A417 Missing Link
TR010056

6.4 Environmental Statement
Appendix 9.1 Preliminary Sources Study Report

Planning Act 2008

APFP Regulation 5(2)(a)
Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

Volume 6

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Infrastructure Planning

Planning Act 2008

The Infrastructure Planning (Applications: Prescribed Forms and Procedure) Regulations 2009

A417 Missing Link

Development Consent Order 202[x]

6.4 Environmental Statement
Appendix 9.1 Preliminary Sources Study Report

Regulation Number:	5(2)(a)
Planning Inspectorate Scheme Reference	TR010056
Application Document Reference	6.4
Author:	A417 Missing Link

Version	Date	Status of Version
C01	May 2021	Application Submission

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1 Introduction

1.1 General introduction

1.1.1 In 2014, the Department for Transport (DfT) announced its 5-year investment programme for making improvements to the Strategic Road Network (SRN) across England. More than 100 schemes were identified as part of this Road Investment Strategy, one of which is the A417 Missing Link between the Brockworth Bypass and Cowley Roundabout in Gloucestershire. This is in recognition of the fact that this area relies heavily on the connectivity provided by the SRN to other parts of the UK for jobs, tourism and the economy.

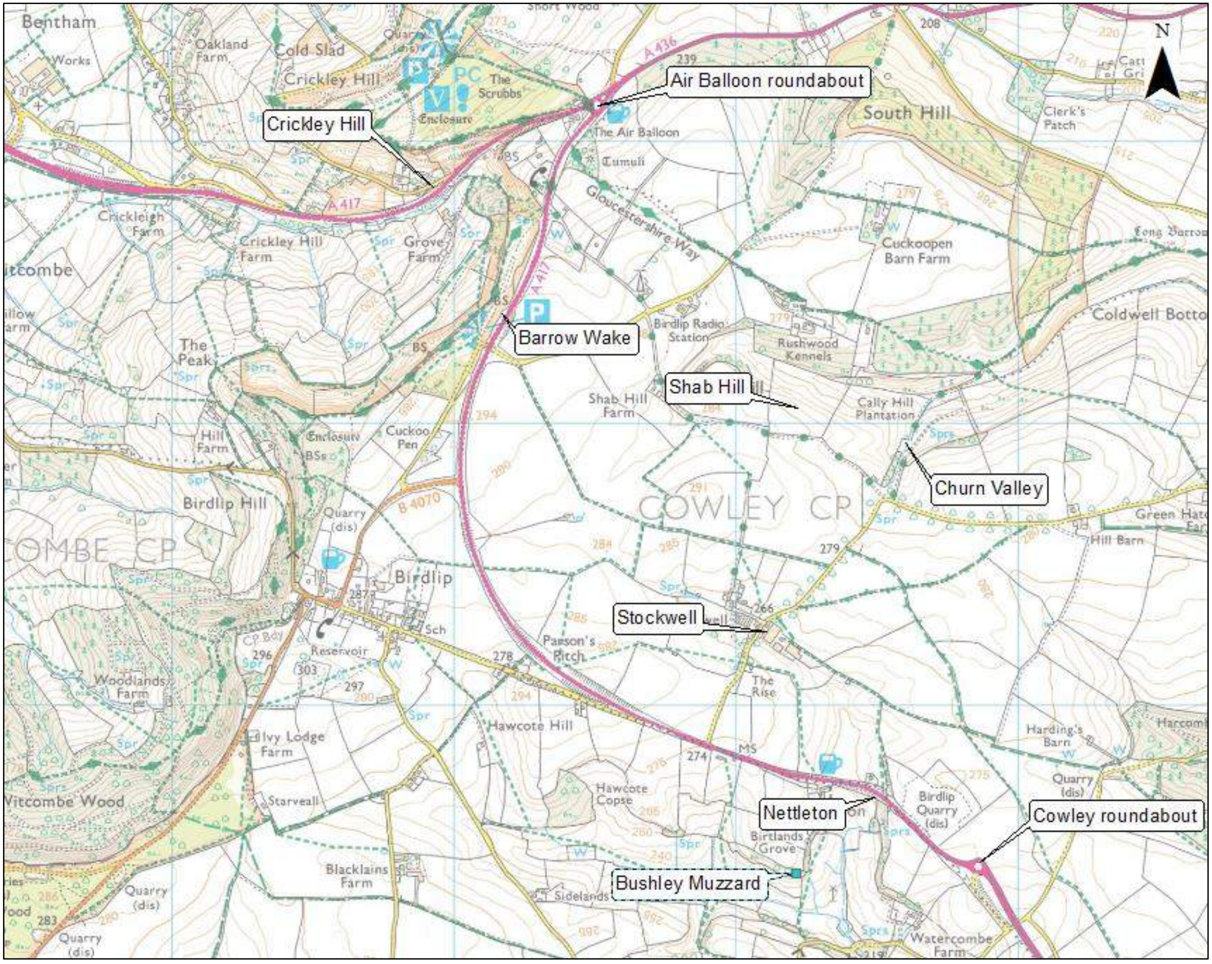
1.1.2 The A417 and A419 is a busy road corridor that links the M5 at Gloucester (junction 11A) to the M4 at Swindon (junction 15). There is a single section of the corridor that is not dual-carriageway, known as the ‘Missing Link’. This stretch of around 3 miles of single-carriageway on the A417 between the Brockworth Bypass and Cowley Roundabout (see Figure 1.1) restricts the flow of traffic causing pollution and congestion. This results in some motorists diverting onto local roads to avoid tailbacks, causing difficulties for neighbouring communities. Poor forward looking visibility and challenging gradients also mean that a disproportionately high number of accidents occur along this stretch of road.

1.1.3 Upgrading this section of A417 to dual-carriageway, in a way that is sensitive to the surrounding Cotswold Area of Outstanding Natural Beauty (AONB), will help unlock Gloucestershire’s potential for growth, support regional plans for more homes and jobs and improve life in local communities.

1.1.4 Over the years, there have been previous attempts to bring forward a scheme to upgrade or improve the A417 Missing Link across the Cotswold escarpment. For various reasons, these have never come to fruition but, in recent years, the case for improvement has become more compelling and improvements are needed to improve safety, ease congestion and pollution, and support the economy.

1.1.5 Highways England have engaged Mott MacDonald Sweco Joint Venture to undertake a Project Control Framework (PCF) Stage 2 Option Selection Study to identify route corridors which meet certain improvement criteria. Two options have been selected, which are both surface routes involving modifications to the existing road alignment up Crickley Hill and new sections of road alignment involving significant earthworks.

Figure 1.1: A417 Missing Link proposed scheme location plan



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1.2 Scope and objectives of this report

1.2.1 Highways England has commissioned Mott MacDonald Sweco Joint Venture to undertake a Preliminary Sources Study Report (PSSR). The A417 Missing Link scheme has been the subject of previous options phase studies, therefore a historic Statement of Intent (WSP Environmental Limited, 2003, HA GDMS Ref 17326) and PSSRs produced by other Design Organisations are available (AMEY, 2014) (WSP, 2002, HA GDMS Ref 16772). This PSSR seeks to consolidate and supersede the earlier reports with a focus on ground information and ground related risks pertaining to the current proposed route options.

1.2.2 This PSSR has been prepared in accordance with; the Design Manual for Roads and Bridges Volume 4 Section1 Part 2 HD22/08 Managing Geotechnical Risk (Highways Agency, 2008); Guide to Good Practice in Writing Ground Reports (Association of Geotechnical and Geoenvironmental Specialists, 2015); TRL Report 192 (Perry & West, 1996); and BS 5930:2015 (British Standards Institute, 2015).

1.2.3 This PSSR provides:

- An overview of the project geology, geomorphology, hydrology, geo-environmental aspects and other background information
- A summary of the historical development of the site
- An assessment of contamination risks
- Preliminary engineering assessment of the project area and likely hazards to the design and construction
- A geotechnical risk register
- Objectives and methodology for future ground investigation and other surveys

1.3 Geotechnical category

1.3.1 The scheme is designated as geotechnical Category 3 as defined by HD22/08 Managing Geotechnical Risk (Highways Agency, 2008).

1.4 Description of the project

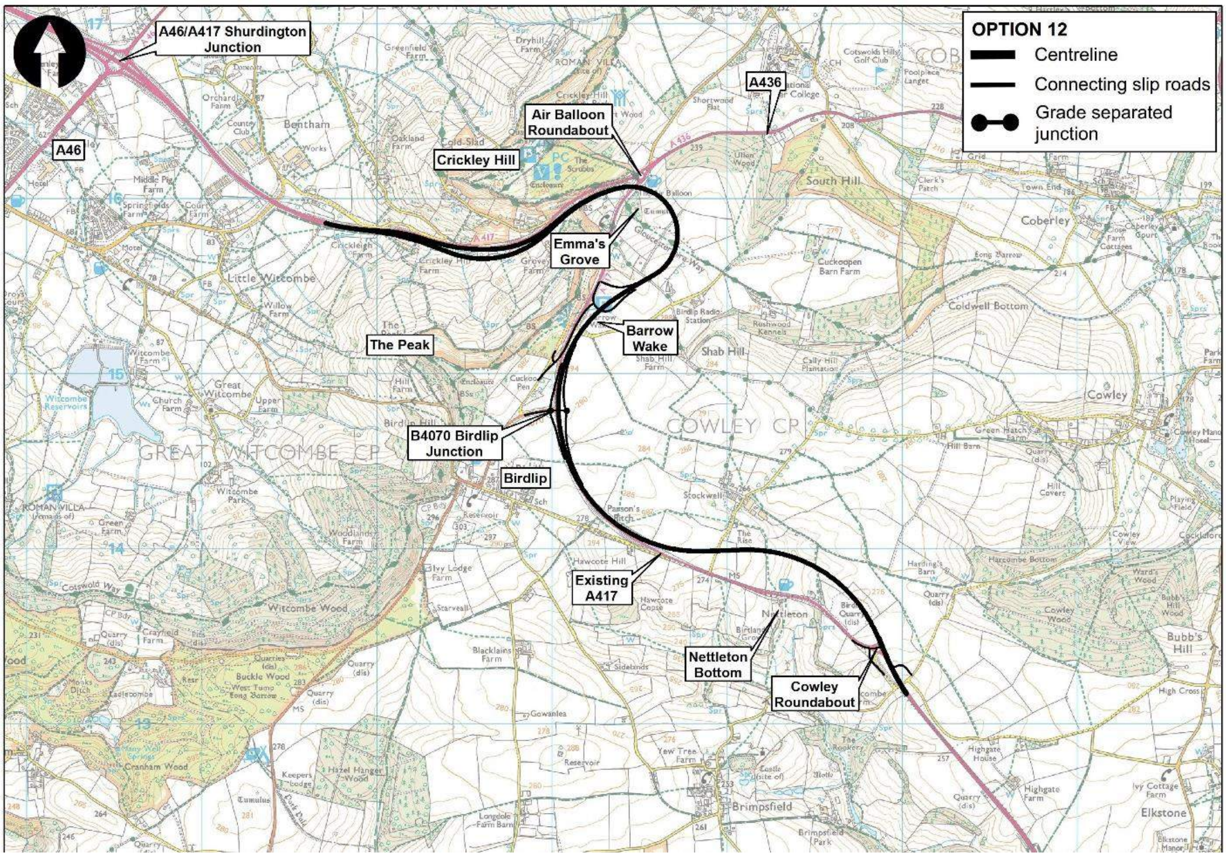
1.4.1 The 2 route options that are being taken forward in PCF Stage 2 Option Selection are termed Option 12 and Option 30. Both proposals include the construction of lengths of new carriageway involving deep cuttings and earthworks, as well as significant upgrading of individual sections of the existing road system, in particular the section of road up the Cotswold escarpment (Crickley Hill).

Option 12

1.4.2 Historically known as the ‘Modified Brown Route’, from west to east this option consists of; dualling the existing A417 up the Crickley Hill escarpment, ~1km of new road in deep cutting prior to returning to the existing A417 alignment, dualling the existing A417 from Barrow Wake to Nettleton Bottom Roundabout (see Figure 1.2).

1.4.3 Deep cuttings and high embankments will be required as shown on the vertical profile presented in appendix A.

Figure 1.2: Option 12



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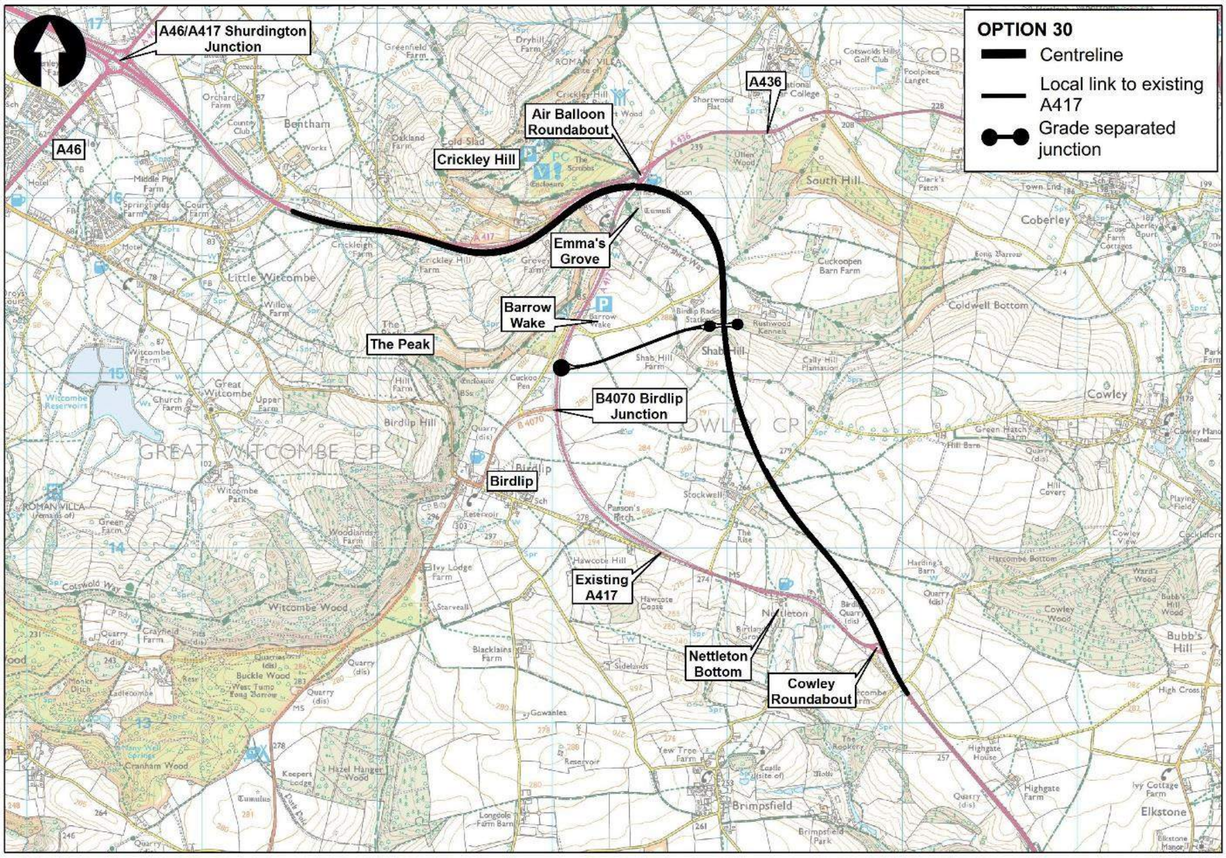
Option 30

1.4.4 From west to east Option 30 consists of dualling of the existing A417 up the Crickley Hill escarpment prior to ~2.5 kilometre of new road, re-joining the existing A417 at Cowley Roundabout. The new alignment includes a deep 1 kilometre long cutting as well as other associated earthwork embankments and cuttings, road bridges, roundabout and link roads (see Figure 1.3).

1.4.5 The scale of the cuttings and embankments is shown on the vertical profile presented in appendix A.

Figure 1.3: Option 30



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2 Sources of information and desk study

2.1.1 The following principal sources of information have been used during the preparation of this PSSR:

Figure 2.1: Sources of information

Feature	References Used
Topography	• An analysis of Cotswold topography: insights into the landscape response to denudational isostasy. (Lane, Watts, & and Farrant, 2008) • Environment Agency LiDAR data (Environment Agency, 2015)
Archaeology	• Archaeology Data Service (Archaeology Data Service, 2017) Accessed September 2017
Site History	• Envirocheck Report for Crickley Hill – A417. Reference 213224-1-1. (Landmark Information Group, 2002) • Groundsure Envirosight: A417 Missing Link. Reference COGL14R011. (Groundsure Environmental Intelligence Solutions, 2014)
Geology	• Gloucester. England and Wales Sheet 234. Solid and Drift. (British Geological Survey, 1975) • Engineering Geology of British Rocks and Soils – Lias Group. (Hobbs, P.R.N. et al., 2012) • Baseline Report Series 7: The Great and Inferior Oolite of the Cotswolds District. (Neumann, Brown, Smedley, & and Besien, 2003) • A417 Crickley Hill Improvements – Geotechnical Investigations and Schemes for Road Widening on the northern valley side report by Professor John Hutchinson (Hutchinson, A417 Crickley Hill Improvement. Geotechnical Investigations and Schemes for Road Widening on the Northern Valley Side, 1991)
Geomorphology	• Engineering Geomorphology of the A417 Stratton By-pass and the A417 North of Stratton to Birdlip Improvement (Geomorphological Services Ltd, 1988) • Edward J Wilson Consulting Engineering Geologist Report on Geomorphological Survey at Crickley Hill (A417) (Edward J Wilson & Associates, 1988, HA GDMS Ref 12609) • Edward J Wilson Consulting Engineering Geologist Addendum to Geomorphological Survey at Crickley Hill (A417) (Edward J Wilson & Associates, 1990 HA GDMS Ref 21576)
Environmental	• Envirocheck Report for Crickley Hill – A417. Reference 213224-1-1. (Landmark Information Group, 2002) • Groundsure Envirosight: A417 Missing Link. Reference COGL14R011. (Groundsure Environmental Intelligence Solutions, 2014)
Hydrology and Hydrogeology	• The geology and hydrogeology of the Jurassic limestones in the Stroud-Cirencester area with particular reference to the position of the groundwater divide. BGS Commissioned Report CR/08/146 (Maurice, Barron, Lewis, & and Robins, 2008)

2.1.2 In addition, the Highways England Geotechnical Asset Management system (HA GDMS) was accessed to obtain and view other background information about the site. A full list of its geotechnical and geomorphological reports relating to the proposed scheme is presented in appendix B.

2.1.3 A full list of references within this report is presented in chapter 9.

2.1.4 Table 2.1 below summarises the various ground investigations which have been undertaken within the vicinity of the alignment options. These were generally in connection with previous upgrades to the A417, obtained from HA GDMS and other sources. A combined exploratory hole plan detailing the location and nature of different ground investigations available across the proposed scheme is included in chapter 8.

Table 2.1: Ground investigation records

Date of Investigation	Scope of Investigation	Comments
April 1981	Gloucester County Council Materials Lab– Report on Brockworth Bypass Preliminary Soil Survey HA GDMS Ref 21588 • 1no. Cable Percussion borehole • 9no. Hand Auger Holes	• Holes are considered to be too shallow to allow best understanding of the conditions in the area below escarpment • Deepest borehole 8.5m bgl • Labelled as preliminary
1983	Gloucester County Council Materials Lab – Birdlip Bypass Soil Survey HA GDMS Ref 12606 • 13no. Cable percussion boreholes • 16no. Machine excavated trial pits • 1no, Machine excavated slit trench • 6no. Permeability (soakaway) tests	• Boreholes to between 3.00 and 8.30m bgl • Trial pits very shallow <2.0m bgl • Very limited lab testing
December 1988	Gloucester County Council Materials Lab and Edward Wilson and Associates (Trial pits) – Preliminary Site Investigation Factual Report – A417 Crickley Hill Widening Proposals HA GDMS Ref 12609 • 11no. Cable Percussion boreholes • 4no. 'Minute man' Auger Holes • 14no. trial pits • 10no.CBR tests	• Conditions were found to be extremely variable because of the disturbed area between Grove Farm and Crickley Hill Farm
March 1989	Foundation and Exploration Services Limited – A417 North of Stratton to Birdlip Improvement – Factual report on site investigation. HA GDMS Ref 12600 • 8no. Cable Percussion boreholes • 5no. Machine Excavated Trial pits (in the vicinity of Nettleton – more GI towards Stratton)	• Investigation focus at eastern extent of proposed scheme around Nettleton • Some deep boreholes (~25m bgl)

Date of Investigation	Scope of Investigation	Comments
October 1989	Fugro McClelland Ltd – A417 Crickley Hill Improvements – Soil Investigation Static Cone Penetration. Within HA GDMS Ref 18693 • 93no. Dutch Cone Probe Holes at 72no. locations	• Renumbering of the exploratory hole locations tends to cause some difficulty in using the report • Records found in 2003 Preliminary Sources Study Report • No location map with CPTs though positions indicated on 2003 Soil and PSSR
1989/1990	Gloucester County Council Materials Lab / Fugro McClelland Ltd – Survey Interim Factual Report – A417 Crickley Hill Improvement HA GDMS Ref 21573 • 4no. Cored boreholes • 5no. Cable Percussion boreholes	• Covers the area below escarpment • Co-ordinates do not match with the report. • Laboratory results in this report are of limited value
January 1991	Exploration Associates A417 North of Stratton to Birdlip – Factual Report on Ground Investigation HA GDMS Ref 12601 • 41no. trial pits • 33no. boreholes (in the vicinity of Nettleton – more GI towards Stratton)	• Significant investigation along the A417 from Stratton to Nettleton at eastern end of proposed scheme • Relevant holes located off existing A417 alignment on former proposed off-line realignment scheme
1991	Exploration Associates - A417 Brockworth Bypass Within HA GDMS Ref 17619 • 73no. boreholes • 94no. trial pits	• Covers the Brockworth Bypass. • Only a portion of the exploration holes are relevant and are at the base of the Crickley Hill escarpment
April 2002	WSP and Geotechnical Engineering Ltd - A417 Grove Farm Access – Crickley Hill HA GDMS Ref 21571 • 3no. Cored boreholes (Geotechnical Engineering Ltd) • 7no. Window Sampling holes (WSP)	• This study identified the ground as marginally stable and identified a number of landslide surfaces, in area of Grove Farm access • Some information on groundwater levels
July 2009	Geotechnical Engineering Limited – A417/A419 between M5 J11A and M4 J15 – CCTV Masts HA GDMS Ref 23973 • 9no. dynamically sampled and cored boreholes (Pioneer Rig) • 9no. dynamic ‘pre-boreholes’ 1m away from each BHs	• 3no. locations relevant to proposed scheme at Air Balloon Roundabout, Nettleton Bottom and Cowley Roundabout

3 Field studies

3.1.1 This section of the report outlines the field study activities undertaken to support the production of this report including any walkovers, geomorphological and geological mapping, investigation and testing, hydrological studies or other studies.

3.1.2 Earlier field studies carried out by other Design Organisations / Parties for similar schemes are also summarised here for completeness where land access issues prevented the incumbent Mott MacDonald Sweco Joint Venture undertaking these assessments / surveys.

3.2 Walkover survey

3.2.1 A site walkover was carried out by a representative from the Mott MacDonald Sweco Joint Venture in April 2017. Due to access restrictions only land accessible to the public was visited along the route. Selected site photographs are presented in chapter 8.

3.2.2 The walkover indicated the following with respect to land use:

- The land use throughout most of the study area is generally agricultural with a number of farms present, both along the section from Brockworth to Air Balloon Roundabout and around Birdlip and Nettleton. The study area includes a mixture of grazing land and woodland, some of which has been identified as areas with scientific or environmental importance.
- The study area lies within an Area of Outstanding Natural Beauty and attracts a certain amount of tourism. Three areas of particular interest are located within the wider proposed scheme extents:
    - Crickley Hill Country Park and the Scrubbs
    - Emma’s Grove
    - Barrow Wake

Crickley Hill Country Park

3.2.3 Most of the northern slopes above Crickley Hill and Air Balloon Roundabout are thickly covered with deciduous trees and scrub vegetation. These slopes form the Crickley Hill Country Park and The Scrubbs. This area is protected by tree preservation orders, is maintained by Gloucester Wildlife Trust and The National Trust; and includes the Late Prehistoric and Iron Age Crickley Hill Camp. Both proposed scheme options involve routes up Crickley Hill.

Emma’s Grove

3.2.4 A woodland immediately south of the Air Balloon Roundabout, known as Emma’s Grove, is an important historic site in the form of a Bronze Age burial mound. This site is listed as a Scheduled Ancient Monument while the surrounding woodland is protected by a tree preservation order. Both proposed scheme options pass in cutting close to this woodland.

Barrow Wake

3.2.5 Barrow Wake is an area to the southwest of the Air Balloon roundabout and forms part of the Crickley Hill Sites of Special Scientific Interest (SSSI). The site comprises areas of ecologically important woodland and open areas including a car park and viewing point. Barrow Wake provides an access point to the Cotswold Way as well as extensive views over the Vale of Gloucester and is therefore a popular tourist attraction. The viewing point provides excellent views of the area between Grove Farm and Crickley Hill Farm clearly showing concave and convex hummocky ground that is indicative of landslide material on a large scale. Both proposed scheme options pass close to Barrow Wake. Both options propose modifications to the existing road adjacent to Barrow Wake, but Option 12 also locates the main line carriageway close by.

3.3 Geomorphological and geological mapping

3.3.1 Geomorphological mapping has been undertaken at the site as part of a previous option studies by WSP in 2003 and earlier by E J Wilson Practice in 1988. The results of the field studies are presented within the PSSR by WSP in 2003, the 2004 WSP report on Geomorphology and the E J Wilson Practice 1988 report on the geomorphology of Crickley Hill. In addition, Professor John Hutchinson provides additional commentary of the geomorphology of Crickley Hill from his report on the feasibility of road improvements to Crickley Hill (1991). Key plans / drawings and figures from these documents are reproduced in appendix C.

3.3.2 To supplement the existing geomorphological surveys, the Mott MacDonald Sweco Joint Venture visited various publicly accessible rock outcrops within the region to record and gain an understanding of the different geologies interpreted to be present below the site. The site visits, carried out in 2017, identified local ‘type’ outcrops to provide a reference for those geologies within the study and wider area. In each of these locations a rock mass assessment of different geological formations was undertaken as presented in appendix D.

3.4 Drainage and hydrogeology

3.4.1 It has not been possible to undertake a surface water features survey in the recent development of the proposed scheme due to land access constraints. The following summarises observations made by WSP in 2002 (WSP, 2002, HA GDMS Ref 16772).

3.4.2 The main feature on Crickley Hill is the stream running east to west down the hill adjacent to the A417, - Horsbere Brook. It is the main drainage for the catchment slope area adjacent to the existing A417 up to the Cotswold escarpment.

3.4.3 The WSP walkover recorded a number of established springs and areas of marshy ground on the slopes below the escarpment. Those springs within the vicinity of Crickley Hill drain into Horsbere Brook.

3.4.4 Above the escarpment a small stream was noted immediately south of Birdlip junction (likely to be the Churn valley). In the area of Nettleton Bottom (likely to be the Frome valley) the survey information records a flat bottom valley which appeared to have been formed by the flow of water. At the time of the WSP walkover there was no running water but the ground was waterlogged suggesting that the water table was very close to the surface in the area (WSP, 2002, HA GDMS Ref 16772).

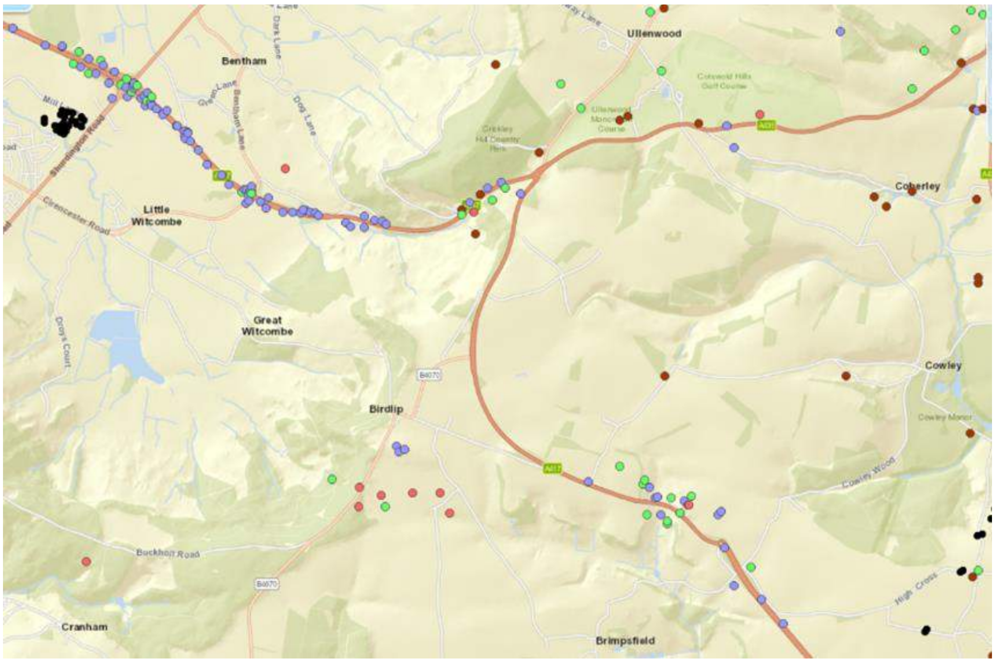
3.5 Ground investigation

3.5.1 A variety of existing ground investigation is available across the project site as detailed in Table 2.1 above. Generally this is focused around the existing A417 highway alignment and earlier road improvement schemes.

3.5.2 Figure 3.1 presents an overview of the borehole data available from the British Geological Survey (BGS). A summary of investigation information from HA GDMS along the existing A417 corridor is summarised in Table 2.1. Some of the BGS records duplicate data in Table 2.1. Those BGS holes that are not duplicates are included, with the HA GDMS data, on a combined exploratory hole plan presented in chapter 8.

3.5.3 Overall the investigation data is sparse, and in areas is of limited depth and quality. It is noteworthy that the data is extremely limited regarding groundwater information (see chapter 4).

Figure 3.1: Available BGS borehole records in study area



Source: British Geological Survey GeoIndex

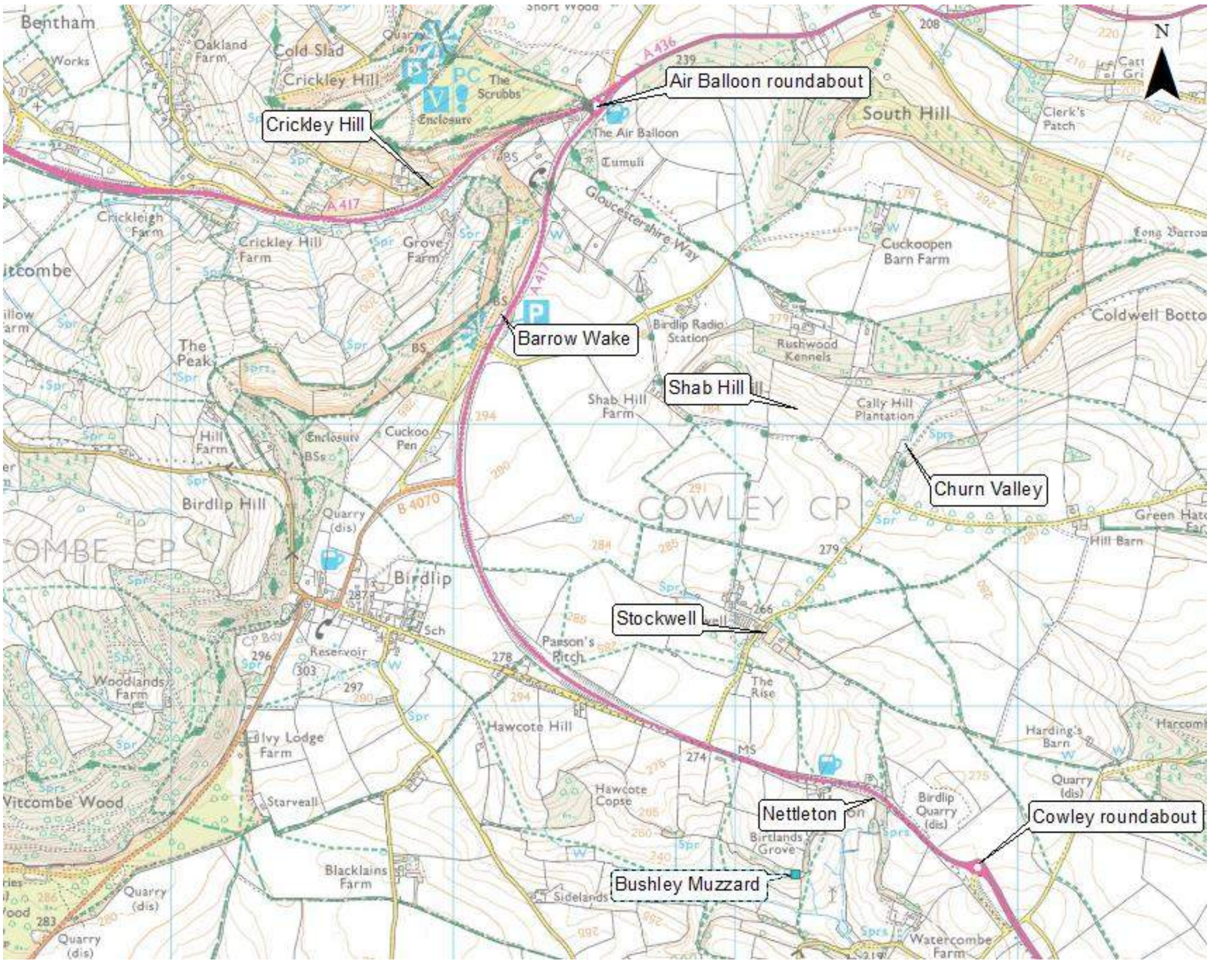
4 Site description

4.1 Site setting

4.1.1 The site is located near Birdlip, approximately 10 kilometres east of Gloucester, on the western part of the Cotswolds. The ‘Missing Link’ stretch is approximately 5 kilometres of the A417, and is located between Brockworth Bypass at the western end and Cowley Roundabout.

4.1.2 The site can be identified between Ordnance Survey National Grid References SO 91121 16193 (Brockworth Bypass), SO 93505 16129 (Air Balloon Roundabout) and SO 94860 13430 (Cowley Roundabout). A site location plan is presented in Figure 4.1 and in appendix A.

Figure 4.1: Site location plan



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4.2 Geology

4.2.1 The following assessment of the geology of the site and ground conditions has been made with reference to available published geological mapping and memoir:

- British Geological Survey (BGS) Map Sheet 234 1:50,000 Gloucester (Solid and Drift) (British Geological Survey, 1975) which has been used to summarise the geology of the proposed scheme
- BGS 1:50,000 digital geology mapping (British Geological Survey, 2018)
- 1: 10,560 series BGS Map Sheet SO91SW (British Geological Survey, 1965)
- 1: 10,560 series BGS Map Sheet SO91NW (British Geological Survey, 1966)
- Geological Memoir for Sheet 235 (Sumbler, Barron, & A.N.Morigi, 2000)

4.2.2 To support the review of the published geology of the site the following technical documents have been used:

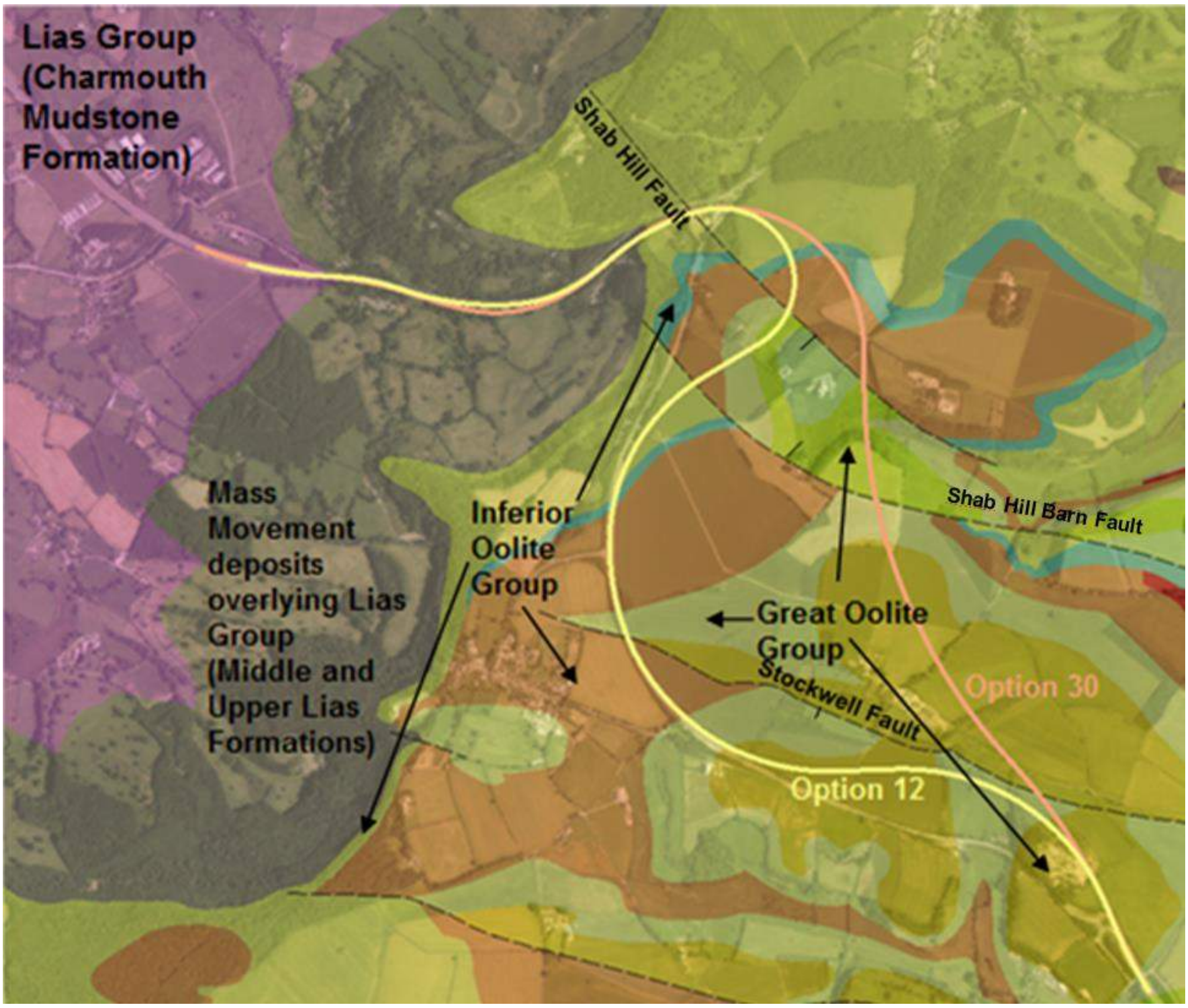
- BGS Report no OR/12/032 Engineering Geology of British Rocks and Soils – Lias Group (Hobbs, P.R.N. et al., 2012)
- BGS commission Report no CR/08/146 addressing the geology and hydrogeology in the Stroud – Cirencester Area ((Maurice, Barron, Lewis, & and Robins, 2008)
- The joint publication by the BGS and the Environment Agency (EA) Baseline Report Series 7 (Neumann, Brown, Smedley, & and Besien, 2003)

Bedrock geology

4.2.3 The bedrock geology beneath the site, shown on Figure 4.2, is characterised by rocks of the Jurassic Period comprising the Lias Group, Inferior Oolite Group, and the Great Oolite Group. A summary of the geological stratigraphic sequence anticipated to be present beneath the project area is presented in Table 4.1.

4.2.4 In the west of the project area the Great and Inferior Oolite Groups are absent (see Figure 4.2 and Figure 4.3). This area is underlain by the Lias Group but the bedrock is largely buried by ancient mass movement deposits (colluvium) (see section 4.3). A composite bedrock geological map is presented in Figure 4.2 and in the drawings presented in chapter 8.

Figure 4.2: Composite annotated bedrock geology map



Source: GiGi GIS Portal. Crown Copyright 2016 100030649 with BGS 1:50 000 Solid Geology overlay © NERC

Table 4.1: Summary of bedrock geological sequence

Period	Epoch	Group			Formation	Rock Type	Estimated Typical Thickness*	Members	Typical Description (Ref BGS Lexicon)
Jurassic	Middle Jurassic	Great Oolite Group (168-165Ma)	🟨	🟩	White Limestone Formation	Limestone (including wackestones, packstones and grainstones) with mudstone and clay beds	Up to 30m	Signet Member	Brownish grey, sandy or clayey peloidal wackestone, commonly with shell-fragments and lignite, associated with green and brown mudstone / clay. Shell-fragmental ooidal grainstones, brown sandy limestone and white carbonate mudstone and coralliferous marl are also present.
								Ardley Member	Pale grey to off-white, or yellowish limestone, peloidal wackestone and packstone; often with ooidal and shelly grainstones. Recrystallised limestone with beds of argillaceous limestone, sandy limestone, marl, and mudstone/clay occur at some levels
								Shipton Member	Of similar lithology to the overlying Ardley and therefore difficult to distinguish. It comprises pale grey to off-white or yellowish limestone, peloidal wackestones and packstones with sub-ordinate ooidal and shell fragmental grainstones: recrystalised limestone beds of argillaceous limestone, marl and mudstone / clay.
				🟩	Hampen Formation	Sandy and ooidal limestone with clay and marl beds	c. 4-11m	-	Limestones with sub-ordinate interbedded marls. The Limestones are characteristically grey to brown, thinly bedded, fine to very fine-grained, well-sorted, ooidal grainstone to packstone. Commonly slightly sandy or silty, with small-scale cross-bedding.
			🟨	🟨	Fuller’s Earth Formation	Grey mudstone with limestone beds	~10 to 15m	Eyford Member	The Eyford Member (formerly known as the Cotswold Slates) and the Trougham Member both form the upper part of the Fuller’s Earth Formation. They comprise pale grey, fissile, fine ooidal grainstone interbedded with grey, laminated fissile calcareous sandstone. Locally the members are decalcified to loose orange-brown sand with minor beds of shelly limestone, marl or fissile mudstone.
								Trougham Member	
								Lower Fuller’s Earth	Where present: olive-grey, silty, calcareous mudstones with thin intervals of argillaceous limestone and oyster shell, rich mudstones.
		Inferior Oilite Group (175-168 Ma)	🟧	🟧	Salperton Limestone Formation	Shelly, ooidal limestone including a ‘hardground’	~10 to 15 m	Clypeus Grit Member	Pale grey to brown rubbly, fine to coarse-grained ooidal, peloidal and finely shell-detrital packstone to grainstone
								Upper Trigonia Grit Member	Very competent / hard, poorly (but thickly) bedded, very shelly and coarsely shell-detrital ooidal grainstone and packstone. Characteristic faun includes trigoniid bivalves and brachiopods.

Period	Epoch	Group			Formation	Rock Type	Estimated Typical Thickness*	Members	Typical Description (Ref BGS Lexicon)
			🟦	🟦	Aston Limestone Formation	Shelly, ooidal limestone	0 to 7m, typically ~5m	Rolling Bank Member	Competent, grey sandy and very shelly limestones, with fauna including bivalves, gastropods and brachiopods. Includes ferruginous peloids in upper part (‘ironshot’). Can be further divided based upon the fauna into Witchellia Grit, Bourguetia Beds, and Phillipsiana Beds.
								Not grove Member	Locally absent. Pale brown-grey, cross-bedded, medium to coarse grained, poorly sorted peloidal and ooidal grainstone. Shell debris rare.
								Gryphite Grit Member	Grey and brown, shelly, variably sandy, peloid (often ferruginous) grainstones, packstones and wackestones. Thin mudstone, marl and sand beds are common. Abundant Gryphaea and Belemnites in the upper part.
								Lower Trigonia Grit Member	Grey, speckled, orange-brown, very shelly, moderately sandy, peloids wackestones, packstone and grainstones with thin marl and sand beds which are occasionally shelly. Ferruginous peloids are often present and commonly pebbly at its base.
			🟨	🟨	Birdlip Limestone Formation	Ooidal, sometimes sandy limestone with sandy clay layers	40 to 50m	Harford Member	Locally absent. Highly variable laterally, comprising grey-brown, fine to medium grained sandstone at the base overlain by grey / brown, silty mudstones with variable sandy or shelly beds.
								Scottsquar Hill (Ooilite Marl and Upper Freestone) Member	Pale grey and brown, medium to coarse-grained, poorly sorted peloidal and ooidal packstone and grainstone, interbedded with shelly limestone dominated by calcitic mud.
								Cleeve Cloud (Lower Freestone) Member	Un-fossiliferous and cross bedded, massive ooidal Limestone.
								Crickley (Pea Grit) Member	Pale grey to yellowish brown pisoidal and shelly peloidal Limestone with thin marl beds.
								Leckhampton Member	Grey, highly bioturbated, finely shell-detrital, medium-grained, peloidal and ooidal sandy, muddy limestone. Thin marl beds are common. Ooids and peloids are commonly ferruginous.
	Lower Jurassic	Lias Group	🟧	🟧	Bridport Sand Formation	Sandy mudstone and fine to v fine-	0 to 10m**	-	Grey, weathering to yellow or brown, micaceous silt, very fine-grained sand and fine-grained sand, locally with calcite-cemented sandstone beds and lenses, variably sandy clay / mudstone at base. Upper boundary on base of

Period	Epoch	Group			Formation	Rock Type	Estimated Typical Thickness*	Members	Typical Description (Ref BGS Lexicon)
		(200-175 Ma)	🟧	🟧		grained sandstone			lowest limestone (commonly sandy) of Inferior Oolite or on the “Cotswold Cephalopod Bed” (sandy and argillaceous, ‘ironshot’ commonly fossiliferous limestone)
			🟫	🟫	Whitby Mudstone Formation	Mudstone with thin limestone beds at the base	45 to 60m	-	Medium and dark grey fossiliferous mudstone and siltstone, laminated and bituminous in part, with thin siltstone or silty mudstone beds and rare fine-grained calcareous sandstone beds; dense, smooth argillaceous limestone nodules very common at some horizons; phosphatic nodules at some levels. Nodular and fossiliferous limestones occur at the base in some areas.
			🟥	🟥	Marlstone Rock Formation	Ferruginous, ooidal limestone and sandstone	5 to 10m	-	Sandy, shell-fragmental and ooidal ferruginous limestone interbedded with ferruginous calcareous sandstone, and generally sub-ordinate ferruginous mudstone beds. Locally any of these lithologies may pass by increase in iron content into generally ooidal ironstone, and in places any of these may dominate. The iron content (as ooids, altered shell material or in the groundmass) is berthierine (dark green iron-rich layered silicate formed in low-oxygen marine conditions), altering to siderite. Fossil content variable throughout but locally abundant especially in limestone beds.
			🟧	🟧	Dyrham Formation	Silty Mudstone and Siltstone	30 to 50m	-	Pale to dark grey and greenish grey, silty and sandy mudstone, with interbeds of silt or very fine-grained sand (locally muddy or silty), weathering yellow. Variably micaceous. Impersistent beds or doggers of ferruginous limestone (some ooidal) and sandstone, which tend to occur at the top of sedimentary cycles. Sporadic large cementstone nodules
			🟥	🟥	Charmouth Mudstone Formation	Mudstone with thin beds and nodulues of limestone	250m	-	Dark grey laminated shales, and dark, pale and bluish grey mudstones; locally concretionary and tabular limestone beds; abundant argillaceous limestone, phosphatic or ironstone (sideritic mudstone) nodules in some areas; organic-rich paper shales at some levels; finely sandy beds in lower part in some areas.

