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British Cave Research Association Field Guide to the Bath Stone quarries, Box, Wiltshire

Geology and Regional Geophysics

Internal Report IR/16/031

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British Cave Research Association Field Guide to the Bath Stone quarries, Box, Wiltshire.

Andrew R Farrant, and Charlie Self

Keywords

Bath Stone Mines, Corsham, Gull Caves, Chalfield oolite., Great Oolite Group, Bath oolite, cambering.

National Grid Reference

NW corner 383000,170000
SE corner, 385000, 168000

Map

265, 1:50 000 scale, Bath

Front cover

Charlie Self examining a gull fissure backfilled with spoil in the Box quarries (Jack's workings).

Bibliographical reference

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1 Introduction

The venue for the 2016 British Cave Research Association Cave Science Symposium Field Trip is the underground 'Bath Stone' quarries around Box, near Corsham, Wiltshire (Figure 1). The aim of the field trip is to examine the cambering and gulling, gull caves and karstic features observed in the quarries. The underground quarries at Box lie at the southern end of the Cotswold Hills, on the southern side of the By Brook valley, a tributary if the River Avon. This valley has incised though the Great Oolite Group, a sequence of Middle Jurassic (Bathonian) limestones and mudstones. The underground quarries are developed within the Chalfield Oolite Formation. This is an excellent building stone, as it can be sawn by hand in any direction as a 'freestone' which then hardens on exposure to air, rather than having a distinct cleavage like slate.

The field trip will focus on the accessible part of the quarry complex, entered via Jack's Entrance (Figure 2). Surveys of the quarries are available from the Shepton Mallet Caving Club.

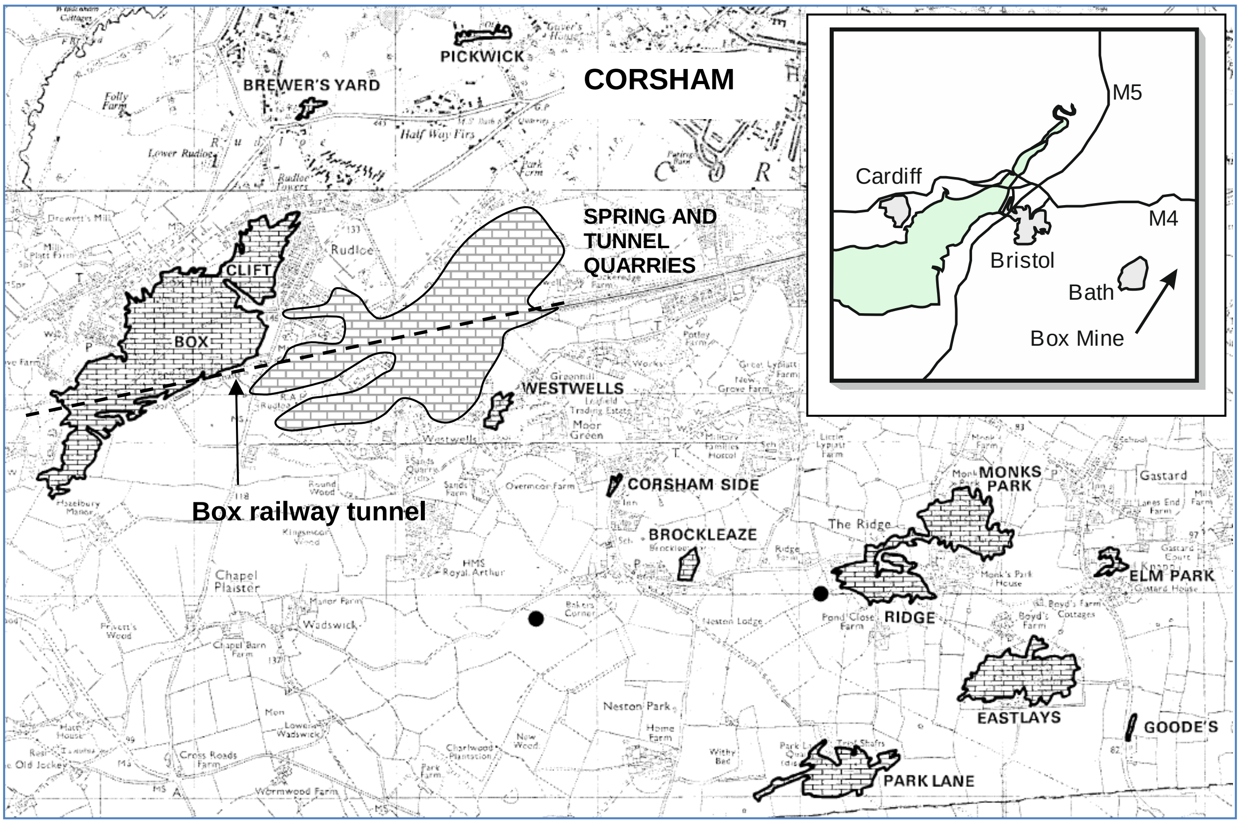

Figure 1. Location of underground quarry workings in the Corsham area (from Forster et al., 1985).

