Groundwater in Cretaceous carbonates: KG@B field trip 21st June 2015

Groundwater Science Programme

Open Report OR/15/042

BRITISH GEOLOGICAL SURVEY

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Lou Maurice, Andrew R Farrant, Andy Butcher and Tim Atkinson

Front cover

Chalk stream sink, Yattendon, Pang catchment.

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email enquiries@bgs.ac.uk

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Acknowledgements

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1 Introduction

The Upper Cretaceous Chalk of southern England is the UK's most important aquifer, providing more than 75% of the public supply for southeast England, including London. The aquifer also sustains rivers and wetlands, and their associated groundwater dependent ecosystems. However, the aquifer is facing a multitude of threats including over-abstraction, nitrate pollution, and climate change.

The Chalk is a complex aquifer in which groundwater flow is through the matrix, fractures and karstic dissolutional voids. The Chalk matrix has a porosity of around 35% (Bloomfield et al., 1995). The matrix is thought to provide an important contribution to storage, although the size of the pore throats is very small, and therefore the permeability is very low (Price et al., 1993). The average permeability of 977 core samples was only 6.3 x 10^{-4} m/day (Allen et al., 1997). The matrix is particularly important in solute transport, because solutes move between the matrix and the more permeable parts of the aquifer via diffusion (Foster 1975). The unmodified fracture network provides an important contribution to storage and flow, and has a hydraulic conductivity of about 0.1 m/d, and a transmissivity of about 20 m^2/day (Price, 1987). However, it is the dissolutionally enlarged fissures and conduits that make the Chalk such a good aquifer. The median transmissivity from 2100 pumping tests is 540 m^2/day, and the 25th and 75th percentiles are 190 and 1500 m^2/day respectively (MacDonald and Allen, 2001). Borehole packer testing, logging and imaging have shown that most of this transmissivity comes from a small number of dissolutional voids (e.g. Tate et al., 1970; Schurch and Buckley, 2002). Laterally extensive lithostratigraphical horizons including marl seams, bedding planes, sheet and tabular flint bands, and hard-grounds have an important influence on these groundwater flows. They are all horizons where downward percolation of water may be impeded. Dissolution often occurs where flow is concentrated along these horizons, creating conduits or fissures, especially where they are intersected by joint sets.

Across much of the UK, the Chalk has not traditionally been considered or managed as a karst aquifer, perhaps because caves are rare. However, it has been recognised for some time that karst processes and conduit flow may be common in many areas of the Chalk aquifer. Although not renowned for its caves, the Chalk does contain some significant cave systems. The largest chalk cave in Britain is Beachy Head Cave, near Eastbourne which is approximately 400 m long. Caves are more common in northern France where some are several kilometres long. As in more classical karst regions, surface karst features such as sinking streams, springs, dolines and dry valleys can be very common in the Chalk (Cooper et al., 2011). There are also many fossil sediment filled karst features associated with the Chalk-Palaeogene unconformity when the climate was warmer and wetter (Newell, 2014).

Locally the Chalk may host a greater density of surface karst features than other more classic karst aquifers such as the Carboniferous limestones of Derbyshire, yet it is rarely treated as a karstic aquifer. There is a rather simplistic tendency to equate karstic groundwater flow with the occurrence of extensive cave systems. Yet subsurface dissolution features are frequently encountered in the Chalk during construction projects (Edmonds, 2008), and tracer testing has demonstrated rapid groundwater flow over distances of up to 20 km (e.g. Harold, 1937; Atkinson and Smith, 1974). Even where there is little evidence of surface karst, the Chalk often has high transmissivity due to the solutional enlargement of fractures to form fissures and conduits. Given the evidence for karstic features, rapid groundwater flow, and considerable spatial heterogeneity, the Chalk is perhaps better described as a weakly cavernous karst aquifer rather than weakly- or non-karstic.

The Pang and Lambourn catchments in Berkshire are good examples of chalk catchments with a high density of surface karst features (Figure 1). These catchments provide an excellent location in which to discuss the extent to which Chalk can be viewed as a karstic aquifer, and the importance of such features to water resource management.

During this field trip we will visit some of the stream sinks and one of the major springs in the Pang catchment (Figure 2). We will also look at the contact between the Chalk and the overlying Palaeogene deposits in a quarry, and observe some sub-surface dissolutional fissures and conduits via a borehole CCTV camera system.