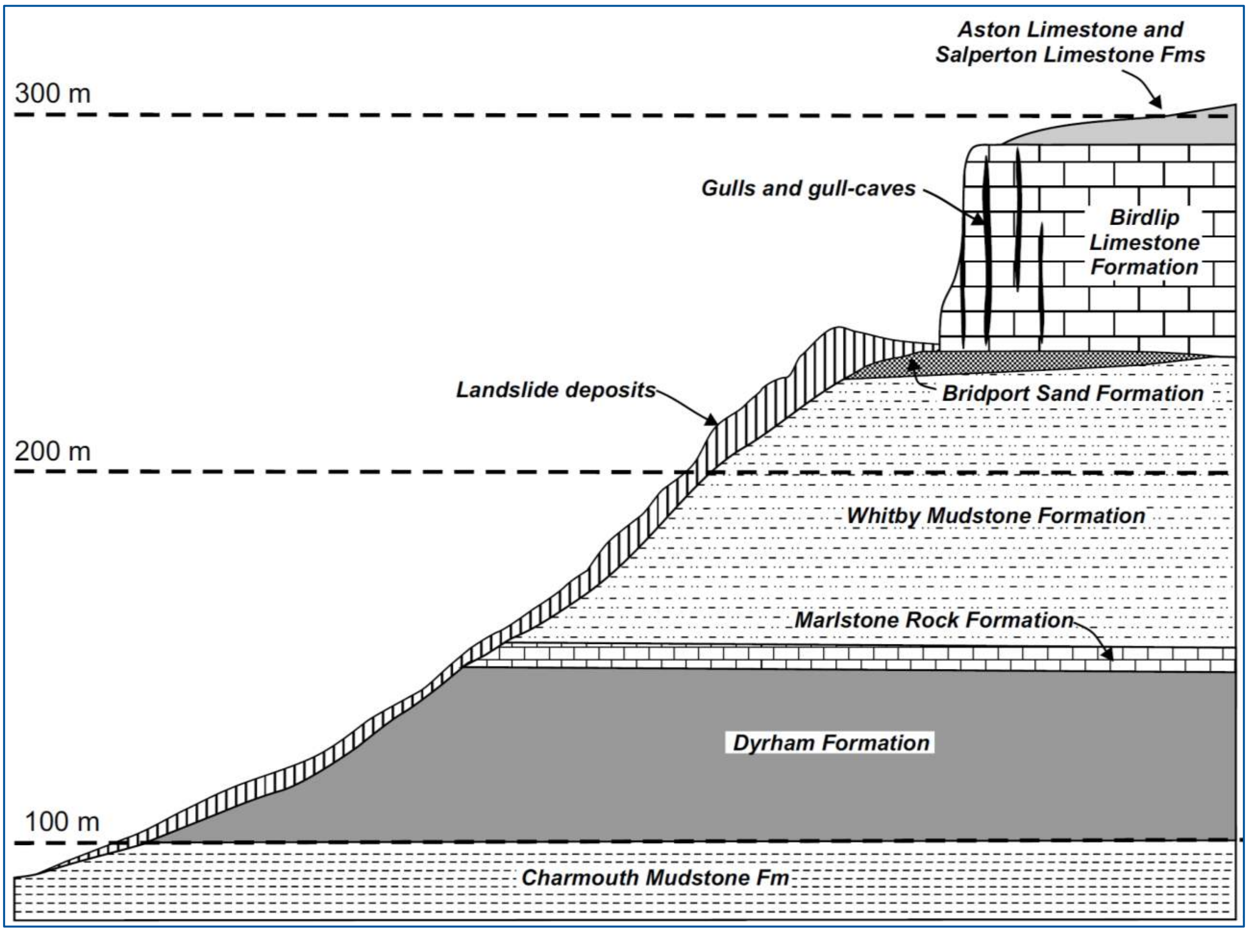
Table Notes

*Typical thicknesses based on BGS Map Cross sections in the vicinity of the site provided on 1:50,000 Sheets 216, 217 and 234 and within Geological memoir for sheet 235 (Sumbler et al. 2000). Where these are not present typical thicknesses are provided based on the information provided in the BGS lexicon.

**There is some contradiction in literature with respect to the likely thicknesses of the Bridport Sand Formation in the study area. BGS mapping (See section 4.2 for references) indicates that this is relatively thin and even locally absent, however other sources (Maurice, et al., 2008) suggest the Formation could be as thick as 50m.

4.2.5 The stratigraphy is conceptually presented in Figure 4.3. As noted in Table 4.1 the Birdport Sand Formation may be significantly thicker than shown, and the landslide / colluvium deposits have been simplified for the purposes of presentation.

Figure 4.3: Conceptual geological cross section of the Cotswold Escarpment in the Cheltenham area (opposite orientation to Figure 4.7)



Source: (Farrant, et al., 2015)

4.2.6 Note that these descriptions are based on published information as there is only sparse intrusive ground investigation records in the study area. Detail on the overlying superficial and mass movement deposits are provided in the following sections.

Superficial deposits

4.2.7 The project area is largely without superficial deposits. However, there is a tract of the Cheltenham Sand and Gravel underlying the western part of the proposed scheme towards the junction between the A417 and A46, and between Little and Great Witcombe at the base of the escarpment. Locally there are small areas of the site underlain by alluvium towards the south-east on the dip slope.

Mass movement deposits

4.2.8 Mass movements such as landslides, cambering, gulls, valley bulging and solifluction are present within the project area. For discussion on their formation refer to section 4.3.

4.2.9 The BGS mapping indicates the whole of the escarpment to be covered in ’landslide deposits’ (Figure 4.4) including Crickley Hill. The mapping also indicates localised ’landslide deposits’ recorded in the relatively shallow valleys on the dip slope – most notably for the proposed route options that of the Churn Valley near Shab Hill Farm and the Frome valley near Stockwell - Nettleton..

4.2.10 The mass movement formed deposits, sometimes known as landslide deposits, are known collectively as colluvial deposits or colluvium. These deposits comprise a random assortment of the underlying parent geology within a matrix of largely cohesive material though the nature of these deposits can vary. As the site is below the glaciation limit, the mass movement deposits are thought to be comprised of locally derived material and reflect the lithology of the underlying geology.

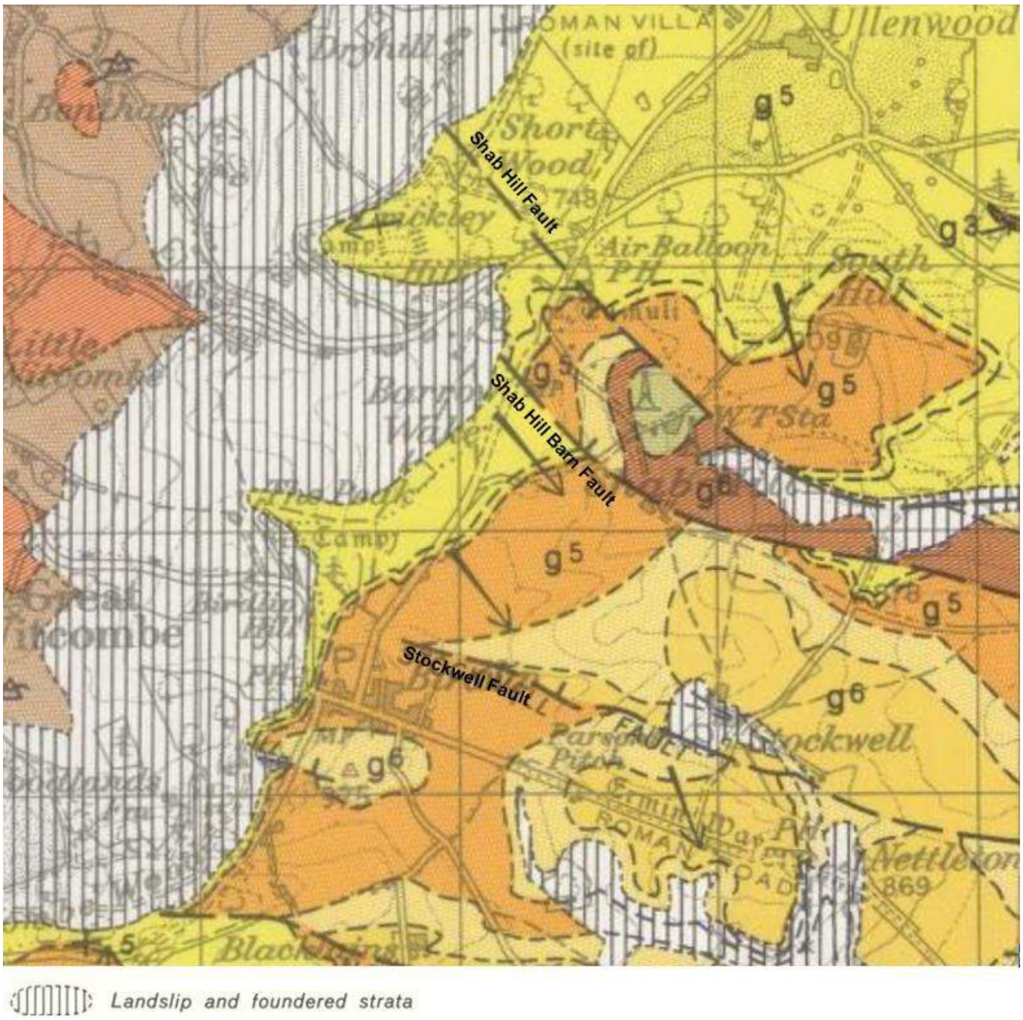
4.2.11 The upper slopes of the escarpment are expected to comprise more coarse material within the colluvium from the Inferior Oolite Group, compared to the lower slopes which are expected to comprise more reworked silts and clays from the Lias Group. The shallow valleys on the dip slope are expected to comprise reworked Fuller’s Earth with limited coarse material from the Great Oolite. The distribution of the colluvium is presented in Figure 4.4.

Structural geology

4.2.12 On a regional scale, the strata dip very gently (2-5 degrees) to the south-east and east but is subject to local variations.

4.2.13 There are 3 mapped and named normal faults in the vicinity of the site, the Stockwell, Shab Hill Barn and Shab Hill faults. The faults trend roughly north-west to south-east and are parallel with each other. An extract of the BGS Map 234 is presented in Figure 4.4.

Figure 4.4: BGS geological map sheet 234 extract



Source: (British Geological Survey, 1975)

4.2.14 The down-throw of the Shab Hill fault is recorded to be to the south-west and the down-throw of the Shab Hill Barn fault is to the north-east. Fault planes which have opposing dips (i.e. dipping towards each other) creates a structure between the faults known as a graben (see Figure 8.3 and Figure 8.4).

4.2.15 It is estimated that the down-throw of the Shab Hill fault is between 10 and 24m. The Shab Fill Barn fault, which down-throws to the north-east, has an estimated throw of between 10 and 13m, less than the Shab Hill fault therefore causing the potential for rotation of strata within the graben structure.

4.2.16 The precise position of the Shab Hill Barn Fault has been contested in recent years. The BGS mapping records this to be ~400m to the south of the Shab Hill fault as shown above. However, Hutchinson (1991) suggested that this fault may lie approximately 170m closer to the Shab Hill fault then indicated by the BGS, as indicated in Huthinson's geomorphological plan reproduced in appendix C. It is thought that the central block of the graben may have been rotated in a similar direction to that of the regional dip direction indicated on the mapping which could have a marked effect on the hydrogeology of the area.

The Stockwell fault meanwhile is recorded to down-throw to the north-east with a throw in the order of 5 to 10m The Stockwell fault is recorded to be ~760m south of the BGS mapped position of the Shab Hill Barn fault.

Rock mass quality – Great Oolite and Inferior Oolite

4.2.17 Solution features, fissures and gulls may be present through the limestone within the project area. During construction of the Birdlip Bypass a number of fissures were encountered in the vicinity of the Barrow Wake bridge and although considered to be exceptional were recorded as 300mm wide at the top with a depth of 17m. These were treated with lean mix concrete, other small fissures were treated with a mixture of rock fill and concrete as used at formation level of the road through the Barrow Wake cutting (Hutchinson 1991).

4.2.18 The Great Oolite and Inferior Oolite limestones within the Cotswolds region are not known for well-developed karst features, but some fluvio-karst features in the form of sink holes and underground channels are known to exist (Owen, Prive, & Reid, 2005)

4.2.19 There is little information available regarding the rock mass quality of the Great Oolite. Information and mapping of the Inferior Oolite however, due to its exposure along the escarpment, does exist / is possible. An assessment of 75 joint surfaces in the Inferior Oolite was carried out in August 1991 by Professor J.N. Hutchinson (Hutchinson, 1991) who, in addition to bedding features, identified 3 principle sub-vertical joint sets were identified:

- J1 002-032 Bearing (sub-parallel to escarpment)
- J2 058-098 Bearing (undetermined alignment)
- J3 130-170 Bearing (sub-parallel to faults)

4.2.20 During the WSP walkover survey (WSP, 2002, HA GDMS Ref 16772) a further 50 joint surfaces were measured and the joint orientations analysed to determine overall patterns. The WSP survey information and the additional geological outcrop records from the Mott MacDonald Sweco Joint Venture rock outcrop surveys (appendix E) confirm the general characteristics of non-bedding joint sets in the Inferior Oolite about the site area. Notwithstanding, it should be recognised that the extent of the effects of cambering on these records is not clearly understood and, therefore, the data may not be reliable in all cases. A summary of the range of rock mass properties encountered at formation outcrops during these field mapping exercises is provided in Table 4.2 below.

Table 4.2: Summary of rock mass properties recorded at outcrops

Formation	Typical Description at outcrop	Range of Q* Values	Range of RMR	Rock Mass Quality Class
Birdlip Limestone Formation	Medium strong to strong, pale yellowish white with occasional brown discolouration, ooidal occasionally shelly Wackestone and Packestone LIMESTONE, medium to thickly bedded and jointed.	22.5 - 30	72 - 82	Good
Bridport Sand Formation	Weak to medium strong, light brown / yellowish, massive to thickly bedded, weakly cemented fine grained micaceous SANDSTONE.	18.75 – 45	68-77	Good
Marlstone Rock Formation	Strong to very strong, massive to thickly bedded brownish yellow, LIMESTONE with ferruginous ooids and some shelly fragments.	47.5- 95	82-85	Very good
Dyrham Formation	Highly weathered, very weak, thinly bedded, laminated, pale greenish grey friable SILTSTONE.	1.6 - 10	39 - 47	Poor to Fair

Reference:

Q system – Barton et al 1974

RMR – Bieniawski, 1989

4.2.21 Man-made cuttings within the Inferior Oolite limestones were formed when historical quarrying was carried out and when forming the existing A417 road cutting. There is a potential for local stress relief features to be associated with these cut faces.

Rock mass quality – Lias Group

4.2.22 Fresh Lias mudstones tend to be weak to moderately strong but undergo considerable deterioration of most engineering properties following stress relief and weathering (Cripps, J.C., and Taylor, R.K., 1981).

4.2.23 It should be noted that due to the landslides covering the escarpment the Lias Group within the project area is predominantly covered by colluvium. The outcrops for the Bridport Sand Formation and other Lias Group deposits mapped for Table 4.2 are from sites 25 kilometres south-west and 8 kilometres west of the site respectively. Formations are subject to local and other variations.

4.2.24 The Lias Group mudstones typically feature a significant weathering profile due to high clay content, with swelling clay minerals, and a laminated structure which breakdown relatively quickly on exposure, variation in water content and stress relief fissures. In additional chemical breakdown may occur rapidly on exposure to air and may result in further mechanical breakdown.

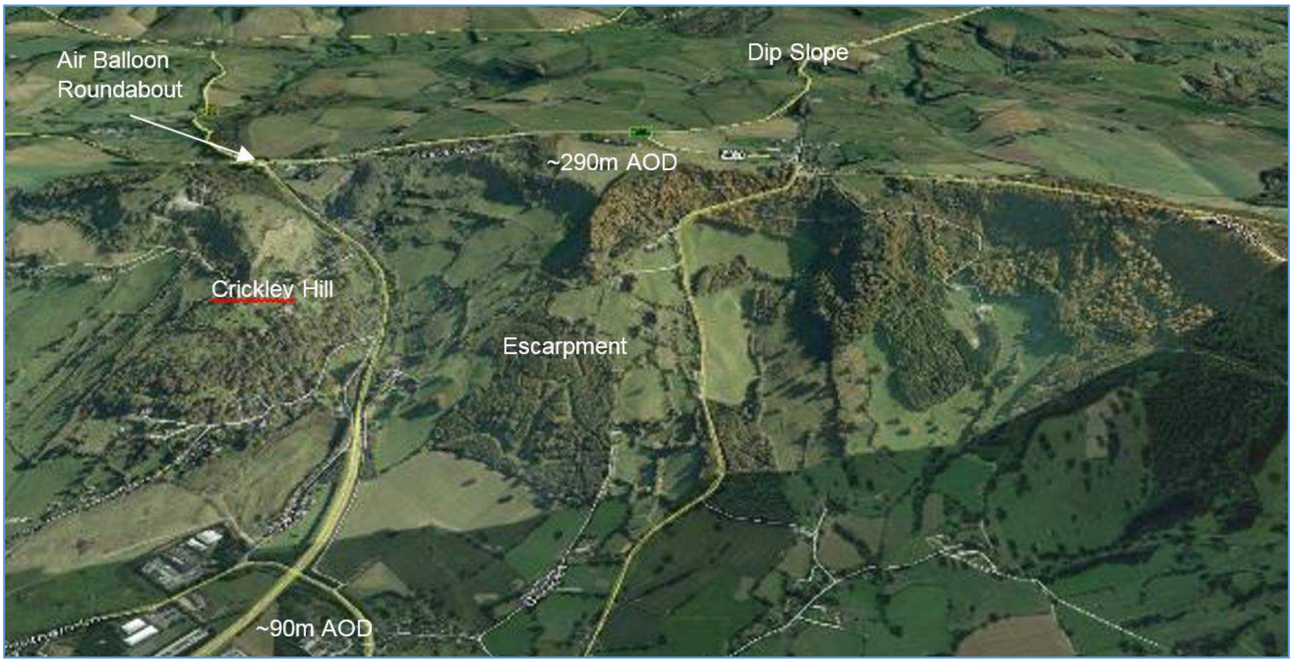
4.2.25 The weathering profile of Lias Group mudstones may be up to 20m thick, although this varies according to the Formation and is more generally considered to be about 10m thick. The most heavily weathered mudstones are encountered as clays.

4.3 Topography and geomorphology

4.3.1 The topography and geomorphology of the project area reflects the underlying geology of the region. The Cotswold escarpment dominates the regional landscape, formed by the Jurassic Limestone overlying more easily eroded Lias Group mudstones. In the project area the escarpment is represented by Crickley Hill, an asymmetrical valley with steeper slopes on the north than the south. The existing A417 runs along the axis of the valley, the only point lower being Horsbere Brook, immediately south of the road. Crickley Hill is approximately 200m high, rising from approximately 90m AOD at Little Witcombe to approximately 290m AOD at Barrow Wake.

4.3.2 From the escarpment the regional landscape forms an extensive plateau surface that follows the dip of the underlying Limestone: 2 to 5 degrees east-south-east: the ‘dip slope’.

Figure 4.5: Oblique view of the project site with aerial photograph draped over the topography



Stream Valleys

4.3.3 Within the project area localised variations in the regional geomorphology occurs where stream valleys are present. The valleys are generally orientated east-west across the dip slope and down the escarpment. The streams that run in the dip slope valleys (Churn and Frome) are generally considered ‘underfit’.

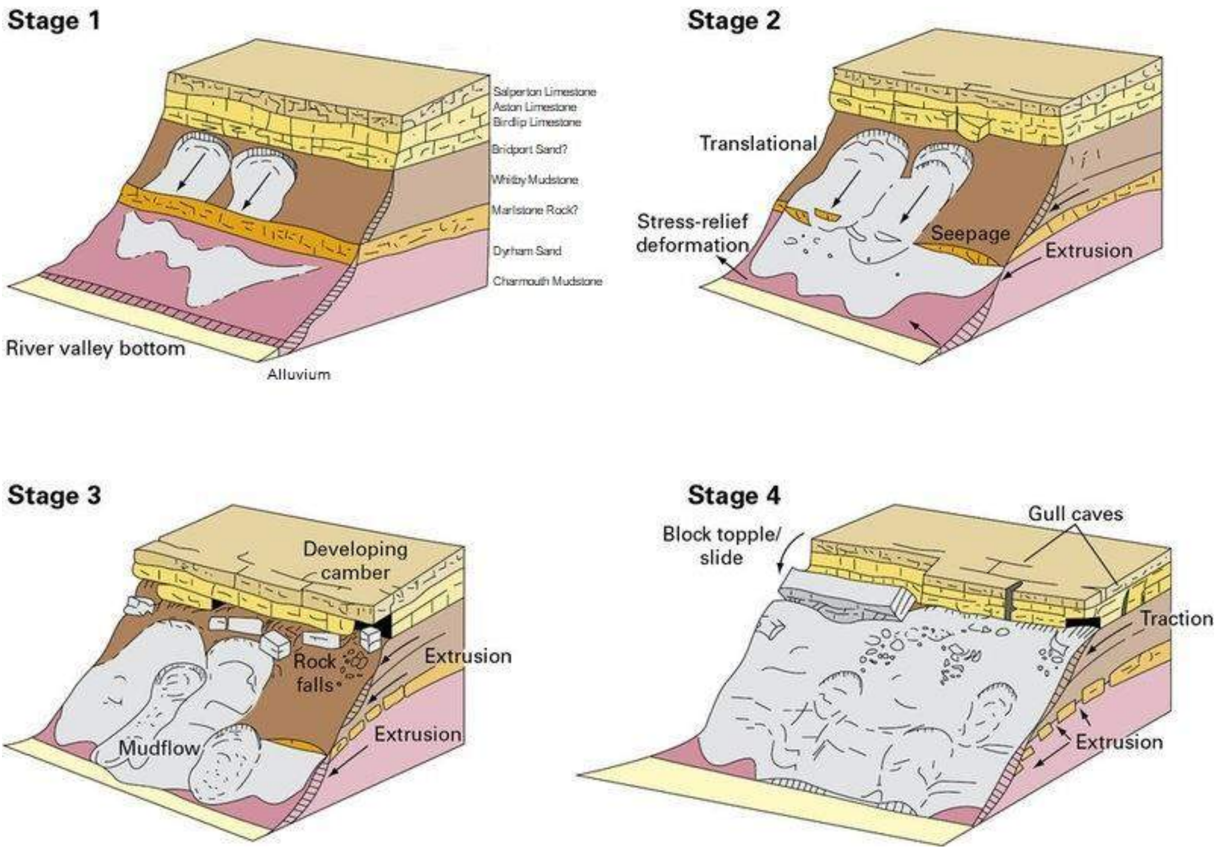
4.3.4 ‘Underfit’ streams are those that have a significantly larger valley and number of meanders, in comparison to the current size of watercourse that runs within it. The valleys of these watercourses were formed in periglacial conditions during the retreat of mid-Pleistocene glaciation. The thawing of the permafrost and glacial meltwater would have resulted in much larger volumes of water than experienced in the present day. For the Churn valley and the Frome valley this also contributes to the instability mapped on Figure 4.4 and discussed in the following section.

4.3.5 'Incised' valleys are those that are much deeper than would be expected of the size of watercourse running within it. Generally, they are steep sided, and are a result of watercourses running over strata that is easily and rapidly eroded. In the case of Horsbere Brook and its associated catchment this stratum comprises the colluvium.

Mass Movement – Escarpment

4.3.6 Mass movement associated with the Cotswold Escarpment is present in the project area – in terms of the proposed route options, Crickley Hill is the primary concern as both route options require some form of construction likely to impact the slopes. The general conceptual model of formation of landslides on the escarpment is presented in Figure 4.6.

Figure 4.6: Cotswold Escarpment Mechanisms of Failure

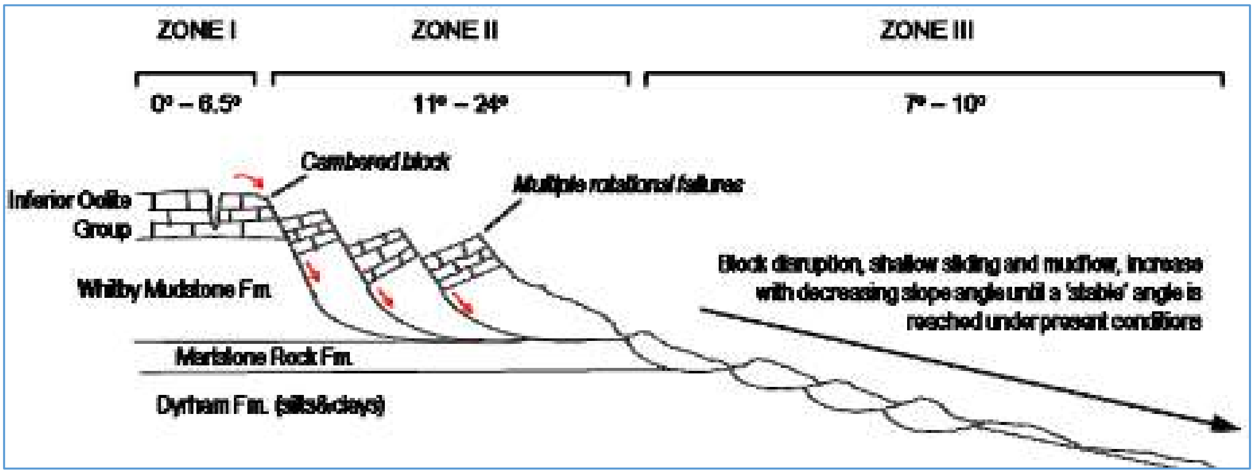


Source: Adapted from (Barron, et al., 2015)

4.3.7 The relationship between the Jurassic strata and the mass movements on the escarpment have been historically discussed by various authors such as Whittaker (1972), Watson (1984) and Butler (1983), and summarised by Whitworth (Whitworth, et al., 2005). From these studies, the main forms of mass movements are outlined below and attributed to Crickley Hill as per Figure 4.7:

- Cambered strata in the Inferior Oolite Group which caps the upper part of the escarpment forming the back scarp of the landslide (Zone I, Figure 4.7)
- Zone of large rotational landslides below the Inferior Oolite Group within the Whitby Mudstone Formation on the upper slope (Zone II, Figure 4.7)
- Zone of successive shallow rotational landslides and mudflows on the lower slope (Zone III, Figure 4.7)

Figure 4.7: Conceptual model of Crickley Hill landslide (opposite orientation to Figure 4.3)



Source: (Butler, P.B. , 1983; Hobbs, P.R.N. et al., 2012)

4.3.8 Cambering is the large-scale flexing and stretching of competent ‘caprocks’ (overlying rock strata) over softer strata on valley slopes. The underlying softer strata deforms under the weight of the caprock which extends down the valley sides. The extension of the caprock can often lead to the formation of deep fractures (gulls) which run parallel to the valley contours and separate the blocks of rock (as shown in Zone I in Figure 4.7). Cambering, gulls and fissures are expected to be encountered in the project area in the vicinty of the escarpment edge, for example, upslope of Barrow Wake.

4.3.9 The rotational failures in the Inferior Oolite form large stepped blocks at the edge of the escarpment, below Barrow Wake and mid-way up the northern slope, which has an average slope angle of up to 30 degrees. The translation and solifluction deposits (Zone III Figure 4.7) in the Lias Group form lobate and undulating features in the ground immediately in front of the scarp, with the average slope angle between 2 to 10 degrees.

4.3.10 The rotational failures and subsequent solifluction (Zone II and III Figure 4.7) initially occurred during the Mid-Pleistocene periglacial climate through a combination of; the physical degradation of the rock due to freeze-thaw action, the interface between the Inferior Oolite and the Lias acting as a spring line allowing large quantities of meltwater to flow over the lower slopes increasing the potential for erosion, and cycles of freeze thaw within a layer of intact soil over a permafrost layer. These mass movements produced shear surfaces which can be re-activated.

4.3.11 Detailed geomorphological mapping of Crickley Hill can be found in Professor Hutchinson's report (Hutchinson, 1991) and presented in appendix C. In summary Professor Hutchinson considered the landslide on Crickley Hill to be stable, but marginally so. His report identifies a number of small localised landslides - reactivations of relict shear surfaces – particularly on the northern slope, caused by the widening of local roads, the widening of the A417 itself or over steepening by private home owners excavations. His report also identifies areas of artesian water encountered at the base of the southern slope, adjacent to Horsbere Brook (see appendix C).

4.3.12 The lower to mid sections of the north slope and upper part of the south slope around Air Balloon are vegetated with woodland and a scattering of dwellings obscuring to some extent the morphology. The majority of the south slope is open pasture land with a scattering of trees and topped by Barrow Wake car park. The upper north slope comprises steep exposures of Inferior Oolite, due to former quarrying, grassland and remains of an iron age fort.

Figure 4.8: Photographs of the Cotswold's escarpment looking north towards Crickley Hill from a view spot north-west of Birdlip

Source:2017 Site Walkover

Mass Movement – Churn and Frome Valleys

4.3.13 Published mapping indicates landslide deposits associated with the Fuller's Earth. There has not been any detailed geomorphological mapping to date, however site walkovers record back scars indicating past instability. Option 30 proposes a road junction adjacent to one of these areas – the Churn valley near Shab Hill Farm; and both options will have some impact on the area between Stockwell to Nettleton (Frome valley) – Option 12 will have a greater impact than Option 30.

4.3.14 During peri-glacial freeze-thaw conditions the downcutting of the meltwater in the Rivers Churn and Frome valleys caused significant unloading resulting in upward bulging of the valley floor comprising the more ductile Fuller's Earth. Bulging is not considered to be an ongoing process but disturbance of the deposits can lead to instability.

4.4 Hydrogeology

Regional hydrogeology

Bedrock

4.4.1 The 2 major bedrock aquifers in the study area are the Great Oolite and Inferior Oolite groups, which are designated as Principal Aquifers by the Environment Agency. These aquifers are separated by a layer of the less permeable Fuller’s Earth Formation.

4.4.2 In addition to these Principal aquifers, the Lias Group is designated as a Secondary Undifferentiated Aquifer by the Environment Agency. The uppermost formation within the Lias Group, the Bridport Sand Formation, is considered to be in hydraulic continuity with the overlying Inferior Oolite aquifer. The Bridport Sand in the study area may comprise thin limestone aquifer units interbedded with lower permeability sandy mudstones rather than the sandstone aquifer unit found further east. Further down in the Lias succession, the Marlstone Rock Formation forms a locally important aquifer.

4.4.3 The Great and Inferior Oolite aquifers are both well cemented leading to low intergranular permeability and low storage. Groundwater flow is largely through secondary fractures and fissures which can be enhanced by dissolution. Fracture density and therefore groundwater flow is likely to increase towards the edge of the scarp due to cambering.

4.4.4 The hydrogeological properties are complicated by the layered and cambered nature of the limestone, and by faults off-setting / connecting various strata.

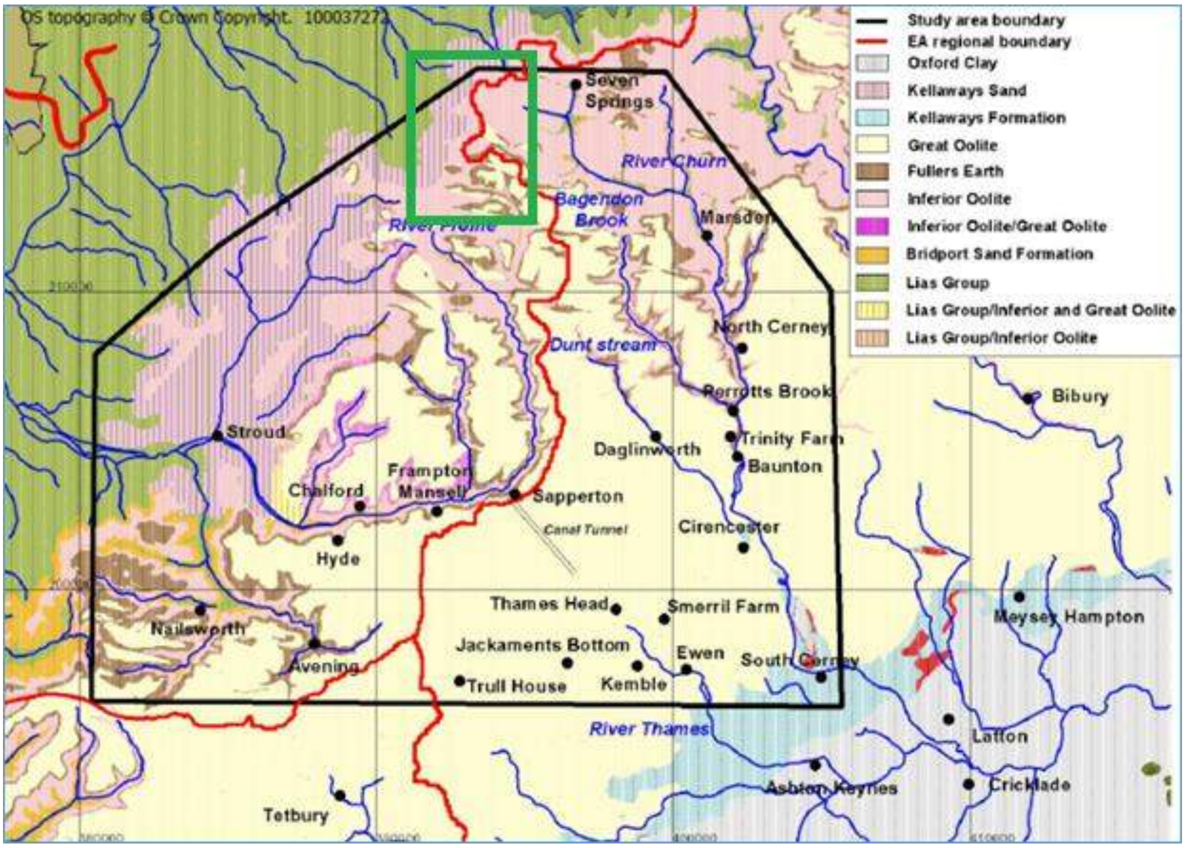
4.4.5 Leakage between the Great and Inferior Oolite aquifers may occur where the less permeable Fuller’s Earth is thin or faulted.

4.4.6 A groundwater divide lies close to the Cotswold escarpment and is believed to approximately follow the topographic divide (Figure 4.9). Within the Thames catchment to the east of the divide, the Great and Inferior Oolite aquifers drain to the River Churn and its tributaries. West of the divide, Great and Inferior Oolite, and underlying Lias aquifers drain to the River Frome and its tributaries, and the Horsbere Brook, both of which join the River Severn. The proposed scheme is likely to straddle both the Thames and Severn catchments.

4.4.7 Regionally, the Thames catchment groundwater flow is towards the south-east, away from the groundwater divide, in both the Great and Inferior Oolite. Both are unconfined in the area around the proposed scheme, but the Inferior Oolite becomes confined by the overlying Fuller’s Earth down-dip.

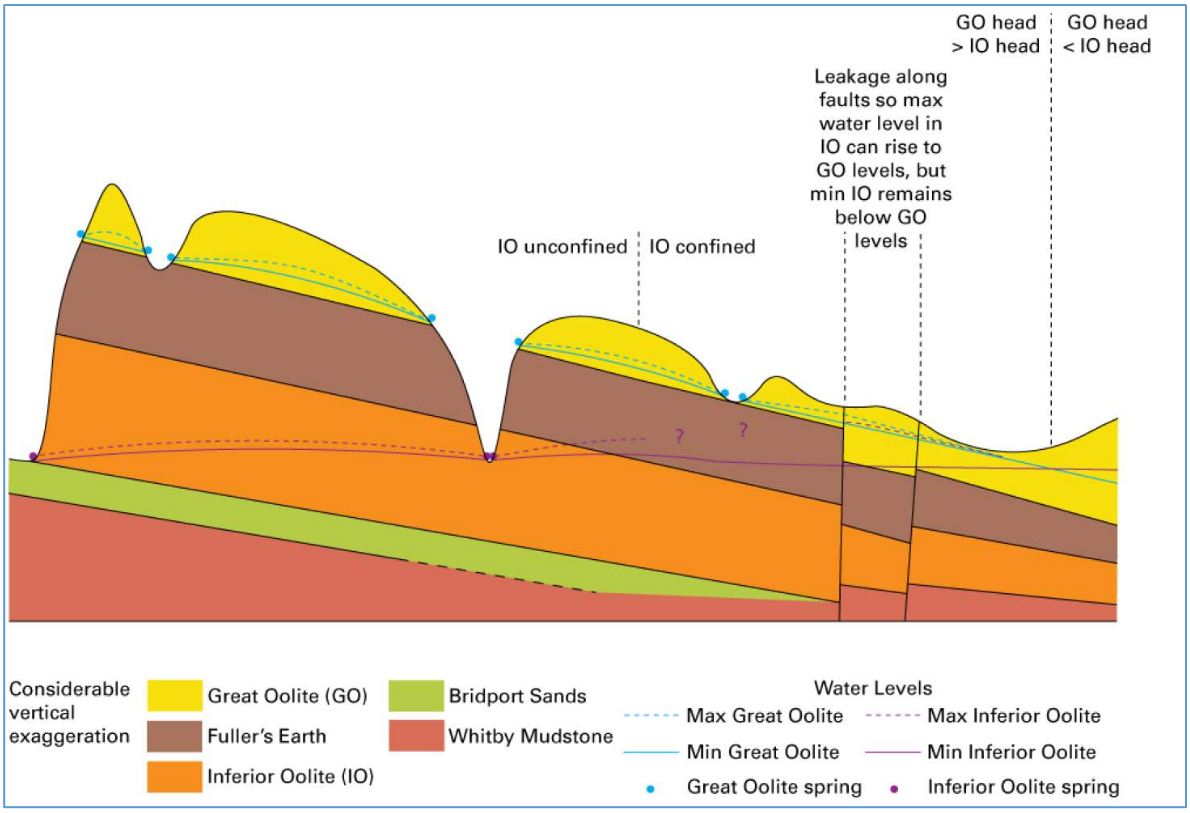
4.4.8 It is believed that groundwater levels in both the Great and Inferior Oolite aquifers can vary by tens of metres annually because of the low storage of the aquifers and rapid transmission of recharge through the unsaturated zone. Saturated aquifer thickness will be controlled by discharges as well as by distance down-dip, and will become thinner towards the scarp where there is discharge via springs. A conceptual hydrogeological model section running north-west (escarpment) down-dip to the south-east is shown in Figure 4.10.

Figure 4.9: Regional geology, river catchments and groundwater divide (green box shows project location)



Source: (Maurice, et al., 2008)

Figure 4.10: Conceptual model section north-west – south-east



Source: (Maurice, et al., 2008)

Superficial deposits

4.4.9 The sand and gravel deposits overlying the Lias at the base of the escarpment in the western part of the site is classed by the Environment Agency as a Secondary A aquifer. Locally, the granular mass movement deposits may contain perched groundwater, leak to or receive leakage from the underlying bedrock aquifers depending on relative groundwater heads, and may support spring and seepage flow.

Local hydrogeology

4.4.10 Most groundwater abstraction takes place from the Great and Inferior Oolite further down-dip to the south and east away from the site. As a consequence, there is almost no data for boreholes drilled within the study area.

4.4.11 Groundwater levels and therefore saturated aquifer thickness are locally influenced by spring discharges, faulting and baseflow. Faults can act as hydraulic pathways between aquifer units or barriers to flow.

4.4.12 The lack of monitoring data means that it is not possible to comment on groundwater levels in proximity to the proposed scheme, but close to the escarpment further to the south, the Inferior Oolite saturated aquifer thickness is typically less than 1m. The saturated aquifer thickness in the Great Oolite slightly down-dip of the proposed scheme is generally less than 10m. No information is available on the groundwater levels within the Lias Group.

4.5 Hydrology

Surface watercourses

4.5.1 The Cotswold escarpment forms a surface water divide between the River Severn and the River Thames. To the west of the divide, the land drains to the River Severn catchment, and on the east of the divide the land drains to the River Thames catchment.

4.5.2 West of the topographic divide, a large number of springs issue from the face of the escarpment to form streams that become the headwaters of the River Frome at Nettleton. Where the bed crosses the Great and Inferior Oolite aquifers, there is little flow accretion and the small flows that do occur are diminished by leakage. The main inflow during high and low flow conditions occurs where the river bed and valley sides intersect the boundary between the Inferior Oolite and Bridport Sand.

4.5.3 Horsbere Brook, a seasonal stream connected to the River Severn, rises from springs on the escarpment and flows along the incised valley down Crickley Hill. Additional spring-fed streams flow into Witcombe Reservoir, which in turn discharges to Horsbere Brook just upstream of Brockworth, close to the A417 / A46 junction.

4.5.4 To the east of the groundwater divide, the land drains to the River Churn, which is part of the River Thames catchment. The headwaters of the River Churn are also largely spring-fed.

4.5.5 The Environment Agency's Flood Map for Planning indicates that the scheme is located within 500m of Flood Zones 2 and 3 for the River Frome and Horsbere Brook at the eastern and western extents of the study area respectively. These Flood Zones are defined as follows:

- Flood Zone 3 is land assessed as having a 1-in-100 or greater annual probability of river flooding (>1%)
- Flood Zone 2 is land having a 1-in-1000 or greater annual probability of river flooding (0.1%)

4.5.6 The Environment Agency's online Flood Map for Planning shows that the scheme is not within an area benefitting from flood defences. The Gloucestershire County Council Strategic Flood Risk Assessment (SFRA) online Flood Zone interactive map indicates that the areas identified as Flood Zone 3 are classified as Flood Zone 3b. Flood Zone 3b is classified as 'the Functional Floodplain' which comprises "land where water has to flow or be stored in times of flood".

4.5.7 There are instances of medium to high risk of surface water flooding at the western extent of the Scheme options associated with Horsbere Brook and at the eastern extent associated with the River Churn and the River Frome. This includes areas of existing carriageway at high risk of flooding at the western and eastern extents of the scheme.

4.5.8 The Cotswold SFRA Update (2016) notes that several groundwater flooding incidents have been recorded in the Cirencester area, to the southeast of the scheme, in addition to a few isolated incidents on the Great Oolite that are likely to be related to springs emerging during periods of high groundwater level.

4.5.9 The BGS Groundwater Susceptibility dataset, available through the Highways Agency Drainage Data Management System (HADDMS), indicates that there are zones where there is the potential for groundwater flooding to occur at surface along the existing carriageway. These are within the incised valley at Nettleton on top of the escarpment, where springs from the Great Oolite and Inferior Oolite feed Bushley Muzzard SSSI and the headwaters of the River Frome, and at the base of the escarpment where the Cheltenham Sand and Gravel superficial aquifer overlies the Lias.

Springs

4.5.10 Springs issue from the face of the escarpment in the study area between Witcombe Wood and Crickley Hill. Springs generally occur locally at the contact between the more impermeable strata within the Upper Lias and the Inferior Oolite / Bridport Sand. Springs may also be structurally controlled or associated with less permeable horizons within the aquifer such as hard bands.

4.5.11 Many springs are within the landslide material on the escarpment, however their location is not always an indicator of a stratigraphic or structural boundary as flow pathways are complicated by the presence of cambering and the generally disturbed nature of the landslide material.

4.5.12 Numerous springs also issue from the dip-slope, draining to the River Churn in the Thames catchment and to the River Frome in the Severn catchment. They generally occur at the contact between the Fuller's Earth and more permeable formations within the Great Oolite Group.

4.6 Groundwater receptors

Introduction

4.6.1 This section summarises the groundwater receptors potentially impacted by the project. For the purpose of this impact assessment, the receptors are split into 2 categories: direct and indirect receptors. Direct groundwater receptors are considered to be the aquifers themselves, whilst indirect receptors are classed as those potentially affected when groundwater is considered to be the pathway. These may include abstractions, springs and surface watercourses receiving spring or baseflow within the catchments of the Frome, Churn and Horsbere Brook, other groundwater dependent features such as wetlands, as well as existing structures and archaeological features.

Direct groundwater receptors

4.6.2 Direct receptors include the Great and Inferior Oolite principal aquifers and the underlying aquifer units within the Lias, classed as a Secondary (undifferentiated) aquifer westwards from the foot of the scarp. The superficial deposits aquifer overlying the Lias can also be considered to be direct receptors and are classed as Secondary A Aquifers.

4.6.3 The Churn catchment lies within the Environment Agency Thames Region, while the Frome and Horsbere Brook catchments lie within Environment Agency Midlands Region. Within the Thames Region, the Great and Inferior Oolite aquifers are included within the Burford Jurassic groundwater body (No. GB40601G600400) under the Water Framework Directive (WFD). The oolite aquifers are not classed as a separate groundwater body within the Severn Region.

4.6.4 The Great Oolite and Inferior Oolite outcrops are extremely vulnerable to pollution due to the absence of overlying, low permeability superficial deposits.

Indirect groundwater receptors

Abstractions

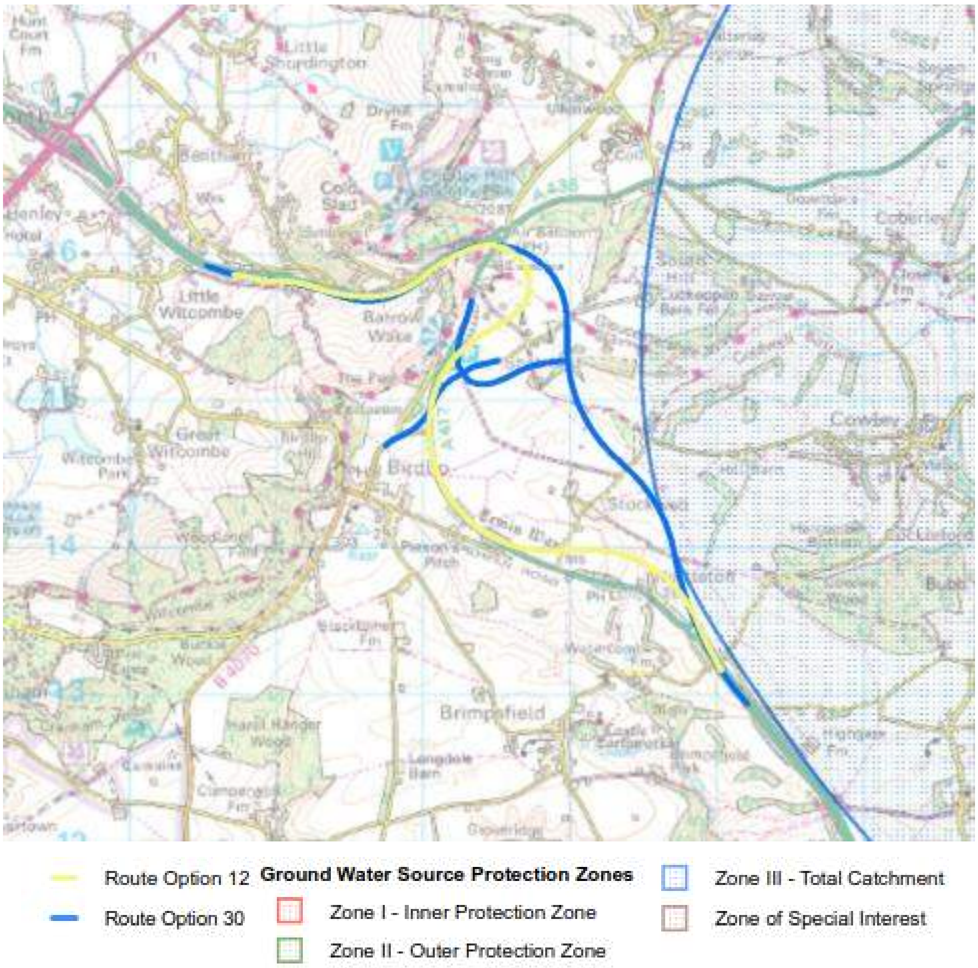
4.6.5 A major public water supply groundwater source is located at Baunton (NGR SO 0159 0484), approximately 11 kilometres down-dip of the proposed scheme. The Source Protection Zone 3 (total catchment) for the Baunton source extends to the study area as presented in Figure 4.11. Option 30 encroaches on the boundary in the Stockwell area, whilst both options are very close to the boundary from Nettleton southwards. The Baunton source is known to be hydraulically connected to the River Churn and receives substantial leakage from it.