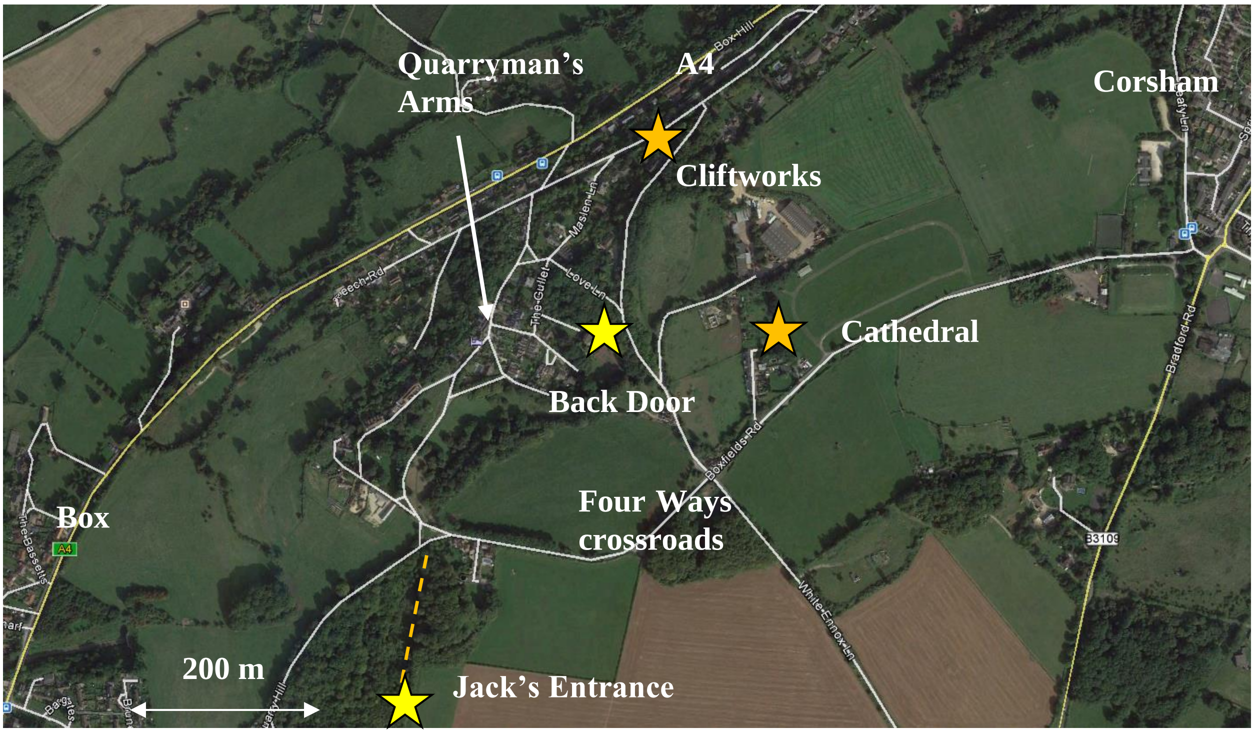

Figure 2. Location of the Box quarries.

Stone extraction in the Box area began during Roman times, initially as separate surface quarries, but then extending underground and eventually amalgamating into a single large underground network. The construction of the Box railway tunnel in 1841 led to the exploitation of stone reserves further down dip (Spring and Tunnel quarries), accessed via a railway siding from the main line. This part of the quarry is connected to the accessible workings at Box via the Wind Tunnel and Brewer's Drift, but is sealed by the MOD. Quarrying continued until just before the Second World War when part of the site was requisitioned by the War Office in around 1935 although the older parts of the quarry were abandoned much earlier.

Many mining artefacts can still be seen including old cranes, saw-sharpening benches, miners' graffiti and old wells. The quarries are also home to a large population of bats with up to 10% of the total British population of greater horseshoe bat using the mine at times. Other bat species including the Lesser Horseshoe, Whiskered, Brandt's, Natterer's and Daubenton's bat have also been recorded.

2 The geology of the Box area.

The primary feature-forming Cotswold escarpment between the M4 motorway and Bradford-on-Avon is formed of Middle Jurassic oolitic limestones and mudstones (Figure 3) belonging to the Great Oolite Group (Barron et al., 2011). The escarpment here is deeply incised by the River Avon and its tributaries. The rivers have incised through the Middle Jurassic sequence (which caps the interfluves) into the underlying Lower Jurassic strata (Lias Group). In the base of the Avon valley, the Blue Lias Formation locally crops out, but it is the Charmouth Mudstone Formation and the rest of the Lias Group that underlies most of the valleys in the Bath area.

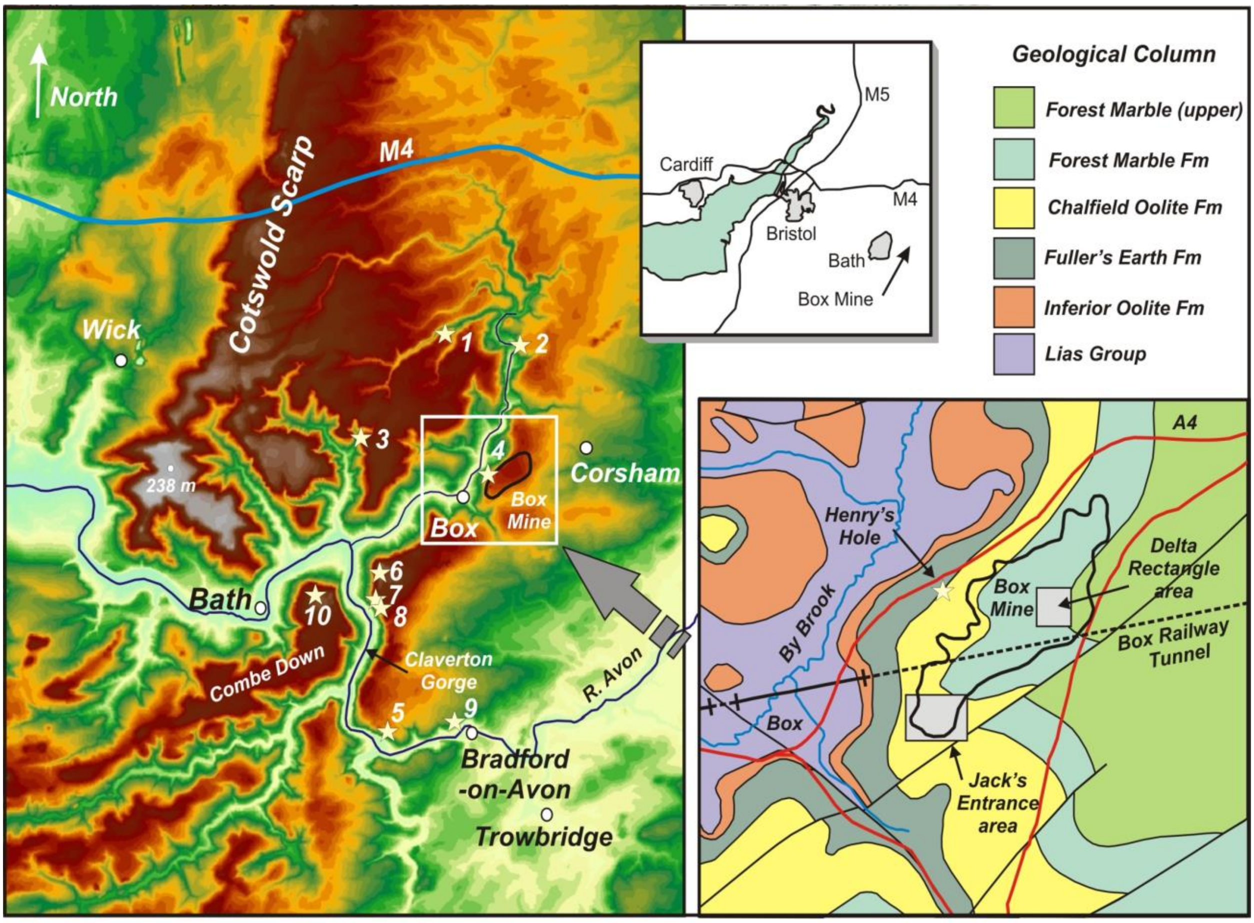

Figure 3. Map of the Avon valley around Bath.

The topography is based on a NextMap digital terrain model, with a 5 m spacing greyscale ramp. The inset map is a geological map of the Box area (based on the British Geological Survey digital geological 1:50,000 scale data). Gull caves are marked with a star and numbered: 1. Bury Wood Camp [ST 8162 7397]. 2. Guy's Rift [ST 8450 7372]. 3. The Rock's Rift [ST 7896 7057]. 4. Henry's Hole [ST 8360 6944]. 5. Murhill Rift [ST 7956 6073]. 6. Gully Wood Cave No. 5 [ST 7937 6600]. 7. Gully Wood Cave No. 4. [ST 7946 6500] 8. Sally's Rift [ST 7941 6506]. 9. Gorton's Rift. 10. Bathampton Down and Bath University. Detailed descriptions of the gull caves are in Self and Boycott, (2000).