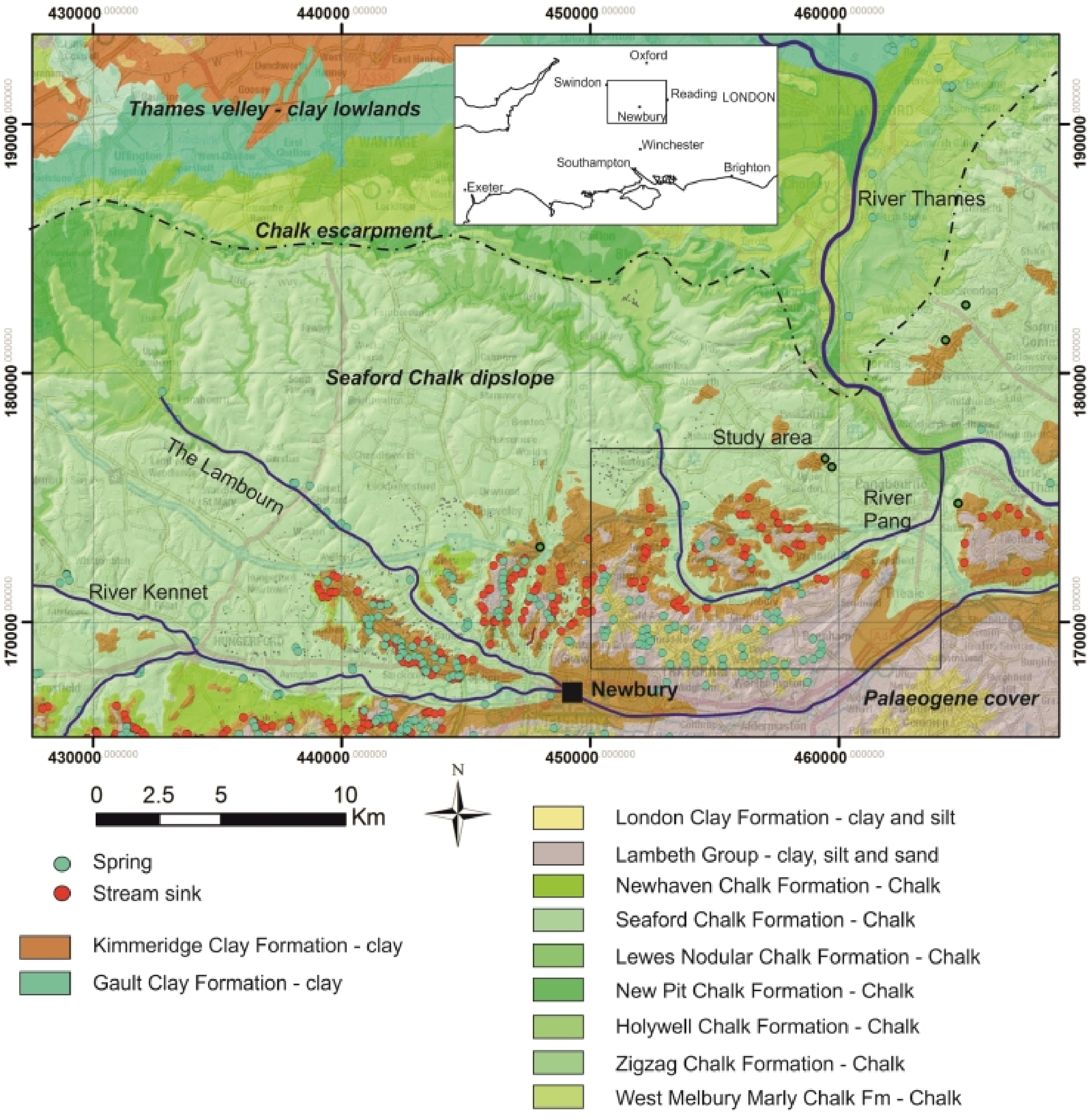

Figure 1 Surface karst in the Pang and Lambourn catchments, UK. Geology based on 1:50,000 scale DigMapGB data. Contains Ordnance Survey data © Crown copyright and database rights 2015. Hill-shaded topography is NEXTMap Britain elevation data from Intermap Technologies.

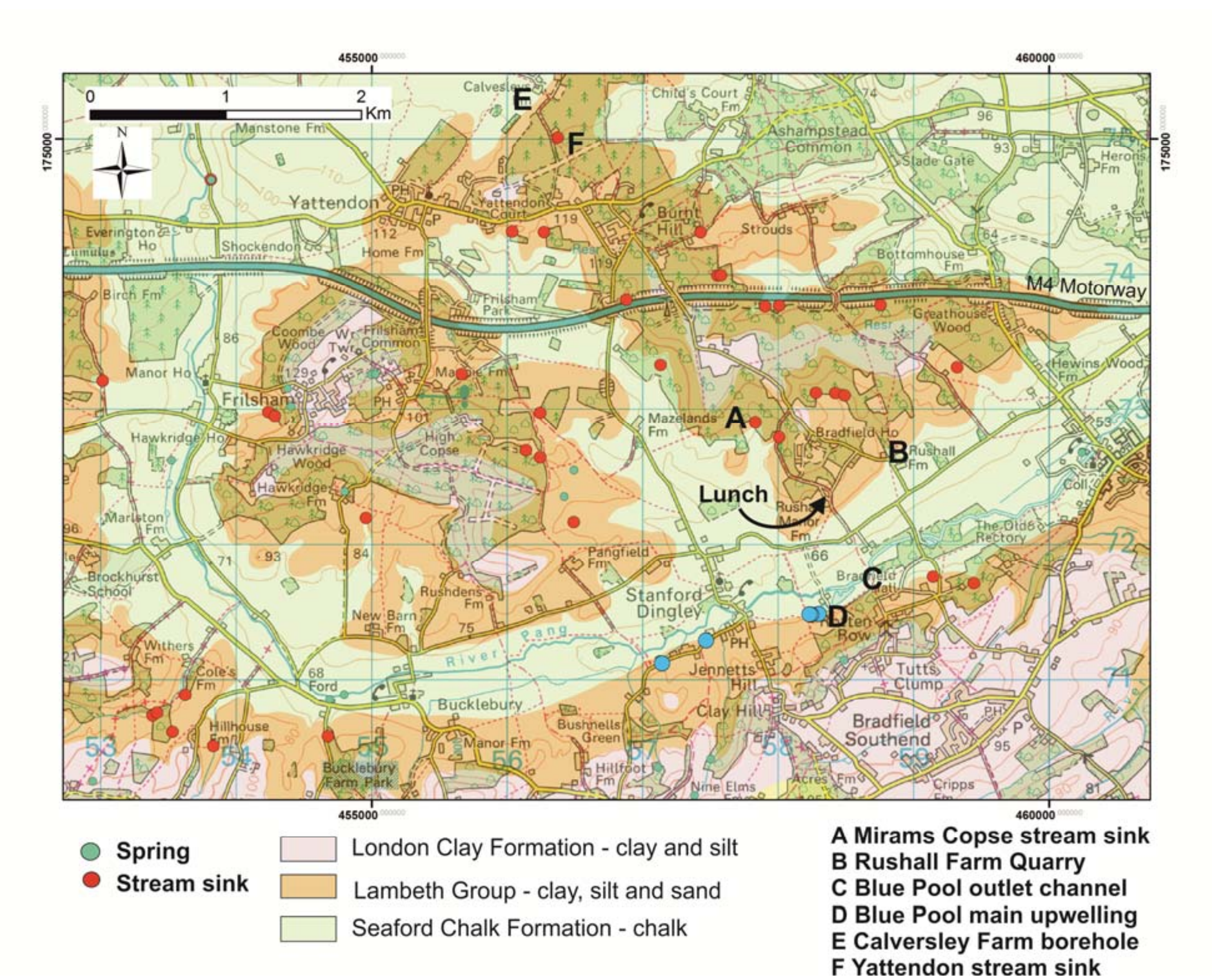

Figure 2 Field trip sites in the Pang catchment. Contains Ordnance Survey data © Crown copyright and database rights 2015. Geology based on 1:50,000 scale DigMapGB data.