4.6.6 Other than Baunton, licensed groundwater abstractions in the study area are generally small and are used for water supply (general farming and domestic), agricultural (spray irrigation) or industrial and commercial (school) activities. According to the Environment Agency What’s in Your Backyard online mapping (accessed August 2017), the nearest licensed groundwater abstractions to the proposed scheme are near Duntisbourne Abbots (general farming and domestic) and at Rencomb College (school), which are 3.4 kilometres south and 4.8 kilometres south-east of Cowley Roundabout respectively. Information on licensed and unlicensed abstractions is currently being sought from the Environment Agency and local authority respectively.

4.6.7 There may also be unlicensed groundwater abstractions in the local area.

4.6.8 In addition to groundwater abstractions, there are a number of surface water abstractions from the Frome and Churn, including the major public water supply abstraction from the River Frome at Chalford.

Figure 4.11: Source protection zones



Source: (Environment Agency, 2017) / GiGi GIS Portal. Crown Copyright 2016 100030649

Potential impacts on receptors

4.6.9 Without mitigation measures, risks to groundwater bodies and indirect groundwater receptors such as springs, surface watercourses, groundwater dependent habitats and designated sites, and abstractions are likely to occur during construction and operation of the scheme. Risks include reductions in groundwater levels and flow, groundwater mounding, and diversion of water between groundwater catchments, as well as effects on water quality. Particular attention is needed with respect to risks associated with construction dewatering, and the potential for permanent cuttings and ground investigation works to create pathways between aquifers or to divert water between catchments. Cuttings and other structures extending below the water table, as well as ground improvements may also create barriers to flow.

4.6.10 Without mitigation, there is also the potential for additional road runoff to watercourses during construction and operation, and an increased potential flood risk. Conversely the loss of groundwater recharge due to increased areas of hardstanding may lead to a reduction in groundwater levels and flow, which could affect groundwater receptors.

4.6.11 On the whole, impacts on groundwater levels due to temporary excavation works are unlikely to persist beyond the end of the construction period, although impacts due to permanent excavations would remain, particularly where these fully intersect aquifers (most likely to be the Great Oolite as this is thin and unsaturated in the study area).

4.6.12 The possible exception, given the duration of the likely construction period, is the potential for a loss or change of habitat within a directly or indirectly groundwater-dependent ecosystem such as Bushley Muzzard SSSI, where any change in level, flow or quality could last for a significant period of time.

4.6.13 The regional groundwater flow direction is towards the southeast in both the Great and Inferior Oolite. Due to potentially rapid flow through these aquifers, groundwater receptors some distance down-gradient of the scheme, such as the Baunton public water supply abstraction may be affected in terms of water quality, particularly during construction.

4.7 Site history

4.7.1 An understanding of the history of the site has been determined through a review of the historical OS maps presented in earlier PSSR’s and other readily available background information.

4.7.2 Notwithstanding quarrying and road infrastructure developments the historical mapping indicates that there has been very little change in the area since the publication of the earlier historic map with the exception of the construction of the Birdlip Radio Communication Station complex circa 1940s. A recent publication by a local historian is understood to provide an account of the development of the radio station through the years (McKeeman, 2015) however the Mott MacDonald Sweco Joint Venture has not been able to attain a copy to summarise the key historical developments. Route Option 30 passes through this site and while the details of the radio station complex will not significantly affect the proposed works, all information on the site is sought to consider the potential for historical storage of ordnance.

The history of A417 improvements / development

4.7.3 The A417 itself has a history of upgrades and modifications most notably:

- The construction of the Birdlip Bypass in 1988
- The construction of the Brockworth Bypass in 1996
- The construction of the north of Stratton to Nettleton Improvements in 2000

4.7.4 Reports available through HA GDMS (Highways England, 2017) which were viewed as part of this PSSR, including details of the earthwork designs for the Birdlip Bypass and Brockworth Bypass, are presented in appendix B. In addition to the HA GSMS Reports a PSSR (AMEY, 2014), was provided by Gloucestershire County Council via Highways England.

4.7.5 During construction of the Birdlip Bypass, in about 1988, an "infilled gull" gave rise to a local stability problem at about NGR SO 9332 1575. This position is at the head of the gully formed by the south-eastern branch of the stream referred to earlier which, as noted, may follow the line of Shab Hill Barn Fault. A spring also exists at this location. The situation was corrected by building a short, piled retaining wall.

4.7.6 In addition, the portion of the A417 up Crickley Hill has been modified over the years including remedial works after slope failures as reported in Hutchinson's report (Hutchinson, 1991) and reproduced below (4.7.7 to 4.7.11):

4.7.7 A road has been in existence along approximately the same route up Crickley Hill as the present A417 for over 200 years. In 1777 it was a turnpike road to Northleach which was doubtless improved somewhat from time to time, becoming before the early sixties a 2-lane road, typically about 7m wide (Wilson, Report 918). No written records of landsliding affecting the road have been found for this period.

4.7.8 A comparison of the various earlier editions of the 1:2,500 O.S. maps (1st edn, surveyed 1882, published 1884; 2nd edn, surv. 1900, pub. 1902; 3rd edn, surv. 1920, pub. 1922; and Revised edn, relevelled 1936, pub. 1939) shows chiefly minor changes to buildings and boundaries, the addition of new buildings and, between 1882 and 1900, the development of limekilns and new quarries to the south-east of the A417, the latter on each side of the present Birdlip Bypass. The most recently worked quarry on Crickley Hill closed in 1963 (Gloucester County Record Off ice, ref. AR 82). In addition, however, 2 changes in the scarp lines north of the A417, appear for the first time on the 3rd edn of the O.S. map, i.e. between 1900 and 1920. The rear scarp between NGR SO 9300 1599 and 9370 1602 is shown to have retreated by about l0m on average. This may have been the result of a further, retrogressive slip or of quarrying.

4.7.9 Also between 1900 and 1920, a new 20m long scarp is shown, centred about NGR SO 93175 16035 and running parallel with the A417, about 10m north-north-west of its northern edge. This may have resulted from landsliding.

4.7.10 In around 1966, the A417 up Crickley Hill was improved by increasing it to 3-lanes and reducing curves and gradients to some extent. In January 1968, during the execution of these works and following an excessively wet autumn and winter a landslide developed in a cut on the north side of the improvement line, opposite the present (former) Cotswold Way Restaurant. It extended about 80m along the road cutting and was up to about 45m in width and occurred in an area where quarry waste had been tipped from above many years earlier. The slip surface is understood to have emerged above the road, in the toe or face of the cutting, and the slip did not interfere with the carriageway. Stabilisation measures, consisting of 5 rock-filled counterfort drains up to 4.6m deep and about a metre wide, discharging into a toe drain carried under the carriageway to the stream, were installed immediately. These measures appear to have been generally successful, although Wilson (Report 918, 1988) reports a fresh, 30-

40cm scar at the rear of the most north-easterly of the counterfort drains, which he attributes to either slope movement or settlement within the drain. The same report notes an area of fresh slip scars and fallen trees in an area between Dog Lane and Cold Slad Lane (NGR SO 9234 1595), observed on aerial photographs of June 1982.

4.7.11 In February 1972, the former GCC Materials Engineer, Mr D.W. Rolfe, made an inspection of a slip at NGR SO 9238 1603, just above the house now called "Crickley", which was threatening Cold Slad Lane at its crest. This slip was caused by excavations at the rear of the house which extended 1.8 to 2.4m into the hillside and produced a 0.9 to 1.2m high face which was retained by a block wall. The slip caused the wall to collapse and produced cracks in the southern verge of Cold Slad Lane. It should be noted that both this slip and that in 1968 occurred in the, generally wet, mid-to late winter period. Cold Slad Lane is likely to be reconfigured for provision of local access. When considering the impact of earthworks construction on the existing slope it would be prudent to keep these events in mind.

4.7.12 Following Hutchinson’s summary of the Crickley Hill road works up to 1991 and these initial feasibility studies to dual this section of the road on behalf of Gloucester County Council it appears that studies were not progressed further, though parallel feasibility studies of potential tunnel options were also undertaken at the time. Plans to progress not only the dualling of the Crickley Hill section of the road were re-ignited between in 2001 to 2004 when Highways England commissioned WSP to undertaken feasibility studies for the widening of the Crickley Hill section and improvements to the dip slope under the Cowley to Brockworth improvement scheme. Again these plans appear to have been halted until Gloucester County Council further progressed studies of the, at the time, favoured ‘Brown Route’ in circa 2014. During this period where major improvements to the A417 were being considered it is known that CCTV masts mid slope and at the top of the Crickley Hill were erected circa 2009.

4.8 Quarrying

4.8.1 Crickley Hill and more over Leckhampton Hill was a hive of industrial activity with quarrying of Inferior Oolite limestone being a major local activity. Records of quarrying exist from the late 16th century to the mid-1920s. The nearby Leckhampton Hill was a major source of ‘Cotswold Stone’ of varying quality with the best used for carving for interior use (e.g. Cheltenham College Chapel) but the bulk of lower quality used for road stone and as a source of material for the production of lime. Of all the Inferior Oolite limestone the Cleeve Cloud Member of the Birdlip Limestone Formation was by far the most important unit used for building stone in the Cotswolds. It consists of a thick succession of massive, uniform oolite, strongly current bedded with very little fossil content. It was the most widely used and versatile of the Cotswold Limestones.

4.8.2 Both route options feature a deep cutting at the top of Crickley Hill which is expected to encounter the full sequence of the Inferior Oolite. Information from the nearby quarries may aid in interpretation of the ground investigation and inform the design of the Crickley Hill cutting.

4.9 Mining

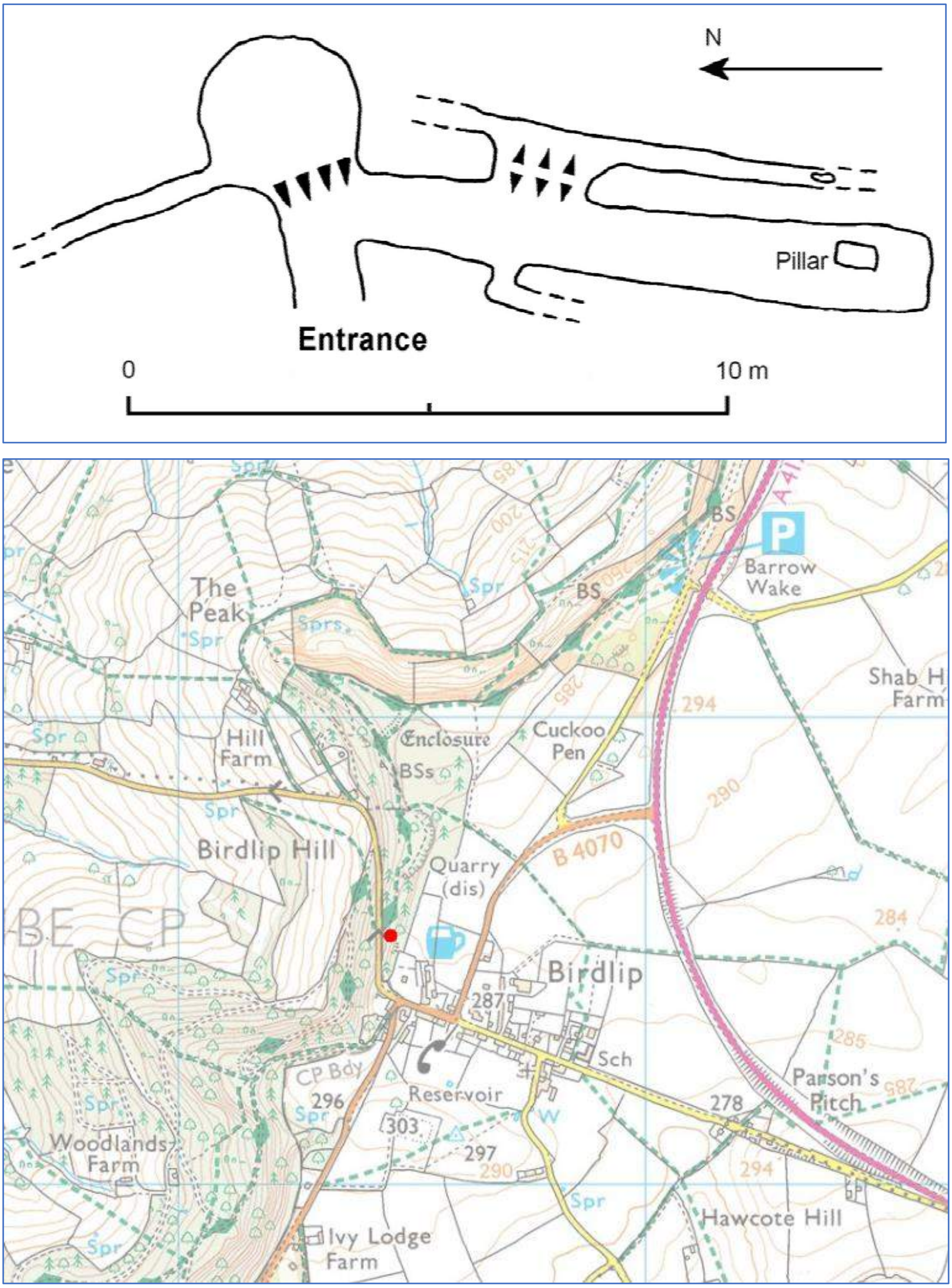
4.9.1 The site falls outside the Coal Authority reporting area however data provided by Ove Arup and Partners through the HA GDMS (Highways Agency, 2008) indicates that there is the potential for mining instability in Birdlip associated with rock commodity (limestone). The same area is shown to have a ‘Likely’ hazard from underground mining by the BGS Non-coal mining areas of Great Britain database (British Geological Survey, 2017). This related to underground mining or suspected within or close to the area, with the commodity indicated to be Limestone – Bath Stone.

4.9.2 There are few details regarding underground mining in the Birdlip area, in reference to the above hazard.

4.9.3 There is reference to a cave entrance ‘modified by miners’ at grid reference SO 9246 1452 on the escarpment by the Royal George Hotel in Birdlip village (Self & Boycott, 2004). This paper refers to the cave as a natural cavity that has been affected by mining activity with a large entrance modified by miners and a passage enlarged by stone extraction. Approximately 35m of the cave is accessible. A sketch plan is presented in Figure 4.12 along with an excerpt of where the grid reference locates it.

4.9.4 It is possible that this cave is related to the mining activity recorded by Ove Arup and Partners and the BGS.

Figure 4.12: Plan and location (red point) of the Royal George Cave, Birdlip



Source: (Self & Boycott, 2004) / GiGi GIS Portal. Crown Copyright 2016 100030649

4.10 Environmental records

4.10.1 For the 2002 PSSR (WSP, 2002, HA GDMS Ref 16772), an ‘Envirocheck Report’ (Landmark Information Group, 2002) was obtained; and for the 2014 PSSR (AMEY, 2014) a ‘Groundsure Envirosight Report’ (Groundsure Environmental Intelligence Solutions, 2014) was obtained. These documents have been used in addition to data held by the Environment Agency to summarise the environmental records for the site.

Groundwater abstractions

4.10.2 There are a limited number of licensed groundwater abstractions in the study area which are small, with the nearest 3.4 kilometres south of Cowley Roundabout (see section 4.6.6).

Discharge consents

4.10.3 Discharge consents within the study area are summarised in Table 4.3.

Table 4.3: Discharge consents

Location	National Grid Reference	Discharge Type	Receiving Water	Status	Dates
Air Balloon Public House, Birdlip, Gloucestershire	393340, 216030	Sewage and trade combined	Underground strata	New Consent	02/04/2012 onwards
1 and 2 Crickley Cottages, Crickley Hill, Gloucestershire	392350, 216020	Sewage discharges	Underground strata	Pre NRA Legislation	20/06/1979 onwards
Birdlip Wastewater Treatment Works, Roman Road, Gloucestershire, GL4 8JL	393110, 213795	Sewage discharges	Groundwater	New issued under EPR 2010	07/03/2013 onwards
Hardings Barn, Cowley, Gloucestershire, GL53 9PF	395200, 213900	Sewage discharges	Inferior Oolite	Modified	30/01/2007 to 31/03/2019
Greycote and Willow Farm, Little Witcombe, Gloucestershire, GL3 4TY	391300, 215350	Sewage discharges	Tributary of Horsbere Brook	Post NRA Legislation where issue date is >31/08/1989	20/09/1994 onwards

Pollution incidents to controlled waters

4.10.4 Up to 2003 the Environment Agency had no records of major or significant pollution incidents to controlled waters within the project area. An up to date data set should be consulted as the scheme progresses.

Contaminated land

4.10.5 No records have been found where any region within 500m of the study site has been determined as contaminated land under Section 78R of the Environmental Protection Act 1990. However, some areas have been identified as potential sources of contamination. These areas include a small agricultural machinery operation located at Grove Farm where fuel and lubricating oils may be stored and localised land raises, Birdlip Quarry that is currently used as a motocross track and a number of other farm buildings where contamination associated with fuel and oil spills are a possibility. It is recommended that soil samples are taken during any ground investigations and relevant chemical testing is undertaken.

4.10.6 There are a number of potentially contaminative industrial land uses within 250m of the site. The on-site land uses are summarised in Table 4.4.

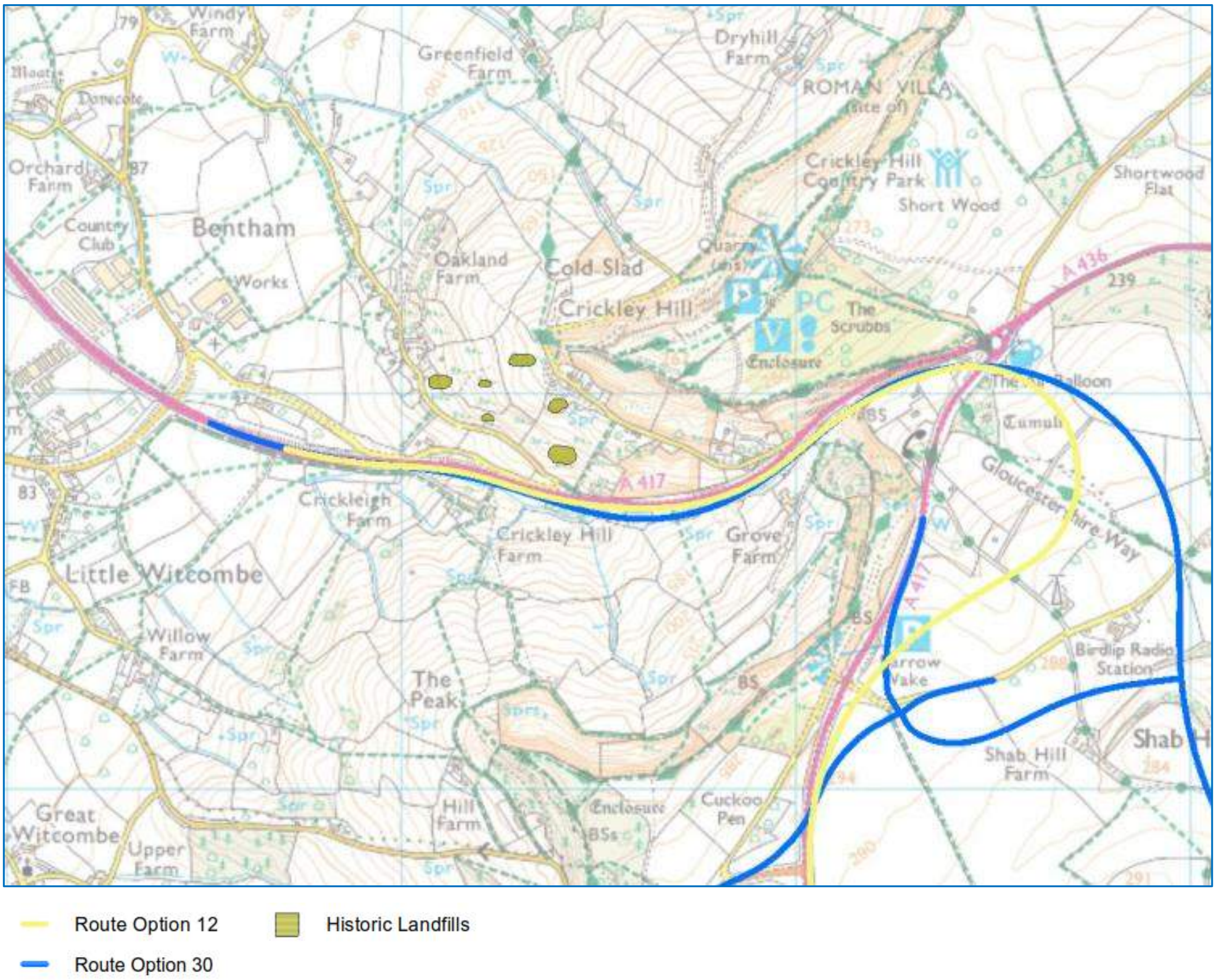
Table 4.4: Industrial land uses

Distance from site (m)	NGR	Address	Activity	Category
On site	393397, 213995	Cirencester Road, Birdlip, GL4 8JL	Vehicle Hire and Rental	Hire Services
On site	391608, 215987	Holly Brae, Crickley Hill, GL3 4UF	Catering and Non-Specific Food Products	Foodstuffs
On site	394713, 213648	GL4	Unspecified Quarries or Mines	Extractive Industries
On site	393320, 215841	GL4	Water Pumping Stations	Industrial Features
On site	393427, 213959	GL4	Unspecified Works or Factories	Industrial Features

Landfill and waste sites

4.10.7 The Environment Agency records indicate that there are no authorised landfill sites within the study area. The records show the boundary of a historic landfill at Crickley Lodge, on the north slope of Crickley Hill (Figure 4.13). The landfill comprises 6no. small sites which accepted inert waste, however there are no details on the site operator or the active dates. The closet of the sites is approximately 70m from Option 12, 85m from Option 30.

Figure 4.13: Environment Agency recorded location of Crickley Lodge landfill



Source: GiGi GIS Portal. Crown Copyright 2016 100030649

4.11 Sensitive land designations

Statutory designations

4.11.1 MAGIC mapping (Natural England: MAGIC mapping, 2017) indicates that the entire site is within the Cotswolds Area of Outstanding Natural Beauty (AONB).

4.11.2 MAGIC mapping indicates that the areas directly north-west and south-east of ‘The Air Balloon Roundabout’ are part of the Crickley Hill and Barrow Wake Site of Specific Scientific Interest (SSSI). This site is also designated as a Local Wildlife Site and Geological Conservation Review.

Archaeology and heritage designations

4.11.3 There is a scheduled monument located within Emma’s Grove named Three Bowl Barrows (locally known as Emma’s Grove Round Barrows). They are 3 barrows, the largest being 4.2m high and 32m in diameter. Bowl Barrows are funerary monuments dating from the Late Neolithic period to the Late Bronze Age (2400 to 1500 BC).

4.11.4 To the north-west of the Air Balloon Roundabout is a scheduled monument: Crickley Hill Camp.

4.11.5 There are a number of archaeology hotspots within the study area, as indicated by the Archaeology Data Service archives (Archaeology Data Service, 2017). The nearest records are:

- The known surviving extent of a medieval moated site and fish pond (Historic England reference SO91NW8). Located at grid reference SO909971676
- Flint artefacts, 6 Roman copper coins and 3 bronze broaches (Historic England reference S091NW26). Located at grid reference SO9216
- Circles observed on aerial photographs interpreted as disc barrows and fungus rings (Historic England reference SO91NW24). Located at grid reference SO930165
- Medieval enclosure or deer park with Roman finds (Historic England reference SO91NW19). Located at grid reference SO934165
- Round Barrow (Historic England reference SO91NW2). Located at grid reference SO93381585
- Possible Roman building and pottery (Historic England reference SO91NW28). Located at grid reference SO92761506
- Two no. leaf-shaped arrowheads (Historic England reference SO91NW9). Located at grid reference SO92251509
- Former Roman site (Historic England reference SO91SW31). Located at grid reference SO93231468
- Former Roman building (Historic England reference SO91SW1). Located at grid reference SO92491442

Further detail relating to archaeological and heritage designations is presented within the Environmental Scoping Report for the scheme (MMSJV, July 2018) and will be presented in the Environmental Assessment Report (MMSJV, under authorship at the time of writing).

4.12 Unexploded ordnance

4.12.1 The Zetica bomb maps were consulted to provide an indication of Unexploded ordnance (UXO) risk to the site. In addition, a pre-desk study assessment was undertaken by Zetica (Zetica, 2018) to support this initial assessment. The pre-desk study assessment findings area summarised in the table below.

Table 4.5: Pre-desk study UXO assessment

Pre-WWI military activity on or affecting the site	None identified.
WWI military activity on or affecting the site	A military hospital was established at Ullenwood, on the northern part of the site, for American troops.
WWI strategic targets (within 5km of site)	The following strategic targets were located in the vicinity of the site: • Military camps and training areas • Transport infrastructure
WWI bombing	None identified on the site.
Interwar military activity on or affecting the site	None identified.
WWII military activity on or affecting the site	A radio station and transmitter site was established on the site at Shab Hill. The hospital at Ullenwood was expanded and renamed the No. 110th United States Army Air Forces (USAAF) General Hospital.
WWII strategic targets **(within 5km of site)**	The following strategic targets were located in the vicinity of the site: • Military camps and training areas • Radio station and transmission masts • Industries important to the war effort, including an aircraft factory • Transport infrastructure • Anti-Aircraft (AA) and anti-invasion defences
WWII bombing decoys (within 5km of site)	4No. The nearest was located approximately 0.9km south of the site.
WWII bombing	During WWII the site straddled the boundary of the Rural Districts (RDs) of Cheltenham and Cirencester. Cirencester RD officially recorded 202No. High Explosive bombs with a very low regional bombing density of 2.4 bombs per 405 hectares (ha). Cheltenham RD officially recorded 185No. High Explosive bombs with a very low regional bombing density of 2.3 bombs per 405ha. No readily available records have been found to indicate that the site was bombed.
Post-WWII military activity on or affecting the site	Shab Hill radio station remained operational and was used by Air Traffic Control. The hospital at Ullenwood was repurposed as a Cold War bunker. In the 1990s it was used for training purposes by the Gloucestershire Fire and Rescue Service. It is now in private ownership.
Recommendation	A detailed desk study, whilst always prudent, is not considered essential in this instance.

5 Ground conditions

5.1 General

5.1.1 An assessment of the likely characteristics of the ground underlying the site has been made using available ground investigation records and other background sources. The site-specific ground conditions and material characteristics need to be confirmed by project specific ground investigation(s).

5.1.2 Factual data has been obtained from a number of ground investigation reports and published borehole logs (BGS) within the vicinity of the site for various development schemes between 1981 and 2009. A summary of the various ground investigations is presented in Table 2.1. Data has been collated and discussed by stratum in the following sub-sections. The discussion, however, is constrained by the quantum and distribution of available data which is relatively limited and of variable quality. At this stage strata have been split by Formation geology level with the properties presented based on results of direct laboratory and in-situ results only. Only direct data is presented and no parameters have been derived using correlations.

5.1.3 As there was only a limited quantity of data specific to the proposed alignment of the route, the properties per stratum are presented at high level and location specific variations about the alignment should be assessed at later stages in the project. The values presented should therefore be viewed as a preliminary global presentation only.

5.1.4 The ranges of parameters given provide, at a desk study level, an indication of the nature of the ground material behaviour to inform risk identified and management and at no point should not be relied on for outline or detailed design.

5.2 Ground model summary

5.2.1 Based on the factual information presented within the various ground investigation reports / factual reports, a summary of the likely ground conditions beneath the site has been compiled, to develop the desktop study conceptual model presented in earlier sections of this report.

5.2.2 As can be seen on the summary of ground investigation drawing (section 8) the existing ground investigation data is centred about previous road development schemes. Some of the new proposed alignment is in ‘greenfield’ land and therefore away from the existing information.

5.2.3 Given the spatial distribution of the data, for the purposes of summarising the ground conditions encountered by the previous ground investigations and variation in ground conditions a number of ground models have been prepared:

- Brockworth Bypass

- Crickley Hill
- Birdlip Bypass
- Stratton to Nettleton

5.2.4 These ground summary models, which are presented in the following tables, are valid along the route areas outlined and not necessarily representative of the new route alignment outside of these areas. Further ground investigation will need to be undertaken to develop more robust and location specific ground models along the proposed road alignments.

Table 5.1: Ground summary – Brockworth Bypass

Ground investigation records / report	Strata	Likely geological unit	Variation of base of strata		Range of stratum thickness (m)
			Depth (m bgl)	Level (m AOD)	
○ Gloucestershire County Council. Materials Laboratory. (April 1981). Report on Brockworth Bypass Preliminary Soil Survey (HA GDMS Ref 21588) ○ BGS Boreholes data (British Geological Survey, 2018)	○ Grass over slightly clayey slightly sandy angular to sub-rounded fine to coarse GRAVEL of limestone ○ Sandy clayey angular to sub-rounded fine to coarse GRAVEL and COBBLES of limestone with occasional rootlets ○ Firm sandy silty clay TOPSOIL with some fine limestone gravel and rootlets ○ Grass over slightly gravelly sandy CLAY with frequent roots and rootlets. Gravel is angular and sub-angular fine	Topsoil	0.05 to 0.5	92.82 to 103.56	0.05 to 0.5
	○ MADE GROUND: Sandy topsoil with some sub-angular fine to coarse limestone gravel ○ MADE GROUND: Firm silty clay with some sub-angular fine to coarse limestone and brick gravel	Made Ground	0.3 to 1.1	128.93	0.3 to 1.1
	○ Firm slightly sandy gravelly CLAY with occasional roots ○ Slightly Clayey sandy angular to rounded fine to coarse GRAVEL and COBBLES of limestone ○ Soft silty CLAY with some sub-angular fine to coarse limestone and chert gravel. Contamination with topsoil	Landslide Deposits	3.5 to 8.4	123.08 to 171.8	3.5 to 11.15
	○ Firm very sandy silty CLAY with a little moderately strong fine to medium angular gravel sized limestone fragments ○ Firm becoming stiff thinly laminated closely fissured sheared sandy silty CLAY with fine angular gravel sized mudstone ○ Thinly to thickly laminated silty MUDSTONE very weak to weak with some silty clay matrix	Lias Group	Proven to 16.02	77.39 to 97.96	16.02*

*Base not proven

Table 5.2: Ground summary – Crickley Hill

Ground investigation records / report	Strata	Likely geological unit	Variation of base of strata		Range of stratum thickness (m)
			Depth (m bgl)	Level (m AOD)	
○ Gloucester County Council. (December 1988). A417 Crickley Hill Widening Proposals. Preliminary Site Investigation Factual Report (HA GDMS Ref 21573) ○ Geotechnical Engineering Ltd. (April 2002). Ground Investigation at AF17 Crickley Hill Improvement, Grove Farm Access Factual Report. Report No. 13239 (HA GDMS Ref 21571) ○ Geotechnical Engineering Ltd. (July 2009). Ground Investigation at A417/A419 Between M5 J11A and M4 J15. Report No. 22307 (HA GDMS Ref 23973) ○ BGS Boreholes data (British Geological Survey, 2018)	○ TOPSOIL, stone and clay ○ Soft dark brown organic clay TOPSOIL ○ Turf	Topsoil	0.2 to 1.0	164.8 to 266	0.2 to 1.0
	○ Topsoil over made ground of clay and stone etc FILL ○ Brown Gritty CLAY ○ Limestone clay and topsoil fill MADE GROUND ○ Limestone clay and TOPSOIL fill, MADE GROUND ○ Firm light brown sandy CLAY with a little to some gravel of angular limestone *(possible made ground)* ○ Medium dense clayey sandy angular gravel of limestone with occasional ash and brick fragments, MADE GROUND ○ Black clayey sandy GRAVEL with ash and clinker, MADE GROUND	Made Ground	0.4 to 3.7	151.6 to 235.5	0.4 to 3.7
	○ Firm and stiff brown slightly fine sandy CLAY with a little coarse calcareous sand ○ Angular to sub-angular fine to coarse GRAVEL, COBBLES and BOULDERS of cream and light brown, slightly weathered fine grained crystalline limestone in a soft brown clay matrix	Alluvium	0.3 to 4.5	247.55 to 244.3	0.1 to 2.5
	○ Soft to stiff silty CLAY / clayey SILT with limestone gravel and cobbles ○ COBBLES and BOULDERS of off-white shelly oolitic limestone locally with a little firm orange brown slightly sandy clay	Landslide Deposits	4.5 to 16.9	142.47 to 257.2	4.5 to 16
	○ Brown slightly weathered crystalline LIMESTONE recovered as gravel with some very sandy silty clay ○ Grey moderately to highly weathered thinly laminated to very thinly bedded closely fissured silty MUDSTONE ○ Light grey moderately weathered fine grained calcareous silty SANDSTONE, recovered as sandy clayey silty gravel ○ Very stiff greyish brown thinly laminated sandy silty CLAY with occasional bands of pink grey thinly laminated fine calcaerous SANDSTONE	Great Oolite Group	1.7 to 17	0.8 to 242.33	13.85
	○ Grey moderately weathered very closely fissured fine sandy SILTSTONE ○ Light brown slightly weathered medium bedded fine grained bioturbated LIMESTONE ○ Grey fresh thinly to thickly laminated silty calcareous MUDSTONE with occasional lenses of siltstone	Fuller's Earth Formation	2.75 to 6.2	241.1 to 279.15	1.3 to 8.1
	○ Dense yellowish white locally orangish brown sandy clayey angular and sub-angular fine to coarse GRAVEL and COBBLES of limestone ○ Yellowish white locally discoloured brownish orange oolitic LIMESTONE. Fractures are sub-horizontal very closely spaced undulating rough. Band of grey speckled bluish white	Inferior Oolite Group	60.96*	182.88 to 231.15	5.8 proven 60.96
	○ Hard thinly laminated SILT ○ Firm to stiff green brown mottled blue grey sandy CLAY ○ Massive fine-grained LIMESTONE ○ Grey MUDSTONE with very closely spaced sub-vertical planar smooth tight fractures often stained orange brown	Lias Group	Proven to 29.8	135.1 to 197.2 (proven)	>5.35 (proven) to 11.7 (proven)

*Base not proven

Table 5.3: Ground summary – Birdlip Bypass

Ground investigation records / report	Strata	Likely geological unit	Variation of base of strata		Range of stratum thickness (m)
			Depth (m bgl)	Level (m AOD)	
Gloucestershire County Council. Materials Laboratory. (November 1983). Birdlip Bypass Soil Survey (HA GDMS Ref 12606)	Brown clayey and stoney Topsoil	Topsoil	0.2 to 0.5	253.15 to 296.96	0.2 to 0.5
	Compact yellow well-graded gravel FILL Compact brown clayey limestone FILL	Made Ground	0.3 to 5.4	248.54 to 297.16	0.3 to 5.4
	Firm to stiff blue / grey and brown mottled yellow silty CLAY with very thinly bedded yellow/grey LIMESTONE bands Firm becoming stiff yellow / brown mottled and banded pale grey very silty CLAY with bands and inclusions of hard calcareous SILTSTONE	Fuller's Earth Formation	5 to 7.4*	280.73 to 284.08	4.7 to 7.1
	Firm light brown, sometimes sandy (oolitic) gravelly silty CLAY Firm russet brown, sometimes sandy (oolitic) gravelly silty CLAY Soft dark brown becoming brown, slightly gravelly silty CLAY	Inferior Oolite Group	0.5 to 6.4	247.54 to 294.96	0.3 to 2.6
	Cream oolitic LIMESTONE in sparse brown silty clay matrix Buff / cream ooditic LIMESTONE Fractured and clay bound becoming very thinly bedded (up to 150mm) buff / cream oolitic, sometimes shelly LIMESTONE		Proven to >7.3	<245.64 to 284.94	>1.0 to 6.7*

*Base not proven

Table 5.4: Ground summary – Stratton to Nettleton

Ground investigation records / report	Strata	Likely geological Unit	Variation of base of strata		Range of stratum thickness (m)
			Depth (m bgl)	Level (m AOD)	
• Foundation and Exploration Services Ltd. (March 1989). Factual Report on Ground Investigation at A417 North of Stratton to Birdlip Improvement (HA GDMS Ref 12600) • Exploration Associates. (November 1990). A417 North of Stratton to Birdlip (HA GDMS Ref 12601) • C.J. Associates (April 1992). Factual Report on Supplementary Site Investigation. A417 North of Stratton to Birdlip Improvement (HA GDMS Ref 12602)	• Dark brown CLAY Topsoil	Topsoil	0.05 to 0.7	239.76 (184.9) to 287.75	0.05 to 0.7
	• Firm yellowish brown silty CLAY with some fine to coarse limestone gravel • Orange brown clayey fine to medium SAND and tabular angular fine to coarse mudstone GRAVEL • Firm buff, orange brown, light brown and grey mottled, silty very sandy CLAY intermixed with silty very clayey fine SAND and with some fine to medium mudstone gravel	Landslide Deposits	1.2 to 8.5	234.14 to 264.85	1.1 to 8.35
	• Stiff light yellowish brown silty, very sandy CLAY with many shell fragments • Medium dense orange, light yellowish brown and buff silty clayey, becoming very clayey, fine SAND with some to many shell fragments • Moderately strong to strong dark greyish brown slightly weathered to fresh crystalline argillaceous LIMESTONE • Strong light brown becoming grey, fresh to slightly weathered medium grained oolitic LIMESTONE with some shell fragments and a band of very weak highly weathered limestone • Strong light brown fresh fine to medium grained shelly LIMESTONE • Dark grey slightly weathered calcareous SILTSTONE. Ironstained rock and shelly in parts • Weak greenish grey slightly weathered calcareous MUDSTONE	Great Oolite Group	26.6*	242.28 to 217.54*	>23.7*
	• Firm orange brown sandy CLAY with some light grey fine to medium mudstone gravel • Firm dark bluish brown and orange clayey sandy SILT grading into very weak siltstone • Weak bluish grey slightly to moderately weathered sandy clayey SILTSTONE, thinly laminated	Fuller's Earth Formation	11.1	245.58	5.6
	• Strong light brown fresh to slightly weathered crystalline LIMESTONE, occasional shell fragments • Strong grey fresh to slightly weathered fine to medium grained shelly LIMESTONE	Inferior Oolite Group	40.04	228.84	>13.44*

*Base not proven

5.3 Preliminary cross sections and models

5.3.1 A preliminary 3D geological model of the project site at Formation level geology has been developed by Mott MacDonald Sweco Joint Venture to aid in geological interpretation as and when new ground investigation data becomes available. The model was built using the Leapfrog Geo (now Leapfrog Works) software package and constructed by creating and then linking cross sections across the study area.

5.3.2 The model development starts with the draping of the published 1:50,000 scale digital geological mapping (British Geological Survey, 2018) onto Environment Agency Composite DTM 2m LiDAR ground surface data (Environment Agency, 2015). Geological cross sections across the study area are then constructed interpreting strata lines between the mapped outcrops of Formations using the structural geology data published in literature and giving consideration to the outcrop of geology on the LiDAR topography. The process is iterative and involves the geologist(s) knowledge and understanding of the structural geology parameters in the model, which can be adjusted in light of a developing interpretation. Faults are drawn by extrapolating their mapped surface outcrop down at a nominal angle depending on their recorded nature. Fault displacements and locations are based on the published BGS information (British Geological Survey, 2018). Strata thickness and range of thicknesses are based on the published data by the BGS discussed in section 4.2.

5.3.3 Some simplifications have been made to aid 3D modelling which can cause minor deviations from published geological information. Of note is the continuous occurrence of the Aston Limestone Formation in the Inferior Oolite Group; this formation is locally absent having been eroded prior to deposition of the Salperton Limestone in some locales.

5.3.4 The cross sections are built from the top down, the degree of uncertainty increases downwards with decreasing data points. The sub-cropping of strata below the landslide mass movement deposits is particularly subject to uncertainty, as is the thickness of the colluvium body which has been drawn indicatively. The boundaries and thickness of deposits shown on the cross section presented in chapter 8 should be considered as indicative only and subject to significant uncertainty, to be confirmed with ground investigation. This model was created to provide an indication of the ground conditions which could be encountered and permit an evaluation of the hydrogeological conditions below the site.

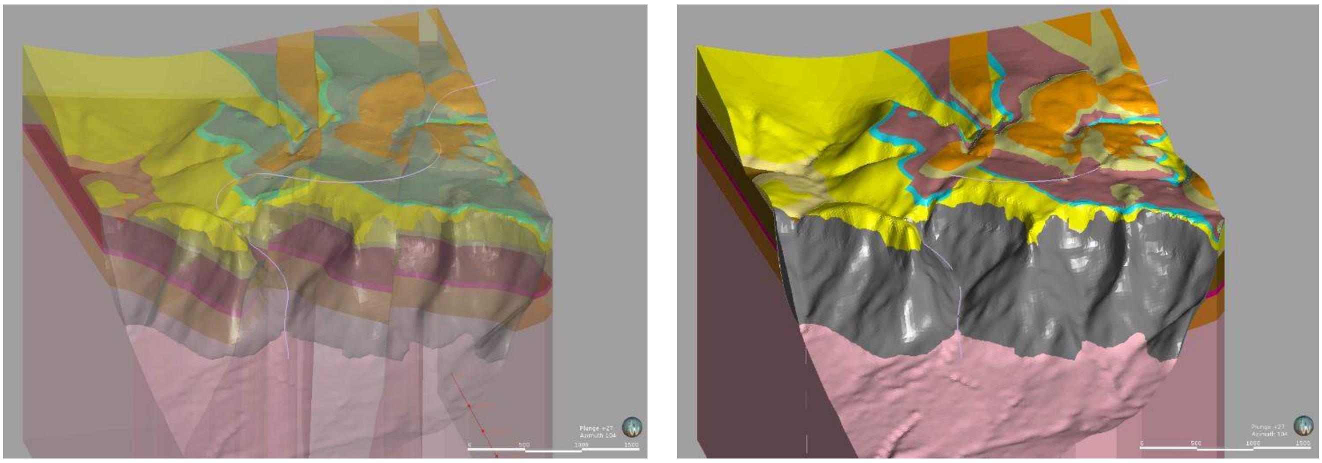
5.3.5 While borehole data is available across the study area at this preliminary stage, only selected deeper boreholes are displayed in the model. As indicated in this report the data is of mixed quality and it is sometimes difficult to interpret with confidence the formation strata boundaries. Where there is potential uncertainty Mott MacDonald Sweco Joint Venture has disregarded the potential boundary information provided by these boreholes.

Primary data used in production of 3D geological model

5.3.6 The following primary sources of geological information has been used in the model development:

- BGS 1:50,000 digital geological mapping (British Geological Survey, 2018)
- 1:10,560 published BGS geological mapping, especially for regional and specific dips (British Geological Survey, 1966) and (British Geological Survey, 1965)
- Environment Agency DTM data (Environment Agency, 2015)
- Formation thickness information from published BGS data (see Section 4.2, with the exception of (Sumbler, et al., 2000)

Figure 5.1: Isometric views from Leapfrog Geo (Leapfrog Works) model of the project site



Comparison with BGS Cirencester cross sections

5.3.7 The BGS's report on the geology and hydrogeology of the Jurassic limestones in the Stroud – Cirencester area for the Environment Agency (Maurice, et al., 2008), has geological cross sections running roughly east-west through the study area adjacent to the project specific Leapfrog model. Although the sections use a similar data set to the Leapfrog model, the BGS cross sections have increased reliance on some of the BGS boreholes which Mott MacDonald Sweco Joint Venture viewed with uncertainty. There are significant differences shown with respect to the inferred thickness of the Bridport Sand Formation.

5.4 Geological strata

Topsoil

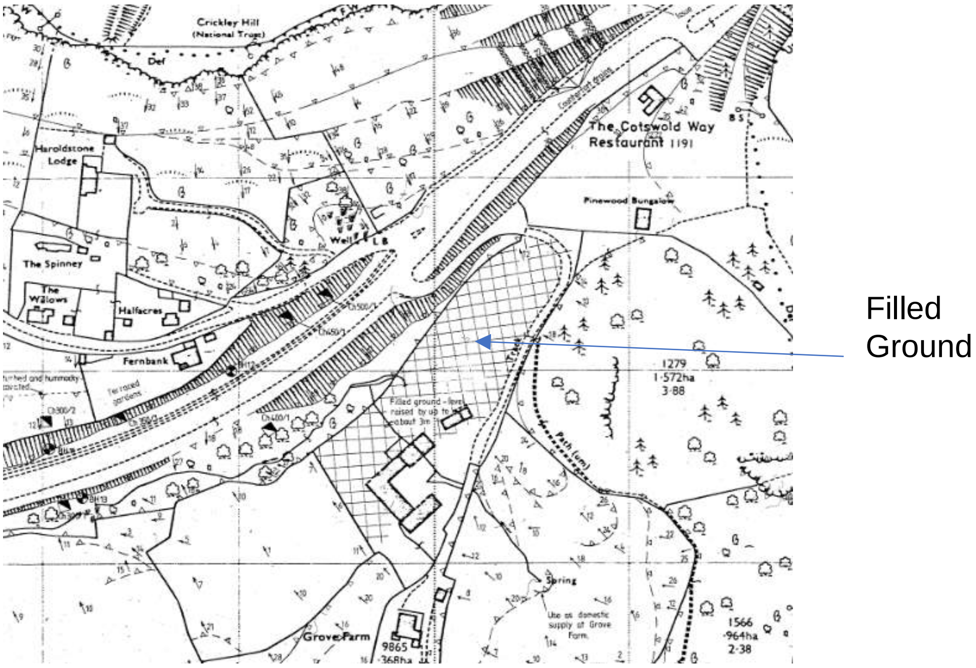
5.4.1 Topsoil is generally expected and was encountered as a thin veneer in investigation across the site given the greenfield conditions in some of the site areas.

Made ground

5.4.2 Made ground was encountered in ground investigations associated with the existing A417 alignment. There is no data regarding its presence on the eastern side of the proposed scheme however should it be encountered it is unlikely to be of significant thickness and extents given the site's history.