The lowest division of the Middle Jurassic is the Inferior Oolite Formation, a succession of flaggy and rubbly oolitic grainstones up to 23 m thick. Above this is the Great Oolite Group, comprising mudstone-dominated and ooidal, bioclastic and fine-grained limestone formations. The basal unit of this Group is the Fuller's Earth Formation, a series of thick calcareous mudstones interspersed with beds of flaggy, coarse bioclastic carbonate grainstones and packstones approximately 46 m thick. An oolitic limestone, 4 to 5 m thick part way up the sequence has been named the Fuller's Earth Rock Member. The upper part of the Fuller's Earth Formation consists of about 28 m of mudstone including a commercially exploited bed of montmorillonite clay ('fuller's earth') with a few subordinate limestones. In general, the Fuller's Earth mudstones are overconsolidated, highly plastic clays.

Above is the Chalfield Oolite Formation. This is the unit that was sought after for building stone and in which the quarries are developed. It is 39 m thick and comprises a succession of fine to coarse, largely matrix-free oolitic grainstones and, at certain levels, much bioclastic debris. At its fullest development, the formation is divisible into three units, the lower Combe Down Oolite Member, the Twinhoe Member and the upper Bath Oolite Member (Figure 4). The basal Combe Down Oolite rests on the underlying Fuller's Earth mudstone with a slight unconformity. It consists of a succession of creamy-grey to yellowish, medium-to coarse-grained, cross-bedded oolitic grainstones, interleaved in the lower part with prominent beds of marl. It reaches its maximum thickness of 17.5 m on Combe Down and around Corsham, but thins to the south-east. This is overlain by the Twinhoe Member, a laterally impersistent unit of pisolitic and detrital limestones with ferruginous ooliths and pisoliths, bioclastic debris and corals. The Twinhoe Member is around 2-5 m thick in the Bath area, but thins and pinches out to the north-east, and is absent around Corsham where it merges into the overlying Bath Oolite Member. The Bath Oolite Member comprises a monotonous succession of fine- to medium grained cross-bedded oolitic grainstones with very subordinate shell debris and without prominent marl interbeds.

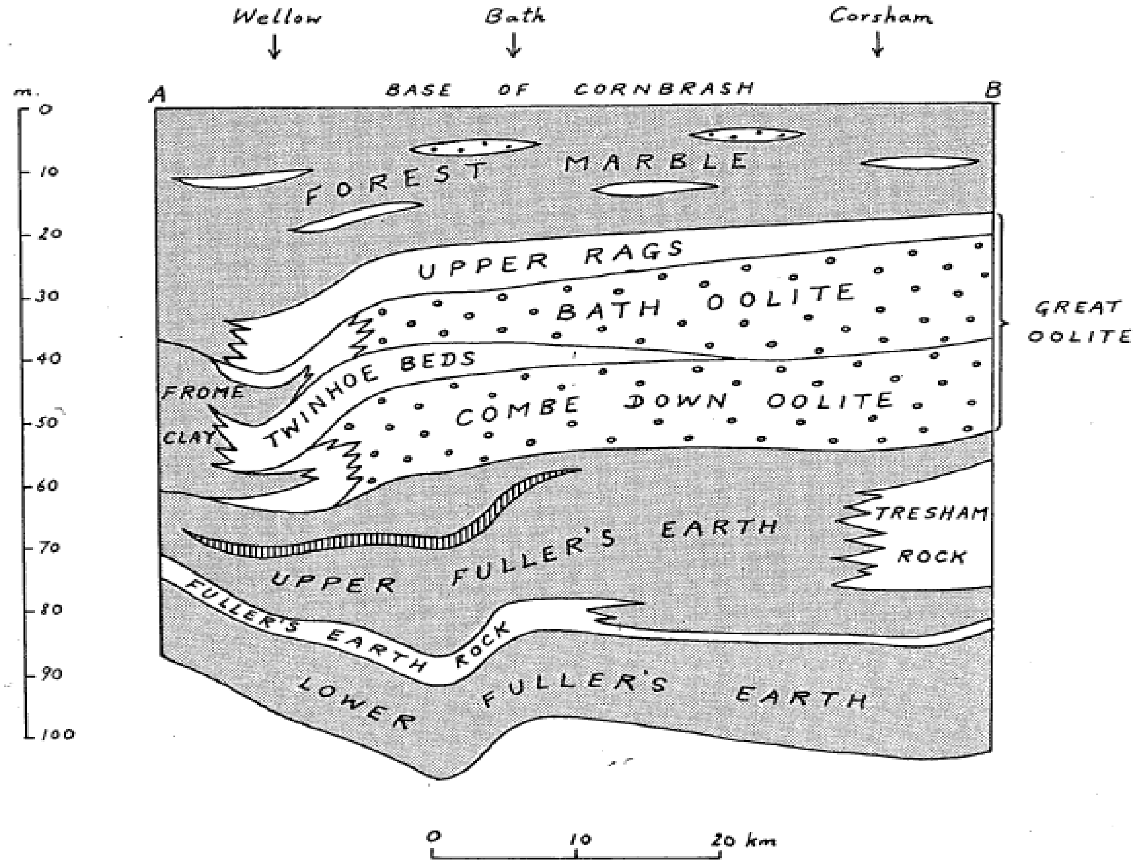

Figure 4. North-south section though the Great Oolite Group (from Forster et al., 1985)

The Bath Oolite and Twinhoe Member together are generally uniform in thickness. Like the Combe Down Oolite, the Bath Oolite attains its maximum thickness of around 15-20 m in the Combe Down and Box Hill areas. The regional dip is about 2º to the south-east, and is locally cut by minor faults.

The Chalfield Oolite Formation is succeeded by the Forest Marble Formation, a sequence of coarse bioclastic limestones and mudstones which is up to 31 m thick in the Bath area.

3 The formation of cambers, gulls and gull caves

The Jurassic mudstones and limestones are prone to mass movement (Figure 5 and 6). The valley sides of the River Avon and its tributaries have extensively foundered, with significant land slipping in and around the city of Bath. These mass-movements include both rotational landslips and extensive cambering. Cambering refers to the gradual down-slope mass-movement of broken blocks of competent rock (limestone), moving over less competent rock (mudstone). Gulls are common in the more competent oolitic limestones. The term gull (derived from gully) is an old quarryman's term, used to describe open joints in solid strata (Fitton, 1836). They are particularly well developed in the Chalfield Oolite where the major joints have opened as the strata has extended valley-ward. When large enough to be explored by cavers, they are termed gull-caves; the anthropomorphological element of this definition is important because it means that they are accessible to direct study. Gull-caves are different from normal dissolutionally widened fissures and caves, and can be identified by their distinct morphology. Gulls are typically narrow, parallel-sided, joint orientated rifts, often with symmetrically opposing wall morphologies (‘fit features’ of Self, 1986), but where there has been vertical as well as lateral movement, bedding planes or other discontinuities may also have parted. They are also known as ‘windy pits’ or ‘crevice’ caves.