2 Geological Setting

The geology of the Pang-Lamborn catchments is relatively simple. Most of the area is underlain by gently dipping Upper Cretaceous Chalk which crops out across much of southern and eastern England, forming the quintessential English rolling 'downland' landscape (Figure 3). In the Pang-Lambourn catchments the Chalk Group dips gently to the south-southeast at 1-2°. To the north, it forms a distinctive escarpment reaching a maximum elevation of around 280 m, overlooking the clay lowlands of the Thames valley. To the south the Chalk is unconformably overlain by Palaeogene sands and clays.

The Chalk can be divided into two subgroups: the Grey Chalk and the White Chalk. The former consist of two constituent formations (Table 1), whilst the White Chalk is divided into five formations. The latter are generally defined by the flint content and the presence or absence of thin marl seams. Most of the Pang and Lambourn catchments lie on the dip slope of the Chalk, mostly on the Seaford Chalk Formation, although locally a few metres of the Newhaven chalk is preserved beneath the Paleogene unconformity.

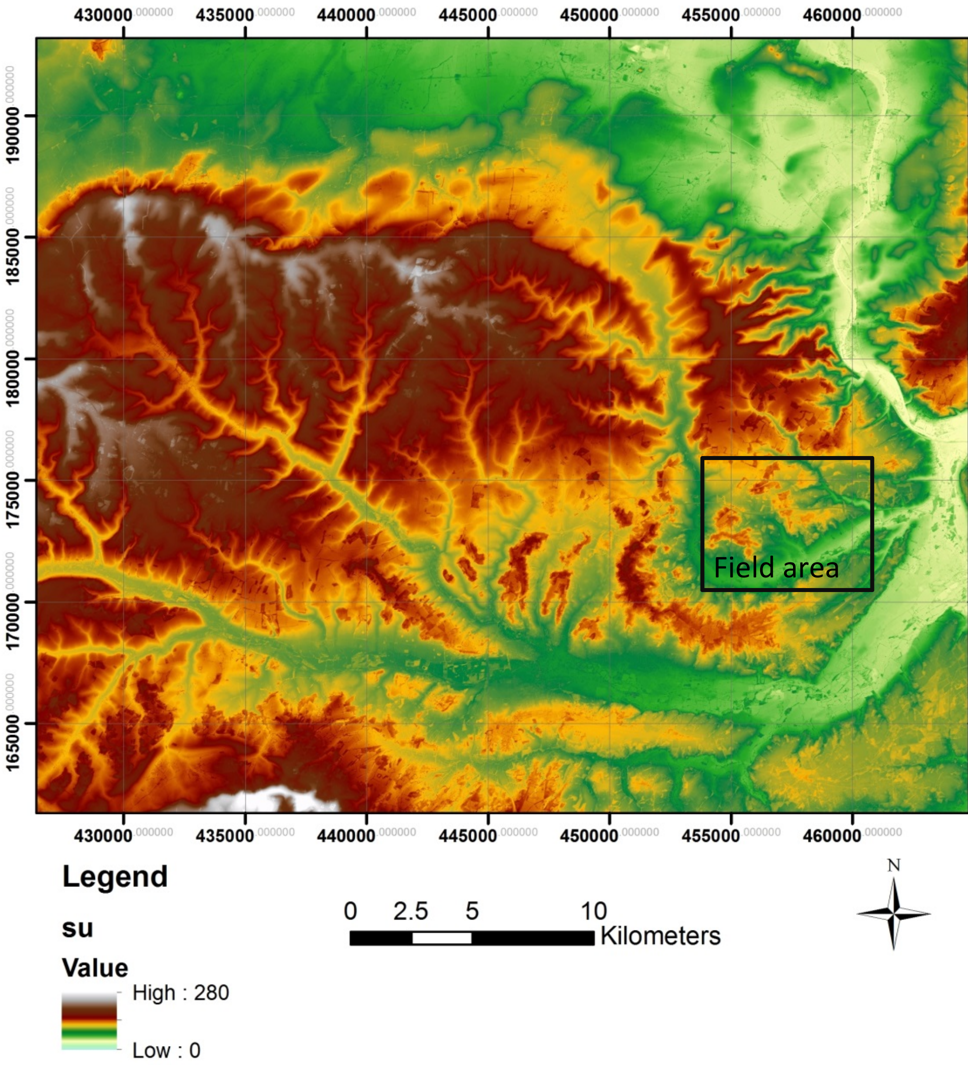

Figure 3 Topography of the Pang-Lambourn catchment. Topography is NEXTMap Britain elevation data from Intermap Technologies. Elevation in metres.

Table 1 Summary of lithostratigraphy of the Chalk of the Pang Lambourn catchment

Formation	Typical composition	Thickness (m)
White Chalk Subgroup		
Newhaven Chalk	Chalk with marl seams, some flint	5-10 m
Seaford Chalk	Chalk with few marl seams, much flint	50 to 80
Lewes Nodular Chalk	Nodular, gritty chalk, marls, much flint	35 to 80
New Pit Chalk	Chalk with marl seams, sparse flint	35 to 50
Holywell Nodular Chalk	Nodular, gritty chalk, with marl seams	25 to 35
Grey Chalk Subgroup		
Zig Zag Chalk	Grey chalk, some marly, some limestones	35 to 50
West Melbury Marly Chalk	Grey marly chalks, some hard limestones	15 to 30

In the south of the catchments, outliers of the overlying Palaeogene strata are preserved, forming low hills and ridges. These outliers are composed of mottled clay and sands of the Reading Formation (part of the Lambeth Group), overlain by the London Clay Formation, locally capped by river terrace gravels. These generate surface streams which sink into the underlying Chalk, and resurge at large springs in the valley.