5.4.3 The main areas of made ground which are likely to be encountered are associated with the construction of the existing highway especially in the shallow embankment between Nettleton and Barrow Wake and in the area between Air Balloon and the base of Crickley Hill where widening has been accommodated on embankment. In addition, the earlier geomorphological studies (Edward J Wilson & Associates, 1988, HA GDMS Ref 12609) indicate the presence of 'filled ground' at Grove Farm part way up Crickley Hill as indicated below.

Figure 5.2: Extract geomorphological plan showing filled ground about Grove Farm



Source: (Edward J Wilson & Associates, 1988, HA GDMS Ref 12609)

5.4.4 Historically there has been quarrying within the area of Option 12, and smaller quarries have been infilled. It is not known what material has been used to backfill these areas. The Birdlip Quarry, at the south end of the route corridor has been partially infilled and quantities of fly-tipped material are known to be present.

5.4.5 Made ground is inherently of varied composition.

Alluvium

5.4.6 Alluvium is expected to be encountered on the western region of the proposed scheme, especially in Crickley Hill, according to the factual data. It has been described as being present in the base of the valley running up and adjacent to the A417 from the area of Grove Farm south of the existing A417 as it descends the escarpment. According to the strongly asymmetric profile of the valley, this deposit is likely to be of varying thickness and localised.

5.4.7 The factual data indicates, that where encountered, it is typically described as mainly soft to stiff slightly fine sandy clays, overlying film silty clay with a typically thickness of less than 1m to approximately 5m.

5.4.8 Table 5.5 gives details about its geotechnical properties derived from past ground investigations.

Table 5.5: Alluvium – summary of factual data

	Natural moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Undrained shear strength from hand vane (kPa)
Number of tests	10	10	10	10	23
Range	18 - 41	39 - 57	17 - 31	15 - 29	60 - 200
Average	31	45	24	21	95
Standard deviation	6.3	6.8	4.4	4.2	34.9

5.4.9 The limited data is consistent with a normally consolidated medium compressibility cohesive material. The presence of localised high compressibility alluvial deposits should not be discounted.

Landslide / colluvium

5.4.10 Colluvial deposits were encountered extensively within the ground investigation carried out across and up Crickley Hill within the slopes below the escarpment. The material is recorded to comprise of a random mixture of the underlying lithologies of the study area. Towards the upper slope of the scarp the colluvium is mainly described as granular, coarse gravels and sands or cobble rubble formed from the underlying Inferior Oolite Limestones while lower down the slope the colluvium is mostly cohesive, dominated by clay and silt most likely to have been derived from the underlying Lias Group materials.

5.4.11 Colluvial deposits were also encountered in some of the investigation holes on the dip slope in the valley around Stockwell Farm.

5.4.12 The geomorphological walkover survey conducted by WSP (WSP, 2002, HA GDMS Ref 16772), identified possible rotational failures immediately beneath the escarpment with a projected vertical displacement in the order of 20 to 30m. A report prepared in 1988 by E.J. Wilson described a number of shallower shear surfaces within this area which may be evidence of the presence of active slip surfaces. It is assumed that further investigation will find similar features throughout this region.

5.4.13 The slopes between Air Balloon Roundabout and Brockworth Bypass along Crickley Hill are considered to be no better than marginally stable (Hutchinson, 1991) and, therefore, will have a significant influence over the design of the proposed scheme involving modification to the existing earthworks on Crickley Hill. It is estimated that the maximum thickness of the colluvium will be in the order of 20 to 30m.

5.4.14 In 1989, 5 inclinometers were installed in the colluvial material as part of the ground investigation to investigate the stability of the landslide material about the A417, but they proved to be inconclusive, partly because they were not installed deep enough to detect major slip surfaces (Hutchinson, 1991). Direct movement of the slumped material is absent. Hence, further data is required to define a soil model than can be used in the detail design. Defining this material properly is expected to be one of the key issues for the development of the proposed scheme.

5.4.15 There are 10 available boreholes with standard penetration test (SPT) carried out at various depths. The majority of the boreholes with SPTs were undertaken on the lower slopes of the landslide. A single N value for the upper slopes (of 333) exists.

5.4.16 Table 5.6 summarises some of the factual data available, including the mean and the standard deviation of each sample.

Table 5.6: Colluvium – summary of factual data

	Natural moisture content (%)	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**SPT *N* value (lower slopes)**
Number of tests	19	19	19	19	9
Range	13 - 39	30 - 117	18 - 40	15 - 77	11 – 40
Average	27	58	24	34	18
Standard deviation	6.5	19.7	5.5	16.5	9.9

Great Oolite Group

Great Oolite Group, undifferentiated limestone dominant formations

5.4.17 According to the factual data, the Great Oolite Group is mainly composed of Limestones, which is in line with the BGS Bedrock map, with interbedded layers of Mudstones, Siltstones or Sandstones, with varying degrees of weathering. On the eastern side (Stratton to Nettleton region), the upper surface was encountered as clays and sands.

5.4.18 It has not been possible to subdivide the Great Oolite Group further based on the available historical ground investigation data although some separation between ‘undifferentiated’ Great Oolite deposits and the Fuller’s Earth Formation has been possible.

5.4.19 Table 5.7 summarises the factual data available, including the mean and the standard deviation for the stratum.

Table 5.7: Great Oolite Group undifferentiated deposits – summary of factual data

	Natural moisture content (%)	**Liquid Limit (%)**	**Plastic Limit (%)**	**Plasticity Index (%)**	**Undrained shear strength from hand vane (kPa)**	**SPT *N* value**
Number of tests	44	45	45	45	39	87
Range	13 - 47	35 - 98	14 - 33	7 - 68.	62 - 225	8 – 750*
Average	24	54	22	32	140	155
Standard deviation	7.9	13.5	3.9	11.7	39.5	140

*The large range of *N* values includes those undertaken in rock. Results should be used with caution and consideration given to limiting use of values to those in weathered material only.

Fuller’s Earth

5.4.20 The Fuller’s Earth Formation is a mixture of sandstones, limestones, siltstones and clays, with a degree of weathering that is highly variable across the site extents. Within the project area it is thought to be present within the graben between Shab Hill and Shab Hill Barn faults (see 4.2.13), near to Air Balloon Roundabout (impacting both options), and to the south of the site near Nettleton Bottom (option 12 only). In both areas, it is associated with areas of mapped landslide deposits thought to comprise shallow landslides. These landslides are thought to have marginal stability.

5.4.21 The Fuller’s Earth clay member is generally a montmorillonite rich clay. As such it may be considered as being a smectite capable of substantial shrinking and swelling depending on the moisture content. It is anticipated that this clay will be of intermediate plasticity with low shear strengths.

Table 5.8 summarises the factual data available for the Fuller’s Earth, including the mean and the standard deviation of each.

Table 5.8: Fuller's Earth Formation – Summary of factual data

	Natural moisture content (%)	Liquid Limit (%)	Plastic Limit (%)	Plastic Index (%)	Undrained shear strength from hand vane (kPa)	SPT *N* value
Number of tests	29	37	37	37	24	38
Range	13 - 41	39 - 70	17 - 27	16 - 45	46 - 200	16 – 600*
Average	21	52	23	30	107	114
Standard deviation	8.3	7.9	3.3	6.8	38.0	124

*The large range of *N* values includes those undertaken in rock. Results should be used with caution and consideration given to limiting use of values to those in weathered material only.

Inferior Oolite

5.4.22 The Inferior Oolite Group comprises a varied succession of ooidal, peloidal, sandy and ferruginous and shelly limestones, with sub-ordinate sandstone, lime-mudstone and mudstone beds. Subdivisions of the Inferior Oolite Group present within the proposed scheme extents are as follows (in lithostratigraphic order):

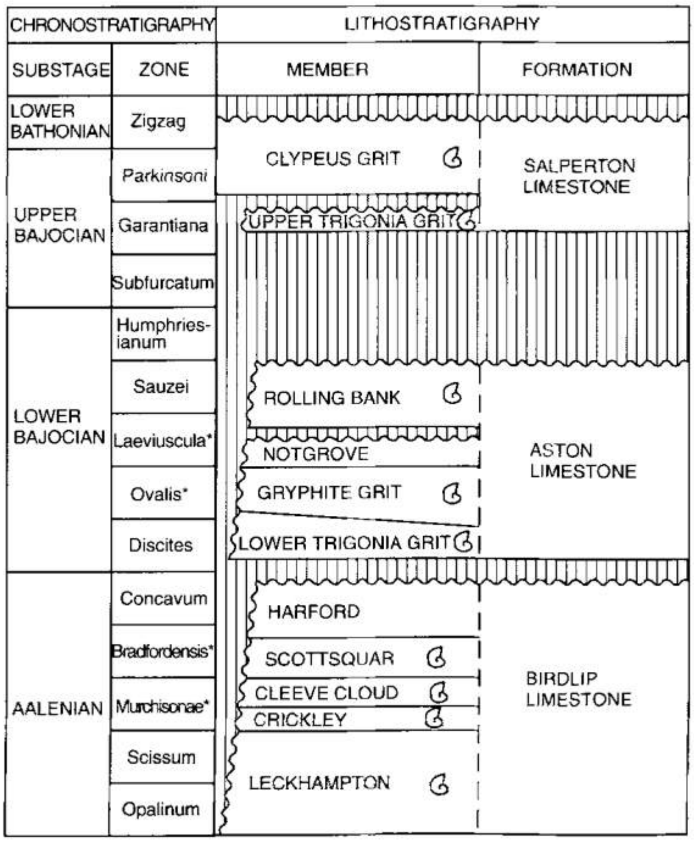
- Salperton Limestone Formation
- Aston Limestone Formation
- Birdlip Limestone Formation

5.4.23 The Inferior Oolite Group's lithostratigraphical framework has been reclassified several times in recent history and where possible former nomenclature is referred to for clarity when referring to historical ground investigation, geomorphology reports and published literature.

5.4.24 Each of them comprises notable Members as indicated in Figure 5.3, Figure 5.4 and further in the sub-sections below.

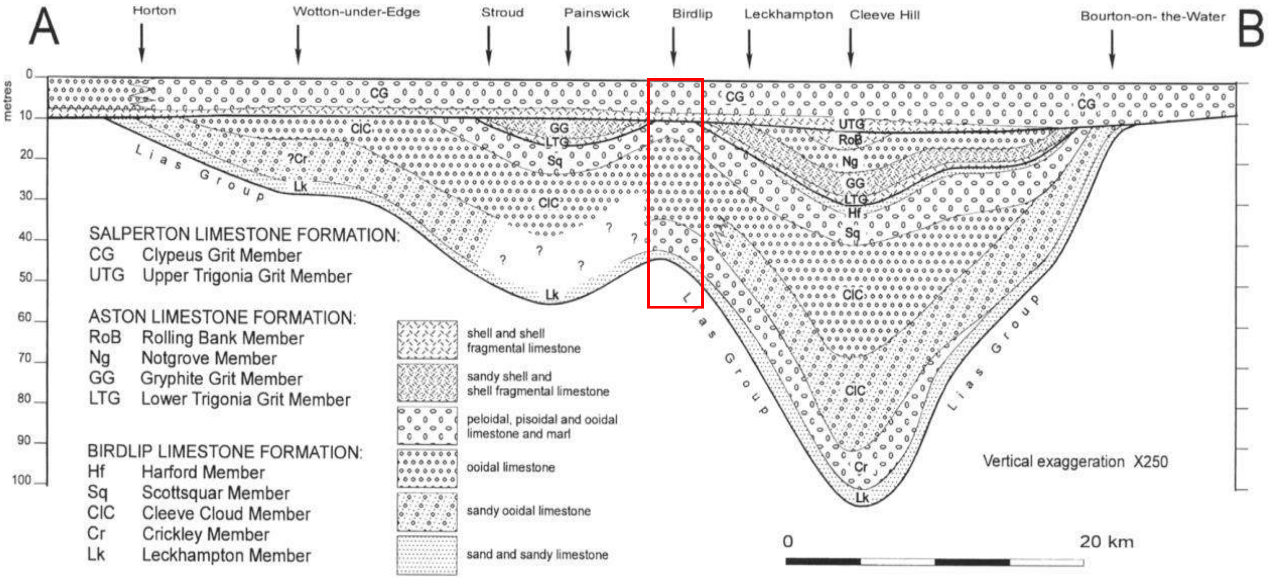
5.4.25 The Middle Inferior Oolite is relatively thin within the project area and locally absent e.g. Knap House Quarry on the escarpment below Birdlip village.

Figure 5.3: Lithostratigraphic divisions of the Interior Oolite Group and their relationship to the standard chronostratigraphic framework



Source: (Barron, et al., 1997)

Figure 5.4: Sketch showing the generalised lithologies of the Inferior Oolite



Source: (Barron, et al., 1997) *Not to scale*

5.4.26 It is expected that not all members of each Formation are likely to be encountered below the site, notwithstanding all Formation members are further discussed below for completeness, see Figure 5.4 (site marked in the figure – Birdlip).

5.4.27 This geological unit is limited to the top of the escarpment and is therefore likely to have a significant effect over the design as will be discussed in subsequent sections.

5.4.28 The Inferior Oolite Limestone is described as weak to strong so it can be expected to have a uniaxial compressive strength with significant variation and potentially locally the material may be stronger.

5.4.29 These formations are expected to be subjected to substantial fissuring, gully features and cambering, which locally can tend to be a considerable size as encountered during construction of the Birdlip Bypass (Gloucestershire County Council, 1989).

5.4.30 5no. SPT *N* values (Geotechnical Engineering Ltd., 2009), located on Crickley Hill within the Inferior Limestone are available ranging from 41-600.

Salperton Limestone Formation (formerly Stroud Formation or Upper Ragstones)

5.4.31 The Salperton Limestone is the upper-most formation in the Inferior Oolite and has readily distinguishable members:

- Clypeus Grit Member (formerly Clypeus Grit and White Oolite or Rubbly Beds and Upper Coral Bed)
  - A pale grey to brown rubbly, fine to coarse-grained ooidal, peloidal and finely shell-detrital packstone to grainstone.
- Upper Trigonia Grit Member (formerly Trigonia Grit)
  - A very shelly and coarsely shell-detrital ooidal grainstone and packstone. The member is very component, poorly bedded and varies between 0m and 3m in the north Cotswolds, which is the region that the project area is located in.

5.4.32 As evident, from currently available BGS information, the Salperton Limestone Formation is present intermittently around Birdlip village, Parson’s Pitch and between Emma’s Grove and Barrow Wake. No data specific to the Salperton Limestone Formation was available from the field tests within the historical ground investigation data or samples tested from pertinent boreholes.

Aston Limestone Formation (formerly Middle Inferior Oolite or Hartley Hill Formation)

5.4.33 The Aston Limestone comprises of grey and brown variously shelly, ooidal, sandy, shell-detrital and bioturbated limestones; rubbly in parts, with sandy and shell-detrital marl beds. Component members include

- Notgrove Member (locally absent, formerly Notgrove Freestone)

    - Pale brown-grey, cross-bedded, medium to coarse grained, poorly sorted peloidal and ooidal grainstone
- Gryphite Grit Member (formerly Gryphaea Bed or Windrush Member)
    - Grey and brown, shelly, variably sandy, peloid (often ferruginous) grainstones, poackstones and wackestones. Thin mudstone, marl and sand beds are common. Abundant Gryphaea and belemnites in the upper part
- Lower Trigonia Grit Member (name unchanged)
    - Predominantly composed of grey, speckled, orange-brown, very shelly, moderate sandy, peloid wackestones, packstone and grainstones with thin marl and sand beds which are occasionally shelly. Ferruginous peloids are often present and commonly pebbly at its base
- Rolling Bank Member (locally absent, formerly Cleeve Hill Beds)
    - Competent, sandy and shelly limestones, very shelly limestones and grey-yellow, shelly, sandy, oidial limestones with ferruginous peloids

5.4.34 Aston Limestone Formation covers little geographic area in comparison with the rest of the Inferior Oolite Group formations present in the proposed scheme area. It is expected to be found as a thin band. No data specific to the Aston Limestone Formation was available from the field tests in the pertinent boreholes within the historical ground investigation data and the samples tested from these boreholes.

Birdlip Limestone Formation (formerly Lower Inferior Oolite)

5.4.35 The Birdlip Limestone Formation forms the basal unit of the mid-Jurassic Inferior Oolite Group. It is predominantly composed of pale coloured ooidal limestones of varying types with occasional interbeds of sandstone and shale. In order of youngest to oldest the Formation comprises the following members:

- Harford Member (locally absent, formerly Harford Sands)
    - Highly variable laterally comprising of grey-brown, fine to medium grained sandstone at the base overlain by grey and brown, silty mudstones with variable sandy or shelly beds
- Scottsquar Member (formerly Oolite Marl and Upper Freestone)
    - Pale grey and brown, medium to coarse-grained poorly sorted peloidal and ooidal packstone and grainstone interbedded with shelly limestone dominated by calcitic mud
- Cleeve Cloud Member (formerly Lower Freestone)
    - Un-fossiliferous and cross bedded, massive ooidal Limestone
- Crickley Member (formerly Pea Grit)
    - Pisoidal and shelly peloidal Limestone
- Leckhampton Member (formerly Scissum Beds)

- A grey highly bioturbated, finely shell-detrital, medium-grained, peloidal and ooidal sandy, muddy limestone. Thin marl beds are common. Ooids and peloids are commonly ferruginous

5.4.36 This unit is the dominant limestone unit of the Inferior Oolite Group present on this site.

5.4.37 It is known to have undergone slope failure resulting from cambering and subsequent landslides. These slipped deposits have become intermixed with Lias Group deposits between Air Balloon Roundabout and the western extremity of the site, and around Barrow Wake.

5.4.38 The following photos and figures provide more information about the various members of the Birdlip Limestone Formation at outcrops within old quarries around Cleeve Common, Crickley Hill and Leckhampton Hill.

Photo 5.1: Salterley Quarry car park (Leckhampton Hill) - Good exposure of the Cleeve Cloud Member and a small section of the Crickley Member at the base

Photo 5.2: Dead Man's Quarry (Leckhampton Hill) – A sequence from the Mid Cleeve Cloud Member through to the Lower Trigonia Grit Member

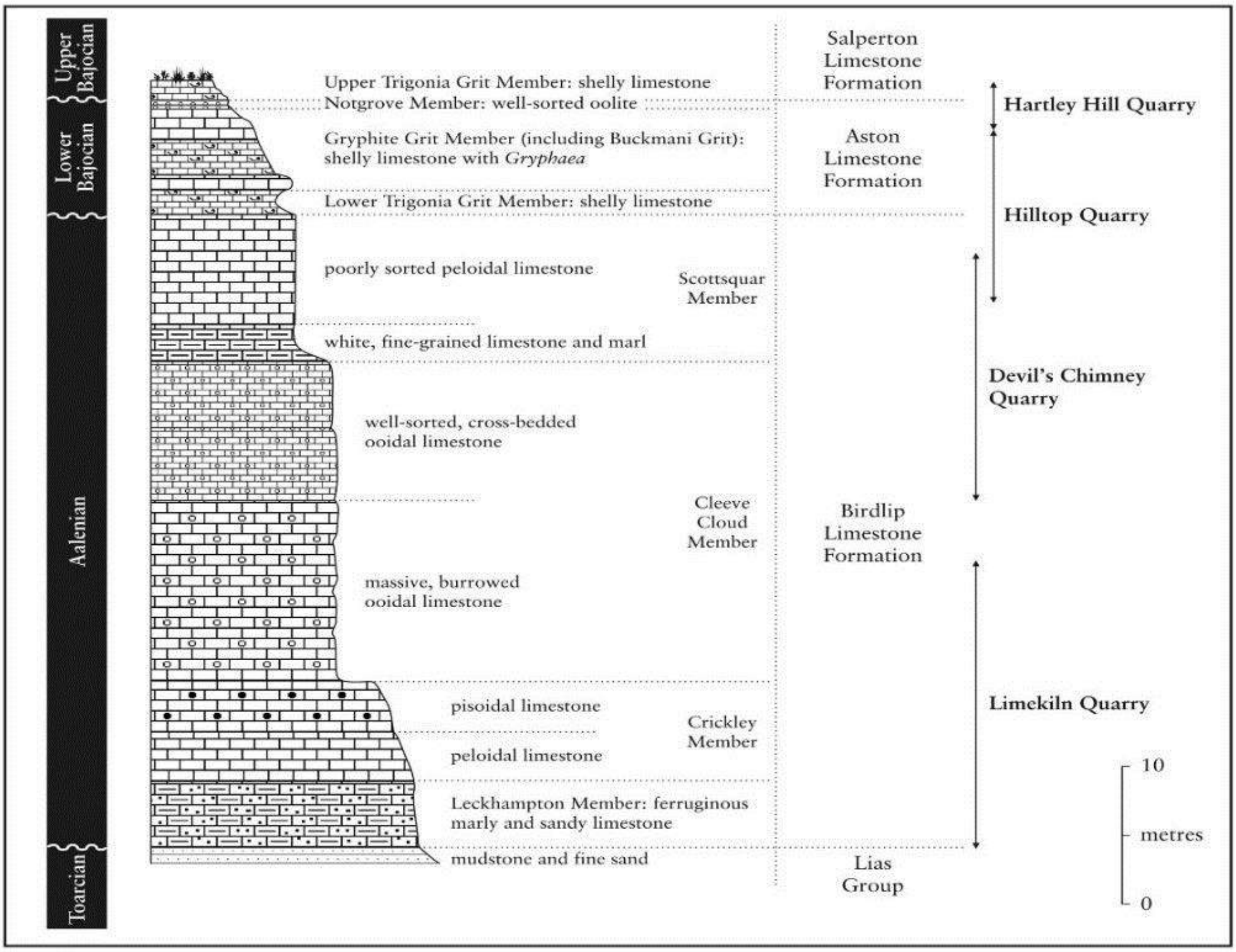
Photo 5.3: The upper part of Dead Man's Quarry (Leckhampton Hill) contains the base of the Lower Trigonia Grit Member of the Aston Limestone Formation

Photo 5.4: Crickley Hill – Crickley Member overlain by the Cleeve Cloud Member.

Photo 5.5: Lower Limekilns Quarry (Leckhampton Hill) – showing succession of the Leckhampton Member (base) overlain by Crickley Member.

5.4.39 At Leckhampton Hill the relative thicknesses of members have been detailed by some authors which provide an indication of the member thickness which could be present at Birdlip, see Figure 5.5.

Figure 5.5: Recorded lithostratigraphy at Leckhampton Hill



Lias Group

5.4.40 The Lias Group was laid down during the Lower Jurassic between 200 and 175Ma. In the project area the Lias Group deposits comprise predominantly grey, well bedded, marine calcareous mudstone and silty mudstones; thin tabular or nodular beds of argillaceous limestone in the lower part, thicker units of siltstone and sandstone in the upper part and ironstone towards the middle.

5.4.41 In the study area, mudstones deposits of variable weathering grades are found west of Air Balloon Roundabout beneath the landslide deposits. They are exposed at ground level close to the western boundaries of the area considered for the proposed scheme, however, a detailed identification of the formations belonging to the Lias Group has not been undertaken due to the lack of data. In addition, no data specific to Lias Group Formations was available from the field tests.

5.4.42 The formations belonging to the Lias Group can be generally sub-divided as following in order of youngest to oldest:

- Bridport Sand Formation
- Whitby Mudstone Formation
- Marlstone Rock Formation
- Dyrham Formation
- Charmouth Mudstone Formation

5.4.43 The BGS publication on the Lias Group (Hobbs, P.R.N. et al., 2012) includes data held in the National Geotechnical database and provides a general indication of parameters for each formation. These are not included here, given the parameters are not region specific,

5.4.44 The Lias Group is generally weathered close to ground level affecting the moisture content, plasticity, strength, sulphate and pH of the formations to varying degrees. Detailed studies have been undertaken on the Whitby Mudstone in the East Midlands area by (Chandler, 1972) and the Charmouth Mudstone Formation in Gloucestershire by (Coulthard, J.M; Bell, F G., 1993). These studies led to adoption of a weathering classification (Anon, 1995) and BS5930 (1999) which was further simplified to a classification system based on colour, by the BGS Lias Group report (Hobbs, P.R.N. et al., 2012). The ‘classes’ used are listed below:

- Disturbed – Predominantly light grey, soliflucted or landslide material (where there is sufficient data, landslide, reworked and soliflucted materials are shown separately in deep profile plots)
- Class D – Brown with light grey streaks
- Class C – Brown
- Class B – Grey with brown on fissure surfaces or mottled brown and grey
- Class A – Grey or dark grey (unweathered)

Bridport Sand Formation

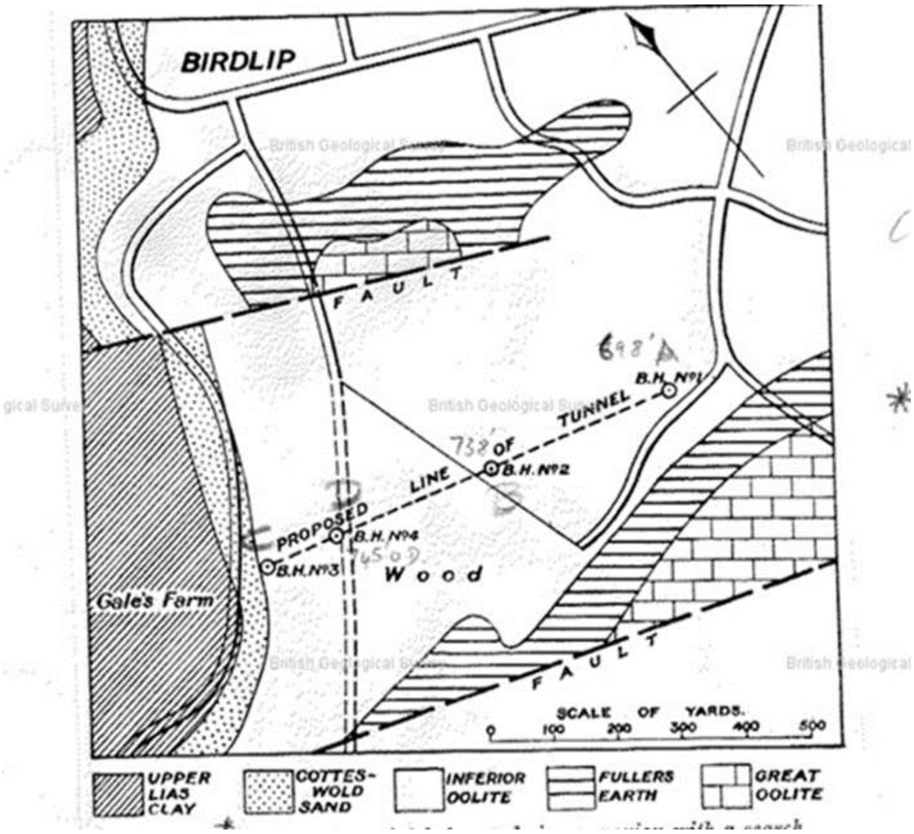
5.4.45 Formerly known as the Cotteswolds Sand, the Bridport Sand Formation forms the top of the Upper Lias comprising grey, weathering yellow or brown, micaceous silt, very fine-grained sand and fine-grained sand, locally with harder calcite-cemented sandstone beds and lenses, variably sandy clay / mudstone at base

5.4.46 Fossils within the formation are scarce. The friable nature of much of the formation leads to rapid weathering and degradation of exposures consequently it is rather poorly documented, although some exposures are described in (Cave, 1977) and the formation as a whole was discussed by (Davies, 1969).

5.4.47 Whilst there are no recognised exposures of the upper part of the Bridport Sand Formation local to the site, there are exposures south on the Cotswold escarpment at the lower quarry at Wotton Hill, Coaley Wood and Harefield Hill. These show the range of lateral variation within the Cotswold Cephalopod Bed Member a unique facies development of the Bridport Sand Formation composed of a sandy and argillaceous, ironshot commonly fossiliferous limestone typically found at the upper boundary.

5.4.48 Locally at Birdlip the Bridport Sand Formation (Cotteswold Sand) has been mapped in early geological maps (see Figure 5.6) however this is not shown on the BGS published 1:50,000 nor 1:10,560 mapping.

Figure 5.6: Historical geology model from the proposed Birdlip water tunnel investigation documentation



Whitby Mudstone Formation

5.4.49 The Whitby Mudstone Formation is not exposed in the study area since it has been covered by the colluvium (which is at least in part derived from it). However, the Whitby Mudstone Formation may be present at depths which may influence the design and construction of the different proposals. It is understood that the Whitby Mudstone Formation may comprise an upper unit which is largely clay and a lower unit which includes sandy clays and siltstones.

Effects of weathering

5.4.50 The effects of weathering on the Whitby Mudstone Formation has been studied in the East Midlands (Chandler, 1972, Coulthard, J.M; Bell, F G., 1993), where the increase in moisture content with increased weathering was marked. Typical descriptions for each weathering class, as defined in the BGS report of the Lias Group (Hobbs, P.R.N. et al., 2012) is presented in Table 5.9.

Table 5.9: Whitby Mudstone typical descriptions for each weathering class

Weathering class	**Typical description (Hobbs, P.R.N. et al., 2012)**
A	Very stiff, very closely to closely vertically fissured, thinly (<2mm) laminated to very thinly bedded dark grey calcareous micaceous silty CLAY with abundant shell fragments. Rare selenite
B	Firm to very stiff, dark grey, very closely fissured, silty CLAY. Occasional shell fragments. Rare calcareous siltstone nodule (<40mm). A trace of oxidation along fissure surfaces. Minor shears
C	Stiff, fissured light brown micaceous silty CLAY. Occasionally brown on fissure surfaces with occasional selenite crystals becoming locally abundant on fissures. Lithorelicts 40%
D	Soft, extremely closely fissured, light grey mottled brown CLAY with occasional rootlets. Fissures are columnar. Minor shear surface <2mm thick, showed undulating striated surface of soft grey clay
E/reworked	Soft to firm, light grey and orange-brown, silty CLAY with occasional rootlets and rare ironstone fragments towards top. Gleyed and highly oxidised. Minor shear surfaces at 0.70m. Major shear surface at 0.90m. Occasional lenses of orange-brown silty sand.

Marlstone Rock Formation

5.4.51 The Marlstone Rock Formation is a massive or flaggy sandy, shell-fragmental and ooidal ferruginous limestone interbedded with ferruginous calcareous sandstone, and generally sub-ordinate ferruginous mudstone beds. Locally any of these lithologies may become ooidal ironstone due to an increase in iron content. The Marlstone Rock potentially underlies the mid slope where the thalweg of the stream adjacent to the A417 on Crickley Hill locally flattens.

Dyrham Formation

5.4.52 This unit is believed to have a maximum thickness of 60m within the study area. It typically comprises pale to dark grey and greenish grey weak silty and sandy mudstone interbedded with silt or very find grain sand with persistent beds of ferruginous ooidal limestone and sandstone (see Figure 5.7). Large cementstone nodules are also sometimes encountered.

5.4.53 The Dyrham Formation tends to form moderately steep slopes capped by the Marlstone Rock Formation. This unit may be expected to be found at the western end of the proposed scheme immediately before the junction with the Brockworth Bypass.

Figure 5.7: Sketch of the Dyrham formation lithography

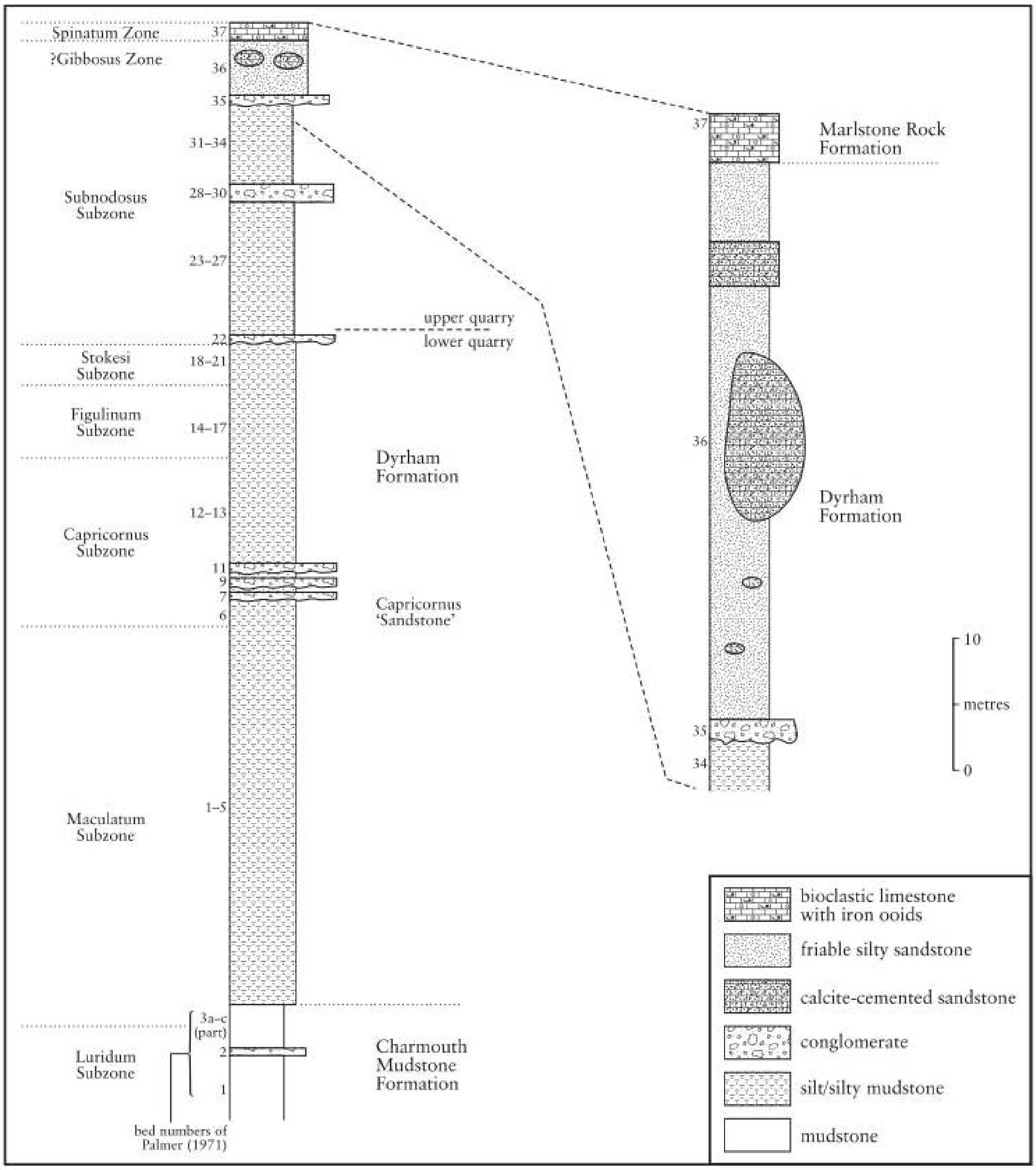


Photo 5.6: Upper and lower quarry of the Robin's Wood Hill Quarry – Lithography of the Dyrham and Marlstone Rock Formation (basal unit of laminated grey shales and silts inferred)

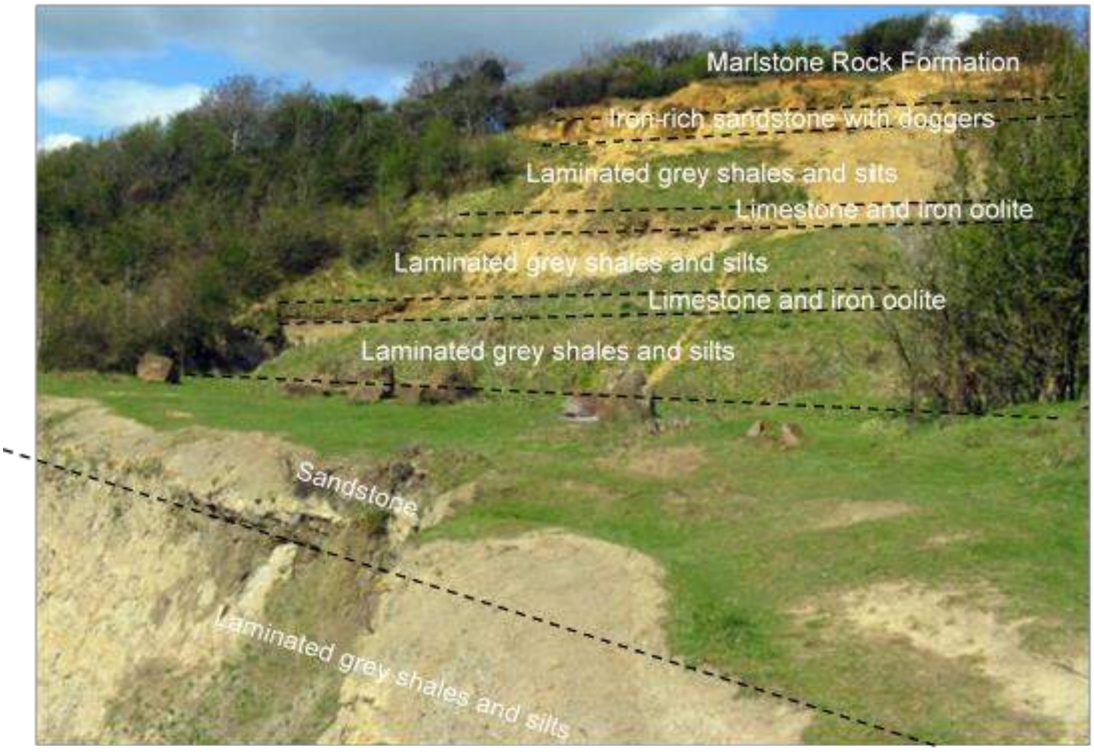


Photo 5.7 Marlstone Rock Formation underlain by the Dyrham Formation, Robins Wood Hill quarry

5.4.54 The upper and lower quarry of the Robin's Wood Hill Quarry (383600, 214900), approximately 8km west of the project scheme area, can be seen in Photo 5.6. The upper part of the quarry shows the top of the escarpment capped with Marlstone Rock underlain by the interbedded laminated grey shales and silts and bands of limestone and iron oolite of the Dyrham Formation. The lower quarry exposes sandstone units interbedded with laminated grey shales and silts also of the Dyrham Formation.

5.4.55 At the top of the exposure (Photo 5.7) the Marlstone Rock Formation can be seen as a sandy limestone and iron oolite. Immediately below this the upper most bed of the Dyrham Rock Formation of iron-rich sandstone with doggers (large nodules of sands cemented together with calcite) can be seen.

Effects of weathering

5.4.56 The effects of weathering on the Dyrham Formation as indicated by the BGS Lias Group report comprise:

- An increase in moisture content and decrease in bulk density with increased weathering
- An increase in Liquid limit, plasticity index and liquidity index in the most weathered classes (class D and 'reworked')
- A decrease in cohesion with weathering class; most of the low values (<100 kPa) are in the top 10m.

Table 5.10: Dyrham Formation typical descriptions for each weathering class

Weathering class	Typical description (Hobbs, P.R.N. et al., 2012)
A	Weak to moderately weak, very thinly bedded to thinly laminated, grey or dark grey, micaceous MUDSTONE or SILTSTONE
B	Weak to moderately weak locally strong widely fissured very thinly bedded grey micaceous clayey SILTSTONE. Occasional red-brown staining on discontinuity surfaces. Fissures are sub-vertical. Slightly weathered
C	Firm to stiff, extremely closely to closely fissured, very thinly irregularly bedded, multi-coloured yellow-brown, light grey orange-brown, and red-brown, micaceous sandy SILT with a trace of clay. Locally calcareous. Fissures are sub-vertical
D	Firm very closely fissured thinly interbedded (100mm) dark brown mottled brown-grey clayey SILT and silty CLAY. Weakly gleyed. Fissures are sub-vertical
E/reworked	Firm to stiff brown-orange mottled clayey SILT with a trace of sand

Charmouth Mudstone Formation

5.4.57 The Charmouth Mudstone comprises mudstone of various types ranging from dark grey laminated mudstone to paler grey blocky mudstone. It contains sporadic, nodular limestone beds and nodule bands and at many levels particular in the upper part, phosphatic or sideritic (ironstone) nodules and silty and finely sandy beds. Basically, the unit is a sequence of overconsolidated, randomly fissured, jointed clays and mudstones. The shear strength of the clays within this sequence is not likely to be substantially greater than that exhibited by the cohesive colluvium. The mudstone portions of the sequence may be more appropriately considered as behaving as a very weak rock.

5.4.58 The Charmouth Mudstone Formation rocks are found at the surface over much of the Vale of Gloucester and as such it is anticipated that they may be encountered at the western end of the study area.

5.4.59 In the Gloucester area, the formation can reach a thickness of almost 300m, although more typically it is around 250m thick. The upper part (50 to 70m) is generally slightly more silty than the lower beds and these higher beds may contain occasional sideritic (ironstone) nodules and beds. The Charmouth Mudstone in the vicinity of the project scheme area has not been sub-divided into members as downhole geophysical logs show a remarkably uniform internal stratigraphy throughout the region.

Effects of weathering

5.4.60 A previous study of the Charmouth Mudstone Formation in Gloucestershire (Coulthard, J.M; Bell, F G., 1993) found an increase in moisture content with increased weathering and a general increase in liquid limit with increased weathering.

5.4.61 Moisture content, liquid limit, plasticity index and liquidity index tend to increase with increasing weathering; the highest values being found in the top 5 - 10m. In the case of moisture content, there is generally an increase with weathering class. For the liquid limit and plastic index, a wide scatter of data for all weathering classes can be observed, while there is a slight trend of increasing plasticity index with weathering classes from A to D.

5.4.62 Bulk density and cohesion both appear to be controlled more by depth than by weathering, but there is a trend of lower values with increasing weathering near surface (within the topmost 5m).

5.4.63 Weathering appears to control total sulphate. Most class A values have values below that required for aqueous extraction sulphate testing, whereas about half of class B samples and most class C samples would require further testing. The reworked samples generally had low total sulphate content, presumably because the sulphate had already been removed by groundwater. Aqueous soluble sulphate does not appear to be controlled by weathering; however, there are few data for the more highly weathered materials. pH values do not appear to be controlled by depth or degree of weathering. The variation in sulphate and pH may be partly explained by oxidation of samples during storage.

5.4.64 There is a trend of decreasing effective cohesion with increased weathering; however, there is no clear trend for the effective shearing angle.

5.5 Groundwater

5.5.1 There is generally very limited groundwater information across the site, although some limited groundwater monitoring data is available from the 1989 A417

Factual report Stratton to Birdlip (Foundations & Exploration Services, 1988, HA GDMS Ref 12600), and the 1990 A417 Stratton to Birdlip Exploratory Associates investigation (Exploration Associates, 1990, HA GDMS Ref 12601). The results of groundwater monitoring are presented in Table 5.11.

5.5.2 As part of any detailed ground investigation of the area it will be important to examine the groundwater and where possible to monitor and model its flows and levels to assist in design. At this stage it is possible to make the following comments:

- There are no substantial bodies of standing water throughout the area, although, there are a significant number of springs in the project area.
- The Inferior and Great Oolite Group of rocks, are classified as Principal aquifers and are highly permeable, with the permeability being governed to a considerable extent by the fracture and fissure geometry.
- The lower permeability Fuller’s Earth Formation acts as an aquiclude between the Great Oolite to Inferior Oolite, although where it thins or fractures and fissures are present localised leakage may occur.
- The springs issuing from the lower slopes of the escarpment reflect the permeability of the overlying limestone since the underlying Lias Group is likely to act as an aquitard.
- The stream running to the south of the A417 as it descends the escarpment issues from just above Grove Farm and although it has a markedly seasonal flow it is considered highly likely that it originates within the limestone of the escarpment.
- The groundwater conditions are quite complicated by the variable nature of the colluvium and it is believed that, in some cases, the springs issuing within this material have originated at a higher level and subsequently entered sinks before re-emerging at a lower level.
- The groundwater has been monitored in the area around Grove Farm. Seasonal variation had been anticipated but the results tend to suggest that this is not the case. However, groundwater levels vary from 4 m bgl to 7.2 m bgl in this location.
- A number of wet areas were noted during a walkover survey (WSP, 2002, HA GDMS Ref 16772). In particular, the area of Nettleton and in the Crickley Hill cutting above Cold Slad.
- Bushley Muzzard is a SSSI which is believed to be fed by groundwater from limestone of the Great Oolite aquifer .

Table 5.11: Groundwater monitoring

GI	Exploratory Hole	Response Zone (m bgl)		Strata	Groundwater depth (range) (m bgl)	No. of monitoring rounds
		Top	Base			
1989 Birdlip	BH1A 1989	1	17.5	Clay and limestone bands	13.07 to 14.12	3
	BH2 1989	1	10.5	Clay, sand and silt over siltstone	1.02 to 4.45	5
	BH4A 1989	11.4	12.5	Siltstone	6.81 to 7.24	4
1990 Stratton to Birdlip	BH302A	7	8	Siltstone	Dry	4
	BH306	12	13	Siltstone	8.75 to 9.15	3
	BH308	*	12	-	8.6 to 8.96	4
	BH316	3	7.25	Clay	7.07 to 7.23	4
	BH318	5.5	6.3	Sand	6.02	4
	BH321	3	3.9	Mudstone	3.79 to 3.92	4
	BH324	*	12.1	-	12.05 to 12.08	4
	BH326	11	12	Mudstone	Dry	4

*Top of response zone not recorded

6 Preliminary engineering assessment

6.1.1 A preliminary engineering assessment of the challenges associated with the anticipated ground conditions and civil engineering works required to enable the proposed scheme is presented below. This assessment primarily considers the design and construction phase but, where appropriate, considers the longer-term operational phase, including any maintenance implications.

6.1.2 The following sub-sections provide an overview of the construction challenges associated with different parts of the proposed scheme as well as overarching geotechnical engineering issues. Section 6.2 below should be read in combination with the longitudinal section drawings presented in chapter 8 and Design Drawings presented in appendix A, to aid in an understanding of the challenges and associated risks.

6.2 Construction challenges

6.2.1 It is recognised that the study area is very complex in terms of the geological, hydrogeological and geotechnical issues, particularly on the steeper western slope of the Cotswold Escarpment up Crickley Hill. The following sub-sections provide an overview of the potential construction challenges throughout the study area for the alignment of Options 12 and 30 moving from west to east across the route alignments.

Brockworth Bypass to Air Balloon Roundabout

6.2.2 From Brockworth Bypass to Air Balloon Roundabout there is no significant variation in horizontal alignment between Options 12 and 30. The main difference between the options is the vertical alignment, which varies by several metres and incorporates vertical separation of the carriageways. Therefore, at this preliminary stage engineering considerations of both options are similar and pertain to the challenge of undertaking major earthwork improvements on historic landslides.

6.2.3 The slopes between Air Balloon Roundabout and Brockworth Bypass are considered to be no better than marginally stable (Hutchinson, 1991) having been subject to previous slope failures and remedial measures. The soils encountered in previous investigations have proven to be variable and design proposals need to take these soil types into consideration, particularly with reference to the construction of cutting into existing slopes or the placing of embankments to carry the new highway.

6.2.4 The groundwater regime on the southern side of the valley is considered to be extremely complex, with a number of randomly located springs arising on the generally shallow slopes. These springs and the groundwater regime will have significant bearing on the long-term stability of the slopes.

Air Balloon Roundabout to Barrow Wake

Deep cutting – Option 12

6.2.5 The alignment of Option 12 is such that a deep cutting will be required. The depth of the cutting would be in the order of 10 to 20m which will cut across many different geologies including the Fuller's Earth Formation, Great Oolite Group Formation, the Inferior Oolite Limestones and potentially the Bridport Sand Formation (see Figure 8.3).