The effects of cambering can be seen in many of the underground quarries. Gulls are common and there are also gull-caves large enough to be accessible for direct study. Moreover, these extensive underground stone quarries enable the spatial extent of the gulls to be mapped out over wide areas, and can be used to identify zones of maximum extension.

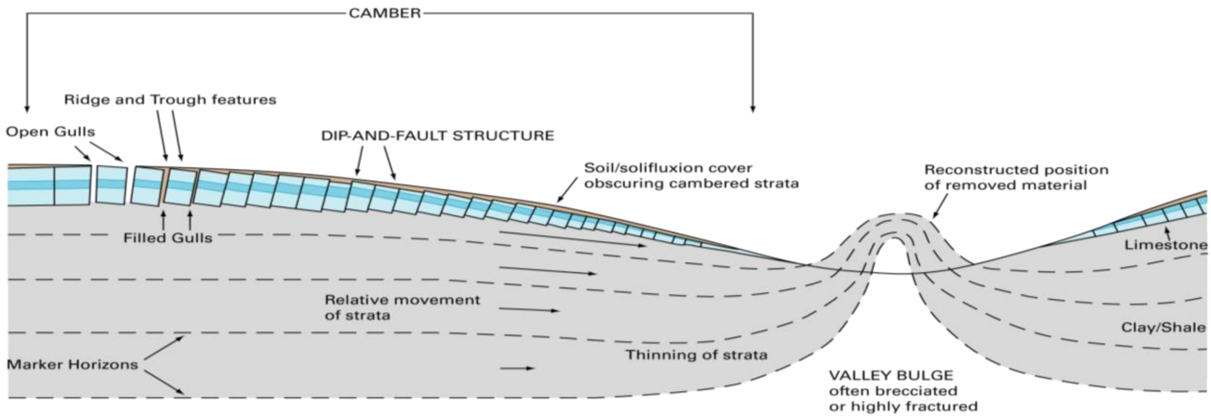

Figure 5. Example of camber and gull formation.

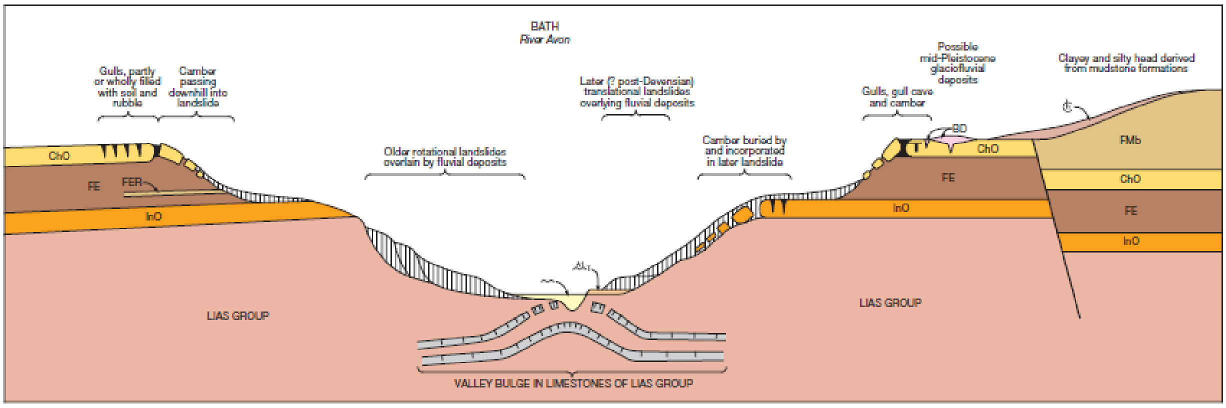

Figure 6 Camber and gull formation in the Bath area. ChO is the Chalfield Oolite Fm; Fe - Fullers Earth Fm; FmB - Forest Marble; and InO - Inferior Oolite.

Gulls form on steep hillsides as a result of mass-movement, when well-jointed strata are unsupported on their downhill side. In sedimentary rocks, extension takes place along bedding planes with bed-over-bed sliding and the opening of joints (Hawkins and Privett, 1981). Gulls are particularly common in flat-lying or gently inclined strata affected by cambering. Cambers are caused by the gravitational lowering of outcropping or near-surface strata towards an adjacent valley. They occur where competent and permeable rocks overlie incompetent and impermeable beds such as clays. The competent beds develop a local dip towards the valleys, swathing the hill-tops and draping the valley sides (Hollingworth et al., 1944). The incompetent material is extruded from beneath the cap-rock, initially as a result of stress relief.

Parks (1991) has suggested that as a camber develops, the competent cap-rock breaks up into joint-bounded blocks above a basal shear plane in the underlying material. A Quaternary cold stage with permafrost conditions is then required, since the underlying strata (if it is mudstone) is much more susceptible to creep when frozen. Thawing at the end of the glacial cycle increases the water content of the mudstone, potentially saturating it and drastically reducing its shear strength. This causes it to behave as a plastic fluid and the competent cap-rock migrates in the direction of slope, opening the joints to form gulls.

The Parks model shows how gulls that are open to the surface can form in a thin cap-rock. In the Cotswold Hills, the limestone cap-rock is much more substantial and the gulls and gull caves generally have intact roofs. They have formed in the lower part of the limestone strata, with little or no mass movement having taken place in the upper part. This requires not only a basal shear plane, but also an upper parting/ sliding plane within the limestone sequence. A possible mechanism, involving the sequential unloading of joint-bounded blocks, was suggested by Self (1986). As extension occurred, individual blocks were able to settle slightly and then move laterally over the mudstone. The blocks move in the same direction but independently of each other, with neighbouring blocks supporting the overlying strata in turn, creating a gull network that propagates away from the valley.

Other features seen in the caves and mines of the southern Cotswolds appear to contradict the Parks model. Significant camber angles are limited in extent, only affecting the strata closest to the hillside margins, whereas gulls continue to occur deep within the stone mines. A possible contributing factor is pyrite oxidation in the upper horizons of the Fuller’s Earth mudstone, with chemical leaching of the calcite cement greatly reducing its shear strength (Brown, 1991) and allowing mass movement at very shallow camber angles. Mass movement in the study area seems to have been triggered by the rapid over-deepening of the valley system resulting from the capture by the River Avon of dip slope streams of the palaeo-Thames drainage. High pore pressures in the mudstone need not have been caused by permafrost, but could have been a result of groundwater percolation from above. The stability of the gulls since their creation (with the growth of speleothem deposits) suggests that there was only one major episode of mass movement. A possible explanation is that mass movement ended when the valleys cut down into the more competent Inferior Oolite limestone, which gave stability to the hillsides above.