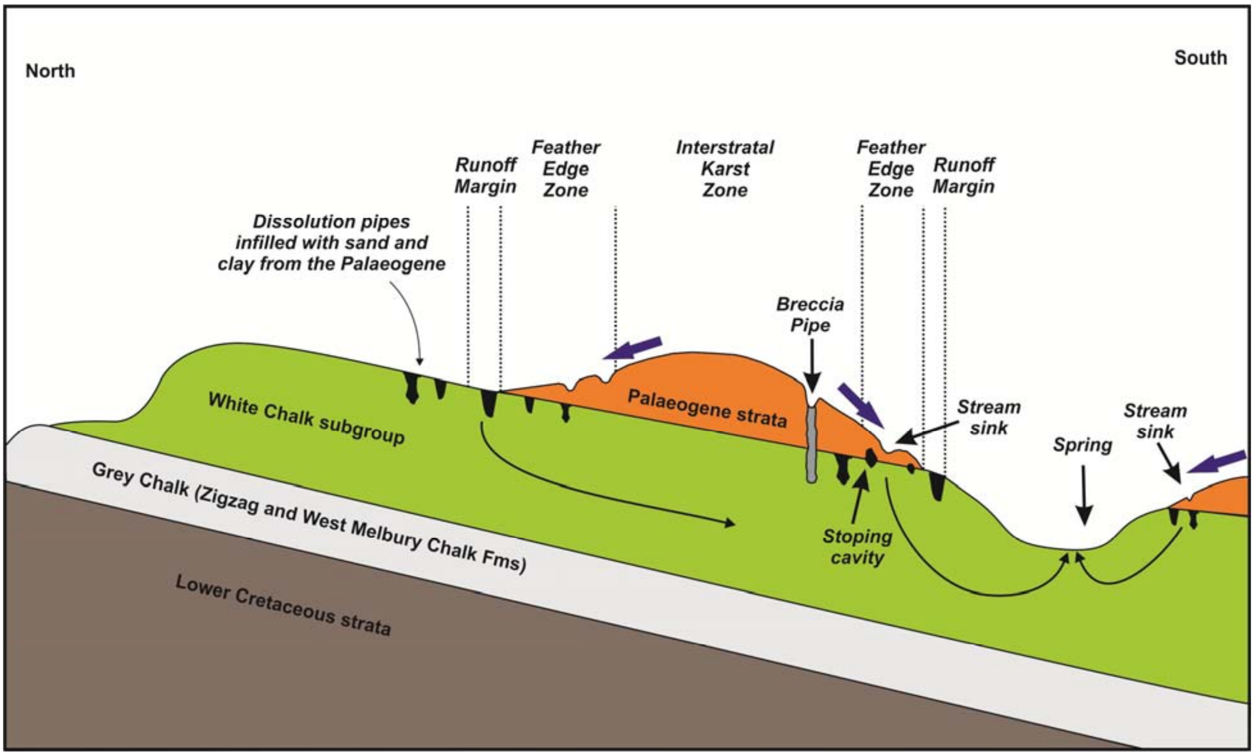

Figure 4 North-south geological cross section across the Chalk outcrop in the Yattendon-Blue Pool area.

3 Chalk karst and groundwater flow in the Pang and Lambourn Catchments.

The Pang and the Lambourn catchments contain ample evidence of karst. The upper parts of both catchments are developed on the Chalk, but in the lower reaches, Palaeogene strata are present. Around the margins of these Palaeogene outcrops surface karst features are widespread (Figure 5). At least 18 stream sinks have been recorded on the west and south side of the River Pang between Hermitage and Bucklebury, with another 25 on the north side of the River Pang in the Yattendon area. Sediment filled dissolution pipes (buried sinkholes) are widespread and well developed, especially beneath thin superficial deposits. In this area they may be up to 20 m deep and 5 m across, and commonly merge to form a very irregular rock-head. This can cause problems during construction, and dissolution pipes presented a significant engineering hazard during the widening of the A34 north of Newbury.