6.2.6 A proportion of the southern end of the cutting is within the Fuller's Earth Formation which, due to lower shear strength than other parts of the Oolite rocks may require shallower cutting slopes than elsewhere or stabilisation measures . The depth of superficial deposits could also impact the upper slope design and ultimately the extent and geometry of the cutting.

6.2.7 If the cutting extends down to the Bridport Sand Formation care will be needed with design and detailing at the Inferior Oolite / Bridport Sand interface, to avoid deterioration of the Bridport Sand from groundwater drainage and lateral stress relief. This will be exacerbated if the Bridport Sand is absent and the Inferior Oolite is underlain by the Whitby Mudstone.

6.2.8 Excavation within the limestone rock forming the cutting is likely to be by hard dig or by easy ripping or even by blasting based upon the approach adopted by (Pettifer, G.S., Fookes, P.G., 1994) considering the rock mass properties and intact rock strength.

6.2.9 Material derived from this exercise is likely to be acceptable for re-use elsewhere in the proposed scheme as granular fill depending on processing of spoil.

Deep cutting – Option 30

6.2.10 As with Option 12 this section of alignment includes a deep cutting in variable geologies up to 20 to 25m deep though is largely expected to be within the Inferior Oolite Limestones (see Figure 8.4). See previous Section for further details, especially regarding excavation of the Inferior Oolite Limestones and design and detailing at the Inferior Oolite / Bridport Sand interface.

Barrow Wake to Stockwell Farm

Embankment – Option 12

6.2.11 The alignment of Option 12 comes out of the deep cutting up onto embankment which is expected to be constructed on bedrock geology of the Inferior Oolite limestones.

6.2.12 Granular or cohesive material derived from elsewhere within the proposed scheme may be suitable for the construction of the embankment, but the slope angles will be dependent upon material available at the time of construction. The cohesive materials derived from site are unlikely to allow slope angles of greater than 1V:3H to be constructed whereas the granular material, essentially derived from the underlying limestone, may allow safe slope angles of 1V:2/2.5H or greater to be constructed.

6.2.13 Drainage requirements will depend to a large extent on the material used. A drainage blanket may be required where cohesive material is used for embankment construction. A separator layer membrane is likely to be required between the drainage blanket and any cohesive material. Such a drainage blanket is likely to be required to be in hydraulic continuity with the toe drain of the embankment.

6.2.14 Organic rich soils below the embankment should be stripped from the area before construction of the embankment commences. A method specification is recommended for compaction of all materials used in the construction of the embankment and plant as detailed in Table 6/4 of Volume 1 of the Specification of Highways Works 1 used accordingly.

Shallow cutting and bridge (junction) – Option 30

6.2.15 The alignment of Option 30 suggests that both a shallow cutting and an embankment will be required to cover the route from Shab Hill to the area near Barrow Wake and Stockwell Farm. The shallow cutting would be in the order of 1 to 2m deep, being largely in the Fuller's Earth Formation and the Great Oolite group.

6.2.16 A split-level interchange with the A417 bridging over the side roads has been proposed, with the A417 alignment above the existing ground level. The reason is that the difference in terms of levels between the existing ground level and the alignment of Option 30 reaches 20m. The bridge structure could be founded on shallow or piled foundations, dependent on the depth and condition of bedrock and location in relation to landslide material mapped as present in Coldwell Bottom valley. The Shab Hill Barn Fault and the Shab Hill Fault are present in the nearby area (of the order of 50 to 200m distance, respectively) and the natural state of the limestones will require careful consideration.

Connection with existing A417 – Option 30

6.2.17 For the connection between the proposed route and the existing A417 a link road is proposed. This link will require a cutting within the Inferior Oolite Limestones, the Fuller's Earth Formation and the Great Oolite Group Formation. It is likely that the connection road will intersect with the Shab Hill Barn Fault.

6.2.18 Potentially 2 bridges, one underbridge and one overbridge, would be required to maintain the existing routes in the area. The bridge foundations would depend on the ground conditions local to the bridges identified by project specific ground investigation and at this stage are equally likely to be piled or shallow foundations.

Stockwell Farm to Nettleton Bottom

Cutting – Option 12

6.2.19 From Nettleton Bottom to Stockwell Farm, and around Parson's Pitch, the alignment of Option 12 will be within a cutting. The cutting would be in the order of 10 to 15m deep, being largely in Great Oolite Group Formation and the Fuller's Earth Formation, additionally, Inferior Oolite Limestones would likely be encountered. The depth of the cutting will fluctuate considerably, varying from 10m deep to a very shallow cutting (in the order of 1m deep) in the region where the Limestones are expected to be encountered. Slope angles may be variable to suit geological conditions, or if the project footprint is to be kept to a minimum the use of slope stabilisation measures could be investigated.

Embankment – Option 30

6.2.20 The embankment within this region will be mainly constructed over the Great Oolite Group Formation, having an expected height ranging from 1m to about 10m. The Great Oolite Group is expected to be a competent rock, although, due to the proximity of the embankment with a mapped landslide area, consideration will need to be given to preventing destabilising existing slopes.

Nettleton Bottom

Embankment – Option 12

6.2.21 Alignment of Option 12 suggests that an embankment will be required at Nettleton Bottom, the height of this embankment would be in the order of 5m. The embankment will be mainly constructed over the area of potentially slumped and unstable ground developed in the Fuller’s Earth Clay. It is anticipated that this might need to either be removed or stabilised.

Embankment – Option 30

6.2.22 The embankment at Nettleton Bottom will be mainly constructed over the Fuller's Earth Formation, having an expected height of approximately 10 m. The embankment will be mainly constructed over the area of potentially slumped and unstable ground developed in the Fuller’s Earth Clay. It is anticipated that this might need to either be removed or stabilised.

Nettleton Bottom to Cowley Roundabout

Cutting – Option 12

6.2.23 A cutting will be required for Option 12 in the vicinity of the disused Birdlip Quarry. The cutting would be in the order of 10m deep and would be largely in the Great Oolite Group Formation and the Fuller's Earth Formation.

Cutting and embankment – Option 30

6.2.24 Option 30 suggests that both a cutting and an embankment will be required to cover the same route. The cutting would be in the order of 8m deep, being largely in the Great Oolite group, while the height of the embankment would be in the order of 10m, being mainly supported on the Fuller's Earth Formation.

6.3 Groundwater

6.3.1 The groundwater regime across the project area is complex. There is insufficient groundwater data to obtain a robust understanding of the groundwater regime, to assess how the groundwater will affect construction, and also how the construction could impact the quality and quantity of water in the Principal and Secondary aquifers.

6.3.2 Both proposed scheme options include deep cuttings and will pass through areas of extensive historic slope instability. The deep cuttings through the Principal aquifers have the potential to permanently change the groundwater regime. They could permanently divert groundwater flow that would otherwise supply springs and other water features such as groundwater abstractions, particularly where they fully intersect the saturated aquifer.

6.3.3 In areas of historic landslide the groundwater regime will have a significant impact on the stability of the slopes, therefore the design of the proposed works could include measures to permanently lower groundwater pressures to maintain stable slopes. This could also have the effect of drying up springs, although it is anticipated that water would be returned to the same catchment further down-stream .

6.3.4 The groundwater related risks were compiled after meeting the Environment Agency to discuss potential surface routes. The Environment Agency’s concerns centre around the lack of knowledge of the groundwater conditions in this region and the potential detrimental effect on both groundwater supply available for abstraction (quantity and quality) and groundwater supply to springs and other surface water bodies. It is apparent that the lack of data prevents these risks from being understood and mitigated and intrusive ground investigation and monitoring is the only method that could alleviate these risks.

6.3.5 A hydrogeological study and ground investigation are required to determine the groundwater conditions and the potential impact, of both the groundwater conditions on the proposed scheme design and the proposed scheme on groundwater receptors. The investigation should consider the groundwater flow through the aquifers, the influence of fractures, fissures and fault areas. Artesian water has also been identified previously on the lower slopes of the escarpment and this will need to be assessed further. The Environment Agency has stated that monitoring for a period of the order of 2 years is required to gain an appreciation of the variability of groundwater conditions and therefore an understanding of proposed scheme construction on the groundwater environment.

6.4 Instability / landslides – colluvium / mass movement deposits

6.4.1 The presence of landslides along the proposed scheme is extensive and complex. Landslide deposits are present across the whole of the escarpment face and also within valleys on the dip slope. The nature and extent of the landslides will significantly impact the design and construction of earthworks and structure foundations.

6.4.2 The series of landslides on the face of the Cotswold Escarpment, from Brockworth Bypass up Crickley Hill approaching the Air Balloon Roundabout are extensive and also postulated to be tens of metres deep. Historical ground investigation has not provided sufficient information to confidently identify the form or extent of landslide movement. In broadly general terms, the colluvium towards the top of Crickley Hill has been demonstrated as being more granular in composition, while that on the lower slopes has been identified to be mostly cohesive. It is however highly variable and as an example can contain soft to stiff clay with layers of gravel, cobbles and boulders. Cone penetration testing has successfully been undertaken within the more cohesive part of the landslide, but with limited calibration to traditional boreholes. Ground investigation to supplement the existing information will be required to better identify the form of slope movement, to assess slope stability and develop outline design. Geomorphological mapping has been carried out at various times for the earlier scheme studies. Verification mapping and, where required, an update will be required for outline design.

6.4.3 It is considered that the landslides on the Cotswold Escarpment are likely to be marginally stable in their current condition and therefore design and construction works that involve excavation, but also filling, are anticipated to prove especially difficult with the potential for reactivation of significant landslides. The proposed scheme design could include engineering works outside the immediate highway corridor and may include permanent ground water drainage measures.

6.4.4 Existing landslides within the valleys on the escarpment dip slope, such as at Coldwell Bottom and Nettleton Bottom relate to isolated weaker horizons within the oolite deposits, such as Fuller’s Earth. While these landslides are relatively constrained by topography and geology, they will have a significant influence on earthworks embankment and cutting design and require assessment for outline design.

6.5 Gulls / cambering

6.5.1 The presence of cavities, gulls, gull caves and fissures associated with faulting, cambering and dissolution are known to be present towards the top of the escarpment. This could promote slope failure or localised ground collapse.

6.5.2 Reviewed data and field observations suggest that cambering, fissures and gulls could be present, especially throughout the Limestones of the Inferior Oolite formations. These will be most prevalent close to the escarpment ridge, but it is considered likely that these could be present on the dip slope for a distance of 100m from escarpment edge although no mapped evidence has been obtained at the time of writing the PSSR.

6.5.3 It is expected that these features may occur in a range of sizes from up to a couple of metres depth to in excess of 20m depth. During the construction of the Birdlip Bypass a number of fissures were encountered in the proximity of the Barrow Wake Bridge. They were recorded as 300mm wide at the top with a depth of 17m. These were treated by infilling from ground level with lean mix concrete and a mix of rock fill, with concrete used at road formation level through Barrow Wake cutting.

6.5.4 Both proposed scheme options include the construction of significant cuttings through the escarpment edge, which is the area with the greatest risk of encountering these features (cavities, gulls, caves and fissures). These represent a risk to cutting instability, both during construction and in the long-term, and could therefore influence design. The greatest stability risk is where gulls or fissures are parallel to the proposed cutting. Given that the proposed road cutting is curved, starting perpendicular and then becoming parallel to the escarpment edge, the scenario of a gull or fissure being parallel to the road cutting is possible. It is therefore recommended that methods of investigating these features are assessed with the aim of reducing construction risk and providing certainty for land boundary requirements. Investigation methods could include geophysical techniques.

6.6 Faulting

6.6.1 There are 3 mapped faults which run across the site. Uncertainty as to the alignment and position of the Shab Hill Barn Fault has been raised by a previous report and there could also be unmapped faults. The nature and extents of faults are not known with certainty. Faults could significantly impact deep cuttings. Moreover, they have a significant impact over the hydrogeological behaviour.

6.7 Mining instability

6.7.1 Data provided by Ove Arup and Partners through the HA GDMS indicates that there is the potential for mining instability in Birdlip associated with rock commodity (limestone). The same area is shown to have a ‘Likely’ hazard from underground mining by the BGS Non-coal mining areas of Great Britain database. This is related to underground mining or suspected mining within or close to the area, with the commodity indicated to be Limestone – Bath Stone.

6.7.2 Based on the above information, this area north of Birdlip could be undermined and cavities may be present beneath this area.

6.8 Re-use of materials

6.8.1 Options 12 and 30 both include a variety of embankment and cutting earthworks along the full length of the proposed scheme. Suitability of excavated material for re-use can be considered in detail once the route options are refined, however the following high-level comments provide an overview for the proposed scheme:

- It is anticipated that a significant proportion of the Great Oolite Group and Inferior Oolite Group limestones will be suitable for re-use as a general granular fill and possibly a selected granular fill
- Caution is required when considering re-use of Fuller's Earth Clay given the material plasticity and potential effect from past instability
- Colluvium, by its nature, is highly variable and general guidance cannot be provided

6.9 Archaeology

6.9.1 Options 12 and 30 pass through areas of significant archaeological interest (AMEY, 2014). For construction activities within these areas an archaeology watching brief will be required, especially in the case of Option 12 that seems to be the most limiting of the 2 options given the known archaeology in the vicinity of the route.

6.9.2 An archaeological specialist should be consulted prior to ground investigation and proposed scheme construction.

6.10 Traffic management

6.10.1 It is recognised that the provision of additional carriageway width will entail significant works adjacent to a live highway. This, in turn may cause substantial disruption to traffic throughout the construction phase. Of particular concern is the section between Brockworth Bypass and Air Balloon Roundabout given the potential impact on traffic on this steep section of road. With regard to carrying out ground investigation on Crickley Hill, current indication is that day-time traffic management is unlikely to be acceptable.

6.11 Subgrade

6.11.1 The topography of the site is such that much of the route will be constructed on embankment and cutting. Within the cuttings much of the road subgrade is anticipated to be within limestone members and therefore California Bearing Ratio (CBR) values are expected to be reasonably high at, say, 10%, however where Fuller's Earth clay or other high plasticity clay is encountered low CBR values of around 2% may be expected. Road subgrade on embankment is wholly dependent on the fill material used. On the assumption that granular fill derived from the Great Oolite and Inferior Oolite limestone cuttings is used for embankment construction reasonably high CBR values can be anticipated.

6.12 Structural foundations

6.12.1 Where the route climbs Crickley Hill, between Brockworth Bypass and Air Balloon Roundabout, it is likely that a series of structures will be needed for widening of the road corridor over the stream valley, such as retaining walls and culverts, and construction of a green bridge. The design of many of these structures is likely to be onerous, being on colluvium with marginal existing stability, but may entail significant embedded retaining walls and piled foundations. Further comment can only be provided once the design of the proposed scheme is more advanced.

6.12.2 On the dip slope of the escarpment there will be a need for a number of structures to accommodate side roads, road junctions, bridging over valleys and culverts. It is believed that the structures will generally be constructed on the Inferior Oolite Limestones, where traditional spread foundations may generally be appropriate.

6.12.3 At this stage, it could be assumed that all the buried structural concrete within the Limestones would be Class 1. For structures founded within the colluvium, which may also extend down into the Lias Group, consideration should be given to the risk of an aggressive environment for concrete.

6.13 Contaminated land

6.13.1 There is no evidence within the historical ground investigation information to suggest that there is any contaminated ground within the confines of either options 12 and 30, according to Section 78R of the Environmental Protection Act 1990. Potential areas of Made Ground have been identified and these will need investigating as part of a project specific ground investigation.

6.14 Man-made obstacles

6.14.1 The alignment of Options 12 and 30 will have an impact on existing man-made features.

- **Air Balloon Public House**: The current proposals would need to demolish this building and purchase the property.
- **Crickley Hill Cottages**: The proposed alignments will not impact these properties.
- **Emma’s Grove Bronze Age Barrows**: This ancient monument is a constraint to both options. The effects will be considerably reduced in case option 30 is selected. Regardless the designated alignment, an archaeological watching brief will likely be required at all times.
- **Crickley Hill Camp**: While no direct effect is expected with either of the proposals, there is a potential for concerns to be raised by National Trust during proposed scheme development.

- **Barrow Wake – Iron Age burial site**: This may prove to be a constraint, especially for Option 12. An archaeologist must be employed with a watching brief throughout any works, including ground investigation undertaken in the study area. This may also have impact on the alignment of the route.
- **Four Winds – Property at top of cutting near Air Balloon Roundabout**: Possible constraints on alignment in respect of widening the cutting in this area. Access will need to be accommodated in the design.
- **Grove Farm buildings and access**: The alignment could have a negative impact upon this existing farm buildings and operations. Any improvement will need to consider an improved access to Grove Farm in horizontal and vertical alignment.
- **Shab Hill Farm, Birdlip Radio Station and adjacent areas**: There are several structures within this area that will be affected by the new alignment. Depending on which solution is finally implemented the degree of severity would vary for each case.
- **Birdlip Quarry**: Options 30 and 12 will have a negative impact on this feature.

6.15 Geotechnical issues

6.15.1 It can be seen that there are several ‘High Threat’ risks for which the main mitigation measures is to carry out an appropriate and extensive ground investigation. This ground investigation should include piezometer installation, groundwater monitoring and be combined with surface water feature studies to build a robust hydrogeological model. Slope stability must also be assessed carefully, and movement monitoring is recommended. Appropriate in-situ and laboratory tests should be carried out to determine the geotechnical properties of the strata. A geomorphological study is also recommended to expand on previous studies where the conditions affecting the proposed scheme are not well defined. This could include the use of drone surveys and geophysical survey.

6.15.2 The existing geotechnical features or constraints can be summarised as following:

- **Faulting**: The Shab Hill Fault and Shab Hill Barn Fault run approximately perpendicular to the existing carriageway trending in a north-western to south-eastern direction, intersecting both Option 12 and 30 twice inthe area near to Barrow Wake and Shab Hill Farm. Both are indicated as being near vertical features. The Stockwell Fault also intersects both options, in case of Option 12 near to Birdlip and in the case of Option 30 near to the Nettleton Bottom. Faults could significantly impact deep cutting design and construction.
- **Existing landslides**: The risk associated with the mass movement deposits is present over significant lengths of the proposed scheme. Landslides are particularly prevalent in the Crickley Hill area below the inferior Oolite escarpment, to the East of Little Witcombe, and Nettleton Bottom which is

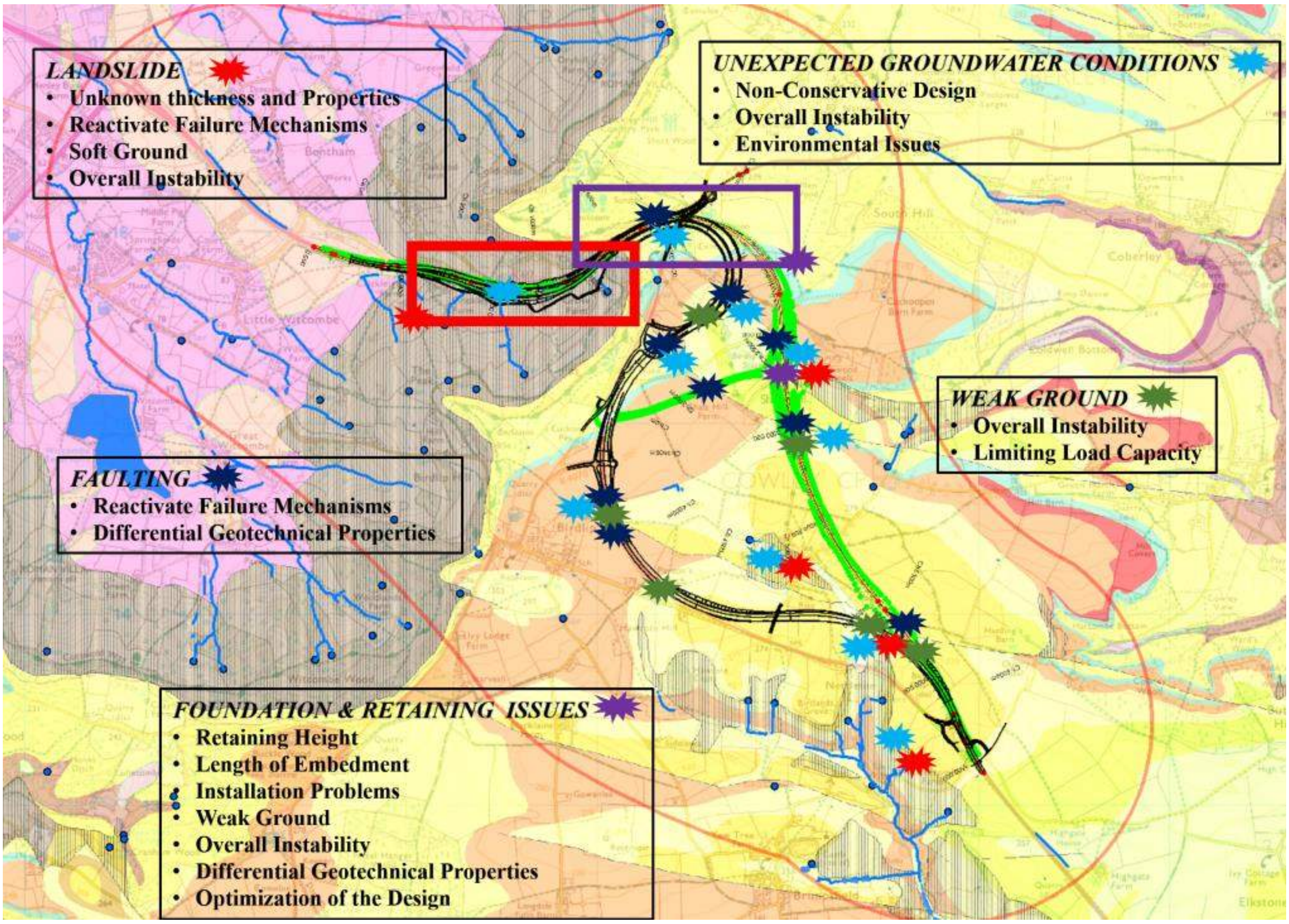
associated with the Fuller’s Earth Formation. These areas will be subjected to modifications as a consequence of the development, therefore, slope stability analysis and ground investigation is required to investigate the ground conditions and material properties of the affected areas. Excavation within existing slips or increase of the current loading on the slips (due to embankments and/or other structures) should be optimised as much as possible.

- **Existing steep slopes**: These are present above A417, between Brockworth Bypass and Air Balloon Roundabout where cutting slopes may be proposed. This geotechnical problem can be addressed by avoiding significant works that would require further cutting / steepening of these slopes or works that are likely to disturb them, such as installation of services.
- **Weak soils**: Special attention to the colluvium / landslide material near the western end of the proposed scheme, the Fuller’s Earth Clay and the Alluvium. All geological units must be investigated thoroughly and the design must be carried out accordingly, in the case of the Fuller’s Earth Formation with particular attention to the properties of the smectite rich clay.
- **Cambering, cavities and gulls**: The presence of cambering has been identified in limestones near Nettleton Bottom and in existing rock cutting at the top of the escarpment. An appropriate ground investigation including a geophysical survey is recommended to identify any daylighting and ground intersection with the proposed scheme.
- **Fractured or fissured rock**: Special attention to the fault zone near Air Balloon Roundabout. This risk should be addressed by investigating the fault zone and design remedial works for any cutting associated with rocks in this area. Additionally, the potential for stress release features associated with existing cuttings should be examined and, if necessary, remedial works for the cutting face designed. Ground investigation is likely to include a geophysical survey.
- **Unknown buried services**: Service plans no older than 6 months need to be obtained.
- **Made Ground obstructions**: Current or historical development of the area may mean that dis-used foundations are buried. These may pose obstructions, hard spots, or variable ground conditions for structural / highway foundations.
- **Variable thickness of superficial deposits**: Variable thickness of superficial deposits is likely to be encountered across the proposed scheme. The change in thickness may result in differential settlements occurring across earthworks and structures. This also includes the abrupt variations of thickness due to the presence of faults.
- **Variable groundwater levels**: Significant variation in groundwater levels should be expected between strata and seasonally.
- **Artesian groundwater**: Artesian and near artesian groundwater has been identified in the Lias clay and Bridport Sand.

- **Groundwater features**: Source protection zones, springs and wells exist within the site area. A hydrogeological study is required to assess groundwater conditions and its influence considered during the design process.
- **Aggressive ground conditions affecting concrete**: The chemical constituents of the ground may affect the integrity of the concrete if it is not suitably designed to resist attack. Ground investigation to assess the chemical condition of the soils is recommended to enable suitably resistant concrete to be used in the ground. Special attention to pile foundations in Lias Group.
- **Soil contamination**: In areas of Made Ground the potential impact on human health should be considered. Soils, groundwater and leachate derived from contaminated ground conditions will need to be assessed.
- **Constraints to ground investigation:** There are external constraints to ground investigation, including topography, land access, highways, ecology, archaeological interest and tree preservation order.

6.15.3 Figure 6.1 summarises the engineering issues that can be expected along the proposed scheme. When the risks are localised, a coloured symbol has been used, whereas when they apply over a length of the route a square of the same colour is employed to remark the region.

Figure 6.1: Summary of engineering issues



7 Geotechnical risk register

7.1.1 At PCF Stage 1 the focus in undertaking a risk assessment and preparing a geotechnical risk register has primarily been in the identification of hazards and associated risks. As this project develops it is anticipated that this risk register will be developed throughout geotechnical certification to provide further quantification of risks and details of risk specific mitigation plans. Risk registers are live documents that should be managed, developed, reviewed and updated throughout the project's lifecycle.

7.1.2 The main risks which have previously been introduced in chapter 6 are:

- **Landslide instability**: Marginally stable existing slopes associated with the historic landslide deposits on Crickley Hill – risk of reactivation of existing dormant slip surfaces and low bearing capacity when widening the road carriageways.
- **Groundwater**: The groundwater of the region is not well understood. Depending on the groundwater baseline conditions the proposed works could have a significant negative impact to the quantity and quality of groundwater in the underlying Principal Aquifer.
- **Faulting and gull features**: The location and nature of faults and gulls are not known. Fault zones could have significant impact on the local stability of deep cuttings and the groundwater regime. Further, the presence of gull features and cambering affected materials could impact cutting stability and ground improvement requirements.
- **Extensive superficial deposits / weak rock**: Should extensive superficial deposits or deeply weathered rock be encountered retaining measures or cutting design may be much more significant than anticipated, leading to additional cost or land requirements.
- **Strong massive rock**: The strength and rock mass properties of the materials in which the deep cutting will be excavated are not known. Should massive strong rock be identified then it is likely that blasting will be required to excavate the deep cutting.

7.1.3 The main mitigation measure identified to manage the risks is to undertake an appropriate ground investigation and site investigation including additional geomorphological assessments that will reduce the current uncertainties associated with the proposed scheme design.

7.1.4 The extent of ground investigation proposed to manage the geotechnical risks to the proposed scheme going forward is attached as Annex A.

7.1.5 The geotechnical risk register is presented in Table 7.2. A project specific geotechnical risk scoring system has been developed and presented in Table 7.1.

Table 7.1: Geotechnical risk criteria

							Probability Score				
						Description	Remote	Unlikely	Possible	Likely	Very likely
						Probability (P)	<5%	5-19%	20 – 49%	50 – 74%	>75%
	Description	Time Delay	Cost £	Health and Safety	Environmental	Scale	1	2	3	4	5
Impacts (I)	Very High	>6 months	>£10m	One or more fatalities or major injuries or occupational health conditions resulting in life changing disability.	Significant new or additional permanent adverse environmental effect on the natural or historic environment or a local community. Recurring significant adverse environmental effect or effect on local community requiring remedy or intervention by the Construction Commissioner and/or management by relevant authorities e.g. Local Authority, Environment Agency, Natural England etc. Unanticipated and unmitigated non-compliance with Environmental Minimum Requirements elevated and requiring remedy or intervention from Secretary of State, Parliament or the Courts.	5	5	10	15	20	25
	High	4 to 6 months	>£2.5m - £10m	Single non-life changing injury, occupational health, RIDDOR Reportable Disease / NOID.	Significant new, recurring or additional transient adverse environmental effect or effect on local community requiring remedy or intervention by the Construction Commissioner and/or remedy or intervention by external authorities e.g. Local Planning Authority, Environment Agency, Natural England etc.	4	4	8	12	16	20
	Medium	2 to 4 months	>£1m - £2.5m	RIDDOR reportable injury (>=7 days lost time) or Occupational Health Condition (>=7 days lost time).	Unanticipated adverse transient environmental effect or effect on local community requiring remedy or intervention by Nominated Undertaker and reportable to regulatory authorities.	3	3	6	9	12	15
	Low	1 to 2 months	£100k - £1m	Lost Time Injury (<7 days lost time); or multiple minor injuries; or Occupational Health Condition (<7 days lost time).	Local impact requiring management response, but from which there is natural recovery.	2	2	4	6	8	10
	Very Low	<1 month	<£100k	Injuries requiring first aid treatment or occupational ill-health condition with no lost time.	Minimal environmental impact.	1	1	2	3	4	5

Table 7.2: Geotechnical risk register

Ref no.	Phase	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk			Proposed mitigation action(s)	Mitigated risk			Residual risk owner
					L	I	R		L	I	R	
1	Proposed scheme design	Ground investigation: Access restrictions preclude targeted ground investigation	Uncertainty in soil parameters used in design leading to either unconservative or over conservative design. Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data.	Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.	4	5	20	Undertake appropriate GI plan assessment, including land access, ecology and archaeology. It is important to be realistic about the possible limitations. Contingencies must be planned to fill possible information gaps. Undertake appropriate Traffic Management plan assessment. Undertake appropriate GI plan assessment. It is important to be realistic about the possible limitations. Contingencies must be planned to fill possible information gaps. Assume Worst credible design scenario where appropriate in case there is a lack of data. Additional funds to be considered for securing enough road space to perform the works in the Landslide area.	2	4	8	Highways England
2	Proposed scheme design	Ground investigation: Poor quality data obtained due to inappropriate performance, incorrect installation, exploratory holes in wrong place, insufficient depth, etc.	Uncertainty in soil parameters used in design leading to either unconservative or over conservative design. Over conservative, i.e. onerous, design is proposed to avoid risks derived from the lack of reliable data.	Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.	3	5	15	Undertake appropriate GI monitoring and contract with quality assured GI Contractor.	1	5	5	Highways England
3	Proposed scheme design	Ground investigation: Unknown buried services. Location of utilities not considered in the current supplementary GI proposals - risk of either service or utility strike during GI.	Site personnel injuries.	Health and Safety implications for site personnel. Service strike provoking electrocution, gas explosion, damage to utilities, or other adverse effects. Impact to cost and programme of GI. Increase of costs.	2	5	10	Service plans no older than 6 months old to be obtained for the proposed scheme. GI contractor to implement a safe system of work with site personnel trained and certified in buried service detection to be utilised to scan the ground for buried services prior to breaking ground. Guidance provided in HSG47 to be followed when breaking ground. Ensure latest buried and overhead utility plans are used during design. Use collaborative tools and common data environment to identify clashes with proposed geotechnical works. Most boreholes have had a check done prior to excavation however geophysical methods such as ground penetrating radar (GPR) or electrical resistivity surveying may give a wider picture. Utility plans to be reviewed prior to final schedule 2 issued for tender. All available pre-construction information to be provided in tender for supplementary GI.	1	5	5	Highways England
4	Proposed scheme design	Ground investigation: Encountering localised contaminated materials.	Illness or injury of site personnel or impact on environmental receptors	Health and Safety implications for site personnel. Additional costs and delays to programme whilst contamination is quantified and remedial measures implemented. Remedial works minimises cross contamination of Principal Aquifer.	2	4	8	Pass all appropriate ground investigation information to the design team and appointed GI contractor. Any visual or olfactory evidence of contamination to be recorded and appropriate personnel notified. Remedial works may be required if contaminated materials are encountered. Appropriate Personnel Protective Equipment (PPE) to be worn at all times.	1	4	4	Highways England
5	Proposed scheme design	Environmental constraints: Archaeological constraints including monuments and listed buildings.	Damage to protected historical constructions.	Delay to programme unless identified prior to final route selection.	2	4	8	Consultation with relevant archaeological / trust governing bodies. Proof excavations to occur in selected areas during SI. Record significant places before removal. Risk is delay.	1	3	3	Highways England

Ref no.	Phase	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk			Proposed mitigation action(s)	Mitigated risk			Residual risk owner
					L	I	R		L	I	R	
6	Detailed design	Design constraints: Difficulty in accurately characterising a variable weathering profile, especially in the case of the Inferior Oolite Limestones and the Lias Group Formations.	Uncertainty in soil parameters used in design leading to either unconservative or over conservative design. Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data. Potential slope failure for embankment and cutting.	Increase of construction costs due to a non-optimised design. Uncertainty in likelihood of ground related risks.	4	3	12	Consider impact of deeper weathered layers on design. Site and structure specific ground models to be prepared. Consider that the main problems will be the cutting and the design of the structures foundations. Scope and carry out supplementary GI.	2	3	6	Highways England
7	Detailed design	Design constraints: Inability to develop an appropriate groundwater model from lack of groundwater information. Insufficient time for groundwater monitoring baseline information.	Uncertainty in groundwater and soil behaviour so soil parameters used in design leading to either unconservative or over conservative design. Alteration of the existing hydrogeological conditions not acceptable to Environment Agency. Over conservative, i.e. onerous design is proposed to avoid risks derived from the lack of data. Negative environmental impact. Ecological damage to spring fed environments	Additional costs and delays to scheme with possible review of scheme options. Ecological damage is quantified and preventative or remedial measures implemented. Increase of construction costs due to a non-optimized design. Uncertainty in likelihood of groundwater related risks. Additional costs and delays in the programme in case underestimation of groundwater conditions. In case of negative environmental impact, additional costs due to remedial measures and delay to the programme.	5	5	25	Undertake groundwater monitoring as part of GI, including piezometers and water surface features studies to develop a robust hydrogeological model, which is important as the proposed scheme has quite complex groundwater conditions. Continue to consult with the Environment Agency. Inspections of slopes for seepages to be carried out during investigation. Undertake appropriate design based on groundwater conditions present. Undertake a detailed hydrogeological survey of the site area.	3	5	15	Highways England
8	Detailed design	Design constraints: Uncertainty in fault location, nature and extent, especially in the case of the Shab Hill Barn Fault.	Affects rock cutting design and groundwater assessment. Additional costs and Delay of the programme. Structure foundation capacity is affected.	Poor ground conditions and variable permeability. Faulting affects cutting design and land take requirements. Higher permeability along fault zone may either locally extend or shorten the cone of drawdown. Unexpected change in lithology. Settlement and damage of structures, potentially leading to local or global failure Additional cost required to mitigate if foundations affected.	4	3	12	Undertake GI (inclined boreholes or geophysics) to assess location and condition of rock, especially in area of deep cutting and vicinity of structures. Design to include impact of local features in rock mass	3	3	9	Highways England
9	Construction	Failure of slopes: Historic landslide with soils of variable composition caused by ground movements. Variable groundwater conditions, with seasonal effects. Construction activities, including excavations for earthworks, drainage or structures, instigate failure.	Major slope failure on Crickley Hill or lesser failure in Churn valley.	Slope movements which require assessment and possible remediation. Damage to scheme construction and surrounding area	5	5	25	Undertake appropriate GI including groundwater monitoring to assess slope stability, employing inclinometers, piezometers, water surface features studies, as well as a geomorphological study, potentially using drone surveys and geophysics (LiDAR). Design to include specification and implementation of stabilisation methods where required. Sufficient land take to provide efficient slope design.	2	5	10	Highways England
10	Construction	Failure of existing slopes: Over-steepened rock cutting.	Collapse of limestone and reactivation of existing failure planes.	Slope movements which could impact on the bypass infrastructure.	2	4	8	Undertake appropriate GI, with geomorphological mapping where required, to assess cutting stability. Design to include specification and implementation of stabilisation methods where required.	1	4	4	Highways England
11	Construction	Deformation of the carriageway: Consolidation settlements, in particular beneath large embankments in sensitive soils, soft and compressive soils near surface. In cutting variable subgrade conditions, including geological fault, hard ground / obstructions at shallow depth.	Long-term settlement causing deformation of carriageway. Settlement of buried services and infrastructure, especially at valley bottom.	Deformation of carriageway requiring maintenance action, potentially adjacent to structures.	3	4	12	Undertake appropriate GI, including long term performance and attention to faults and rock fissures. Design to include specification and implementation of stabilisation methods where required and consideration of interface with structures.	1	4	4	Highways England

Ref no.	Phase	Hazard description (the cause of a potentially unfavourable event)	Risk Event (Description of the consequences)	Impact description (description of the impact if the hazard is realised)	Pre-mitigation risk			Proposed mitigation action(s)	Mitigated risk			Residual risk owner
					L	I	R		L	I	R	
12	Construction	Cutting: Design using inappropriate Rock mass properties.	Over estimate how good the Rock mass is. Under conservative assumptions regarding rock behaviour.	Health and safety implications for site personnel and end users. Slope failure or collapse - cause delays, additional costs, remediation likely to be required. More land could be required due to instability of vertical slopes, additional damage to the environment provoking additional remedial methods. Additional cost and delays to programme for redesign.	3	5	15	Undertake topographic survey of site. Undertake appropriate GI to assess slope stability. Design to include slope stability analysis and reinforcement / retaining structures if required.	1	5	5	Highways England
13				Excavatability / rippability of rock - difficult digging conditions not anticipated leading to delays and additional costs. Inappropriate methods used.	3	5	15	Undertake appropriate GI to assess ground conditions in existing cuttings. Design to include assessment of excavatability. Inspect quarry near Nettleton Bottom. Rock quality may still lead to high construction cost, but quantified at outset.	1	5	5	Highways England
14				Material Classification - incorrectly classified could result in material unsuitable for re-use. Could lead to additional costs for imported material.	3	4	12	Undertake GI to assess the geotechnical properties of the strata.	1	4	4	Highways England
15	Construction	Cutting: Weak / weathered rock. Variations in groundwater caused by seasonal effects of perched water resulting from variations in slumped areas.	Slope failure.	Health and Safety implications for site personnel and end users. Reinforcement of Limestone slopes could be required, even requiring additional retaining measures. Delay in programme and additional costs. More land could be required due to instability of vertical slopes, additional damage to the environment provoking additional remedial methods and costs.	3	5	15	Undertake appropriate GI including groundwater monitoring to assess slope stability, employing inclinometers, piezometers, water surface features studies, as well as a geomorphological study. Design appropriate geotechnical solutions for ground conditions present.	1	5	5	Highways England
16	Construction	Cutting: Soft / unsuitable soils at formation level.	Formation level is unsuitable and additional excavating is required.	Delay in programme and additional costs.	2	3	6	Undertake GI and laboratory testing along the structure location. Design appropriate geotechnical solutions for ground conditions present.	1	3	3	Highways England
17	Construction	Structures: Soft / unsuitable soils at foundation level, variable conditions between foundations	Settlement leading to damage of structures. Bearing capacity failure.	Health and Safety implications for site personnel and end users. Damage to infrastructure later on in the design life. Local Failure. Increased cost of proposed scheme. Degradation of carriageway / maintenance issues.	3	3	9	Undertake GI and laboratory testing along the structure location. Design appropriate foundation solutions for ground conditions present.	1	3	3	Highways England
18	Construction	Structures: Sulphate bearing strata.	Aggressive ground conditions for buried concrete.	Damage to concrete and failure of foundations. Increased costs to proposed scheme to repair or replace.	4	3	12	Undertake chemical testing in accordance with BRE-SD1 during GI. Use appropriate concrete design in construction.	1	3	3	Highways England
19	Construction	Drainage: Unidentified perched groundwater	Slope failure due to localised feature, especially in area of historic landslide and colluviium	Health and Safety implications for site personnel and end users. Dewatering required during construction. Increased drainage costs.	2	4	8	Undertake groundwater survey and monitoring as part of GI. Undertake appropriate design based on groundwater conditions present. Undertake a detailed hydrogeological survey of the site area.	1	4	4	Highways England

8 Drawings and photographs

8.1 Selected overview site walkover photographs

8.1.1 Selected annotated site photographs taken during the 2017 site walkover carried out by a Mott MacDonald Sweco Joint Venture representative are presented here below.

Figure 8.1 Crickley Hill upper slope from Barrow Wake

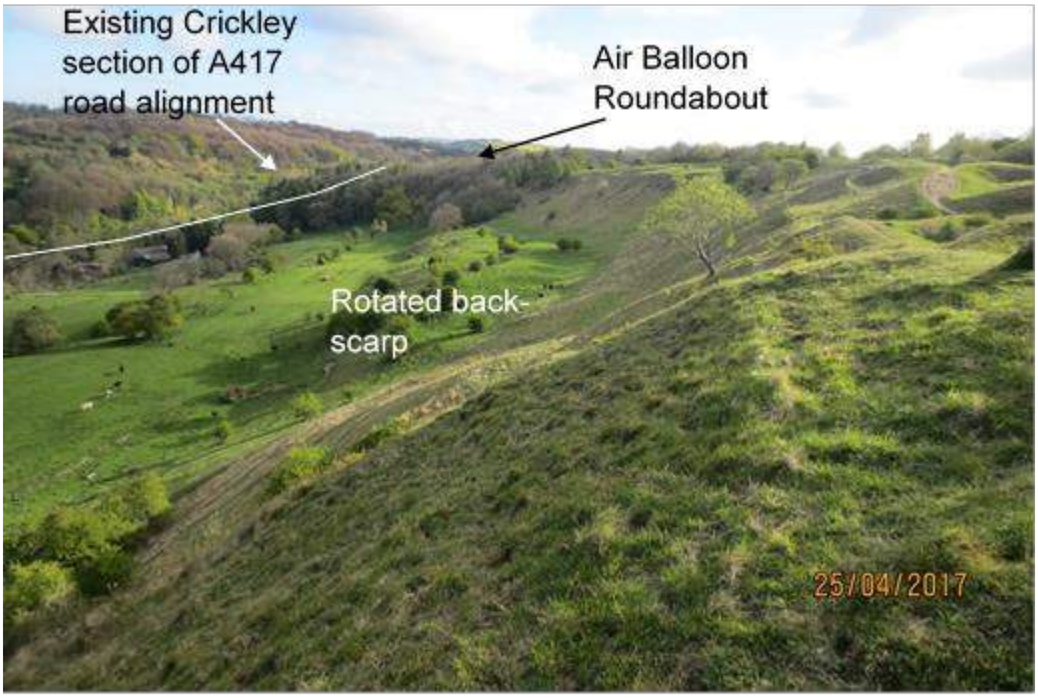
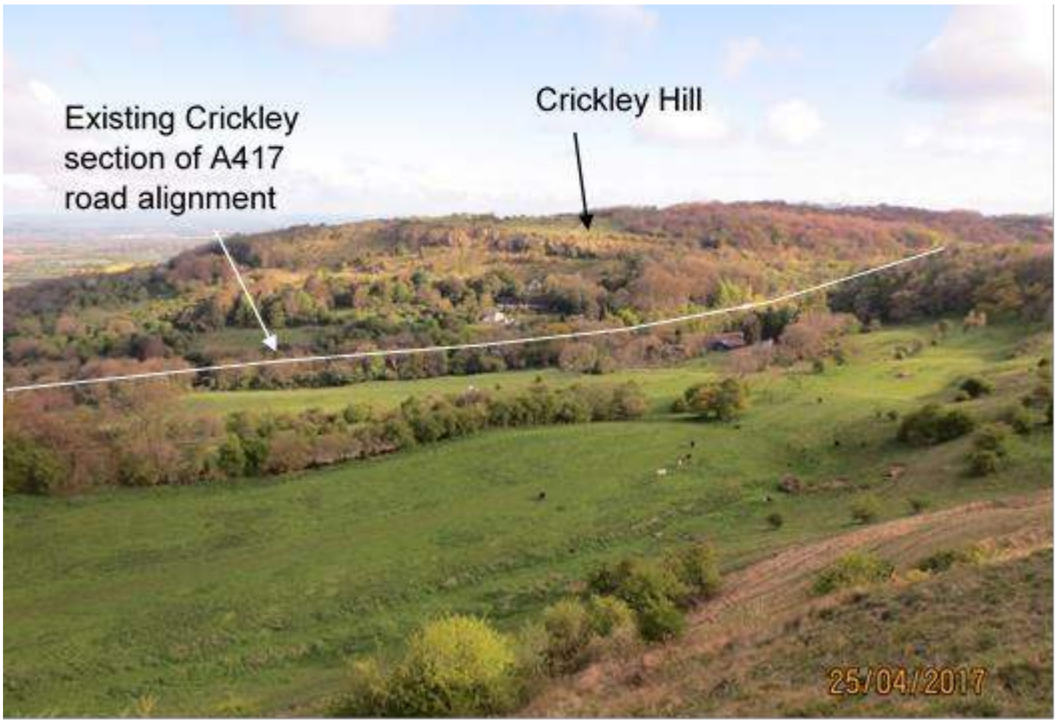


Figure 8.2 Crickley Hill from Barrow Wake



8.2 Drawings and sketches

Drawings

8.2.1 The following drawings have been produced to support this study and are presented in appendix A:

- HE551505-MMSJV-HGT-000-DR-CE-00006 – British Geological Survey mapping 1:50, 000 information
- HE551505-MMSJV-HGT-000-DR-CE-00007 – Site location plan
- HE551505-MMSJV-HGT-000-DR-CE-00004 –Existing ground investigation plan sheet 1 of 2
- HE551505-MMSJV-HGT-000-DR-CE-00004 –Existing ground investigation plan sheet 2 of 2
- HE551505-MMSJV-HGN-000-DR-CH-00001 – Option 12 general arrangement and long section
- HE551505-MMSJV-HGN-000-DR-CH-00004 – Option 30 alternative general arrangement and long section

Sketches

8.2.2 The following conceptual tentative ground model longitudinal sections are provided overleaf:

- Preliminary conceptual model – Option 12

- Preliminary conceptual model – Option 30

8.2.3 As noted in section 5 the interpreted long sections should be considered as tentative only and subject to uncertainty, particularly with respect to the location of faults and thickness of superficial and mass movement deposits.