3. The gull caves

Typically, gull cave entrances in the southern Cotswolds are found in the cliff faces of abandoned small valley-side quarries (Self and Boycott, 2000). Some are single fissures a few metres long, while others form more extensive systems. The main jointing directions are NW-SE and NE-SW, so the more complex gull caves tend to be rectilinear networks. N-S and E-W joints are also present in the study area, but they generally have not been opened by mass movement. The known caves all occur on north- or west-facing (up-dip) slopes, probably because such slopes are less prone to rotational failure. Many more caves certainly exist, but these either do not intersect the surface or are buried under colluvium.

The largest gull caves occur in the Claverton Gorge where the River Avon cuts through the Cotswolds escarpment (locations 5-10 on Figure 3). Gorton’s Rift is a very deep gull accessed from within a small stone mine. The rift is 24 m deep from the mine level and must reach almost to the lithological boundary with the underlying Fuller’s Earth mudstones. Several caves can be found on the east side of the gorge. Gully Wood Cave No. 5 is a network of 50 metres, developed on several levels whilst Gully Wood Cave No 4 is a 90 metres long contour-aligned gull with impressive passage dimensions (Figure 2). Murhill Rift comprises a major passage 80 m long linked to a complex network of rifts and passages on three levels close to the hillside, giving a total length of over 300 metres.

The largest cave in the region is Sally’s Rift (Self, 1986; 1995) (Figure 7). It has three entrances and is 365 metres long. The passages are typically over 10 metres tall and between 20 cm and 50 cm wide; the largest passage lies closest to the hillside and is 15 metres tall and 2 metres wide.

The cave is a series of contour-aligned gulls linked by gulls aligned along a camber spreading axis which runs directly into the hill side (Self, 2008).

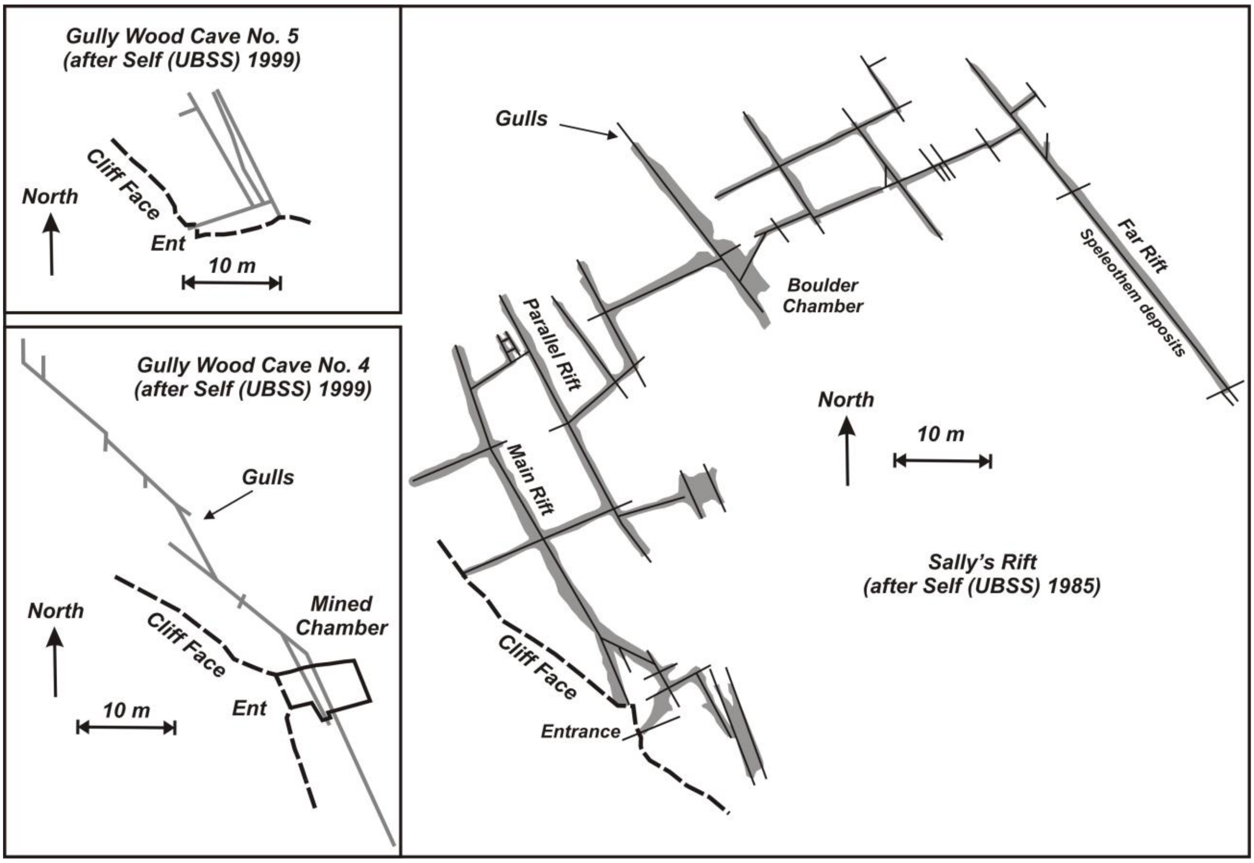

Figure 7. The Gully Wood gull-caves, including Sally's Rift.

This zone of lateral extension is the result of an abrupt change of direction of the River Avon valley just north of the cave, resulting in mass movement in two different directions (Self, 2008). The cave has several examples of "fit features", whereby a ledge on one wall matches an overhang at the same level on the opposite wall. In both Sally's Rift and Gully Wood Cave No. 4, there are localized deposits of gravel containing Cretaceous flints with occasional clasts of Carboniferous rocks; these are identical to local superficial deposits preserved on the plateau above the cave, identified by Donovan (1995) as an early Quaternary deposit.

4. Gulls in the Box quarries

Gull fissures are pervasive throughout the Box system and reach into the remotest parts, more than 600 m from the escarpment. The fissures range in width from a few centimetres up to gull caves over a metre wide and many tens of metres long. Locally they can extend up to 10 m above the level of the mine floor. These larger gulls are sometimes passable, but many have been used for storage of waste stone (Figure 8).

Figure 8. Charlie Self next to a gull used for the storage of waste stone, Jack’s workings.

A detailed survey of the gull fissures was made in two separate parts of the mine, around Jack’s Entrance and in the Delta Rectangle area (see Figure 3), in an attempt to determine their spatial extent. In the Jack’s Entrance area (Figure 9), the majority of gulls are aligned on the 150° joint set and are fairly regularly spaced around 3-8 m apart. Thirty-five gulls were recorded along a 200 metre transect due east from the entrance, showing an average extension of the strata of just over 5% along the length of the passage (Figure 10). However, in the middle part of the transect, there is a zone with much larger gulls, which give an extension value of 9% for this part of the survey. These zones of extension were first reported by Hawkins and Privett (1981) on a building site in cambered lower Jurassic strata. Cambering is obvious along the western edge of the mine, reaching a maximum of 11° close to a collapsed former entrance. However, the camber angle decreases sharply a short distance into the mine and within 200 m the bedding becomes essentially horizontal.