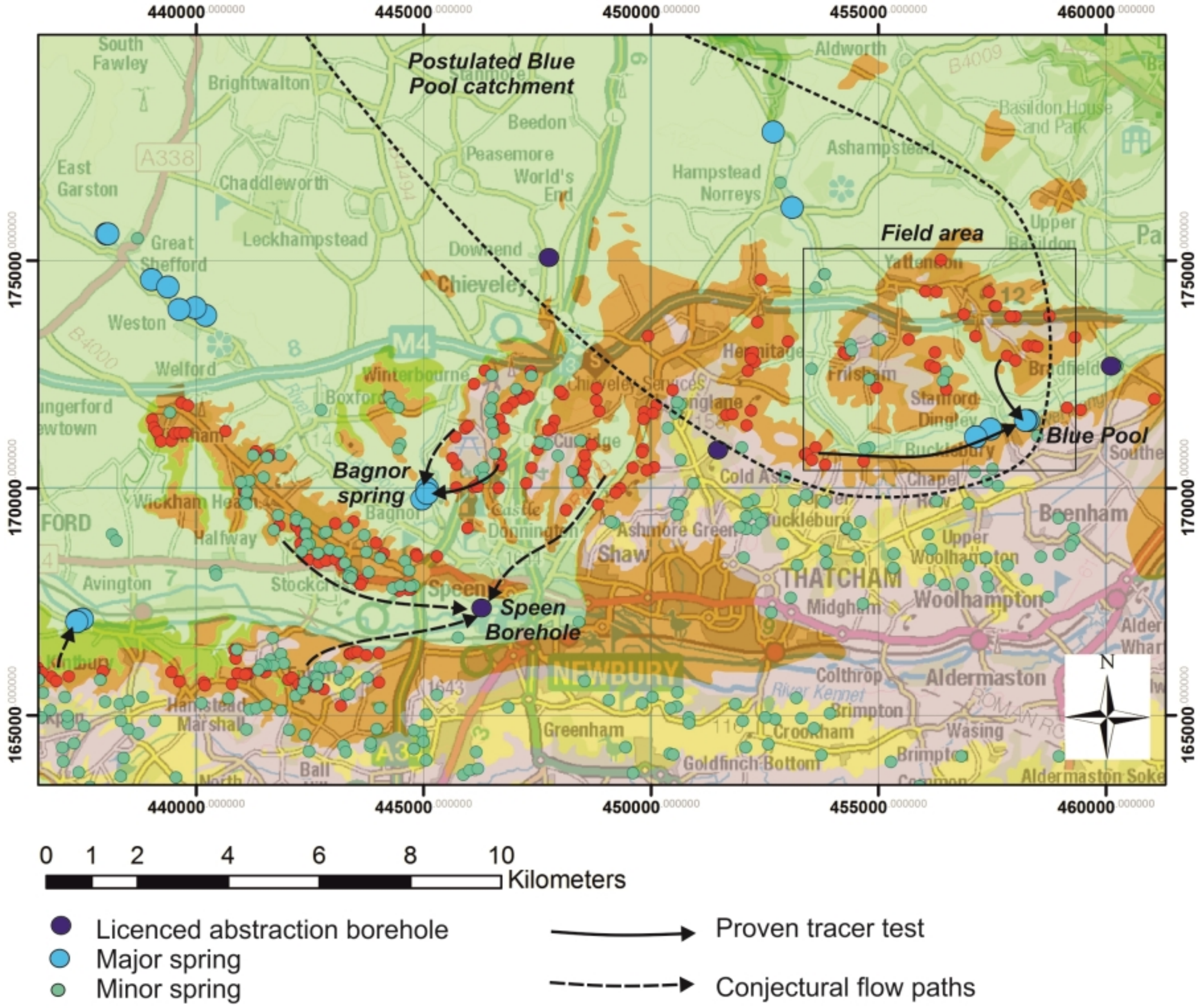

Figure 5 Karst in the Pang and Lambourn catchments. Contains Ordnance Survey data © Crown copyright and database rights 2015.

There is also evidence of karstic groundwater flow. Tracer testing between stream sinks and springs has demonstrated very rapid groundwater flows of several kilometres per day over distances of several kilometres suggesting fully integrated karstic flow (Banks et al., 1994; Maurice et al., 2005; Maurice et al., 2010).

Although surface karst features are less prevalent in the upper parts of the catchments, there are good examples of ephemeral winterbourne streams. At the head of the rivers there are seasonally active springs, sometimes known as bourne holes. These can be several kilometres upstream of the perennial river head. These seasonal springs become rapidly reactivated over a short period of time, suggesting that they are fed by karstic fissures and conduits.

Single borehole dilution testing in 24 boreholes in the Pang and Lambourn catchments showed that flow horizons are prevalent in areas with and without surface karst (Maurice et al., 2012). Borehole imaging and geophysical logging data revealed that most flowing features identified from the borehole dilution tests were dissolutional in nature, and there is a strong lithological influence on flow (Figure 6).

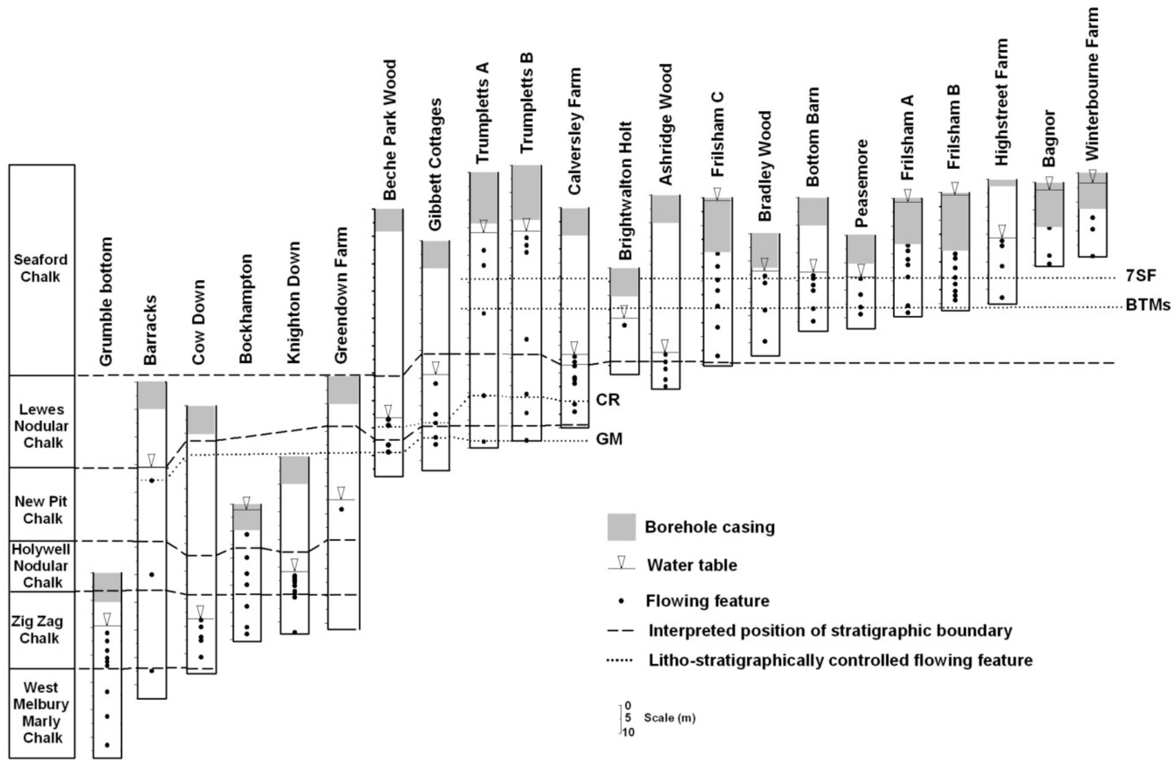

Figure 6 Flowing features identified from single borehole dilution tests in the Pang and Lambourn catchments.

4 Localities

4.1 MIRAMS COPSE STREAM SINK

Mirams Copse stream sink (Figure 7) is a fairly typical chalk stream sink. It is situated about 80 m above sea level and is fed by small springs in the Palaeogene and some very local surface runoff. It has a maximum flow of about 5-10 l/s, when water sometimes backs up to form a small pool. It has no flow following dry periods. The stream sink is located on thin Palaeogene deposits overlying the Chalk, and the unsaturated zone is about 17-24 m thick.

