand years (ka) have been calculated for the Cheddar catchment (Farrant, 1995). Applying this rate to the Burrington area suggests that during the last interglacial (Marine Isotope Stage 5) the water-table in the vicinity of the swallets would have been at around 115-120 m AOD. Given that the relief in the Burrington area is considerably lower than in the Cheddar catchment, this rate is probably too high. If we assume that the capture of Rickford Rising by Langford Rising, which is about 17 m lower, is a consequence of base-level erosion during the last interglacial-glacial cycle (10^5 years), this gives an approximate rate of base-level lowering of ~0.15 m per ka. Applying this estimate to the water-tables identified in the caves suggests the 127 m water-table was developed around 200-240 ka, and that the last interglacial is represented by the complex of phreatic passages developed at around 112-114 m AOD seen in the lower parts of Goatchurch Cavern, Lionel's Hole and East Twin Swallet. This rate implies that the highest levels of Goatchurch Cavern were active around 460 to 500 ka.

The age of the Mendip Plateau is estimated to be around 1 to 1.2 million years old (Barrington and Stanton, 1977; Farrant 1995). Applying the estimated base-level lowering rate of 0.15 m per ka over this timescale, and allowing for around 50 m surface dissolutional lowering during this time (at a rate of ~ 0.05 m per ka) suggests the plateau surface should be between 185 and 215 m AOD. These figures accord well with the maximum elevation of Burrington Ham and the summit of the hill south of Mendip Lodge Wood (behind the UBSS hut). Clearly, some speleothem, palaeomagnetic or cosmogenic isotope dating work is needed to test this timescale.

CONCLUSIONS

The caves in the Burrington area are classic examples of caves developed in steeply dipping limestones. Their morphology is significantly different from neighbouring cave systems on the southern side of Black Down. The typical Burrington cave consists of a complex network of dominantly strike-orientated, locally sediment infilled, phreatic conduits developed at certain preferred elevations, along either bedding planes or bedding normal joints. These are linked by steeply descending, often near vertical vadose inlet passages. This typically creates a locally complex three-dimensional maze network, usually developed within the lower part of the Black Rock Limestone. The strike dominated model is borne out by tracer testing experiments.

This complex morphology arises from the interplay between geological structure, base-level lowering in the softer Triassic rocks infilling the Vale of Wrington and sediment influx from the northern slopes of Black Down. The geological structure, in particular the steep dip and consequent bedding parallel fractures opened by bedding plane slip facilitates the development of strike-aligned conduits. This strike parallel flow leads to flow convergence close to the Avon Group – Black Rock Limestone contact, rather than forming a series of independent streamways converging near the resurgence. These passages have developed at certain preferred elevations governed by the local base-level, related to the erosion of the impermeable Mercia Mudstone in the adjacent Vale of Wrington. Successive base-level fall has created a stacked sequence of relict phreatic passages each related to a former base-level. This process is ongoing with the capture of Rickford Rising by Langford Rising.

Cave passage morphology has also been locally modified by paragenetic/floodwater enlargement and modification both during and after initial passage development. Paragenesis occurs following periods of high sediment influx, the sediment being derived from the steep north facing slopes of Black Down and its associated periglacial weathering deposits. The effect has been to locally modify existing passages, blocking existing phreatic routes causing the development of floodwater bypass tubes and generally making exploration difficult!

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This paper could not have been written without the work of the many cavers who have helped discover, survey and describe the Burrington caves. We would like to thank Chris

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Table 1 *Stream sinks in the Burrington area (see also Barrington and Stanton, 1977).*