Figure 8.3: Preliminary conceptual geological longitudinal section – Option 12

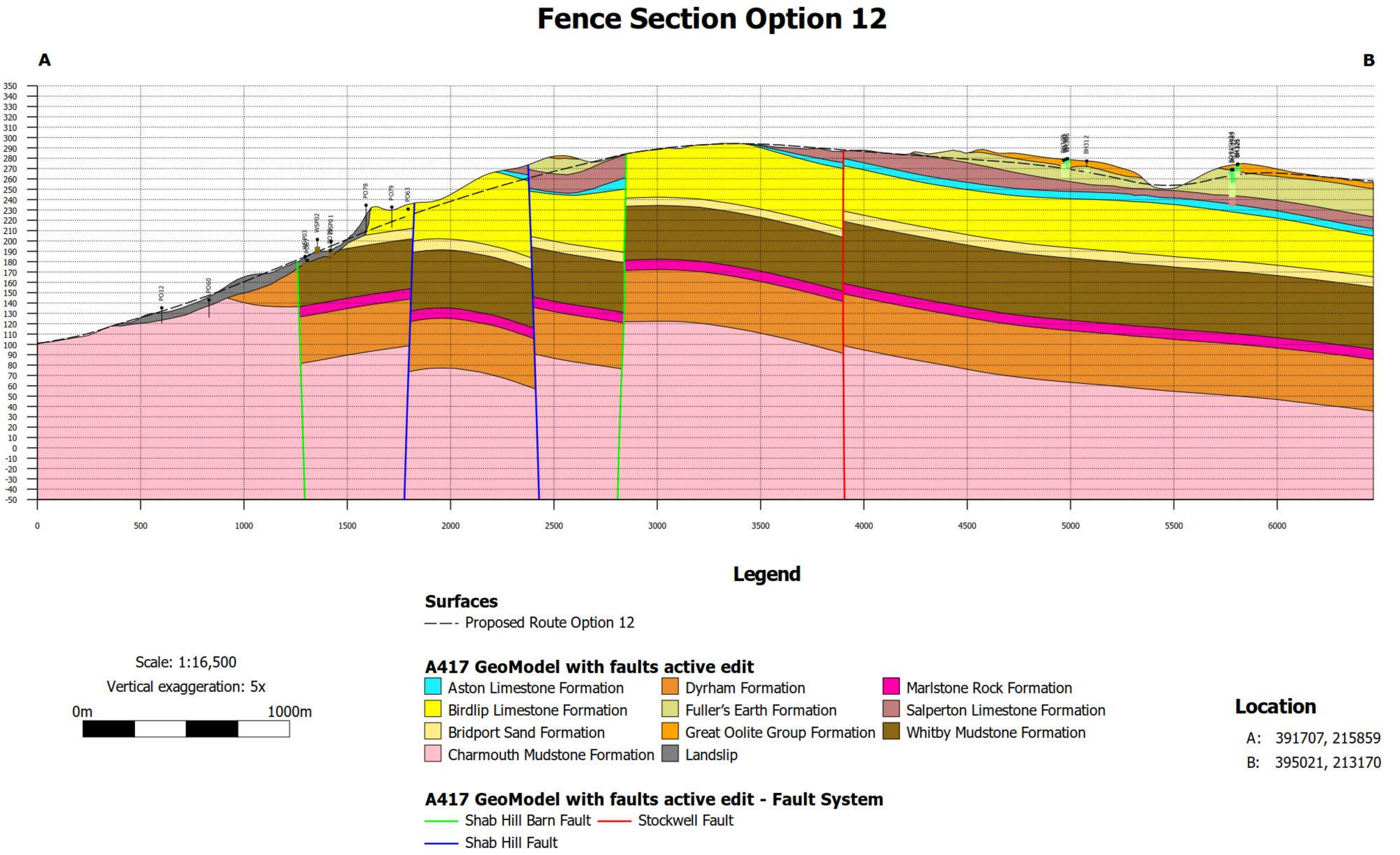
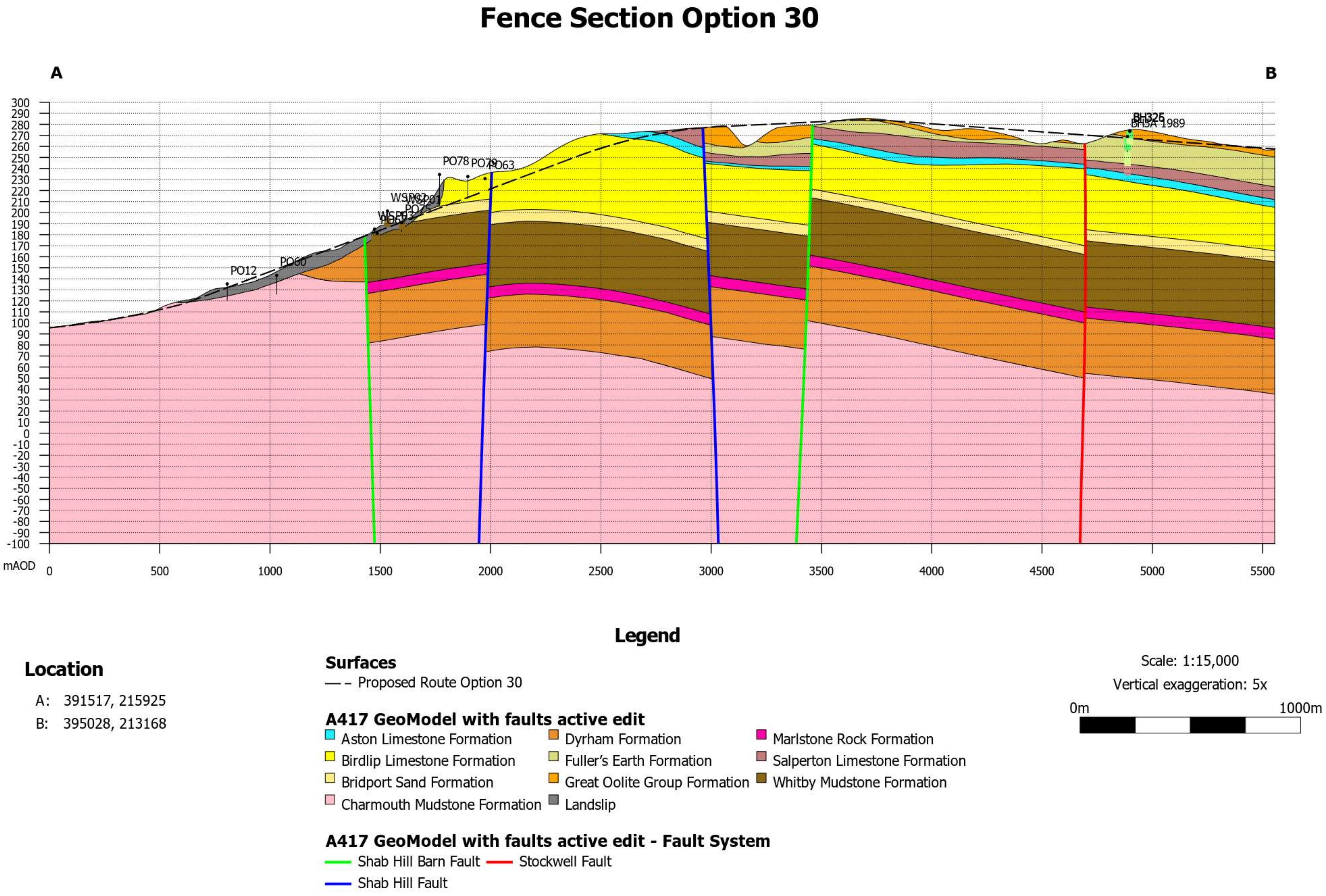


Figure 8.4: Preliminary conceptual geological longitudinal section – Option 30



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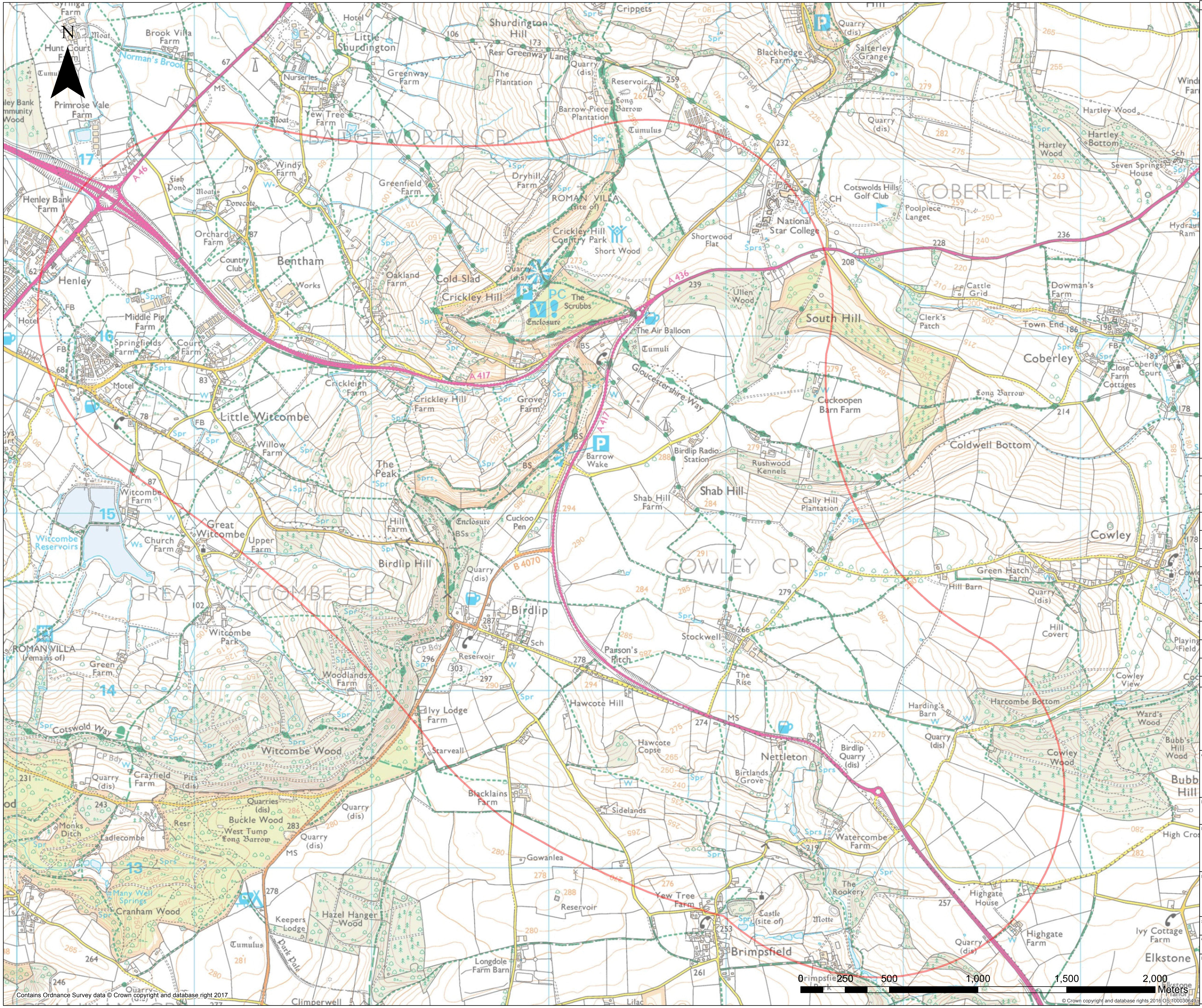
Appendix A Route drawings



Notes

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	30/07/18	First issue	CB	PAC	GS

Mott MacDonald
Sweco

Client

highways england

Drawing Status S02	Suitability For Info

Project Title

A417 Missing Link

Drawing Title

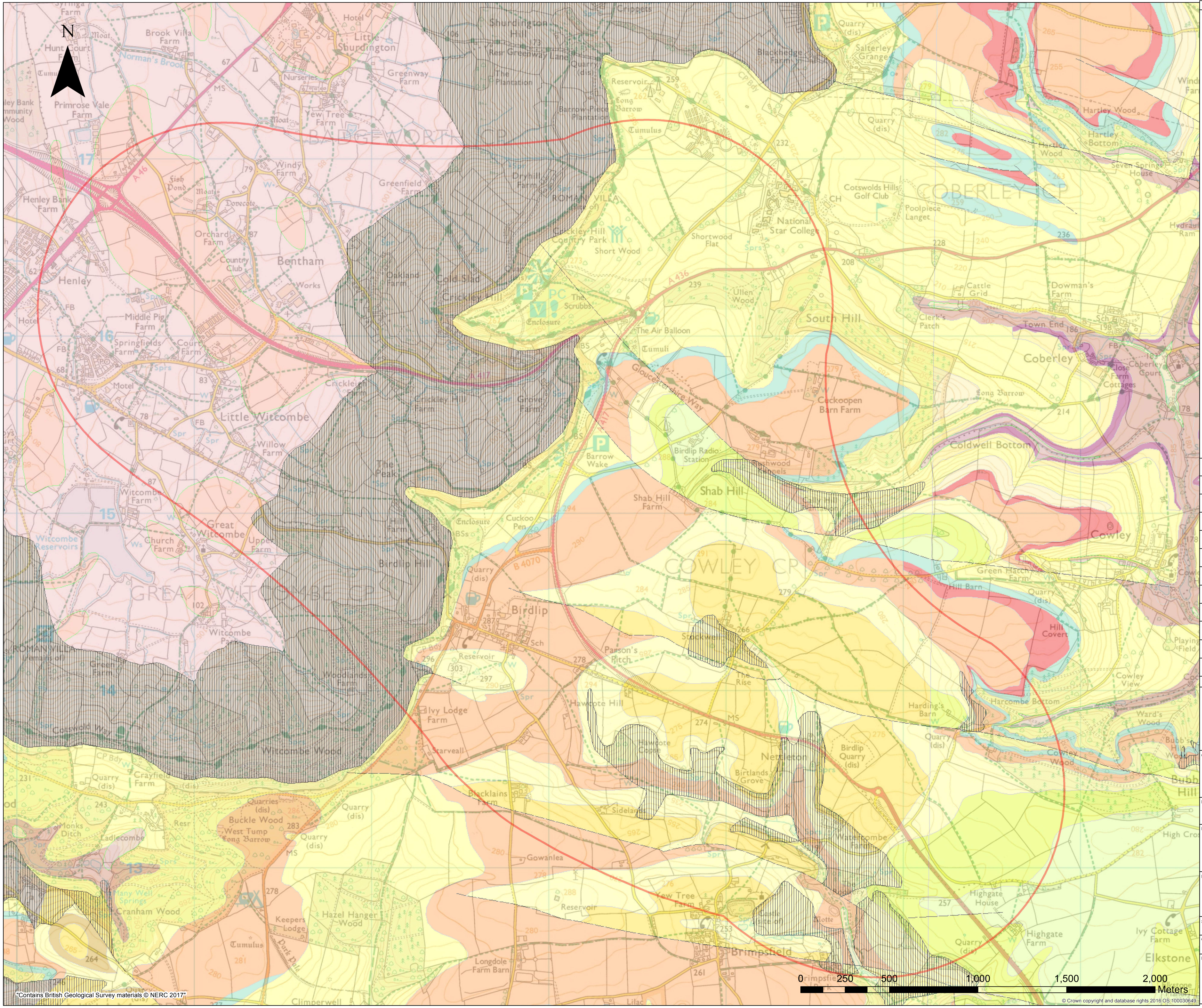
Site location plan

Scale 1:10,000	Designed CB	Drawn CB	Checked PAC	Approved GS
Original Size A1	Date 30/07/18	Date 30/07/18	Date 30/07/18	Date 30/07/18

Drawing Number
HE PIN | Originator | Volume
HE551505 - MMSJV - HGT -
000 - DR - CE - 00007
Location | Type | Role | Number

Project Ref. No.
HE551505

Revision
P01



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Notes

Legend

1:50 000 scale geology

Superficial deposits

- ⬜ ALLUVIUM - CLAY, SILT, SAND AND GRAVEL
- 🟧 CHELTENHAM SAND AND GRAVEL - SAND AND GRAVEL
- 🟫 HEAD - CLAY, SILT, SAND AND GRAVEL

Bedrock geology

- 🟦 EYFORD MEMBER - LIMESTONE
- 🟨 FULLER'S EARTH FORMATION - MUDSTONE
- 🟨 GREAT OOLITE GROUP - LIMESTONE
- 🟩 HAMPEN FORMATION - LIMESTONE
- 🟫 THROUGHAM TILESTONE FORMATION - LIMESTONE
- 🟩 WHITE LIMESTONE FORMATION - LIMESTONE
- 🟩 ASTON LIMESTONE FORMATION - LIMESTONE
- ⬜ NOTGROVE MEMBER - LIMESTONE, OOIDAL
- 🟧 SALPERTON LIMESTONE FORMATION - LIMESTONE, OOIDAL
- 🟥 UPPER TRIGONIA GRIT MEMBER - LIMESTONE
- 🟨 BIRDLIP LIMESTONE FORMATION - LIMESTONE, OOIDAL
- 🟨 CLEEVE CLOUD MEMBER - LIMESTONE, OOIDAL
- 🟨 CRICKLEY MEMBER - LIMESTONE
- 🟪 HARFORD MEMBER - MUDSTONE, SANDY
- 🟨 INFERIOR OOLITE GROUP AND GREAT OOLITE GROUP (UNDIFFERENTIATED) - LIMESTONE AND MUDSTONE, INTERBEDDE
- 🟪 LECKHAMPTON MEMBER - LIMESTONE
- 🟨 SCOTTSQUAR MEMBER - LIMESTONE
- 🟫 BRIDPORT SAND FORMATION - SANDSTONE
- 🟫 WHITBY MUDSTONE FORMATION - MUDSTONE
- 🟧 DYRHAM FORMATION - SILTSTONE AND MUDSTONE, INTERBEDDED
- 🟥 MARLSTONE ROCK FORMATION - LIMESTONE, FERRUGINOUS
- ⬜ BLUE LIAS FORMATION AND CHARMOUTH MUDSTONE FORMATION (UNDIFFERENTIATED) - MUDSTONE
- 🟫 LIAS GROUP AND INFERIOR OOLITE GROUP (UNDIFFERENTIATED) - LIMESTONE, ARGILLACEOUS ROCKS AND SUBORDIN

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	30/07/18	First issue	CB	PAC	GS

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Drawing Status
S02

Suitability
For Info

Project Title
A417 Missing Link

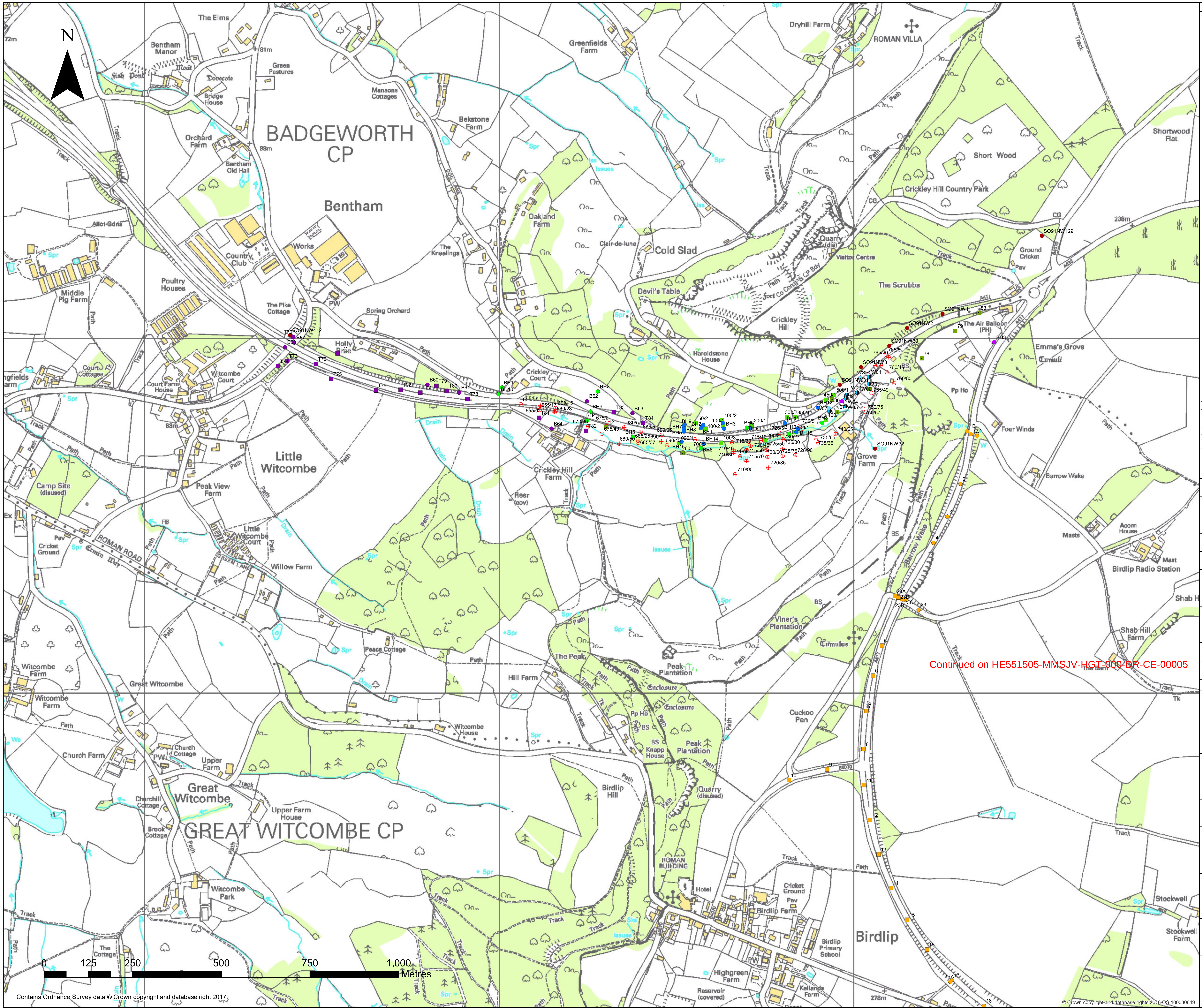
Drawing Title
British Geological Survey mapping
1:50,000 information

Scale 1:10,000	Designed CB	Drawn CB	Checked PC	Approved GS
Original Size A1	Date 30/07/18	Date 30/07/18	Date 30/07/18	Date 30/07/18

Drawing Number
HE PIN | Originator | Volume
HE551505 - MMSJV - HGT -
000 - DR - CE - 00006
Location | Type | Role | Number

Project Ref. No.
HE551505

Revision
P01



Continued on HE551505-MMSJV-HGT-000-DR-CE-00005

Notes

Legend

- 🔴 British Geological Survey Historical Boreholes
- 🟢 GI 1981 Brockworth Bypass to Crickley GCC-Boreholes
- 🟩 GI 1988 Crickley Hill GCC Exploratory Holes
- 🔵 GI 1988 Crickley Hill GCC BHs
- 🟩 GI 1988 Crickley hill Edward Wilson TPs
- ⊕ GI 1989 Fugro McClelland Crickley CPTs

GI 2002 Crickley Hill, GroveFarm WSP & Geo Eng Ltd

- ● BHs
- ◐ WSs
- 🟣 GI 2009 Crickley Hill CCTVGI

GI 1983 Birdlip Bypass GCC

- 🟧 TPs
- 🟠 BHs

GI 1991 Brockworth Bypass Exploration Associates

- 🟪 TPs
- 🟣 BHs

GI 1989 Statton Birdlip Bypass Foundation & ExplorationsServices

- 🟨 TPs
- 🟡 BHs

Notes

1. All dimensions in metres unless otherwise stated.
2. Do not scale any items or information from this drawing
3. All exploratory hole locations are indicative and subject to the confirmation by the GI Contractor following their consultation of utilities plans and service checks on site.
4. All exploratory hole locations to be commenced by CAT scanning, 1.2m deep hand dug inspection pit and additional CAT scanning at the base of the pit.
5. All exploratory hole locations to be surveyed to NGR co-ordinates and levelled following completion of installation.
6. Installation Instructions to be provided by the Ground Investigation Supervisor (MMS).
7. Work areas should be fenced and secured at all times.
8. All works to be undertaken in accordance with the Ground Investigation Specification Phase 1 GI.

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	27/07/18	Addition of BGS boreholes	JT	PC	GS

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Drawing Status
S03

Suitability
For Review

Project Title
A417 Missing Link at Air Balloon

Drawing Title
Existing ground investigation information - sheet 1 of 2

Scale	Designed	Drawn	Checked	Approved
1:5,000	CB	JT	PC	GS
Original Size	Date	Date	Date	Date
A1	21/11/2017	27/07/2018	27/07/2018	27/07/18

Drawing Number
HE PIN | Originator | Volume
HE551505-MMSJV-HGT-000-DR-CE-00004
Location | Type | Role | Number

Project Ref. No.
HE551505

Revision
P01

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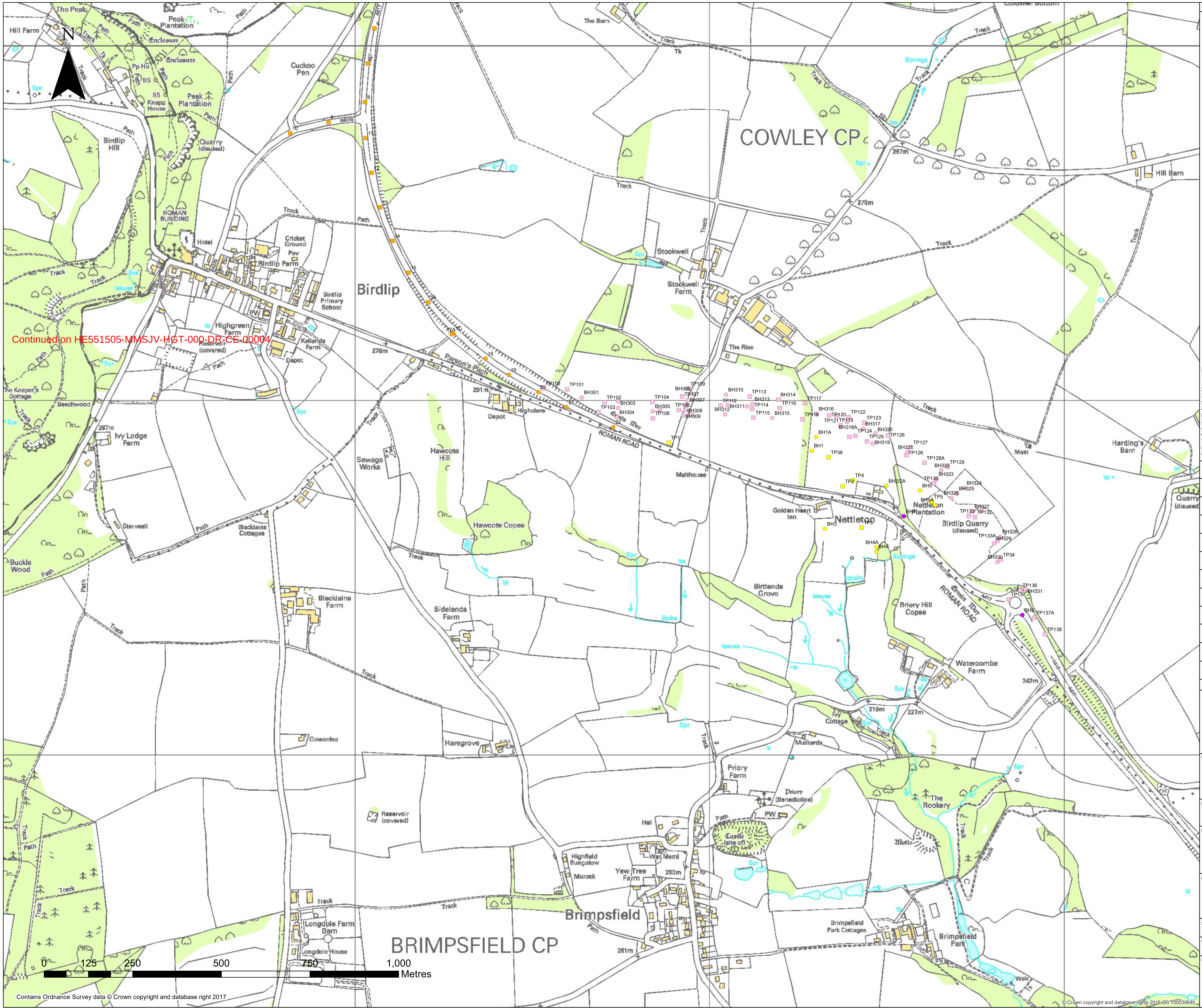

Continued on HE551505-MMSJV-HGT-000-DR-CE-00004

Notes

Legend

- 🔴 British Geological Survey Historical Boreholes
- 🟢 GI 1981 Brockworth Bypass to Crickley GCC-Boreholes
- ▣ GI 1988 Crickley Hill GCC Exploratory Holes
- 🔵 GI 1988 Crickley Hill GCC BHs
- 🟩 GI 1988 Crickley hill Edward Wilson TPs
- ⊕ GI 1989 Fugro McClelland Crickley CPTs

GI 2002 Crickley Hill, GroveFarm WSP & Geo Eng Ltd

- ● BHs
- ◐ WSs
- ● GI 2009 Crickley Hill CCTVGI

GI 1983 Birdlip Bypass GCC

- 🟧 TPs
- 🟠 BHs

GI 1991 Brockworth Bypass Exploration Associates

- 🟪 TPs
- 🟣 BHs

GI 1989 Statton Birdlip Bypass Foundation & ExplorationsServices

- 🟨 TPs
- 🟡 BHs

Notes

1. All dimensions in metres unless otherwise stated.
2. Do not scale any items or information from this drawing
3. All exploratory hole locations are indicative and subject to the confirmation by the GI Contractor following their consultation of utilities plans and service checks on site.
4. All exploratory hole locations to be commenced by CAT scanning, 1.2m deep hand dug inspection pit and additional CAT scanning at the base of the pit.
5. All exploratory hole locations to be surveyed to NGR co-ordinates and levelled following completion of installation.
6. Installation Instructions to be provided by the Ground Investigation Supervisor (MMS).
7. Work areas should be fenced and secured at all times.
8. All works to be undertaken in accordance with the Ground Investigation Specification Phase 1 GI.

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	27/07/18	Addition of BGS boreholes	JT	PC	GS

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Drawing Status S03	Suitability For Review

Project Title
A417 Missing Link at Air Balloon

Drawing Title
Existing ground investigation information - Sheet 2 of 2

Scale	Designed	Drawn	Checked	Approved
1:5,000	CB	JT	PC	GS
Original Size A1	Date 21/11/2017	Date 27/07/2018	Date 27/07/2018	Date 27/07/18

Drawing Number
HE PIN | Originator | Volume
HE551505-MMSJV-HGT-000-DR-CE-00005
Location | Type | Role | Number

Project Ref. No.
HE551505

Revision
P01

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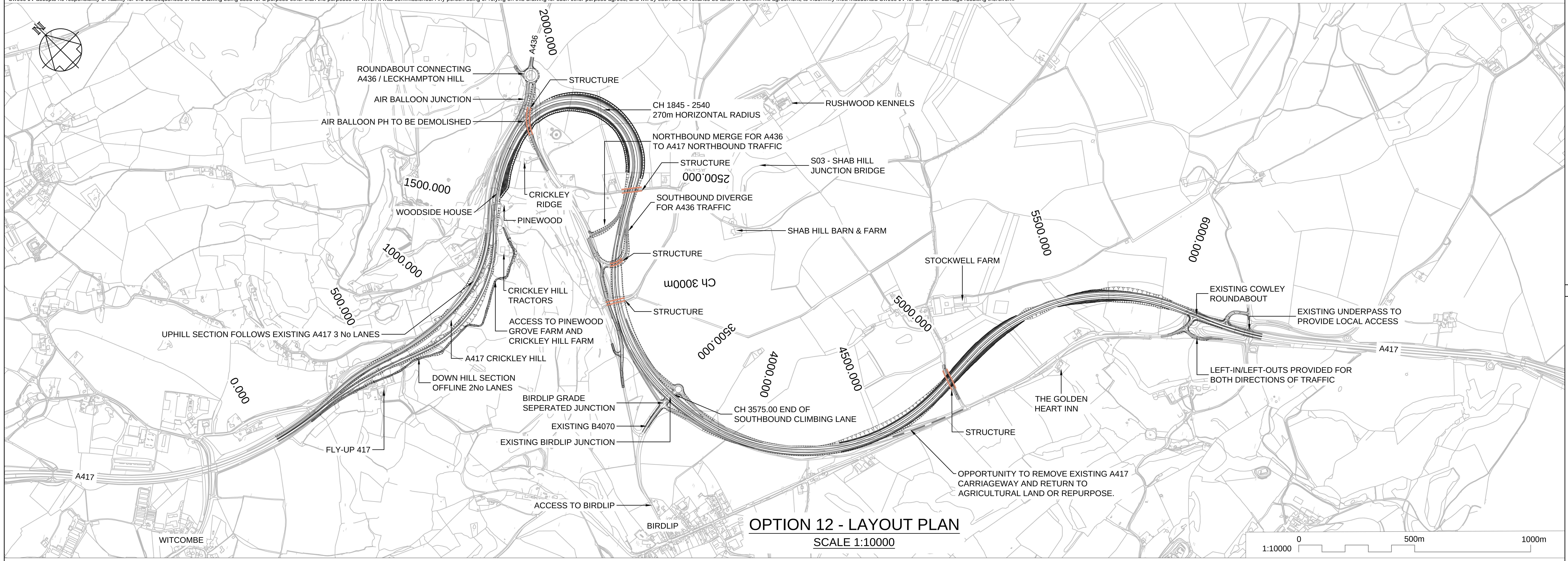
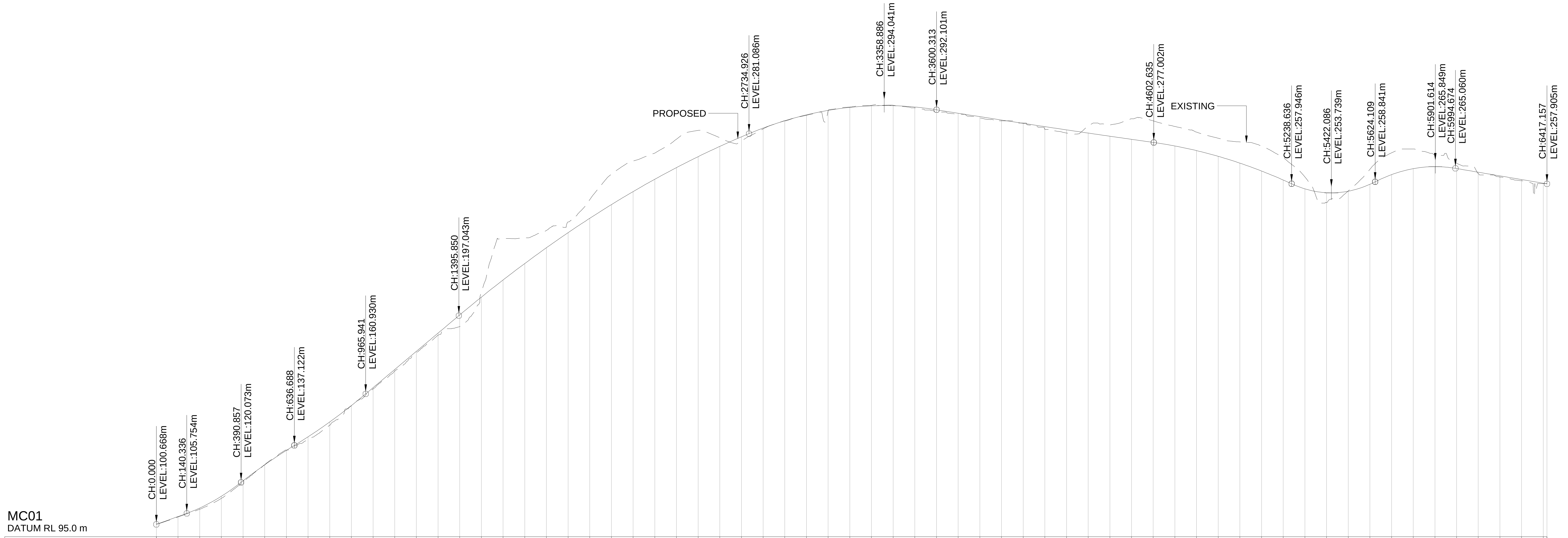


OPTION 12 - LAYOUT PLAN

SCALE 1:10000



DESIGN LEVELS	100.668	104.292	108.213	113.669	120.784	128.172	134.850	141.102	147.969	155.546	163.791	172.191	180.591	188.991	197.391	205.619	213.530
EXISTING LEVELS	100.677	104.093	107.673	112.709	120.214	128.211	135.000	139.954	146.450	155.496	163.192	171.455	179.901	187.990	191.978	208.027	232.617
CHAINAGE	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600
GRADIENT		3.624	3.921	5.455	7.115	7.388	6.678	6.252	6.867	7.577	8.246	8.400	8.400	8.400	8.400	8.228	7.911

DESIGN LEVELS	221.124	228.401	235.360	242.002	248.327	254.335	260.026	265.399	270.456	275.195	279.617	283.647	287.034	289.755	291.811	293.201	293.926
EXISTING LEVELS	233.000	236.371	240.311	250.586	262.389	268.438	272.085	278.525	282.572	279.217	277.718	283.256	287.000	289.549	291.643	293.360	294.166
CHAINAGE	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100	3200	3300
GRADIENT	7.594	7.277	6.959	6.642	6.325	6.008	5.691	5.373	5.056	4.739	4.422	4.031	3.387	2.721	2.056	1.390	0.725

DESIGN LEVELS	293.985	293.378	292.106	290.510	288.933	287.376	285.839	284.323	282.826	281.349	279.892	278.456	277.039	275.396	273.253	270.610	267.466
EXISTING LEVELS	294.186	293.000	291.421	290.000	288.347	287.000	286.000	283.000	281.373	285.000	285.097	287.921	286.996	284.402	281.782	278.971	277.260
CHAINAGE	3400	3500	3600	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600	4700	4800	4900	5000
GRADIENT	0.059	-0.606	-1.272	-1.597	-1.577	-1.557	-1.537	-1.517	-1.497	-1.477	-1.457	-1.437	-1.417	-1.643	-2.143	-2.643	-3.143

DESIGN LEVELS	263.823	259.680	255.602	253.800	254.498	257.696	262.150	264.909	265.848	264.970	263.277	261.583	259.889	258.105	257.905
EXISTING LEVELS	275.326	270.051	261.090	249.252	254.634	264.628	272.234	274.000	271.025	267.480	262.668	261.000	259.344	258.000	258.000
CHAINAGE	5100	5200	5300	5400	5500	5600	5700	5800	5900	6000	6100	6200	6300	6400	6417
GRADIENT	-3.643	-4.143	-4.078	-1.802	0.698	3.198	4.454	2.759	0.939	-0.878	-1.694	-1.694	-1.694	-1.694	-1.694

VERTICAL DATA: P | R | R | R | P=8.400% L=429.909 | R=-31525.851 L=1339.076 | R=-15026.296 L=865.387 | R=500000.000 L=1002.323 | R=-20000.000 L=636.001 | R | R | L=422.483 P=-1.694%

HORIZONTAL DATA: R | CL | CL | R | CL | CL | R | CL | R | CL | CL | R | CL | R=270.000 L=706.857 | CL | CL | R | CL | R=-720.000 L=671.390 | CL | R | CL | R=-800.000 L=995.803 | CL | D | CL | R=800.000 L=880.329 | CL | D | CL | R

HORIZONTAL SCALE: 1:12,500, VERTICAL SCALE: 1:1250

PROPOSED A417 OPTION 12 LAYOUT - LONGSECTION

1:12500 0 625m 1250m

Notes

1. ALL JUNCTION AND SLIP ROAD LAYOUTS SHOWN ARE INDICATIVE ONLY AT THIS STAGE.
2. FOR THE PURPOSES OF EARLY CONSIDERATION THE LEVEL OF BLIGHT ON THE FOLLOWING PROPERTIES MAY REQUIRE DEMOLITION: GROVE LODGE AND PINEWOOD. THE AIR BALLOON PUBLIC HOUSE AND WOODSIDE HOUSE WILL HAVE TO BE DEMOLISHED.
3. THE ACCESS TO RESIDENTIAL / COMMERCIAL PROPERTIES HAS NOT BEEN FULLY DEVELOPED AT THIS STAGE AND ARE SUBJECT TO SEPARATE DESIGN PACKAGES. THESE INCLUDE ACCESS TO COLD SLAD / CRICKLEY HILL TRACTORS AND FLY UP 417 / RUSHWOOD KENNELS AND SHAB HILL FARM. DETAILS TO BE CONFIRMED LATER WITHIN STAGE 2.

Key to symbols

LAYOUT PLAN

═	PROPOSED STRUCTURES
— —	SECTION OF EXISTING A417 / B4070 CARRIAGEWAY WILL HAVE THE OPPORTUNITY TO BE REMOVED OR RE-PURPOSED. (ARRANGEMENT SUBJECT TO APPROVAL)

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	20/06/18	INITIAL ISSUE	RJ	LJ	GS

Mott MacDonald
Sweco

Client
highways england

Drawing Status: FOR INFORMATION
Suitability: S2

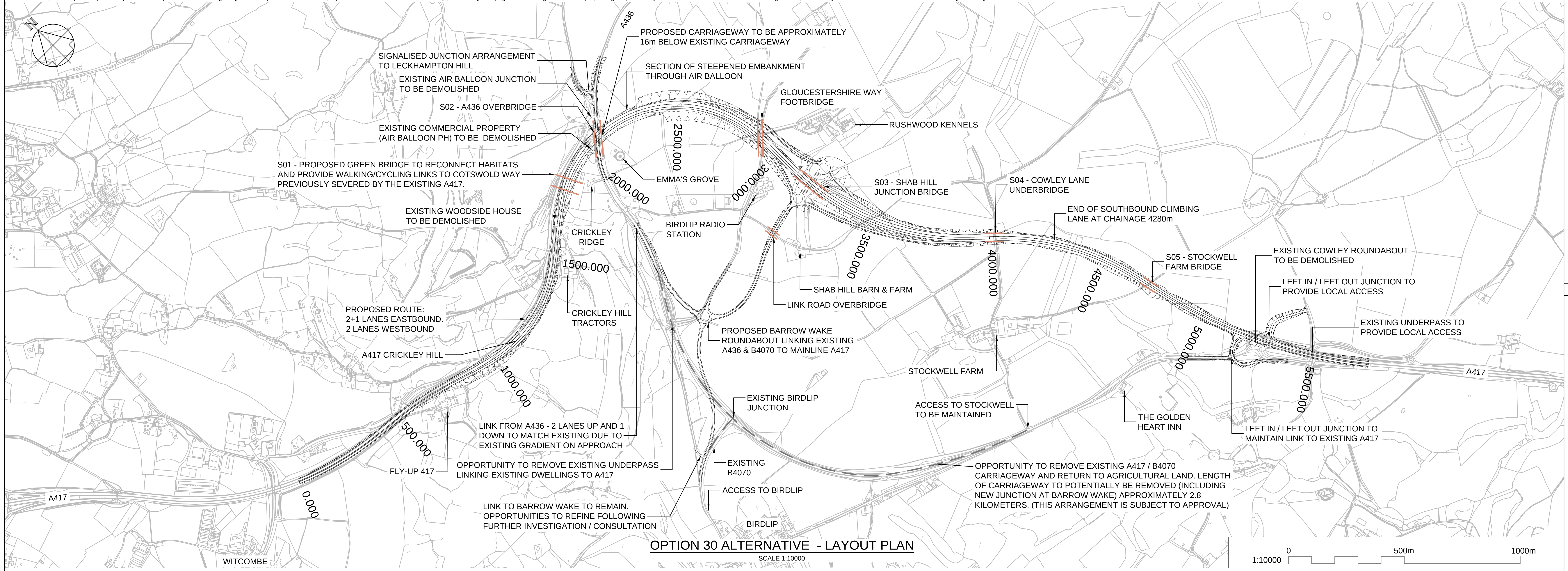
Project Title: A417 MISSING LINK - PCF STAGE 2
PCF STAGE 2

Drawing Title: OPTION 12
GENERAL ARRANGEMENT & LONG SECTION

Scale	Designed	Drawn	Checked	Approved
As Shown	Porter, Adrian	Ellis, Patrick	Smith, Graeme	Jorgensen, Lars
Original Size A1	Date 11/01/18	Date 16/03/18	Date 20/06/18	Date 20/06/18

Drawing Number
HE PIN | Originator | Volume
HE551505 - MMSJV - HGN -
000 - DR - CH - 00001
Location | Type | Role | Number

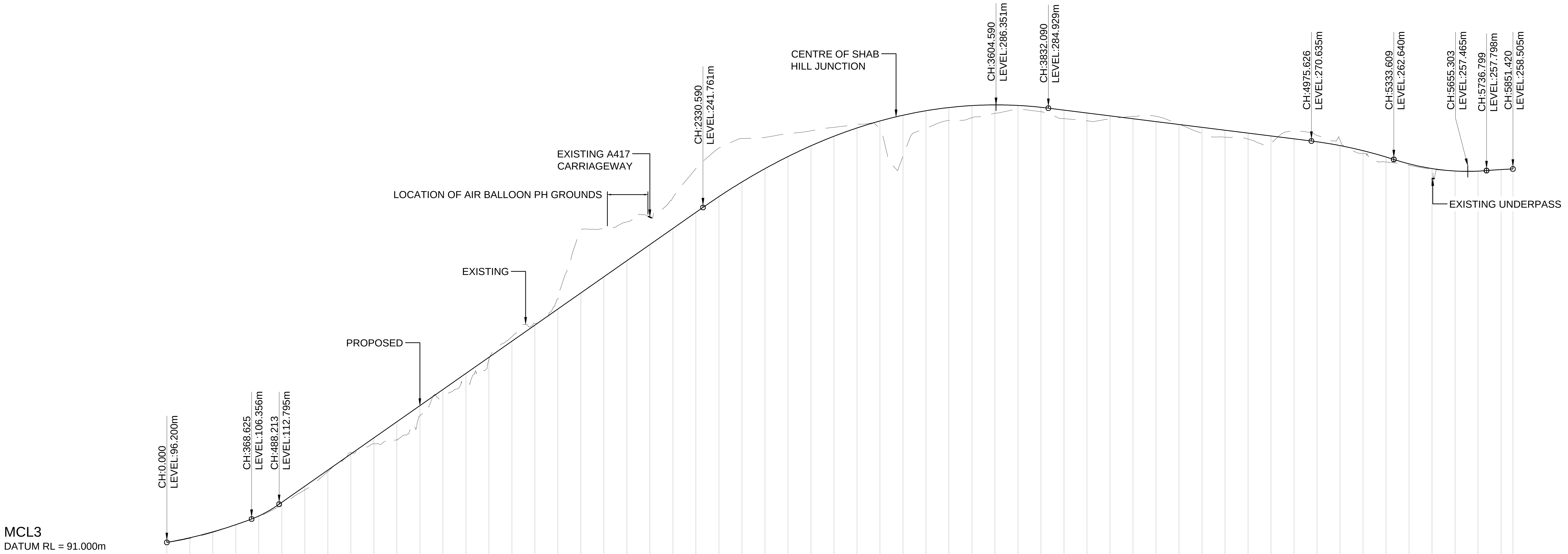
Project Ref. No.: HE551505
Revision: P01



OPTION 30 ALTERNATIVE - LAYOUT PLAN

SCALE 1:10000

1:10000 0 500m 1000m



DESIGN LEVELS	96.200	98.217	100.784	103.900	107.672	113.620	120.620	127.620	134.620	141.620	148.620	155.620	162.620	169.620	176.620
EXISTING LEVELS	96.132	97.958	100.570	103.955	107.456	112.491	119.018	127.002	135.321	139.058	140.749	151.242	159.496	166.732	175.700
CHAINAGE	0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
GRADIENT		2.017	2.567	3.116	3.772	5.948	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000

DESIGN LEVELS	183.620	190.620	197.620	204.620	211.620	218.620	225.620	232.620	239.620	246.488	252.832	258.626	263.871	268.567	272.713
EXISTING LEVELS	185.663	191.356	202.031	231.759	232.713	235.507	237.705	246.047	258.657	267.568	271.759	272.230	273.916	275.079	276.602
CHAINAGE	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900
GRADIENT	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	7.000	6.868	6.344	5.794	5.245	4.696	4.146

DESIGN LEVELS	276.309	279.356	281.854	283.803	285.201	286.051	286.351	286.101	285.302	284.081	282.831	281.581	280.331	279.081	277.831
EXISTING LEVELS	277.893	276.062	264.004	276.255	279.568	280.783	282.685	284.407	283.358	280.348	279.454	280.193	281.358	281.401	277.933
CHAINAGE	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000	4100	4200	4300	4400
GRADIENT	3.597	3.047	2.498	1.948	1.399	0.849	0.300	-0.250	-0.799	-1.222	-1.250	-1.250	-1.250	-1.250	-1.250

DESIGN LEVELS	276.581	275.331	274.081	272.831	271.581	270.314	268.656	266.447	263.690	260.724	258.671	257.618	257.565	258.244	258.505
EXISTING LEVELS	274.039	272.317	271.487	269.659	274.621	272.987	271.082	265.195	261.525	260.103	251.220	257.613	257.593	258.192	258.505
CHAINAGE	4500	4600	4700	4800	4900	5000	5100	5200	5300	5400	5500	5600	5700	5800	5851
GRADIENT	-1.250	-1.250	-1.250	-1.250	-1.250	-1.266	-1.659	-2.208	-2.758	-2.966	-2.053	-1.053	-0.053	0.678	0.508

VERTICAL DATA	R=18200.000 L=368.625	R	P=7.000% L=1842.377	R=-18200.000 L=1501.500	P=-1.250% L=1143.536	R=-18200.000 L=357.983	R=10000.000 L=403.190	R

HORIZONTAL DATA	R	CL	R=-1440.000 L=253.576	CL	CL	R=1440.000 L=224.562	CL	CL	R=-510.000 L=278.391	CL=238.260	CL	R=510.000 L=923.368	CL=238.260	CL	R=-1020.000 L=731.357	CL	CL	R=1020.000 L=519.280	CL	CL	R=-2040.000 L=967.016	CL	D

HORIZONTAL SCALE: 1:12,500, VERTICAL SCALE: 1:1250

OPTION 30 ALTERNATIVE LAYOUT - LONGSECTION (MCL3)

1:12500 0 625m 1250m

Notes

1. ALL JUNCTION AND SLIP ROAD LAYOUTS SHOWN ARE INDICATIVE ONLY AT THIS STAGE.
2. FOR THE PURPOSES OF EARLY CONSIDERATION THE LEVEL OF BLIGHT ON THE FOLLOWING PROPERTIES MAY REQUIRE DEMOLITION: GROVE LODGE AND PINEWOOD. THE AIR BALLOON PUBLIC HOUSE AND WOODSIDE HOUSE WILL HAVE TO BE DEMOLISHED.
3. THE A417 MISSING LINK SCHEME IS IN PCF STAGE 2, OPTION SELECTION. THIS LAYOUT REPRESENTS OPTION 30 WITH ALTERNATIVE DESIGN ARRANGEMENTS FOLLOWING NON-STATUTORY PUBLIC CONSULTATION. THE CHANGES SINCE THE OPTION ASSESSED FOR PUBLIC CONSULTATION ARE AS FOLLOWS:
   - (i) MAINLINE SHIFTED EAST (APPROXIMATELY 230m) BETWEEN CHAINAGE 3250 - 5500 TO FIT MORE CLOSELY WITH THE EXISTING LANDSCAPE.
   - (ii) RE-LOCATED JUNCTION AT BARROW WAKE AND RE-ALIGNED LINK ROAD BACK TO SHAB HILL GRADE SEPARATED JUNCTION.
   - (iii) AMENDED VERTICAL PROFILE PROVIDING MAXIMUM MAINLINE GRADIENT OF 7% (PREVIOUS OPTION 7.5%).
   - (iv) INCLUSION OF LEFT IN/LEFT OUT JUNCTION AT COWLEY (NOT SHOWN).
4. THE ACCESS TO RESIDENTIAL / COMMERCIAL PROPERTIES HAS NOT BEEN FULLY DEVELOPED AT THIS STAGE AND ARE SUBJECT TO SEPARATE DESIGN PACKAGES. THESE INCLUDE ACCESS TO COLD SLAD / CRICKLEY HILL TRACTORS AND FLY UP 417 / RUSHWOOD KENNELS AND SHAB HILL FARM. DETAILS TO BE CONFIRMED LATER WITHIN STAGE 2.