Initial tracer testing using the optical brightener Photine CU produced negative results in 6 different tracer tests that involved injecting progressively more tracer (125 to 5000 mls of a 20% solution). Monitoring was carried out using passive cotton detectors at 13 spring, borehole and river sites (Figure 8). During a later test using bacteriophage, tracer was conclusively detected 1.7 km away at the Blue Pool spring. Groundwater velocities were very rapid – 4.3 km/d based on first arrival of the tracer. However tracer attenuation was high: <0.00005 % of the tracer was recovered. This was a big contrast to tracer tests from Smithcroft Copse stream sink (Figure 8) which showed similar rapid flow rates of 5 km/day but combined with much lower attenuation (about 25 % of the tracer was recovered).

Figure 7 Mirams Copse stream sink

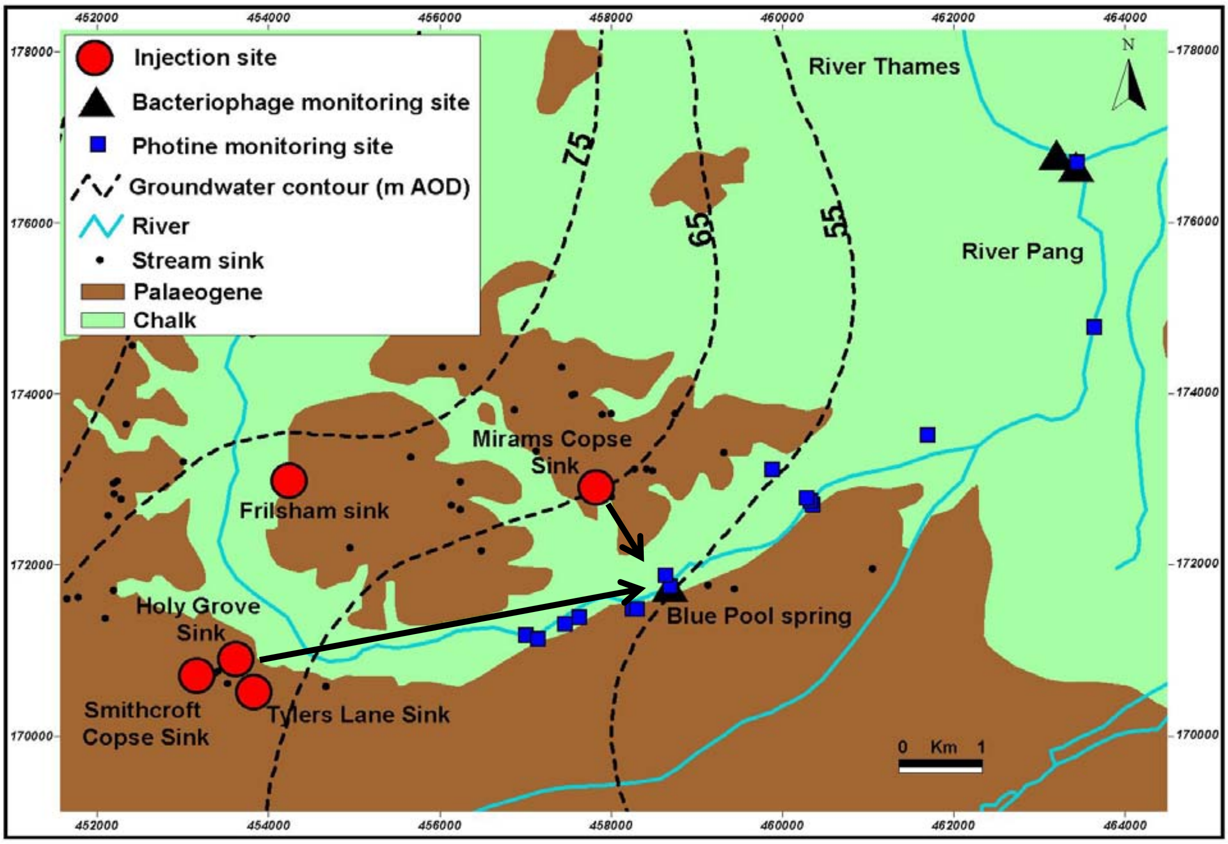

Figure 8 Tracer testing in the Pang catchment

4.2 RUSHALL FARM QUARRY

Streams sinking into the Chalk commonly do so at or near the boundary between the Chalk and the overlying Palaeogene deposits. The unconformable contact between these strata is often characterised by dissolution pipes which are visible in quarries, and present a geotechnical hazard during engineering projects.

The Quarry at Rushall Farm gives a clear section through the Palaeogene- Chalk contact (Figure 9). The unconformity surface is marked by small scale dissolution pipes infilled with sand and clay derived from the overlying strata. Some small conduits are visible in the Chalk (Figure 10).

Figure 9 The quarry at Rushall Farm in 2004

Figure 10 Small scale conduits exposed in quarry face, 2004

4.3 BLUE POOL SPRING

The Blue Pool spring comprises a series of powerful upwellings that form several pools (Figure 11). The spring is at an elevation of about 55-60 m above sea level. The upwellings combine to form a single channel which discharges into the River Pang (Figure 12). The Blue Pool has a fairly consistent flow of around 200 l/s and continued to have a good flow throughout the 1976 drought. Water level monitoring over the past few years in the outlet channel has revealed a seasonal increase in stage, and a rapid response to rainfall that only occurs after the seasonal increase in stage.