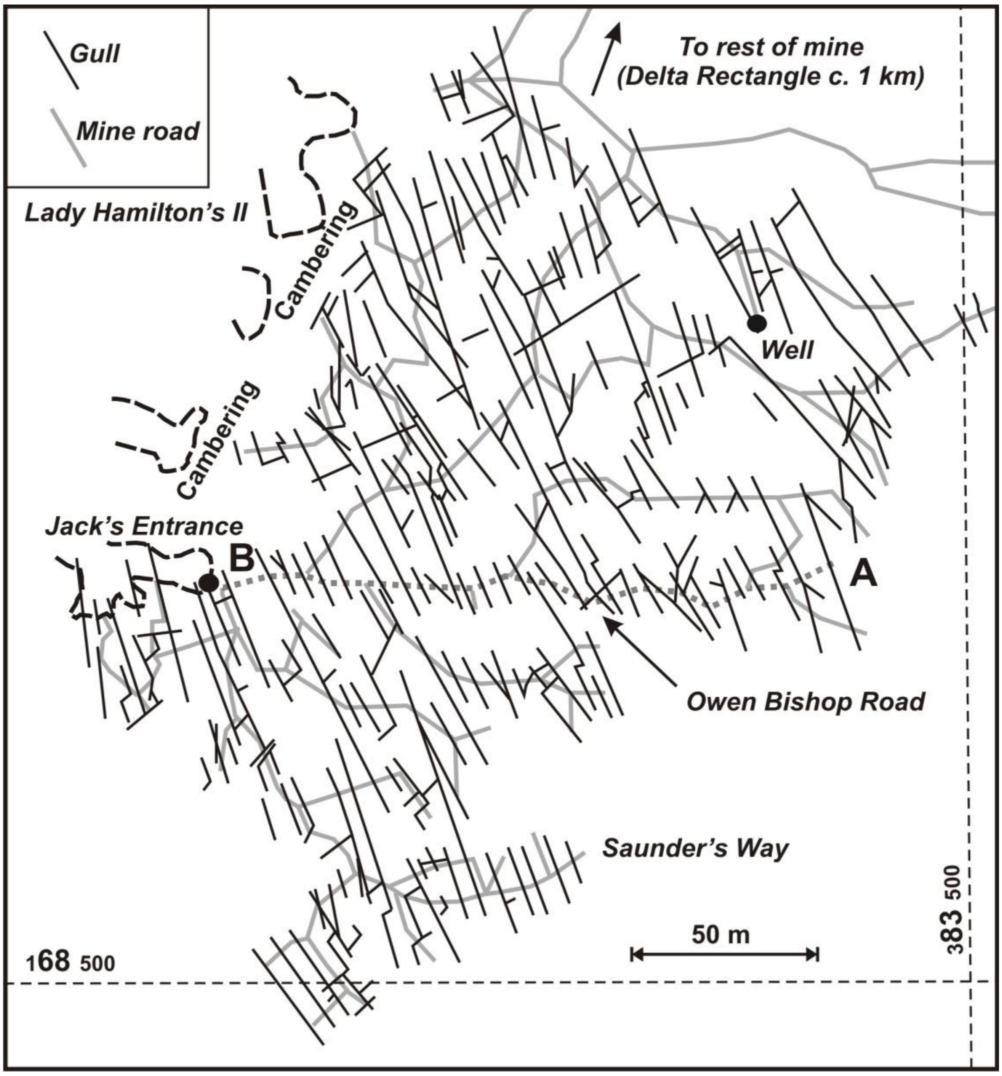

Figure 9. Gulls in the Jack's Entrance area of the Box Freestone Mine.

In the Jack's Entrance area, the nearby hillside is aligned approximately north-south. Ordinarily, this valley orientation might cause both the NW and NE joint sets to have opened. However, the regional dip of the strata, around 2° to the southeast prevents this. Opening of the NE joint set would require cambering up-dip, whereas for the NW joint set cambering is in the much easier direction of strike of the strata. The measured camber directions are not in the direction of slope, but consistently have a dip component, which explains the dominance of NW aligned gulls.

The Delta Rectangle area lies almost directly beneath the summit of Box Hill, about 400 m from the nearest escarpment edge. Numerous gull fissures are present but they are more widely spaced than those seen in the southern part of the mine. The gulls are typically 5 to 20 cm wide and both joint sets have opened, with no clear direction of extension (Figure 11). A 200 m east-west transect recorded 16 gulls with c. 1% extension of the strata along the length of the passage.

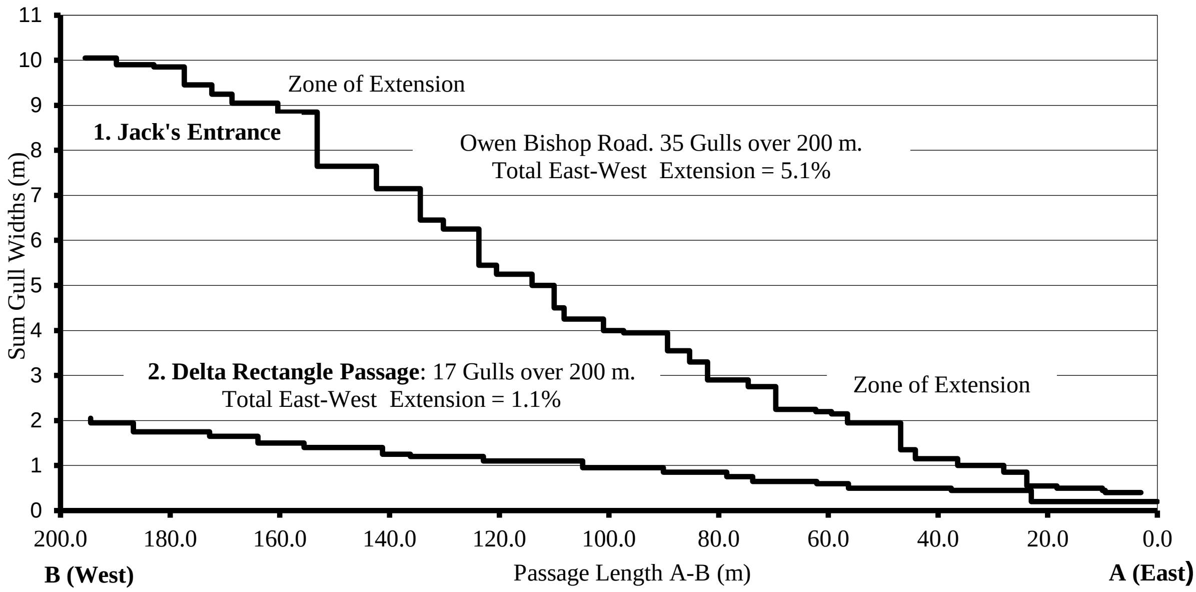

Figure 10. Transects through Box Freestone Mine: 1. Owen Bishop Road close to Jack's Entrance and the hillside (Jack's Entrance to the west); and 2. Delta Rectangle Passage in the interior of the mine beneath the interfluve. Two zones of extension are apparent on Owen Bishop Road in the Jack's Entrance area.