Key to symbols

LAYOUT PLAN

═	PROPOSED STRUCTURES
— —	SECTION OF EXISTING A417 / B4070 CARRIAGEWAY WILL HAVE THE OPPORTUNITY TO BE REMOVED OR RE-PURPOSED. (ARRANGEMENT SUBJECT TO APPROVAL)

Rev	Date	Amendment Details	Drawn	Chk'd	App'd
P01	13/04/18	INITIAL ISSUE	RJ	GS	GS
P02	15/05/18	MODEL AND NOTES UPDATED	PE	LJ	GS

Mott MacDonald
Sweco

Client
highways england

Drawing Status
FOR INFORMATION

Suitability
S2

Project Title
A417 MISSING LINK - PCF STAGE 2

Drawing Title
OPTION 30 ALTERNATIVE
GENERAL ARRANGEMENT & LONG SECTION
UPDATE FOLLOWING NON-STAT
PUBLIC CONSULTATION

Scale	Designed	Drawn	Checked	Approved
As Shown	Woodward, Andrew	Ellis, Patrick	Jorgensen, Lars	Smith, Graeme
Original Size	Date	Date	Date	Date
A1	28/03/18	11/05/18	14/05/18	15/05/18

Drawing Number
HE PIN | Originator | Volume
HE551505 - MMSJV - HGN -
000 - DR - CH - 00004
Location | Type | Role | Number

Project Ref. No.
HE551505

Revision
P02

pw:\\CSPWInt.grontmij.net:PW_UK Production\Documents\Projects\Transportation\HE551505 - A417 MISSING LINK - PCF STAGE 2\Highways\General\Drgs & Models - 2D drawing\HE551505-MMSJV-HGN-000-DR-CH-00004

Appendix B HA GDMS A417 search

Note: (Search made January 2018 - Geotechnical and Geomorphological Documents)

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
21588	Brockworth Bypass, A417 Crickley Hill Proposals	A417	Preliminary Soil Survey, Addendum	1981	Factual Report	No	No	Halcrow
12606	A417 Birdlip Bypass	A417	Soil Survey	1983	Geotechnical Report (Factual Report not included)	No	No	Gloucs CC
21589	A417(T) Crickley Hill	A417	Scheme Identification Study Report	1986	Preliminary Sources Study	No	No	Halcrow
12599	A417 HUNGERFORD - HEREFORD TRUNK ROAD BIRDLIP BYPASS	A417	Soil Assessment Report- Geotechnical Brief	1987	Geotechnical Report (Factual Report not included)	No	No	Gloucs CC
12604	A417 STRATTON BYPASS	A417	A417 North of Stratton to Birdlip Improvement	1988	Geotechnical Report (Factual Report not included)	No	No	Geomorphological Services Ltd
12609	A417 Crickley Hill Improvement Scheme	A417	A417 Crickley Hill Improvement Scheme	1988	Miscellaneous	No	No	Edward J Wilson
21577	A417 Crickley Hill	A417	Geomorphological Survey, Addendum Report	1988	Miscellaneous	No	No	Edward J Wilson
16207	A417 Crickley Hill Improvement Scheme	A417	Report On Geomorphological Survey at Crickley Hill (A417), Gloucestershire, For the Highways Laboratory, Gloucestershire County Council.	1988	Geotechnical Report (Factual Report not included)	No	No	EJ Wilson & Associates
12600	A417 North of Stratton to Birdslip	A417	Site Investigation	1989	Factual Report	No	No	Foundations & Exploration Services
12611	A417 HUNGERFORD - HEREFORD TRUNK ROAD BIRDLIP BYPASS	A417	Geotechnical Feedback Report	1989	Feedback Report	No	No	Gloucs CC
21572	A417 Crickley Hill Improvement	A417	Geotechnical Certification, Procedural Statement	1989	Stage 1 Assessment Report	No	No	Gloucestershire

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
21573	A417 Crickley Hill Improvement	A417	Soil Survey, Interim Interpretive Report	1989	Geotechnical Report (Factual Report not included)	No	No	Gloucestershire County Council
21574	A417 Crickley Hill Improvement	A417	Technical Appraisal Report	1989	Geotechnical Report (Factual Report not included)	No	No	Gloucestershire County Council
21578	A417 Crickley Hill Tunnel Study	A417	Supplementary Report	1989	Geotechnical Report (Factual Report not included)	No	No	Frank Graham & Partners
21579	A417 Crickley Hill Tunnel Study	A417	Geotechnical Report	1989	Geotechnical Report (Factual Report not included)	No	No	Frank Graham & Partners
12601	A417 Stratton to BirdlipGI Factual Report	A417	Factual	1990	Geotechnical Report (Factual Report not included)	No	No	Exploration associates
16846	A419/A417 CIRENCESTER/STRATTON BYPASS	A417, A419	Churn Valley Viaduct	1990	Geotechnical Report (Factual Report not included)	No	No	Frank Graham
21575	A417 Crickley Hill, Northern Widening Options	A417	Geotechnical Report	1990	Geotechnical Report (Factual Report not included)	No	No	Gloucestershire County Council
21576	A417 Crickley Hill Off Line Improvement Scheme	A417	Interim Report	1990	Geotechnical Report (Factual Report not included)	No	No	E J Wilson Associates
12597	A417 Crickley Hill improvement	A417	Geotechnical Investigations and Scheme for Road Widening on the Northern Valley Side	1991	Geotechnical Report (Factual Report not included)	No	No	Gloucestershire CC
12598	A417 North of Stratton to Birdlip Improvement	A417	Addendum Report on Ground Investigation	1991	Geotechnical Report (Factual Report not included)	No	No	Exploration associates
12607	A417 BROCKWORTH BYPASS	A417	Geotechnical Interpretative Report	1991	Geotechnical Report (Factual Report not included)	No	No	

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
12608	A417 NORTH OF STRATTON TO BIRDLIP IMPROVEMENT	A417	Geotechnical Interpretative Report	1991	Geotechnical Report (Factual Report not included)	No	No	Frank Graham
12629	A419/417 Cirencester & Stratton Bypass	A419, A417	Detailed Ground Investigation A419/417 Cirencester & Stratton Bypass	1991	Factual Report	No	No	Soil Mechanics
17619	A417 Brockworth Bypass	A417	Ground Investigation Data	1991	Contract Documents	No	No	Frank Graham Consulting Engineers Ltd
12602	A417 North of Stratton to Nettleton Improvement	A417	Supplementary Site Investigation	1992	Factual Report	No	No	CJ Associates
12610	A417, M5 TO A40 (ELMBRIDGE COURT) IMPROVEMENT	A417, A40, M5	Report On Preliminary Geotechnical Assessment	1992	Geotechnical Report (Factual Report not included)	No	No	Frank Graham
12627	A419/417 Cirencester & Stratton Bypass	A419, A417	Factual Report on Supplementary Investigation no. B1238	1992	Geotechnical Report (Factual Report not included)	No	No	CJ Associates
12628	A419/A417 CIRENCESTER & STRATTON BYPASS	A419, A417	Geotechnical Interpretative Report	1992	Geotechnical Report (Factual Report not included)	No	No	Frank Graham
16843	A417 NORTH OF STRATTON TO NETTLETON IMPROVEMENT	A417	Geotechnical Addendum Report	1992	Geotechnical Report (Factual Report not included)	No	No	Frank Graham
18999	A417 Brockworth Bypass	A417	Outline Approval in Principle Brockbere Culvert No. 9107/S52	1992	Contract Documents	No	No	
17621	A417 Brockworth Bypass	A417	Tender Amendment , Contract Documents	1993	Contract Documents	No	No	Frank Graham Consulting Engineers Ltd
12615	A417 BROCKWORTH BYPASS	A417	Earthworks Design Report	1994	Geotechnical Report (Factual Report not included)	No	No	
12630	A419/417Swindon to Gloucs Earthworks design report	A419, A417	Factual	1996	Geotechnical Report (Factual Report not included)	No	No	Howard Humphreys

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
12631	A419/A417 Swindon to Gloucester	A417, A419	Earthworks Design Report-A417 North of Stratton to Nettleton Improvements	1996	Geotechnical Report (Factual Report not included)	No	No	
12632	A419/A417 SWINDON TO GLOUCESTER-A419/A417 CIRENCESTER AND STRATTON BYPASS	A417, A419	Earthworks design Addendum Report	1996	Geotechnical Report (Factual Report not included)	No	No	Howard Humphreys
12633	A419/A417 SWINDON TO GLOUCESTER-A419 LATTON BYPASS	A419, A417	Earthworks Design report	1996	Geotechnical Report (Factual Report not included)	No	No	Howard Humphreys
12634	A419/A417 SWINDON TO GLOUCESTER-A417 NORTH OF STRATTON TO NETTLETON IMPROVEMENTS	A418, A417	Earthworks Design Report	1996	Geotechnical Report (Factual Report not included)	No	No	Howard Humphreys
16842	A419/A417 SWINDON TO GLOUCESTER	A417, A419	Earthworks design Addendum Report-A419 Latton Bypass- Additional Structure Design Summaries	1996	Geotechnical Report (Factual Report not included)	No	No	Howard Humphreys
12622	A419/A417 SWINDON TO GLOUCESTER	A419, A417	Supplementary Earthworks Design Report - Canal Culvert	1997	Geotechnical Report (Factual Report not included)	No	No	Humphreys & Partners
16755	A419/A417 Swindon - Gloucester	A417, A419	Latton Scheme Earthworks & Cirencester Scheme Earthworks	1997	Miscellaneous	No	No	Parkman
12603	A417 BROCKWORTH BYPASS	A417	Construction (Design and Management) Regulations 1994 Healt and Safety File-	1999	Feedback Report	No	No	
21587	A417 (T) Missing Link Tunnel Option	A417	Pre-Feasibility Study	2000	Preliminary Sources Study	No	No	Mott MacDonald
16205	A417 Crickley Hill Improvement Scheme	A417	Interim Report on Slope Stability Studies For A417 Crickley Hill Off-Line Improvement Scheme For The Highways Laboratories	2001	Miscellaneous	No	No	EJ Wilson & Associates

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
			Gloucestershire County Council					
16208	A417 Crickley Hill Improvement Scheme	A417	Addendum Report To Geomorphological Survey at Crickley Hill (A417), Gloucestershire, For the Highways Laboratory, Gloucestershire County Council.	2001	Geotechnical Report (Factual Report included)	No	No	EJ Wilson & Associates
22335	A417 Crickley Hill	A417	Geotechnical Feasibility Report	2001	Geotechnical Report (Factual Report not included)	No	No	
16772	A417 CRICKLEY HILL IMPROVEMENT	A417	Preliminary Sources Study	2002	Preliminary Sources Study	No	No	WSP Environmental Ltd
17332	A417 GROVE FARM ACCESS	A417	GEOTECHNICAL INTERPRETATIVE REPORT	2002	Geotechnical Report (Factual Report not included)	No	No	WSP
21571	A417 Crickley Hill Improvement, Grove Farm Access	A417	Ground Investigation	2002	Factual Report	No	No	Geotechnical
17326	A417 COWLEY TO BROCKWORTH BYPASS IMPROVEMENT	A417	STATEMENT OF INTENT	2003	Miscellaneous	No	No	
18693	A417 Cowley to Brockworth Bypass Impovement	A417	Preliminary Sources Study	2003	Preliminary Sources Study	No	No	WSP
21568	A417 Cowley to Brockworth Bypass Improvement	A417	Preliminary Route Selection, Ground Investigation Contract	2003	Contract Documents	No	No	WSP
18694	A417 Cowley to Brockworth Bypass Impovement	A417	Geomorphological Survey	2004	Geotechnical Report (Factual Report not included)	No	No	WSP
21567	A417 Cowley to Brockworth Bypass Improvement	A417	Hydrogeological Assessment	2004	Miscellaneous	No	No	
21570	A417 Cowley to Brockworth Bypass Improvement	A417	Environmental Stage 2 Report (Geology and Soils)	2004	Geo-Environmental Report	No	No	WSP
23794	Area 2 A417 & A419 Ground Investigation Report	A417, A419	Ground Investigation Report	2009	Geotechnical Report (Factual Report not included)	Yes	Yes	Highways Agency

Report Number	Proposed scheme Title	Road	Report Title	Year	Report Type	AGS Data Available?	Boreholes Attached?	Report Author
23973	Area 2 A417 & A419 CCTV	A419, A417	Area 2 A417 & A419 CCTV	2009	Factual Report	Yes	Yes	Geoechnical Engineering Ltd
23976	A417 / A419 CCTV Camera Mast Foundations	A417, A419	Geotechnical Design Report	2009	Geotechnical Design Report	No	No	Mott MacDonald
28636	A417 Missing Link at Air Balloon	A417	PCF Stage 1 - Statement of Intent	2015	Statement of Intent	No	No	WSP UK Ltd

Appendix C Historical geomorphological plans

Figure C.1: Extract plan showing geomorphology (Edward J Wilson 1988 report)

Figure C.2: Extract plan showing geomorphological features (Edward J Wilson 1988 report)

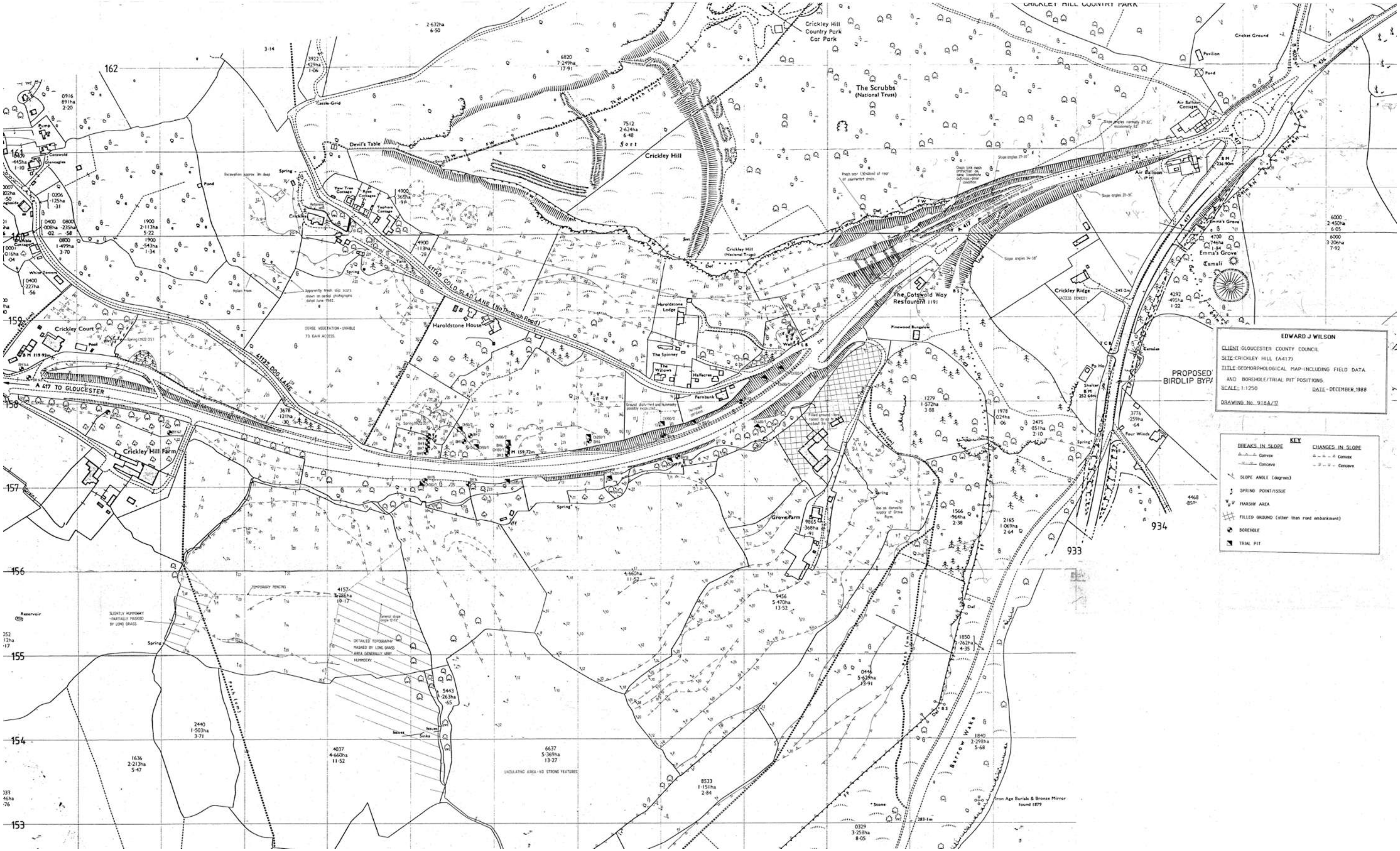


Figure C.3: Extract Plan from Hucthinson's 1991 technical feasibility assessment at Crickley Hill

Figure C.4: Extract Plan from WSP's Geomorphological report for Cowley to Brockworth (2004)

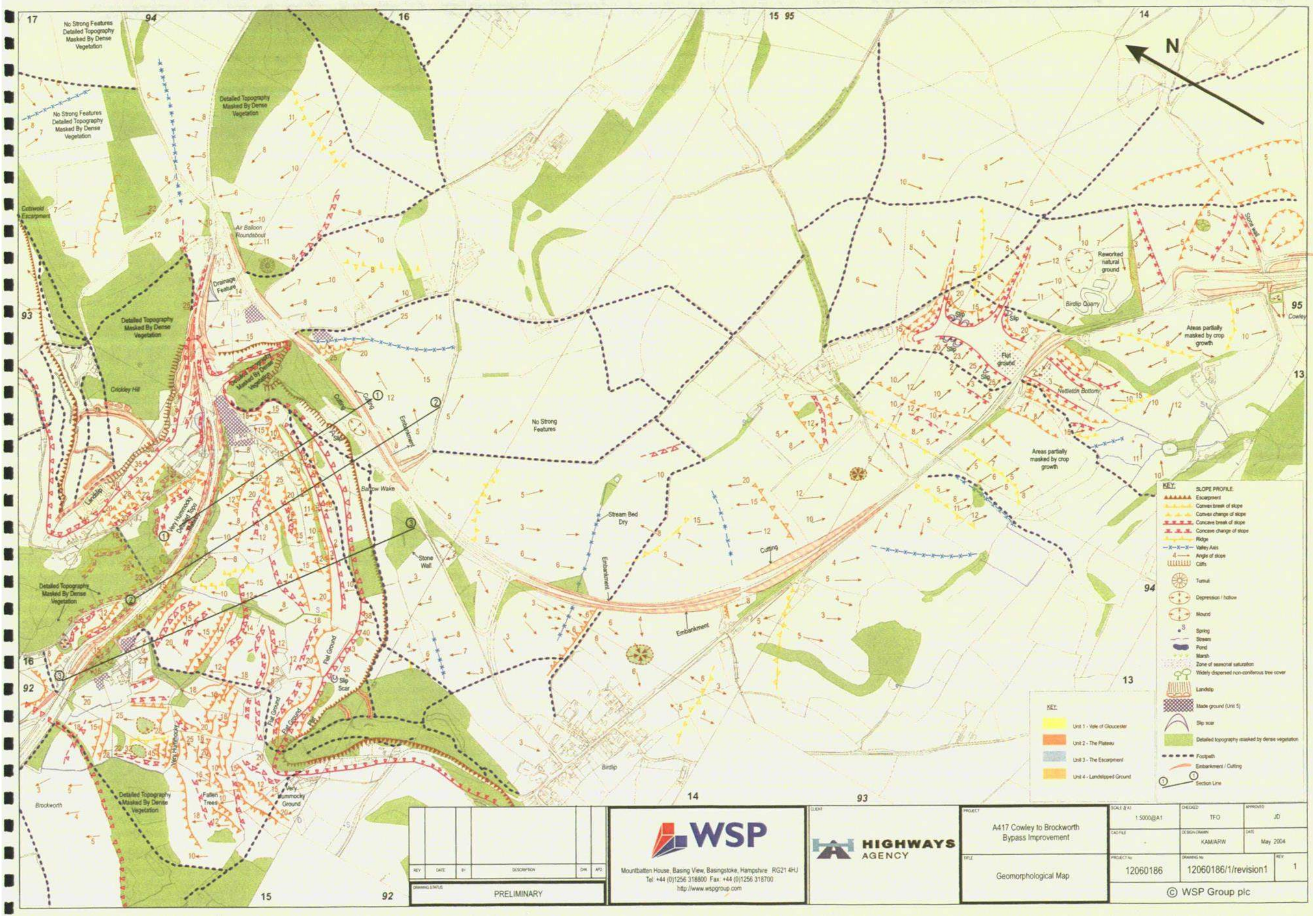
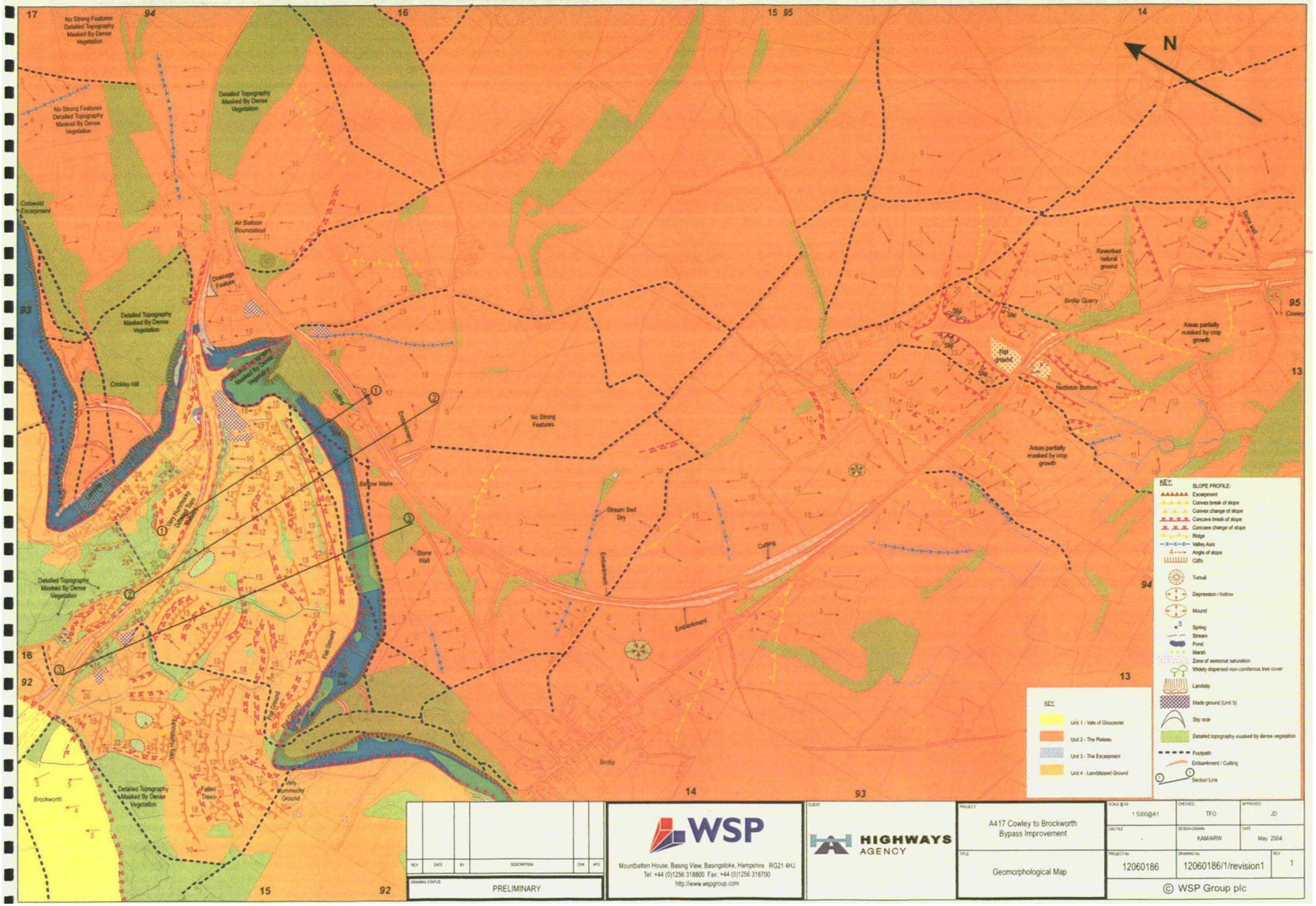


Figure C.5: Extract Plan 2 from WSP's Geomorphological report for Cowley to Brockworth (2004)



Appendix D Geological outcrop type location surveys

Preliminary rock mass outcrop mapping was carried out at reference / type outcrops of the Birdlip Limestone and other key geological stratum. Where possible outcrops in the immediate vicinity of the study area were assessed, else, where exposures in the Worcester / Severn Basin provided outcrop. There are no known outcrops of Lias Group deposits close to the Birdlip site due to the draping of landslide material over the escarpment therefore resource to Joint Nature Conservative Committee’s Geological Conservation Review (GCR) sites were taken. These GCR sites are type localities or best representative sections of name rock units or their boundaries are conspicuous in relevant basins. Further information on GCR sites can be found in the Geological Conservation Review Series.

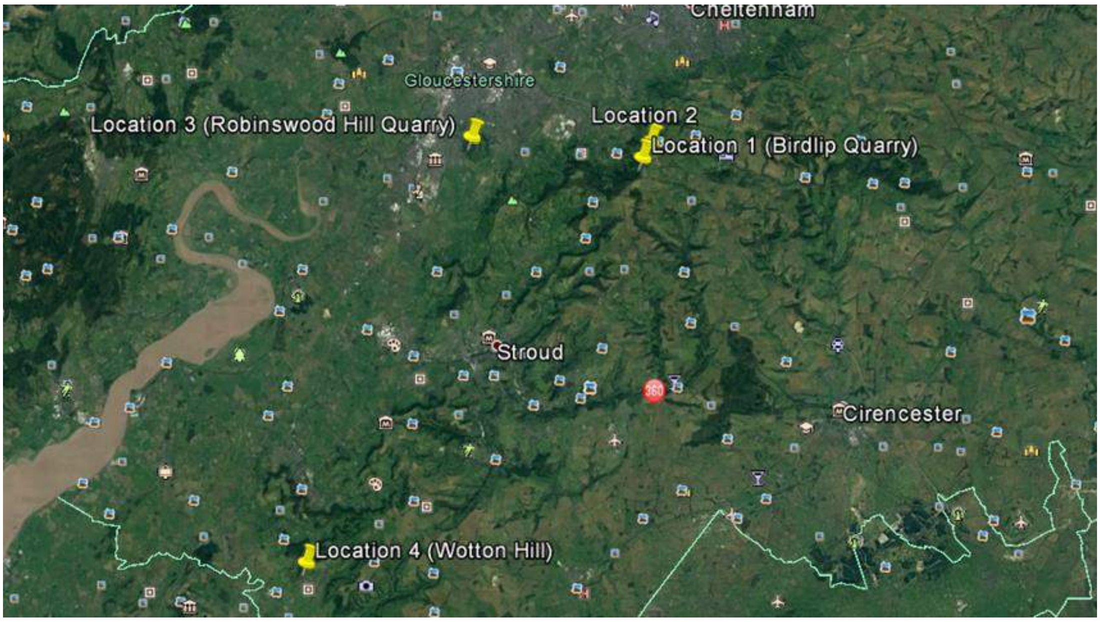
Rock exposures of the Birdlip Limestone Formation, Bridport Sand Formation, Dyrham Formation and Marlstone Rock Formation were observed.

This preliminary rock mass mapping was undertaken to assist in determining the characteristics and quality of rock masses across the proposed scheme and included the following level of detail:

- Annotated sketches
- Photography
- Rock descriptions
- Rock mass classification (Q and RMR schemes) of outcrop where appropriate

The full data sheets are presented below, while the mapping locations are presented below.

Figure D.1: Type rock mass assessment outcrops



Rock mass classification of each location was completed MML Geologists. Rock mass classification systems provide a means of developing a quantitative description of a rock mass for use in engineering design. The Q-system developed by Barton et al (1974) of the Norwegian Geotechnical Institute and the rock mass rating (RMR) system developed by Bieniawski were both used. Both systems are based on observed tunnel behaviour and have had sufficient use to confirm reliable correlations.

Rock Mass Quality (Q-System)

The Q value is a well-recognised parameter for assessing the quantities of support needed to safely construct rock tunnels (Barton et al., 1974). The Q value is determined by assessing 6 parameters:

- rock quality designation, RQD
- number of joint sets, Jn
- joint roughness, Jr
- joint alteration, Ja
- groundwater conditions, Jw
- stress state, SRF

By setting the parameters for groundwater inflow and stress state to unity, a second value (known as Q*) can be derived which relates only to the rock quality. Rock mass mapping included an assessment of Q* at each location. The in-situ stress and groundwater conditions are very important factors in tunnel design for tunnel schemes and the designers need to use the Q* data appropriately.

Rock Mass Rating (RMR)

The RMR classification scheme derives another parameter for assisting with determining the quantities of support appropriate for tunnelling. The 1989 Bieniawski version of the classification has been used on the project. The RMR value is determined by assessing the following parameters:

- unconfined compressive strength, UCS
- rock quality designation, RQD
- spacing of discontinuities
- condition of discontinuities
- groundwater condition
- discontinuity orientation relative to tunnelling

In the classification, adjustment is made for tunnelling orientation and the discontinuity orientation. Due to the very gentle dip of bedding the values presented in this report have been adjusted and assume ‘Fair’ discontinuity orientations. Groundwater values are based on those encountered at outcrop generally completely dry.

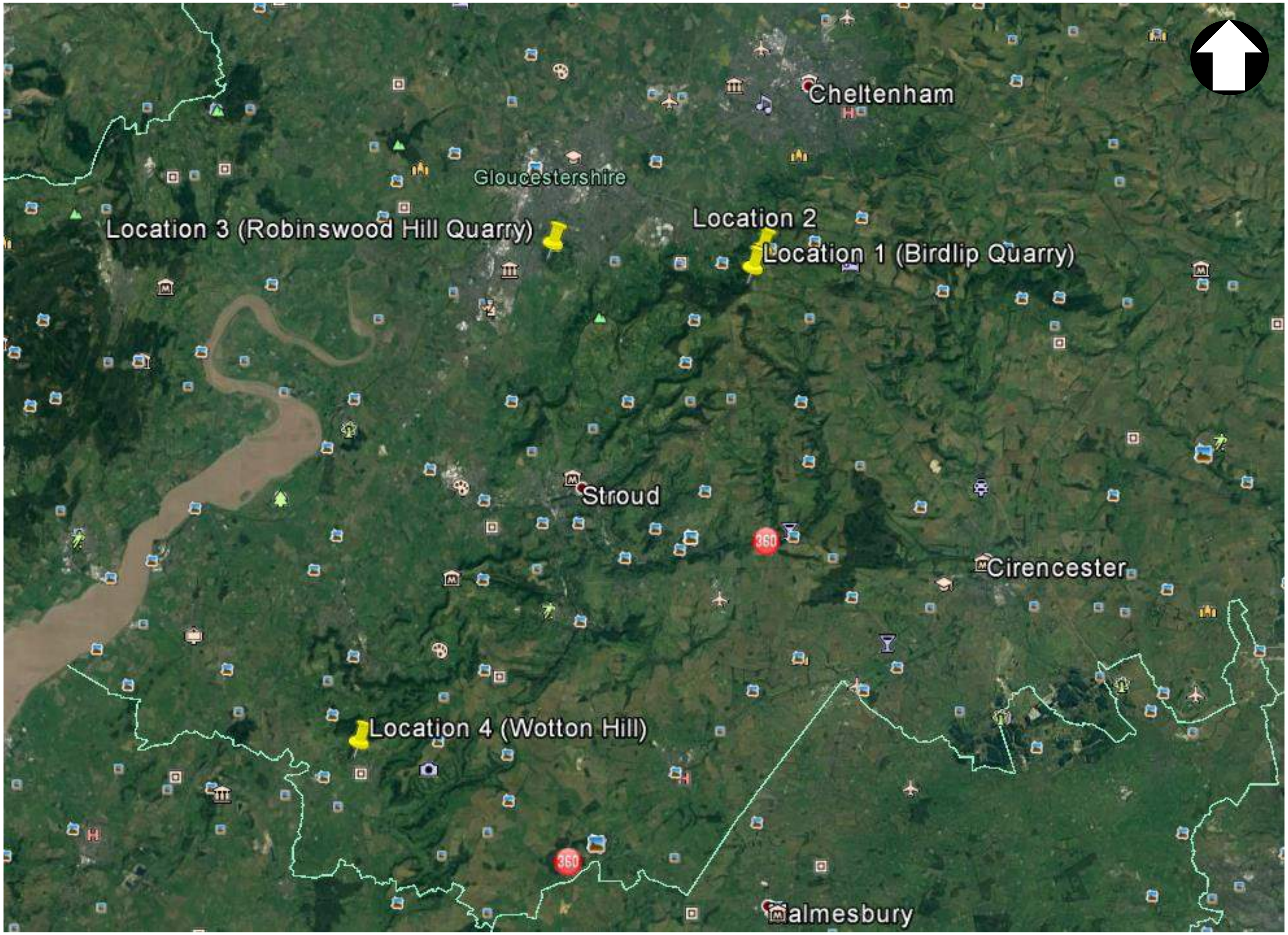
D.2 Rock Mass Properties

Rock Mass Assessment records from the type outcrop assessment are included in the following pages.

A417 Type Outcrop Rock Mass Assessment

Annotated Rock Outcrop Photographs

Locations Assessed



Location 1 (Birdlip Quarry)

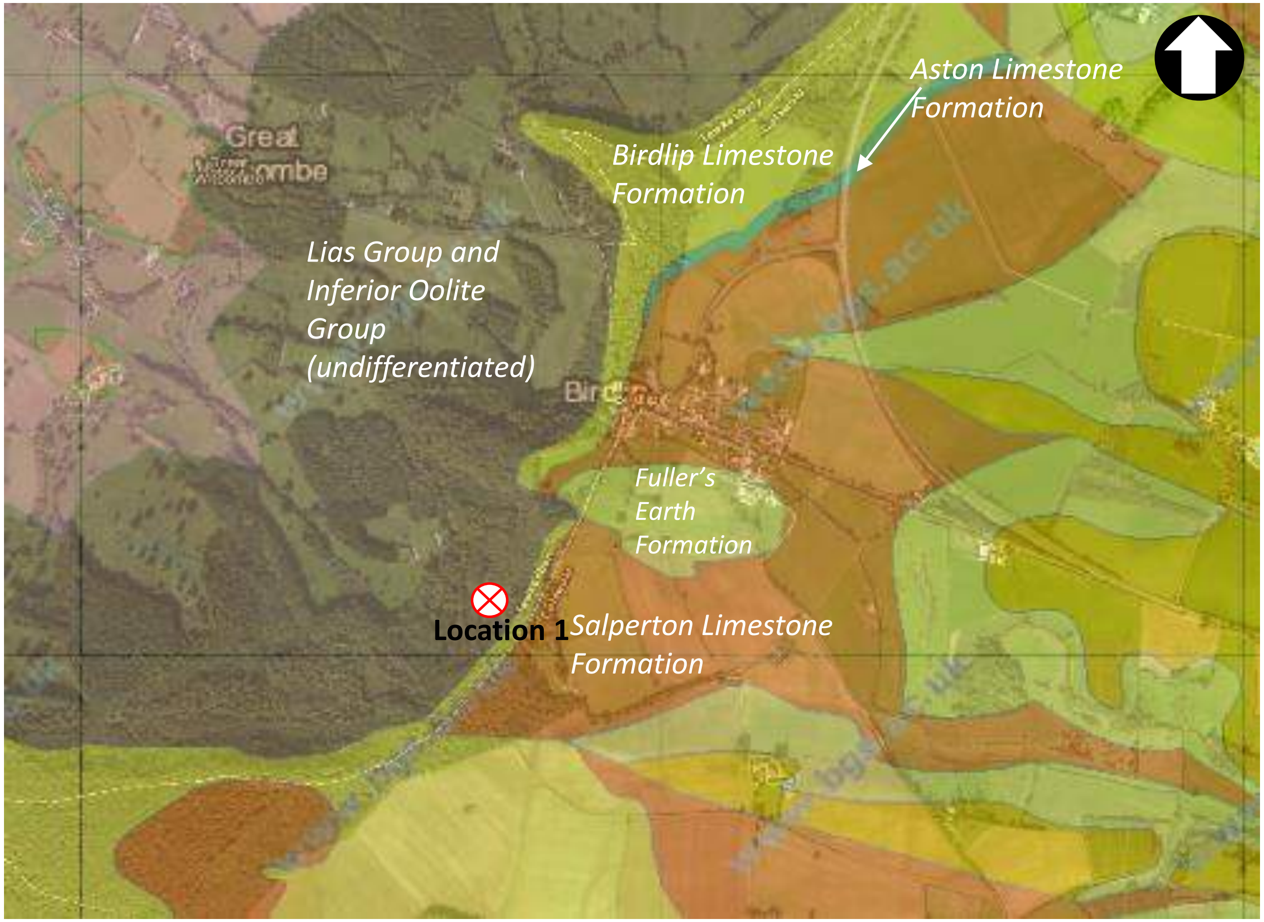
Latitude: 51.8234333

Longitude: -2.11608333333333

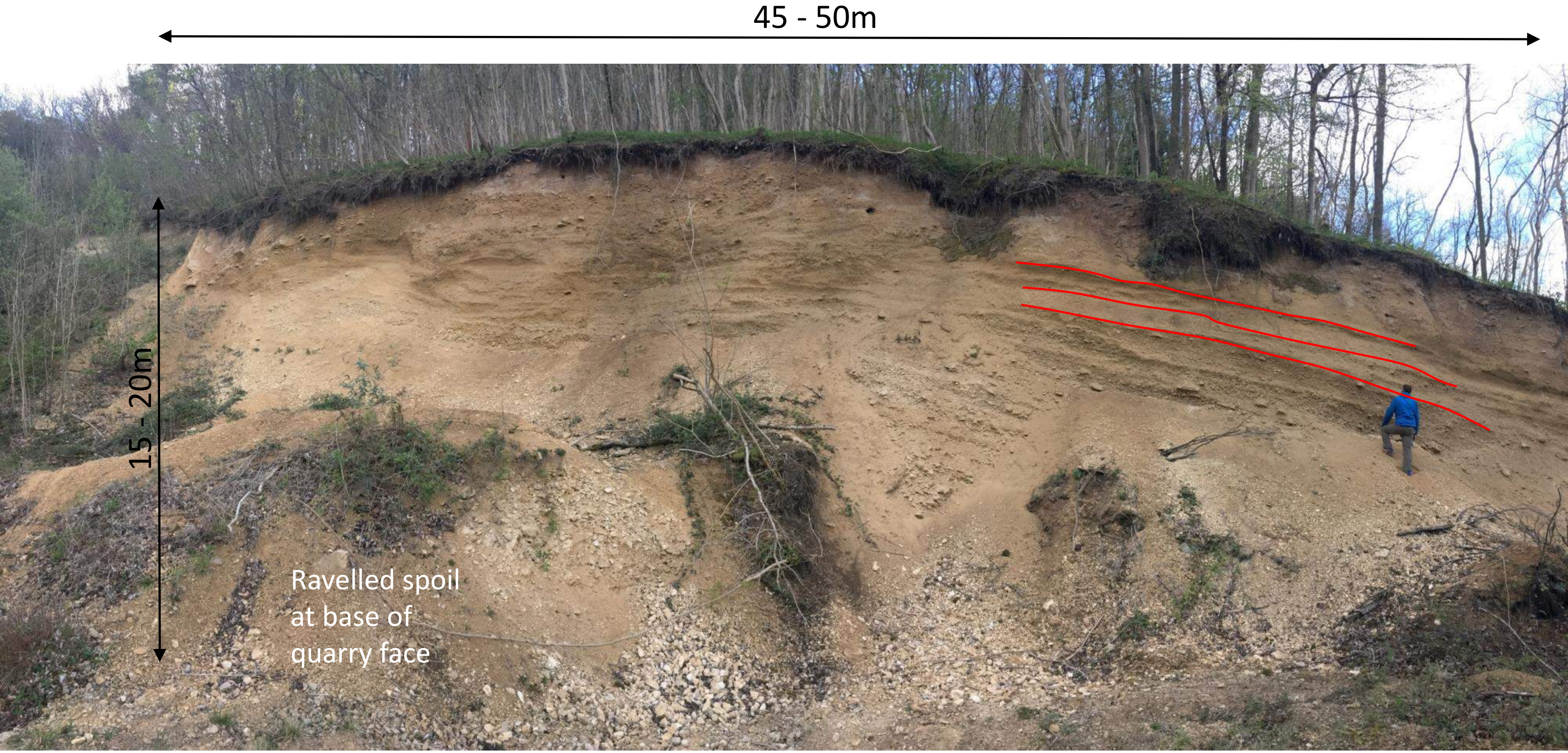
Rock outcrop mapped

Location 1 (Birdlip Quarry)

Published Geology

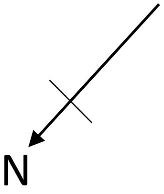


Location 1 (Birdlip Quarry)



Joint Set 1

Image Orientation



Location 2

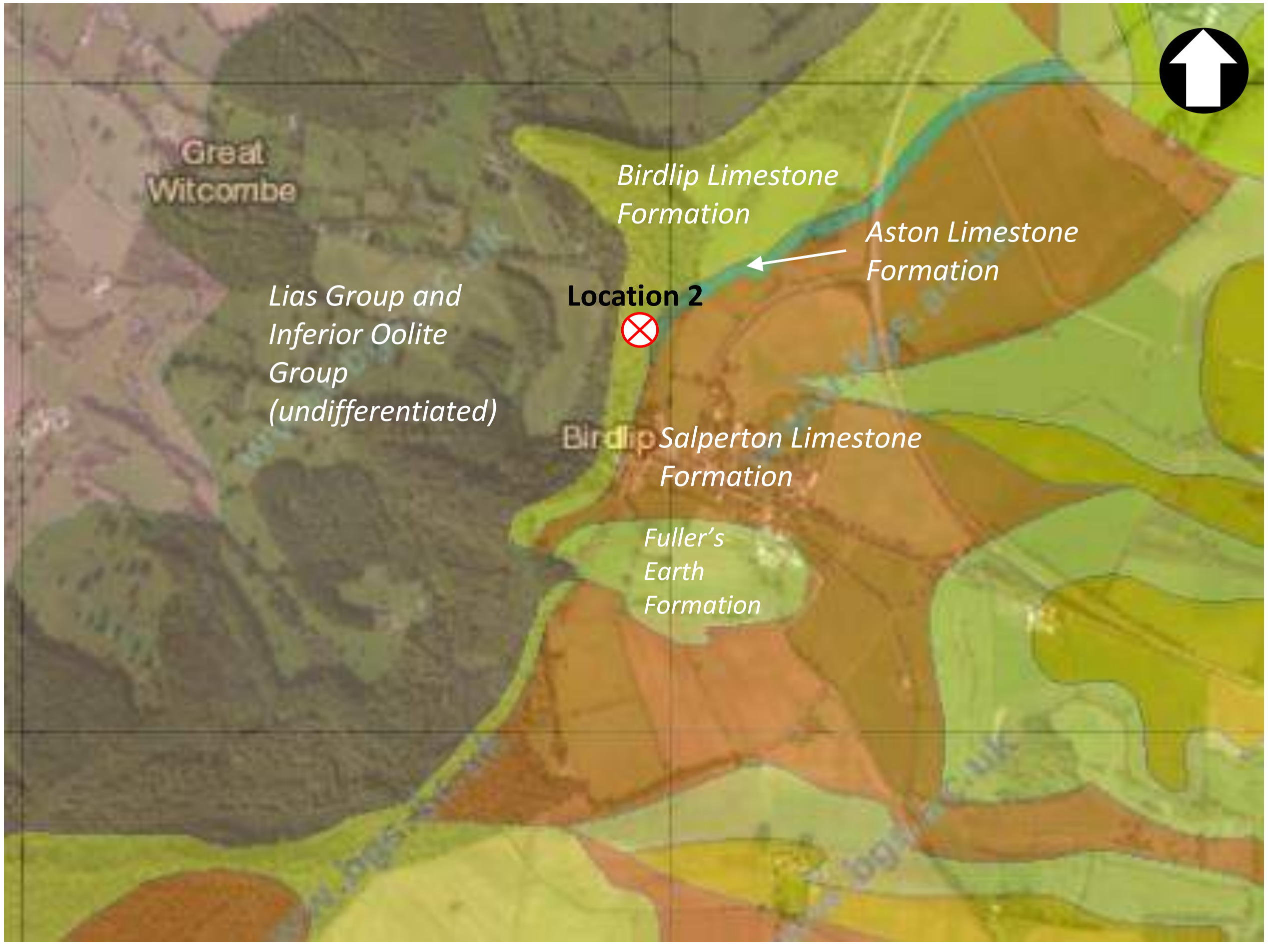
Latitude: 51.8306167

Longitude: -2.11035

Rock outcrop mapped

Location 2

Published Geology



Location 2

Bedding: 1-2/120

Vertical Joints:
90/20(200)