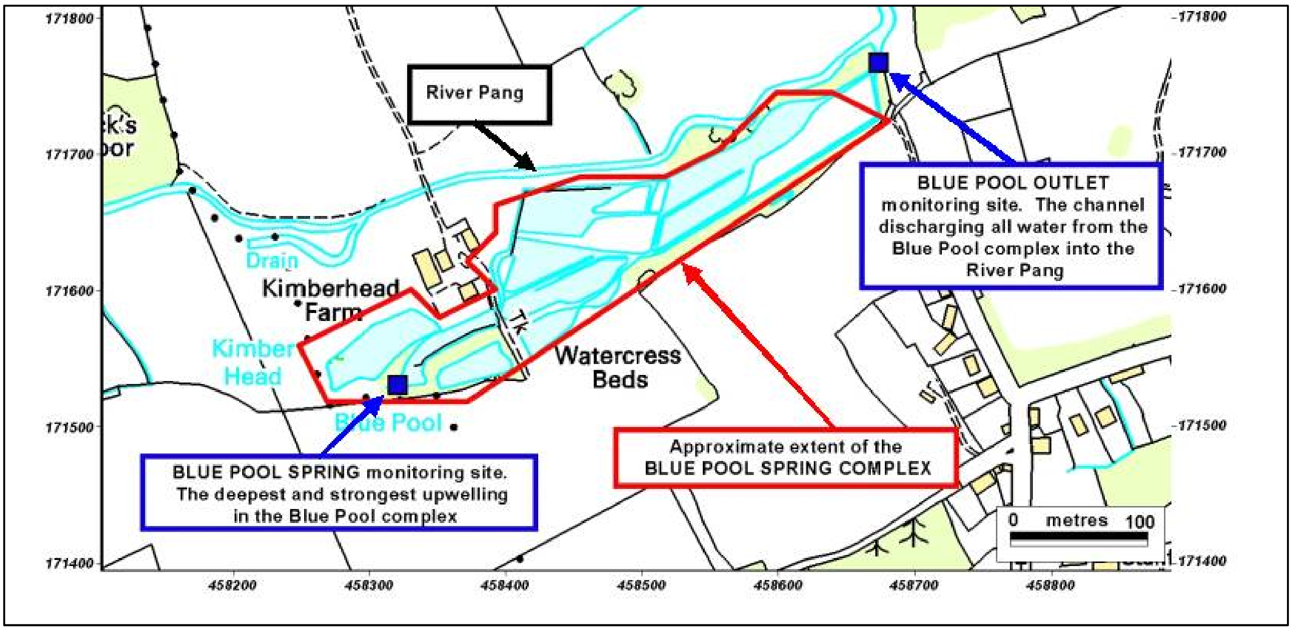

Figure 11 Layout of the Blue Pool Spring. Contains Ordnance Survey data © Crown copyright and database rights 2015.

Figure 12 The Blue Pool outlet channel

The first tracer tests demonstrating rapid groundwater flow to the Blue Pool were carried out from Holly Grove and Tylers Lane stream sinks (Banks et al., 1994). Subsequent quantitative tests revealed rapid groundwater flow from Smithcroft Copse and Mirams Copse stream sinks, combined with variable attenuation (Maurice et al., 2010). Attenuation can be low (Figure 13). 610 grams of a 70% solution of Sodium Fluorescein injected at Smithcroft Copse stream sink was visible at the Blue Pool, 5.1 km away, after a travel time of only 24 hours. The dye concentration at the spring was about 60 ug/l, and the tracer recovery was about 20%. This clearly demonstrates the vulnerability of the Chalk aquifer to pollution.

Figure 13 Low attenuation over 5.1 km

4.4 CALVERSLEY FARM BOREHOLE

Borehole investigations in the Chalk have revealed that most groundwater flow occurs through dissolutional fissures and conduits (Schurch and Buckley 2002; Maurice et al., 2012). Calversley Farm borehole is an Environment Agency groundwater level monitoring borehole. Imaging of the borehole walls has shown that it intercepts a number of dissolutional fissures and conduits, and that these may be sediment filled (Figure 14). We will use a borehole CCTV system which can be moved around to look at the borehole walls from different angles.