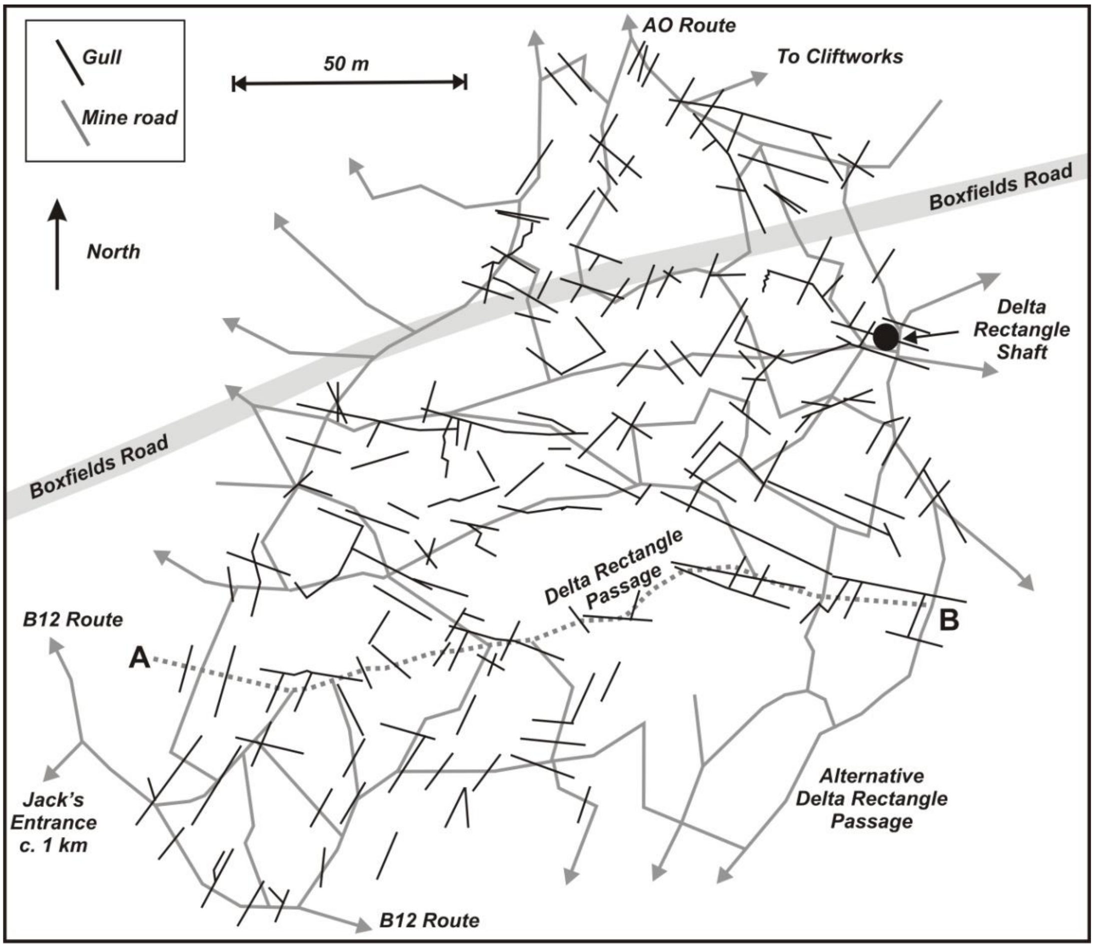

Figure 11. Gulls in the Delta rectangle area of the Box Freestone Mine.

The Chalfield Oolite is an important aquifer, but it is only weakly karstic and groundwater travels freely along the joints. On the south side of the By Brook and the east side of the Claverton gorge of the River Avon, including in the Box quarries, the NW-SE trending joint set is heavily corroded with extensive dissolutional fretting (Figure 12) while the walls of the NE-SW joint set are smooth with no dissolution (Figure 13) (Self, 1995). This etching of the joint walls is the result of slow groundwater movement which pre-dates the onset of cambering (and de-watering of the strata). This suggests that preferred orientation of groundwater flow prior to incision of the River Avon was in a NW-SE direction. Drainage could not have been down-dip to the south-east because the Forest Marble forms an impermeable cap-rock. The outlet was therefore up-dip towards the By Brook valley.

In parts of the workings, small scale dissolutional features including small-scale bedding guided phreatic conduits (Figure 14) and vadose shafts can be seen. These would have been formed before significant incision of the River Avon when the water-table was much higher.

Figure 12. NW-SE trending water worn gull, showing cross-bedding in the oolitic limestone picked out by dissolution.

The significance of the up-dip palaeodrainage of the NW joints in Sally's Rift and the Box quarries is that the nearby River Avon flows in this direction. The Claverton Gorge (and the entire River Avon valley system upstream) could not have existed at this time; otherwise the groundwater movement would have been towards this valley using the conjugate joint set. This suggests that the proto- River Avon was an aggressive scarp stream tributary to the By Brook, while the Cotswold dip slope drainage was to the headwaters of the River Thames. Eventually, head-ward erosion by the River Avon allowed it to break through into dip-slope territory and capture these former Thames headstreams. With a greatly enhanced flow, the River Avon rapidly over-deepened its valley and formed the steep-sided Claverton Gorge. The tributary valleys also cut down to this new base level and the entire valley system was primed for cambering.

Figure 13. Smooth sided NE-SW trending gull, Delta Rectangle series.

Figure 14. Phreatic half tube preserved in the roof of the passage, AO route, near the Cliftworks entrance

4 Age of the gull caves

Dating erosional landscape features such as escarpments is usually difficult because of the lack of datable deposits. Some escarpments and valley margins such as those in the Cotswolds are associated with the formation of gull caves, which are typically restricted to within 0.5 km of the valley margin or scarp edge. As in other caves these mass-movement cavities may host speleothems which can be dated. As gull-caves only develop following valley incision, uranium-series dating of speleothems within them can provide a minimum age for the timing of valley excavation and scarp formation. Dating of 5 sites in the Cotswolds (Figure 15) has provided data on the minimum age of the Cotswold escarpment (Farrant et al., 2015). The uranium-series data (Figure 16) show that the gull-cave speleothems record carbonate deposition over a large age range, between 49.5 ± 0.5 ka and 346 ± 19.3 ka. All the sites dated were formed during or before the last interglacial, and in some cases before c. 350 ka. This implies that the Cotswold escarpment is actually quite a long-lived feature which has undergone relatively little (<0.5 km) retreat in this time. Rather, the escarpment has developed 'in-situ' by the erosion of the Lias Group mudstones to the west, rather than by lateral incision. The dates from Sally's Rift indicate the River Avon had incised sufficiently for gull cave formation to take place before 350 ka. By inference, some of the gulls and gull caves in the Box quarries may be of a similar vintage.