Sink	Grid Ref.	Elevation	Notes
Hunter's Brook	ST 4679 5843	158 m	This stream sinks into Read's Cavern and in marshy area to west of the cave entrance. In drought it sinks in its bed upstream.
Bath Swallet Stream	ST 4725 5845	168 m	An intermittent stream which sinks in the depression at Bath Swallet. Part of the stream is derived from an old leat which once fed water from the Hunter's Brook towards the cottages adjacent to the UBSS hut.
West Twin Brook (Flange Swallet)	ST 4758 5832	134 m	The West Twin Brook sinks at Flange Swallet downstream of Sidcot Swallet. Some of this stream is derived from the outflow from the West Twin Brook Adit [4755 5820] a short distance upstream. The surface stream is often dry upstream of the adit.
Yew Tree Swallet	ST 4756 5828	141 m	The West Twin Brook used to sink at Yew Tree Swallet, but the site was blocked after tipping of debris from the adit upstream. This swallet is shown in Figure 12.
East Twin Brook	ST 4795 5810	150 m	The East Twin Brook currently sinks into the entrance of East Twin Swallet. In the past it has sunk in a hollow further downstream near the road.
East Twin Middle Sink	ST 4794 5804	168 m	Also known as Dreadnought Holes, this is a small sink in a thin limestone bed within the Avon Group mudstone.
East Twin Top Sink	ST 4792 5796	183	A sink in a thick limestone bed within the Avon Group. This sink takes varying amounts of water, sometime the whole stream sinks here, and at other times it is blocked.
Ellick Farm Swallet	ST 4927 5780	216	The sink beside the farm track for this stream is rather indistinct. The stream has probably sunk at various places in the past.

Table 2 *Springs in the Burrington area (see also Barrington and Stanton, 1977).*

Resurgence	Grid Ref.	Elevation	Notes
Rickford Rising	ST4879 5917	61 m	Large resurgence issuing from slot in Dolomitic Conglomerate adjacent to the A361.
Gauge House Rising	ST 4868 5931	58 m	Small rising in Dolomitic Conglomerate next to water fall downstream of roadside lake.
Squire's Well	ST 4927 5908	70 m	Intermittent spring at edge of wood in Dolomitic Conglomerate. Possibly a flood overflow for Rickford Rising.
Langford Rising	ST 4663 5932	41 m	Large resurgence rising from Dolomitic Conglomerate through a thin cover of Mercia Mudstone above
Saye's Lane Rising	ST 4571 5954	43 m	Small intermittent rising in Mercia Mudstone, no proved feeders
West Twin Brook Adit	ST 4755 5820	159 m	300 m long horizontal adit for water supply, now abandoned, largely within the Avon Group but penetrating into the Portishead Formation at the end. The water emerges from a series of discrete inlets from limestone beds within the Avon Group and from the Portishead Formation. The water is conveyed to a stone trough near the entrance.

Table 3. *Significant caves in the Burrington area (see also Barrington and Stanton, 1977).*

Major Caves	Grid Ref	Elevation	Lithogy
Read's Cavern	ST 4682 5844	161 m	Basal Black Rock Lst
Bos Swallet	ST 4709 5837	178 m	Basal Black Rock Lst
Drunkard's Hole	ST 4719 5839	175 m	Lower Black Rock Lst
Rod's Pot	ST 4721 5845	167 m	Lower Black Rock Lst
Bath Swallet	ST 4725 5845	168 m	Lower Black Rock Lst
Sidcot Swallet	ST 4757 5829	143 m	Basal Black Rock Lst
Goatchurch Cavern	ST 4758 5823	163 m	Basal Black Rock Lst
Pierre's Pot	ST 4763 5837	129 m	Lower Black Rock Lst

Tween-Twins Hole	ST 4774 5827	137 m	Lower Black Rock Lst
Goon's Hole	ST 4791 5825	126 m	Middle Black Rock Lst
Lionel's Hole	ST 4796 5823	134 m	Middle Black Rock Lst
Foxes Hole	ST 4823 5822	172 m	Middle Black Rock Lst
East Twin/Spar Pot	ST 4795 5810	150 m	Lower Black Rock Lst
Aveline's Hole	ST 4761 5868	99 m	Burrington Oolite
Plumley's Hole	ST 4766 5875	100 m	Burrington Oolite

Table 4. *Summary of published tracer tests in the Burrington area between 1910 and the present day. BWW = Bristol Water Works, MKHP = Mendip Karst Hydrology Project. WWA = Wessex Water Authority. L & R = Langford and Rickford respectively***.**