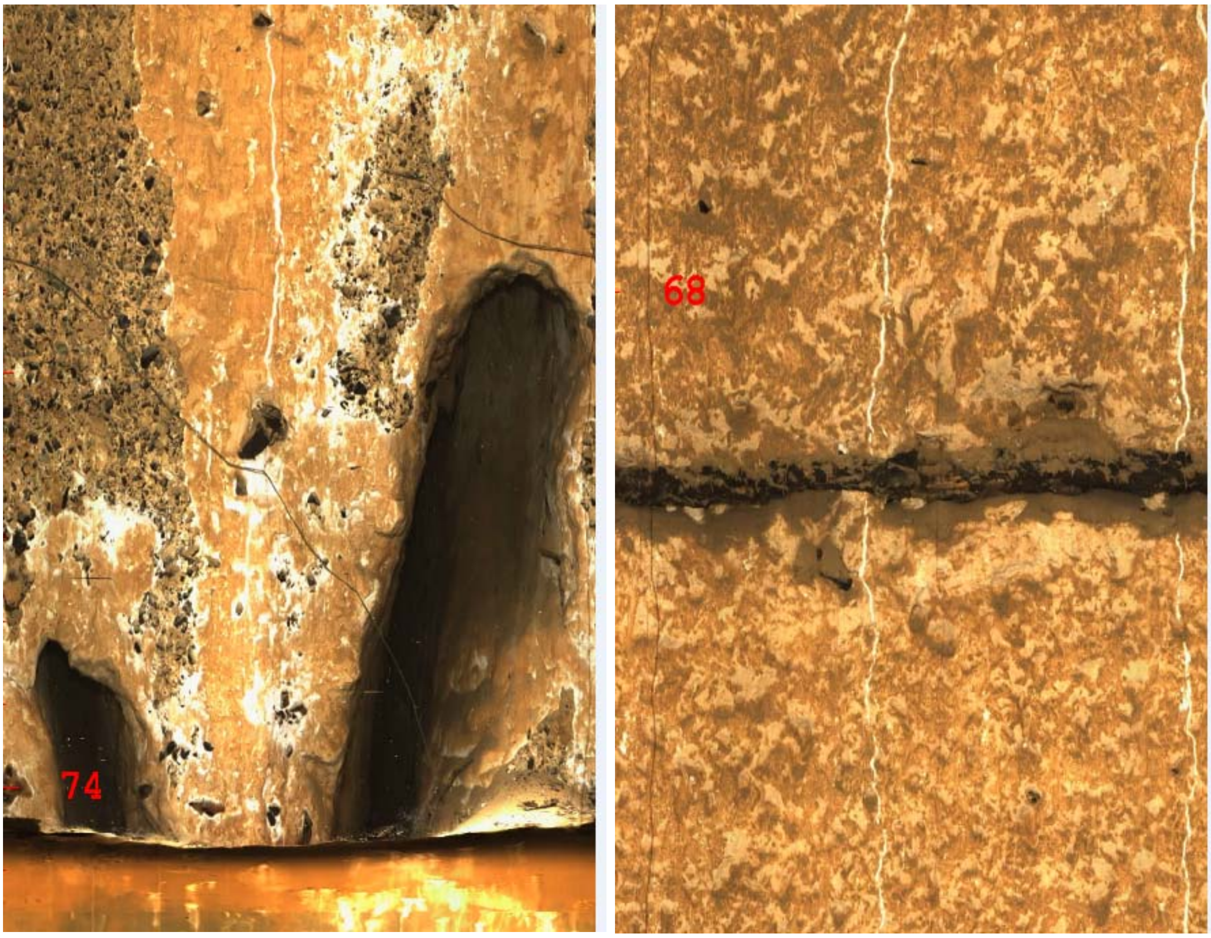

Figure 14 Dissolutional conduit and fissure in Calversley Farm borehole

Groundwater ecology sampling has found a diverse community of invertebrates in Calversely Farm borehole including *Niphargus kochianus*, copepoda, springtails, nematoda, oligocheata and mites. The most common invertebrate found in the borehole is the amphipod *Niphargus kochianus* (Figure 15). This is a stygobitic species, usually between 0.5 and 5 mm in length, which is only found in groundwater, and is specially adapted to live in an environment with no light and limited resources. Genetic work has demonstrated that the British population of *Niphargus kochianus* separated from European populations about 2.9 million years, so it is an ancient endemic lineage that provides an important contribution to biodiversity (McInerary et al., 2014). Stygobitic invertebrates are widespread in the Chalk and a recent study found them in more than 70% of boreholes sampled. Whilst we have not observed the stygobitic invertebrates in Calversley Farm borehole with CCTV before, we have observed them using CCTV at another borehole in the catchment (Figure 16).

Figure 15 *Niphargus kochianus*

Figure 16 Stygobite observed in Cow Down borehole using CCTV

4.5 YATTENDON STREAM SINK

The Yattendon stream sink is an unusual example of a Chalk stream sink where the stream can be observed to sink into a cavity within the Chalk. At this site, a small stream has eroded through the Palaeogene material to reveal the Chalk underneath (Figure 17). The water sinks into a narrow vadose canyon, disappearing into a chalk cave about 30 cm wide and several metres deep (Figure 18). Most streams sinking into the Chalk sink into clay and sand deposits overlying the Chalk and therefore the karst features within the Chalk cannot be observed. It is possible that many other Chalk stream sinks are underlain by features like this which are concealed under the Palaeogene sediments.

Figure 17 Yattendon Chalk cave

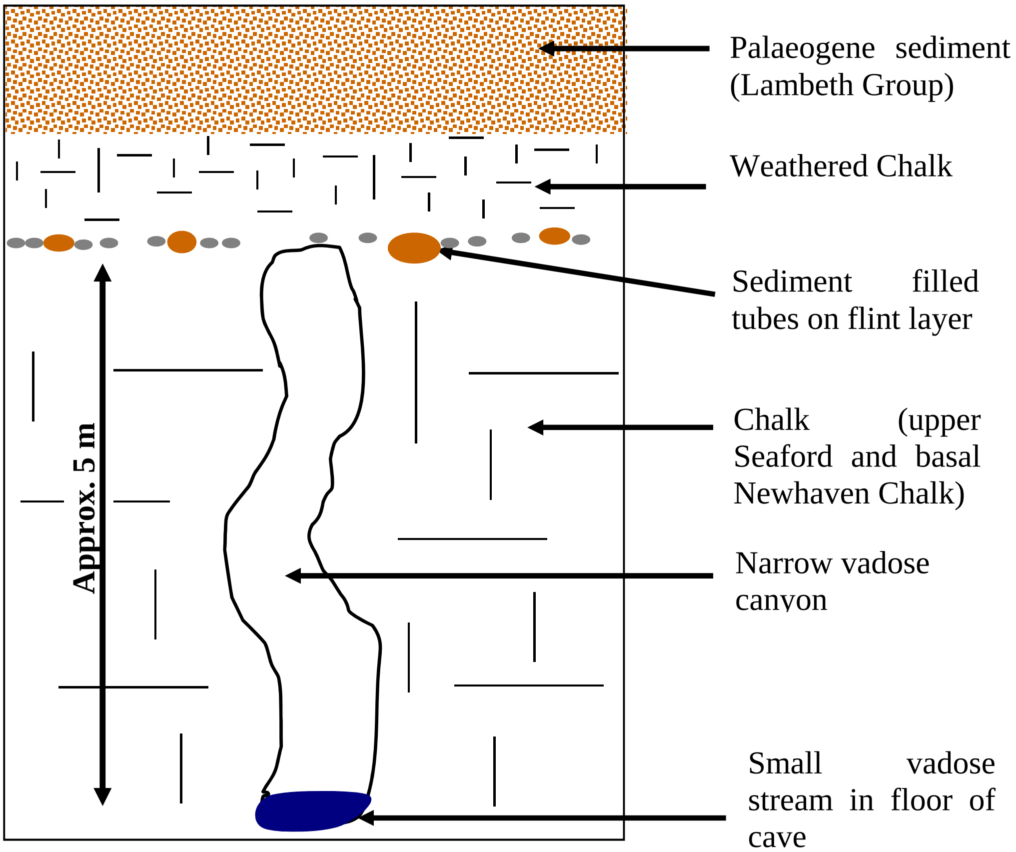

Figure 18 Schematic cross section of Yattendon Chalk Cave.

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Field Trip Itinerary
(With approximate timings)

08:30	Leave Birmingham
11:00	Arrive at Rushall Farm
11:15 to 13:15	Visit Blue Pool spring (2 groups, about 2.5 km walking)
13:15 to 14:00	Lunch (Rushall Farm picnic area)
14:00 to 15:30	Mirams Copse stream sink and Rushall Quarry (trailer transport)
15:45 to 16:15	Group A: Borehole viewing
	Group B: Yattendon stream sink
16:15 to 16:45	Group A: Yattendon stream sink
	Group B: Borehole viewing
16:45	Depart for Birmingham
19:15	Arrive Birmingham