This guide is dedicated to the memory of Charlie Self who sadly passed away early in 2016. This field trip would not have been possible without his passion for the small, muddy and seemingly insignificant Cotswold gull caves.

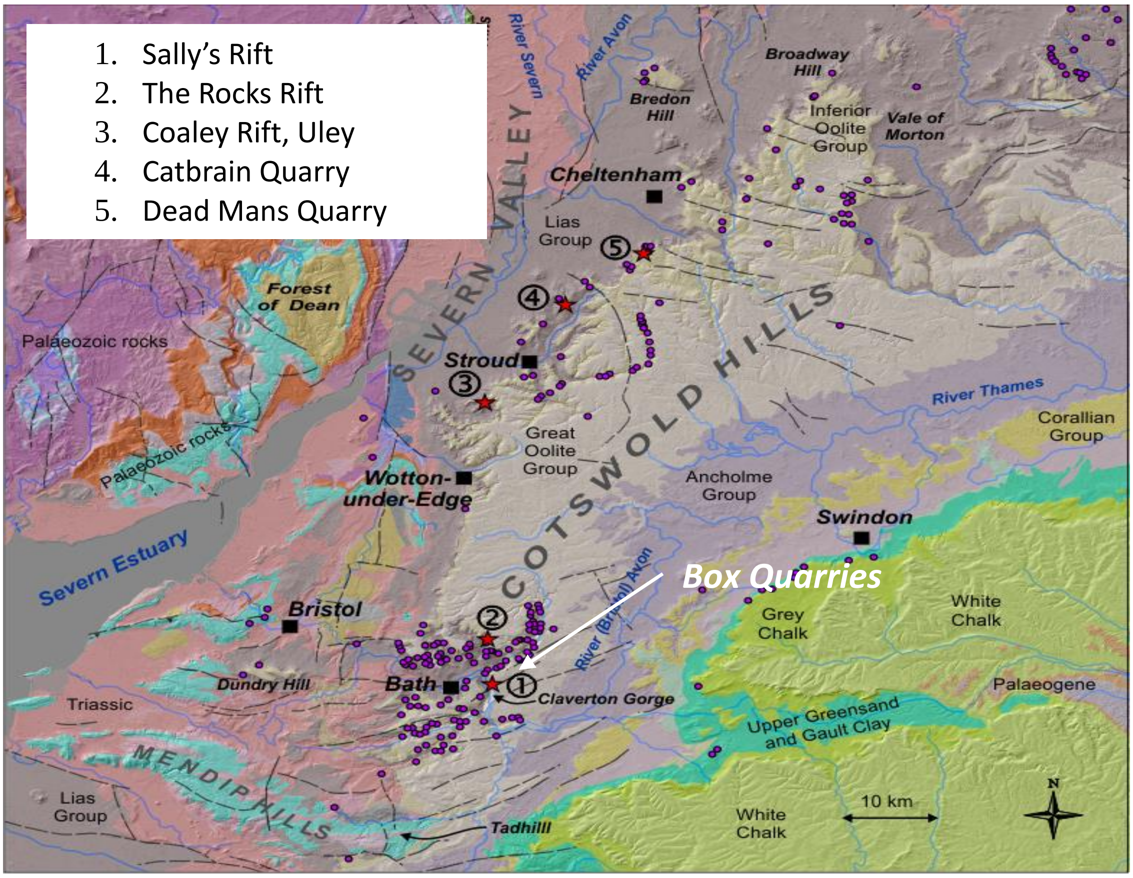

Figure 15. Geological map of western England. Known gulls and caves are shown as circles, whilst dated gull caves are shown as stars. Geology is based on BGS 1:625,000 scale digital data. Topography is NEXTMap Britain elevation data from Intermap Technologies.

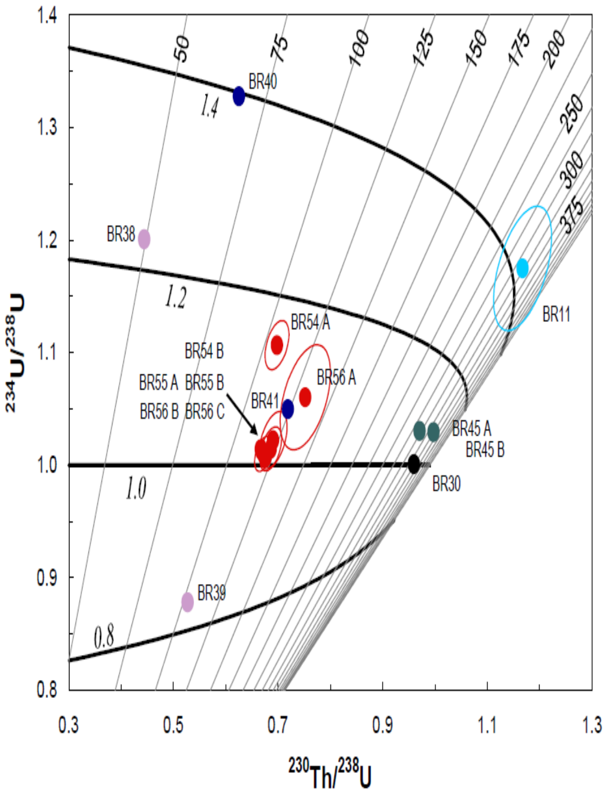

Figure 16. U-series data for sites in the Cotswolds (from Farrant et al., 2015).

Sample	Location	Age(ka)
BR11 42-2	Far Rift Sally's Rift	320.4
BR30 42-3	Dead Man's Quarry	345.9
BR38 42-4	Coaley Rift, Uley	49.5
BR39 42-5	Coaley Rift, Uley	102.8
BR40 42-6	Coaley Rift, Uley	67.1
BR41 42-7	Coaley Rift, Uley	123.8
BR45 A 58-12	Catbrain Quarry,	294.5
BR45 B 58-13	Catbrain Quarry,	348.2
BR45 C 58-14	Catbrain Quarry,	n/a
BR54 A 58-15	The Rocks Rift, Bath	105.8
BR54 B 58-16	The Rocks Rift, Bath	116.1
BR55 A 58-17	The Rocks Rift, Bath	122.1
BR55 B 58-18	The Rocks Rift, Bath	118.6
BR56 A 58-19	The Rocks Rift, Bath	131.8
BR56 B 58-20	The Rocks Rift, Bath	120.8
BR56 C 58-21	The Rocks Rift, Bath	121.6

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