From	**To Langford**	**To Rickford**	**Test carried out by**	**Tracer**	**Arrival Time**	**Reference**
West Twin Brook	+ve	-ve	BWW 1910			Tratman 1963
East Twin Brook	+ve	-ve	BWW 1910			Tratman 1963
Ellick Farm Swallet	-ve	+ve	BWW 1910			Tratman 1963
East Twin Swallet	+ve	-ve	UBSS 1963	Flourescein	2-5 days	Tratman 1963
West Twin Brook	+ve	-ve	UBSS 1963	Flourescein	2-5 days	Tratman 1963
Bath Swallet	+ve	-ve	UBSS 1963	Flourescein	2-5 days	Tratman 1963
Hunters Brook	-ve	-ve	UBSS 1963	Flourescein		Tratman 1963
Hunters Brook	+ve	+ve	MKHP 1968	Lycopodium	L 42-46 hrs R > 4 hrs	Drew *et al* 1968
West Twin Brook	+ve	+ve	MKHP 1968	Lycopodium	L 15-19 hrs R 17-21 hrs	Drew *et al* 1968

East Twin Brook	+ve	+ve	MKHP 1968	Lycopodium	L 15-19 hrs R 4-8 hrs	Drew *et al* 1968
Ellick Farm Swallet	+ve	+ve	MKHP 1968	Lycopodium	L > 4 hrs R > 4hrs	Drew *et al* 1968
Ubley Hill Pot	-ve	+ve	MKHP 1968	Lycopodium	> 4hrs	Drew *et al* 1968
Burrington Ham	+ve	+ve	MKHP 1968	Pyranine	10-12 days	Drew *et al* 1968
Read's Cavern	+ve	+ve	Crabtreee 1977	Dyes	L 45/57 hrs R 46/97 hrs	Crabtree 1979
West Twin Brook	+ve	+ve	Crabtree 1977	Dyes	L 46/127 hrs R 47 hrs	Crabtree 1979
East Twin Brook	+ve	+ve	Crabtree 1977	Dyes	L 105/118 hrs R 95/192 hrs	Crabtree 1979
Ellick Farm Swallet	+ve	+ve	Crabtree 1977	Dyes	L 50 hrs R 41 hrs	Crabtree 1979
Ubley Hill Pot	-ve	+ve	Crabtree 1977	Dyes	85 hrs	Crabtree 1979
Lamb Leer	-ve	+ve	WWA 1977	Rhodamine W.T.	58 hrs	Barrington and Stanton 1977

Bos Swallet	Drunkard's Hole	Rod's Pot	Bath Swallet	Sidcot Swallet	Goatchurch Cavern	Pierre's Pot	Lionel's Hole	East Twin Swallet
166					162-166			
148	**150**	**148-152**			150-152			
142	**141-143**	**140-143**	**141-143**		**140-143**			
	127	**127**	133	127	**127**	127	127	**127**
					112-115			**115**
					110?		**105-106**	
					c.105	106	95?	
						96	92?	

Table 5. *Former water-table elevations (m. AOD) identified in the Burrington caves. Those in bold have been determined by vadose-phreatic transitions.*

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APPENDIX

This paper has benefited from modern surveys and re-surveys of many of the caves. Although few finished drawings have been produced at this time, the raw data has been put together to produce a 3D model of the caves using 'Survex' visualisation software written specifically for viewing cave survey data. This has proved extremely useful in visualising the relationships between different passages and different caves. The model can be downloaded from the UBSS website at:

http://www.ubss.org.uk/resources/surveys/survex/Burrington.3d.

The data has been compiled from many sources and details of the various contributions to this can be found the UBSS website at:

http://www.ubss.org.uk/cave_survey_archive.php.

It is intended to keep this model up to date as more data becomes available. For generously sharing their data with us, we are grateful to Andrew Atkinson, Christopher Binding, John Cordingley, Steve Cottle, David Cundy, Pete Moody, Carmen Smith, Andy Sparrow, Willie Stanton, Roger Stenner and their many collaborators and helpers.

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