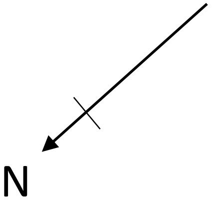
🟥 Joint Set 1 (Bedding)

🟦 Joint Set 2 (Face of Cliff)

🟩 Joint Set 3 (Into Face)

Image Orientation

120°



Location 2

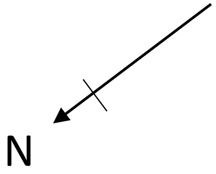
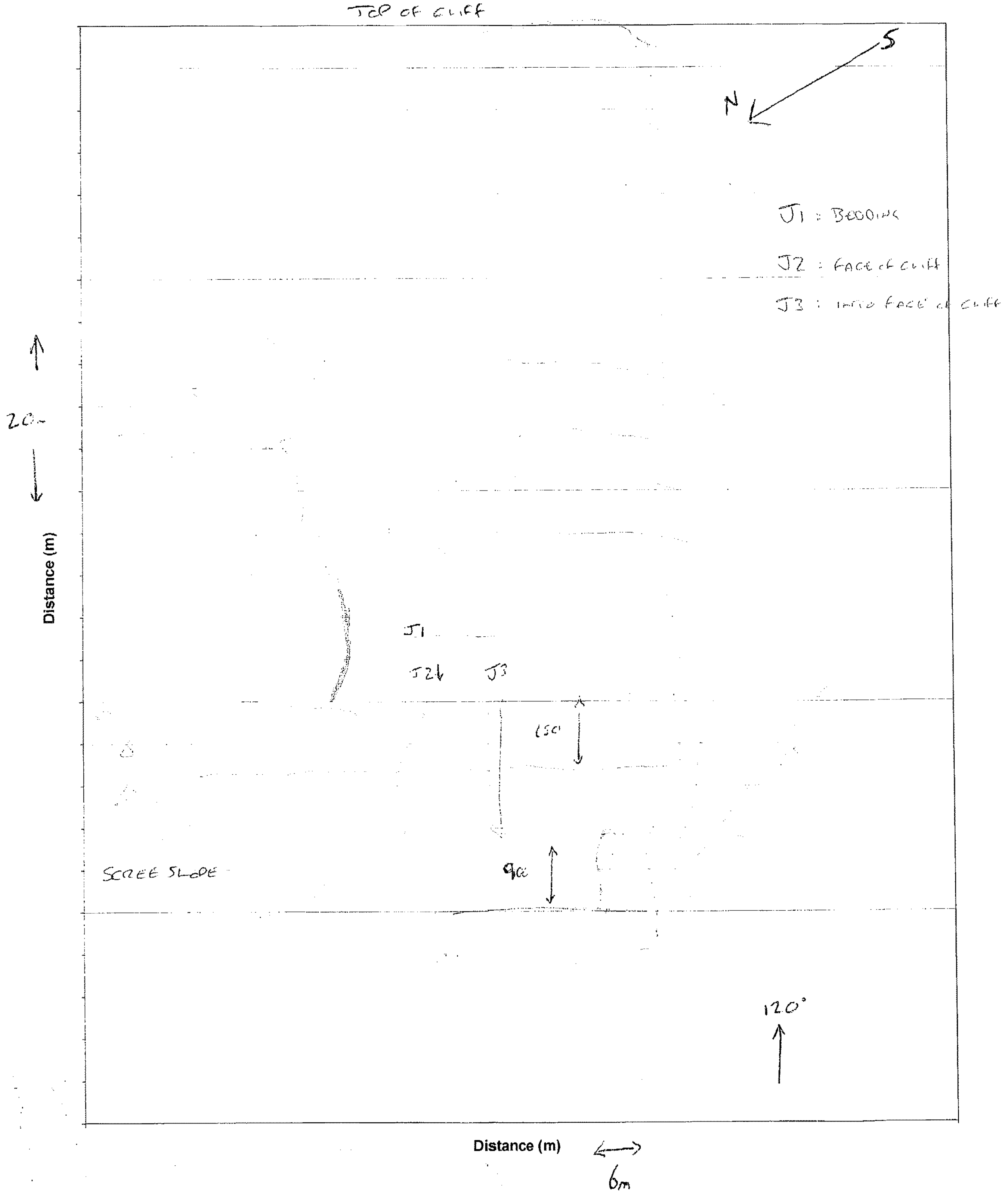


Image Orientation

120°

SECTION SKETCH

Client:	Highways England	**GPS Easting:**	N 51' 49.837
Project:	A417	**GPS Northing:**	W 002° 06.621
Site Location:	L2 - NW BIRDLIP QUARRY	**Date:**	25/4/17
Logged By:	JW	**Time:**	10:40
Checked By:	CB	**Weather:**	SCATTERED CLOUD, SUN, MILD/COLD
Face Orientation	120°		



MOTT MACDONALD

LITHOLOGICAL DESCRIPTION AND DISCONTINUITY SUMMARY

Client:	Highways England	**Site Location:**	L2	**Logged By:**	JW	**GPS Easting:**	N 51° 49. 837
Project:	A417			**Checked By:**		**GPS Northing:**	W 002° 06. 621

LITHOLOGICAL DESCRIPTION

(BS5930 Strength, Structure, Colour, Texture, Grain Size, Rock Type, minor constituents, weathering (describe state and changes in strength, fracture state, colour, presence of absence of weathering products), number and type of discontinuity sets (describe below)

MEDIUM STRONG TO EXTREMELY STRONG, PALE YELLOWISH [illegible] [illegible] [illegible] BROWN DISCOLOURATION, [illegible] OCCASIONALLY [illegible] surface ? [illegible] / [illegible] SLIGHTLY WEATHERED MEDIUM TO THICKLY BEDDED, 3 [illegible] RANDOM DISCONTINUITIES

DISCONTINUITIES SUMMARY

Zone	Discontinuity Set	Dip	Dip Direction	Spacing (mm)			P	R	Aperture (mm)	Infilling		Term 1	Term 2	Per (m)	Amplitude (mm)	Wave Length (m)	Weathering	Wall Strength	Water	Comments
				Min	Max	Typ														
-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
	C1	1-2	120	300	1000	600	U	R			—			10m	—	—	SW	MS-VS	D	
	C2	90	20(20-)	500	4000	1500	U	R	1-20	N-S	SA	D		3m	—	—	SW	MS-VS	D	
	C3	90	120(30)	100	600	400	U	R	0-20	N-S	-	D		3m	—	—	SW	MS-VS	D	

PLANARITY (7)	ROUGHNESS (8)	INFILLING (10)	INFILLING (11)	TERMINATION (12,13)	WEATHERING (17)	STRENGTH (18)	WATER (19)
P-Planar U-Undulating/Curved S-Stepped	K-Slickensided S-Smooth R-Rough	N-Clean Surface F-Surface Film (<0.5mm) S-Soil C-Cemented (>0.5mm) B-Breccia X-Other	CL-clay SI-Silt SA-Sand I-Iron Oxides C-Calcite/Carbonate Q-Quartz/Silica S-Iron Sulphides, pyrite X-Other (comment)	D-Terminates against another discontinuity R-Terminates within exposure X-Extends beyond exposure	F-Fresh SW-Slightly Weathered MW-Moderately weathered HW-Highly Weathered CW-Completely Weathered RS-Residual Soil	EW-Extremely Weak VW-Very Weak W-Weak MS-Moderately Strong S-Strong VS-Very Strong ES-Extremely Strong	D-Dry ST-Stained DA-Damp S-Seepage F-Flow (quantify in comments)

MOTT MACDONALD

RMR - Rock Mass Classification

Client: Highways England
Project: A417

Site Location: L2 (Birdlip Limestone)
Logged By: JW
Checked By: CB

Chainage: NA

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values							
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred			
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa	12
	Rating		15 →	12	7	4	2	1	0	
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%			
	Rating		20	17	13	8	3			20
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm			
	Rating		20	15 ←	→ 10	8	5			10 - 15
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous			
	Rating		30	25 ←	→ 20	10	0			23
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125			
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5			
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing			
	Rating		15	10	7	4	0			15

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable	
Ratings	Tunnels & mines	0	-2	-5	-10	-12	- 5
	Foundations	0	-2	-7	-15	-25	
	Slopes	0	-5	-25	-50		

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

SUMMARY **RMR = A+B**

Rating: 72 - 81

MOTT MACDONALD

Q System - Rock Mass Classification

L2 - Phillip Limestone Formation

1. ROCK QUALITY DESIGNATION	*RQD*
A. Very poor	0 - 25
B. Poor	25 - 50
C. Fair	50 - 75
D. Good	75 - 90
E. Excellent	90 - 100

2. JOINT SET NUMBER	J_n
A. Massive, no or few joints	0.5 - 1.0
B. One joint set	2
C. One joint set plus random	3
D. Two joint sets	4
E. Two joint sets plus random	6
F. Three joint sets	9
G. Three joint sets plus random	12
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J. Crushed rock, earthlike	20

3. JOINT ROUGHNESS NUMBER	J_r
a. Rock wall contact and	
b. Rock wall contact before 10 cm shear	
A. Discontinuous joints	4
B. Rough and irregular, undulating	3
C. Smooth undulating	2
D. Slickensided undulating	1.5
E. Rough or irregular, planar	1.5
F. Smooth, planar	1.0
G. Slickensided, planar	0.5
c. No rock wall contact when sheared	
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)

4. JOINT ALTERATION NUMBER	J_a
a. Rock wall contact	
A. Tightly healed, hard, non-softening, impermeable filling	0.75
B. Unaltered joint walls, surface staining only	1.0
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0

SUMMARY:

RQD = 90

Jn = 9 → 12

Jr = 3

Ja = 1.0

Jw

SRF

Rock Quality Index $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

4. JOINT ALTERATION NUMBER	J_a
b. Rock wall contact before 10 cm shear	
F. Sandy particles, clay-free, disintegrating rock etc.	4.0
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0
c. No rock wall contact when sheared	
K. Zones or bands of disintegrated or crushed	6.0
L. rock and clay (see G, H and J for clay	8.0
M. conditions)	8.0 - 12.0
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0
O. Thick continuous zones or bands of clay	10.0 - 13.0
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0

5. JOINT WATER REDUCTION	J_w
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66
C. Large inflow or high pressure in competent rock with unfilled joints	0.5
D. Large inflow or high pressure	0.33
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1
F. Exceptionally high inflow or pressure	0.1 - 0.05

6. STRESS REDUCTION FACTOR	*SRF*
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)	10.0
B. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth < 50 m)	5.0
C. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth > 50 m)	2.5
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)	5.0
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)	2.5
G. Loose open joints, heavily jointed or 'sugar cube'. (any depth)	5.0

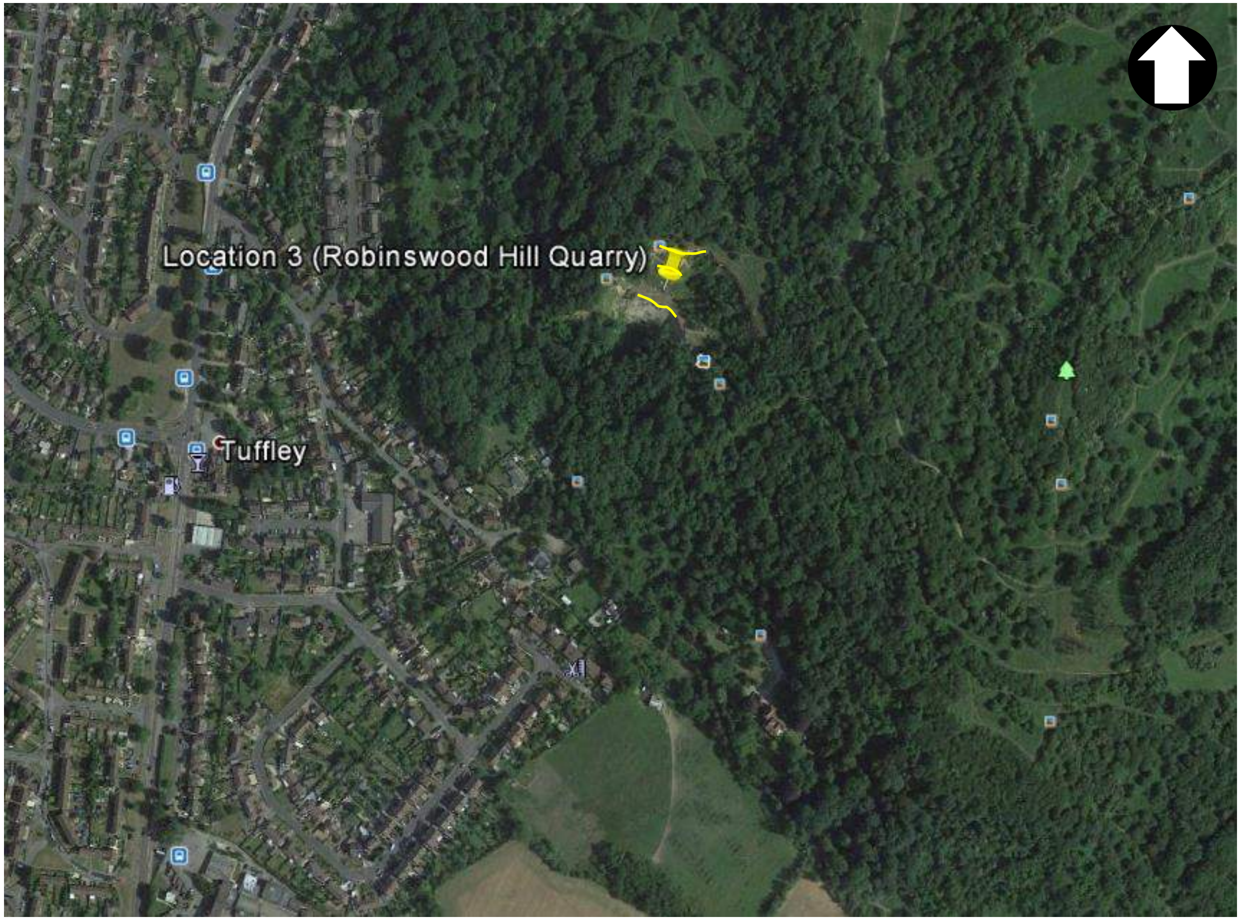
6. STRESS REDUCTION FACTOR			*SRF*
b. Competent rock, rock stress problems	σ_c/σ_1	$\sigma_t\sigma_1$	
H. Low stress, near surface	> 200	> 13	2.5
J. Medium stress	200 - 10	13 - 0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure			
N. Mild squeezing rock pressure			5 - 10
O. Heavy squeezing rock pressure			10 - 20
d. Swelling rock, chemical swelling activity depending on presence of water			
P. Mild swelling rock pressure			5 - 10
R. Heavy swelling rock pressure			10 - 15

Q = $\frac{90}{9(12}$ **x** $\frac{3}{1}$ **x** **=** 22.5 → 30

Location 3 (Robinswood Hill Quarry)

Latitude: 51.8329

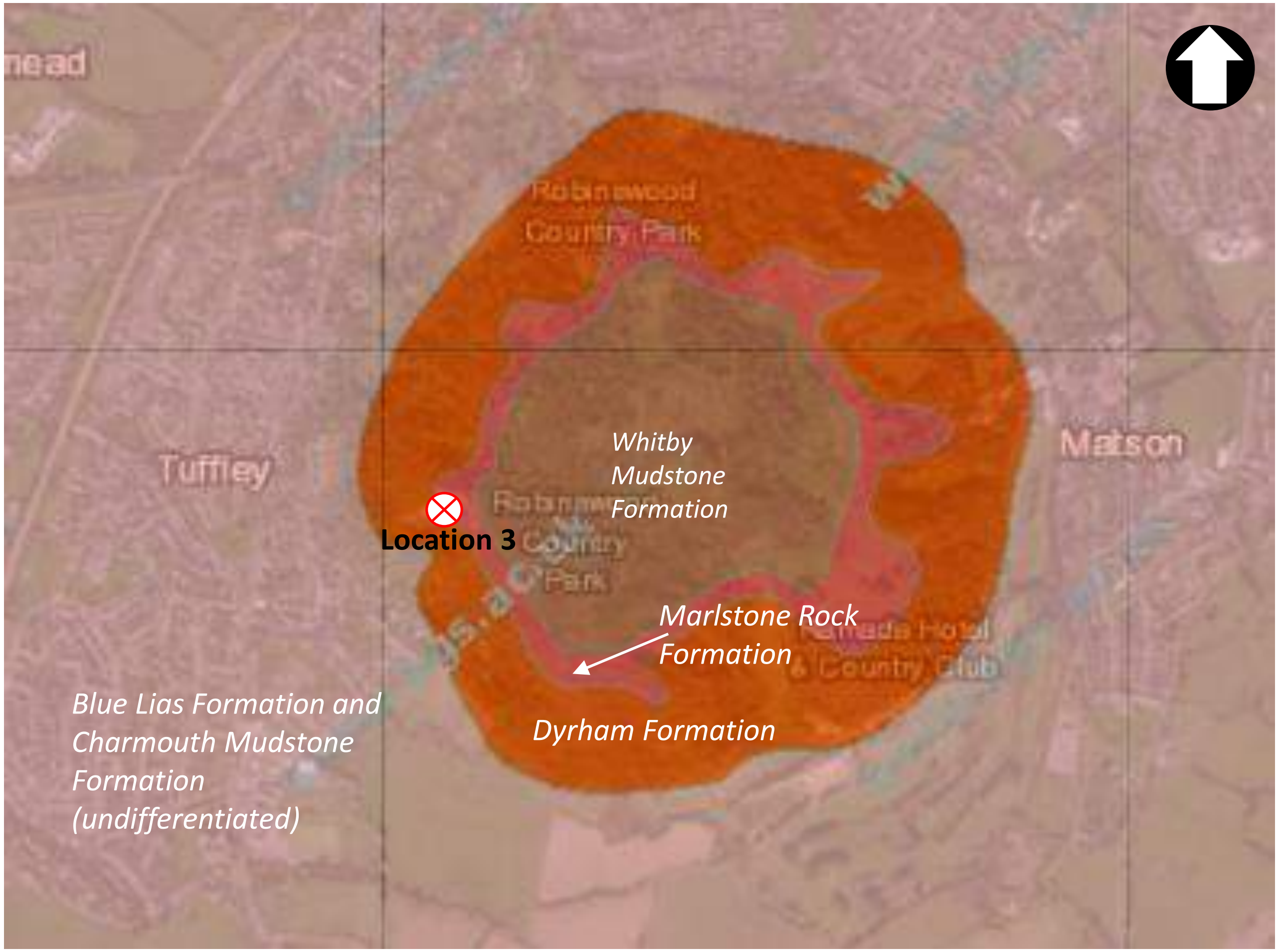
Longitude: -2.23946666666666



Rock outcrop mapped

Location 3 (Robinswood Hill Quarry)

Published Geology



Location 3

- 🟥 Joint Set 1 (Bedding)
- 🟥 🟥 Joint Set 1 (Indicative of Bedding for Massive)
- 🟦 Joint Set 2 (Face of Cliff)
- 🟩 Joint Set 3 (Into Face)

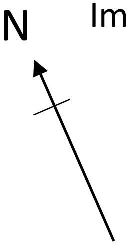
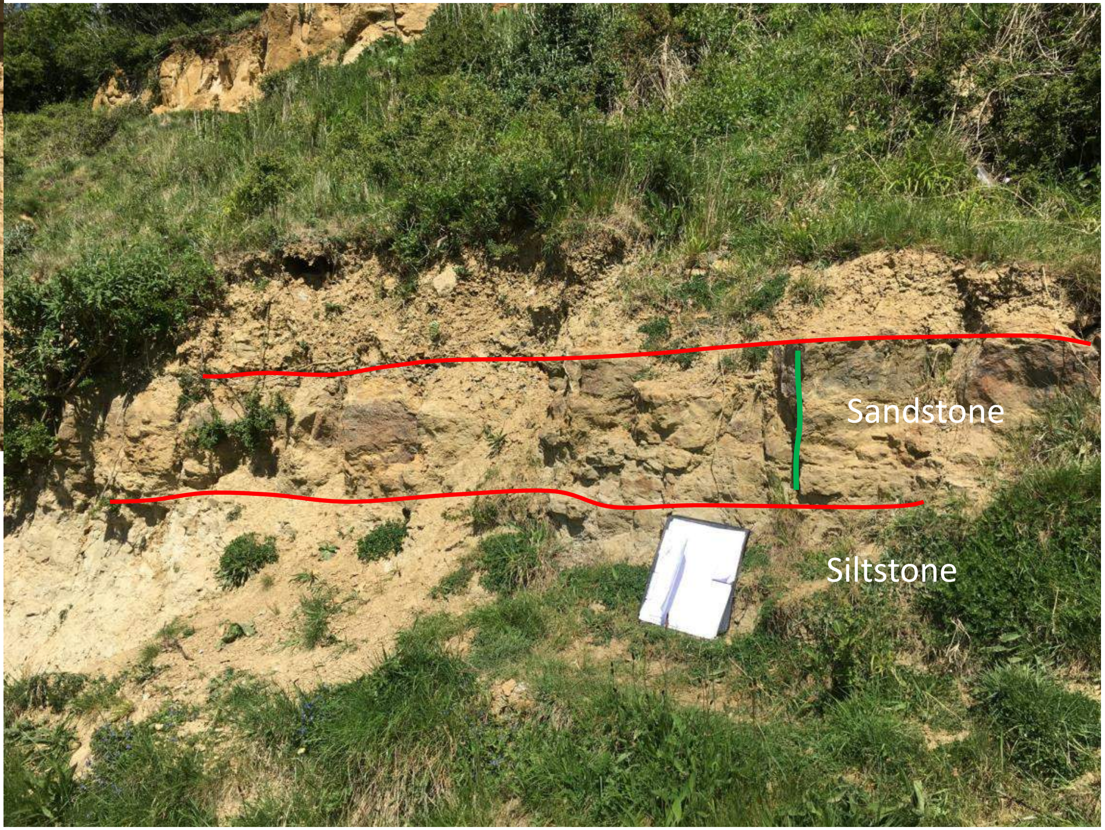


Image Orientation

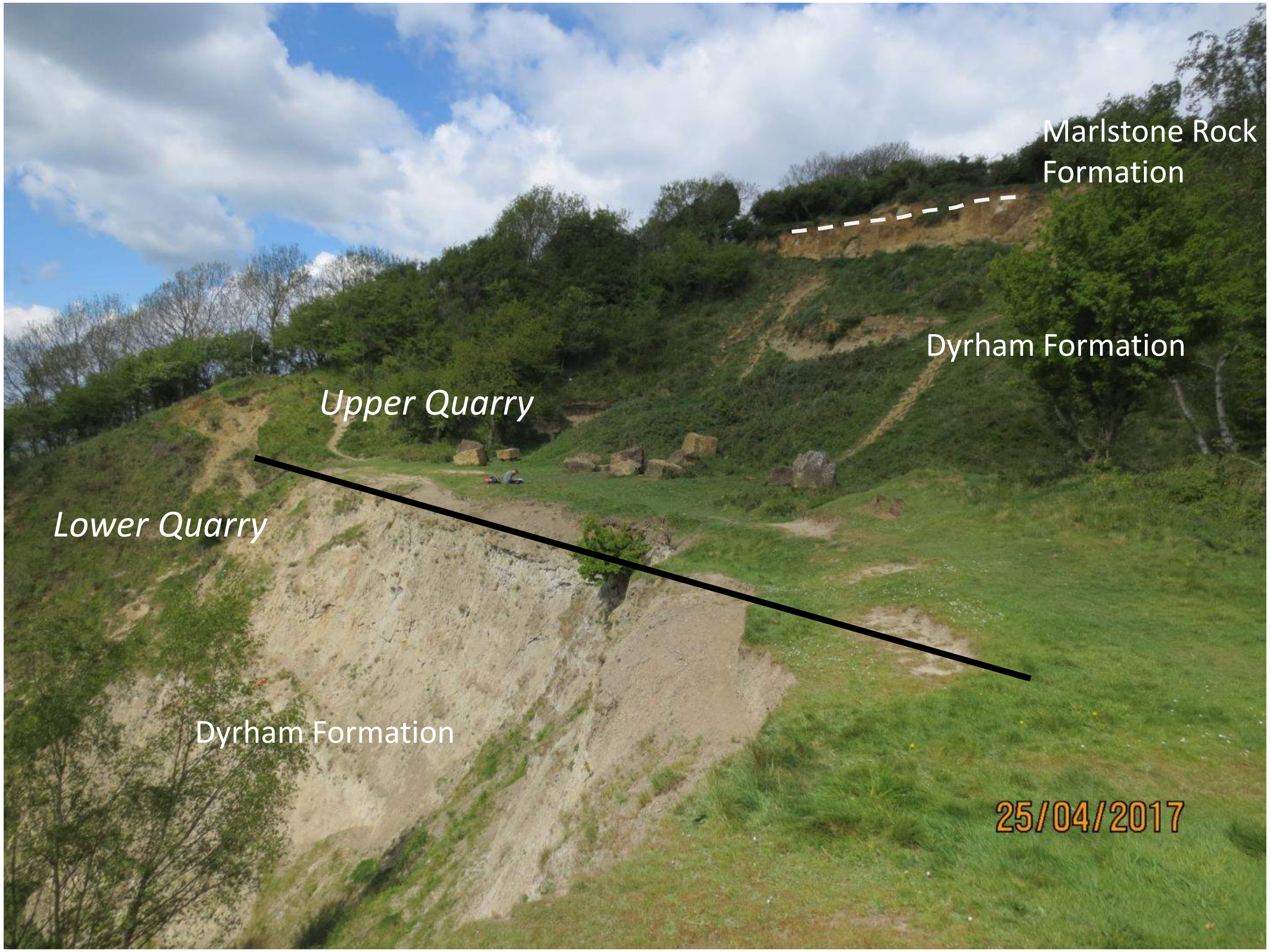
30°

Location 3

Fine silty micaceous ferruginous Sandstone overlying friable micaceous Siltstone



Location 3


Marlstone Rock Formation
Upper Quarry
Dyrham Formation
Lower Quarry
Dyrham Formation
25/04/2017

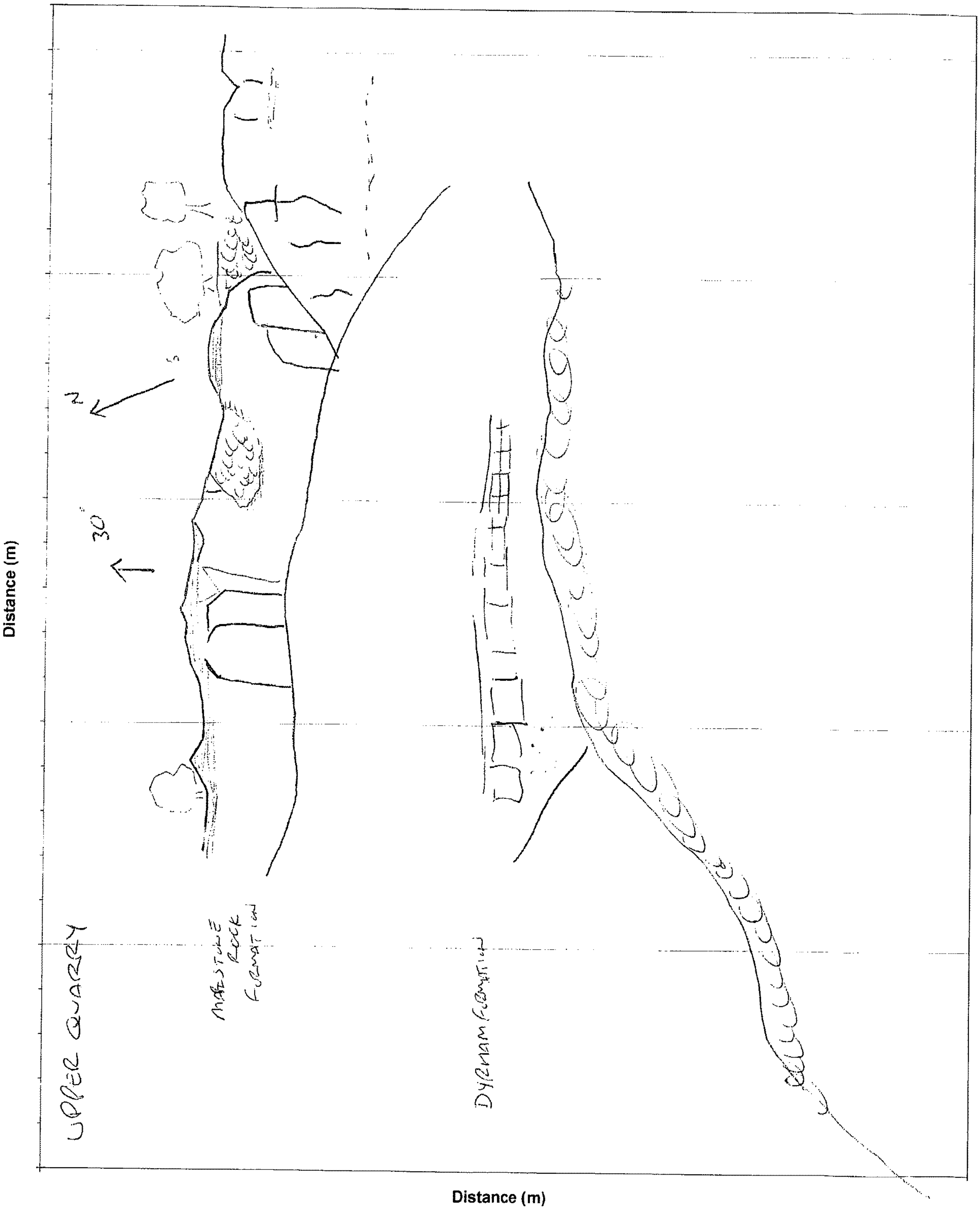
Location 3

Dyrham Formation overlying
Charmouth Mudstone
Formation

MOTT MACDONALD

SECTION SKETCH

Client:	Highways England	**GPS Easting:**	N. 51° 49.974
Project:	A417	**GPS Northing:**	W 002° 14.368
Site Location:	L3 - TOP OF ROBINSWOOD QUARRY	**Date:**	25/4/17
Logged By:	JW	**Time:**	12.30
Checked By:		**Weather:**	
Face Orientation	30°		



MOTT MACDONALD

LITHOLOGICAL DESCRIPTION AND DISCONTINUITY SUMMARY

Client: Highways England

Project: A417

Site Location: L3

Logged By: JW

Checked By: CB

GPS Easting: N 51° 49.974

GPS Northing: W 002° 14.369

LITHOLOGICAL DESCRIPTION

(BS5930 Strength, Structure, Colour, Texture, Grain Size, Rock Type, minor constituents, weathering (describe state and changes in strength, fracture state, colour, presence of absence of weathering products), number and type of discontinuity sets (describe below)

MARLSTONE · VERY ~~HIGHLY~~ TO EXTREMELY STRONG, MASSIVE, BROWNISH YELLOW, LIMESTONE WITH FINE SANDSTONE AT BASE SLIGHTLY TO MODERATELY WEATHERED, LOCALLY REDUCED STRENGTH, DISCOLOURED, IRON STAINING, ON SOME FACES, VERTICAL AND HORIZONTAL (BEDDING) FRACTURES.

SANDSTONE HIGHLY WEATHERED, FRIABLE. ~~MASSIV~~ FINE SILTY MICACEOUS SANDSTONE. YELLOW - BUFF WEATHERED COLOUR

SILTSTONE · HIGHLY WEATHERED, THINLY BEDDED, LAMINATED PALE GREENISH GREY FRIABLE MICACEOUS SILTSTONE.

DISCONTINUITIES SUMMARY

Zone	Discontinuity Set	Dip	Dip Direction	Spacing (mm)			P	R	Aperture (mm)	Infilling		Term 1	Term 2	Per (m)	Amplitude (mm)	Wave Length (m)	Weathering	Wall Strength	Water	Comments
				Min	Max	Typ														
-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	

PLANARITY (7)
- P-Planar
- U-Undulating/Curved
- S-Stepped

ROUGHNESS (8)
- K-Slickensided
- S-Smooth
- R-Rough

INFILLING (10)
- N-Clean Surface
- F-Surface Film (<0.5mm)
- S-Soil
- C-Cemented (>0.5mm)
- B-Breccia
- X-Other

INFILLING (11)
- CL-clay
- SI-Silt
- SA-Sand
- I-Iron Oxides
- C-Calcite/Carbonate
- Q-Quartz/Silica
- S-Iron Sulphides. pyrite
- X-Other (comment)

TERMINATION (12,13)
- D-Terminates against another discontinuity
- R-Terminates within exposure
- X-Extends beyond exposure

WEATHERING (17)
- F-Fresh
- SW-Slightly Weathered
- MW-Moderately weathered
- HW-Highly Weathered
- CW-Completely Weathered
- RS-Residual Soil

STRENGTH (18)
- EW-Extremely Weak
- VW-Very Weak
- W-Weak
- MS-Moderately Strong
- S-Strong
- VS-Very Strong
- ES-Extremely Strong

WATER (19)
- D-Dry
- ST-Stained
- DA-Damp
- S-Seepage
- F-Flow (quantify in comments)

MOTT MACDONALD

RMR - Rock Mass Classification

Client: Highways England
Project: A417

Site Location: L3 - DYRHAM SILTSTONE
Logged By: JW
Checked By: CB

Chainage: NA

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values							
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred			
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	[✓ 1 - 5 MPa]	< 1 MPa	
	Rating		15	12	7	4	2	[✓ 1]	0	1
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%			
	Rating		20	17	13	[✓ 8] ←→	[✓ 3]			3 – 8
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm			
	Rating		20	15	10	[✓ 8] ←→	[✓ 5]			5 – 8
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous			
	Rating		30	25	[✓ 20]	10	0			20
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125			
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1 - 0.2	0.2 - 0.5	> 0.5			
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing			
	Rating		[✓ 15]	10	7	4	0			15

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable	
Ratings	Tunnels & mines	0	-2	[✓ -5]	-10	-12	– 5
	Foundations	0	-2	-7	-15	-25	
	Slopes	0	-5	-25	-50		

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	[✓ 40 ← 21]	< 21
Class number	I	II	III	[✓ IV]	V
Description	Very good rock	Good rock	Fair rock	[✓ Poor rock]	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

SUMMARY **RMR = A+B**

Rating: 39 → 47

MOTT MACDONALD

Q System - Rock Mass Classification

L3 - Robinswood Hill Quarry - Dyrham Formation

1. ROCK QUALITY DESIGNATION

	RQD
A. Very poor	0 - 25
B. Poor	25 - 50
C. Fair	50 - 75
D. Good	75 - 90
E. Excellent	90 - 100

2. JOINT SET NUMBER

	J_n
A. Massive, no or few joints	0.5 - 1.0
B. One joint set	2
C. One joint set plus random	3
D. Two joint sets	4
E. Two joint sets plus random	6
F. Three joint sets	9
G. Three joint sets plus random	12
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J. Crushed rock, earthlike	20

3. JOINT ROUGHNESS NUMBER

	J_r
a. Rock wall contact and	
b. Rock wall contact before 10 cm shear	
A. Discontinuous joints	4
B. Rough and irregular, undulating	3
C. Smooth undulating	2
D. Slickensided undulating	1.5
E. Rough or irregular, planar	1.5
F. Smooth, planar	1.0
G. Slickensided, planar	0.5
c. No rock wall contact when sheared	
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)

4. JOINT ALTERATION NUMBER

	J_a
a. Rock wall contact	
A. Tightly healed, hard, non-softening, impermeable filling	0.75
B. Unaltered joint walls, surface staining only	1.0
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0

SUMMARY:

RQD

Jn

Jr

Ja

Jw

SRF

Rock Quality Index $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

4. JOINT ALTERATION NUMBER

	J_a
b. Rock wall contact before 10 cm shear	
F. Sandy particles, clay-free, disintegrating rock etc.	4.0
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0
c. No rock wall contact when sheared	
K. Zones or bands of disintegrated or crushed	6.0
L. rock and clay (see G, H and J for clay	8.0
M. conditions)	8.0 - 12.0
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0
O. Thick continuous zones or bands of clay	10.0 - 13.0
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0

5. JOINT WATER REDUCTION

	J_w
A. Dry excavation or minor inflow i.e. < 5 l/m locally	1.0
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66
C. Large inflow or high pressure in competent rock with unfilled joints	0.5
D. Large inflow or high pressure	0.33
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1
F. Exceptionally high inflow or pressure	0.1 - 0.05

6. STRESS REDUCTION FACTOR

	SRF
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)	10.0
B. Single weakness zones containing clay, or chemically distegrated rock (excavation depth < 50 m)	5.0
C. Single weakness zones containing clay, or chemically distegrated rock (excavation depth > 50 m)	2.5
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)	5.0
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)	2.5
G. Loose open joints, heavily jointed or 'sugar cube'. (any depth)	5.0

6. STRESS REDUCTION FACTOR

	σ_c/σ_1	$\sigma_t\sigma_1$	SRF
b. Competent rock, rock stress problems			
H. Low stress, near surface	> 200	> 13	2.5
J. Medium stress	200 - 10	13 - 0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure			
N. Mild squeezing rock pressure			5 - 10
O. Heavy squeezing rock pressure			10 - 20
d. Swelling rock, chemical swelling activity depending on presence of water			
P. Mild swelling rock pressure			5 - 10
R. Heavy swelling rock pressure			10 - 15

$$Q = \frac{15(60)}{9(6)} \times \frac{3}{4(2)} \times \quad = 166 \rightarrow 10$$

MOTT MACDONALD

RMR - Rock Mass Classification

Client: Highways England
Project: A417

Site Location: L3 MARLSTONE
Logged By: JW
Checked By:

Chainage:

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values					
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred	
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa 1 - 5 MPa < 1 MPa	
	Rating		[✓ 15]	[✓ 12]	7	4	2 1 0	15
2	Drill core Quality RQD		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%	
	Rating		[✓ 20]	17	13	8	3	20
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm	
	Rating		20	[✓ 15]	10	8	5	15
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous	
	Rating		30	[✓ 25]	20	10	0	25
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125	
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5	
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing	
	Rating		[✓ 15]	10	7	4	0	15

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable	
Ratings	Tunnels & mines	0	-2	[✓ -5]	-10	-12	-5
	Foundations	0	-2	-7	-15	-25	
	Slopes	0	-5	-25	-50		

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	[✓ Fair]	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et al (1972).

SUMMARY **RMR = A+B**

Rating: 82 - 85

M M
MOTT MACDONALD

Q System - Rock Mass Classification

L3 - Robinstown 4th Quarry - [illegible] Rock

1. ROCK QUALITY DESIGNATION	*RQD*
A. Very poor	0 - 25
B. Poor	25 - 50
C. Fair	50 - 75
D. Good	75 - 90
E. Excellent	[✓ 90 - 100]

2. JOINT SET NUMBER	J_n
A. Massive, no or few joints	0.5 - 1.0
B. One joint set	2
C. One joint set plus random	[✓ 3]
D. Two joint sets	[✓ 4]
E. Two joint sets plus random	[✓ 6]
F. Three joint sets	9
G. Three joint sets plus random	12
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J. Crushed rock, earthlike	20

3. JOINT ROUGHNESS NUMBER	J_r
a. Rock wall contact and	
b. Rock wall contact before 10 cm shear	
A. Discontinuous joints	4
B. Rough and irregular, undulating	[✓ 3]
C. Smooth undulating	2
D. Slickensided undulating	1.5
E. Rough or irregular, planar	1.5
F. Smooth, planar	1.0
G. Slickensided, planar	0.5
c. No rock wall contact when sheared	
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)

4. JOINT ALTERATION NUMBER	J_a
a. Rock wall contact	
A. Tightly healed, hard, non-softening, impermeable filling	0.75
B. Unaltered joint walls, surface staining only	[✓ 1.0]
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	2.0
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0

SUMMARY:
RQD
Jn
Jr
Ja
Jw
SRF

Rock Quality Index $Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$

4, JOINT ALTERATION NUMBER	J_a
b. Rock wall contact before 10 cm shear	
F. Sandy particles, clay-free, disintegrating rock etc.	4.0
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0
c. No rock wall contact when sheared	
K. Zones or bands of disintegrated or crushed	6.0
L. rock and clay (see G, H and J for clay	8.0
M. conditions)	8.0 - 12.0
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0
O. Thick continuous zones or bands of clay	10.0 - 13.0
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0

5. JOINT WATER REDUCTION	J_w
A. Dry excavation or minor inflow i.e. < 5 l/m locally	[✓ 1.0]
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66
C. Large inflow or high pressure in competent rock with unfilled joints	0.5
D. Large inflow or high pressure	0.33
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1
F. Exceptionally high inflow or pressure	0.1 - 0.05

6. STRESS REDUCTION FACTOR	*SRF*
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)	10.0
B. Single weakness zones containing clay, or chemically distegrated rock (excavation depth < 50 m)	5.0
C. Single weakness zones containing clay, or chemically distegrated rock (excavation depth > 50 m)	2.5
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)	5.0
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)	2.5
G. Loose open joints, heavily jointed or 'sugar cube'. (any depth)	5.0

6. STRESS REDUCTION FACTOR			*SRF*
b. Competent rock, rock stress problems			
	σ_c/σ_1	$\sigma_t\sigma_1$	
H. Low stress, near surface	> 200	> 13	2.5
J. Medium stress	200 - 10	13 - 0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure			
N. Mild squeezing rock pressure			5 - 10
O. Heavy squeezing rock pressure			10 - 20
d. Swelling rock, chemical swelling activity depending on presence of water			
P. Mild swelling rock pressure			5 - 10
R. Heavy swelling rock pressure			10 - 15

$Q^{*} = \frac{95}{3(6)} \times \frac{3}{1} \times \quad = 47.5 \rightarrow 95$

Location 4 (Wotton Hill)

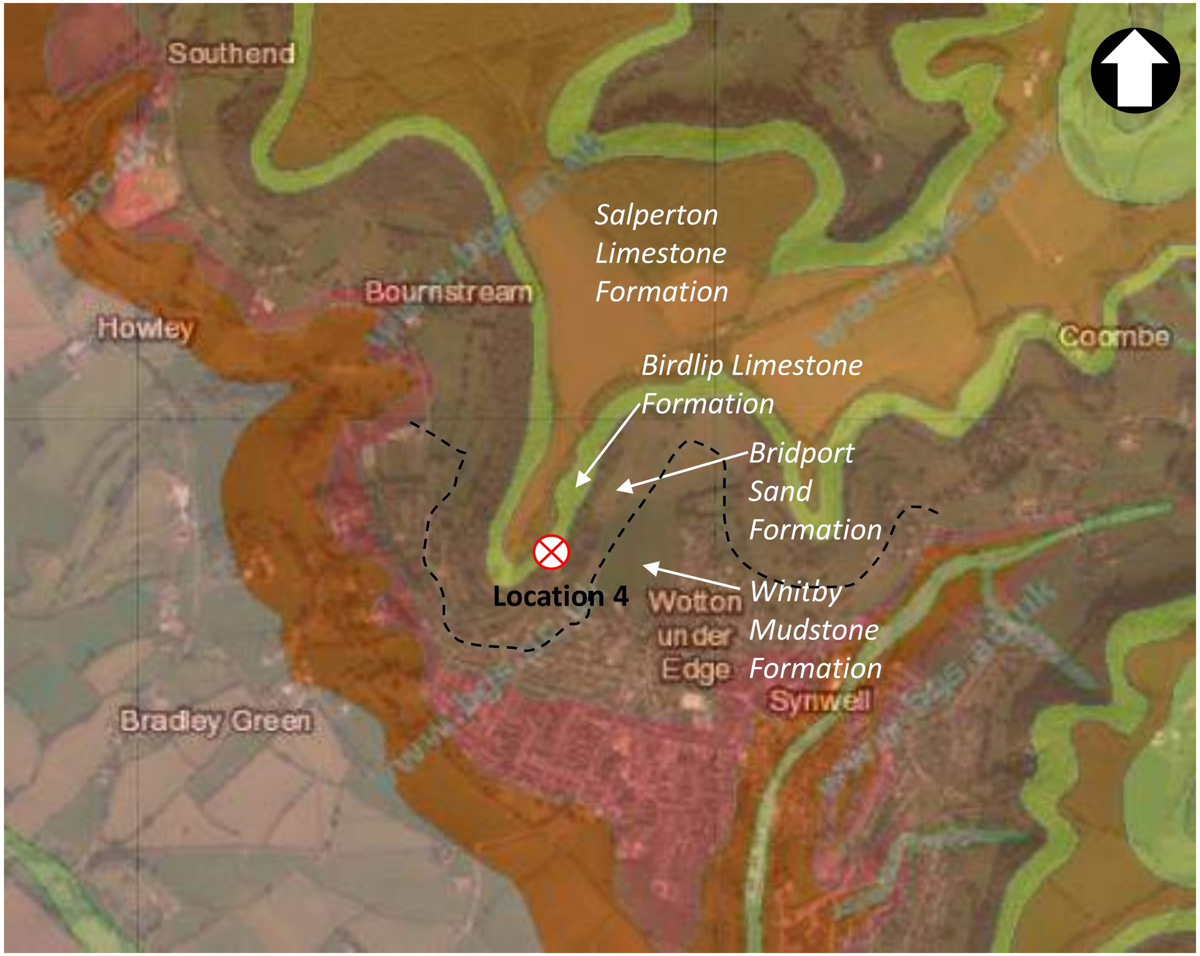
Latitude: 51.6420833

Longitude: -2.35766666666666

Rock outcrop mapped

Location 4 (Wotton Hill)

Published Geology



Legend

Strata Boundary

Location 4

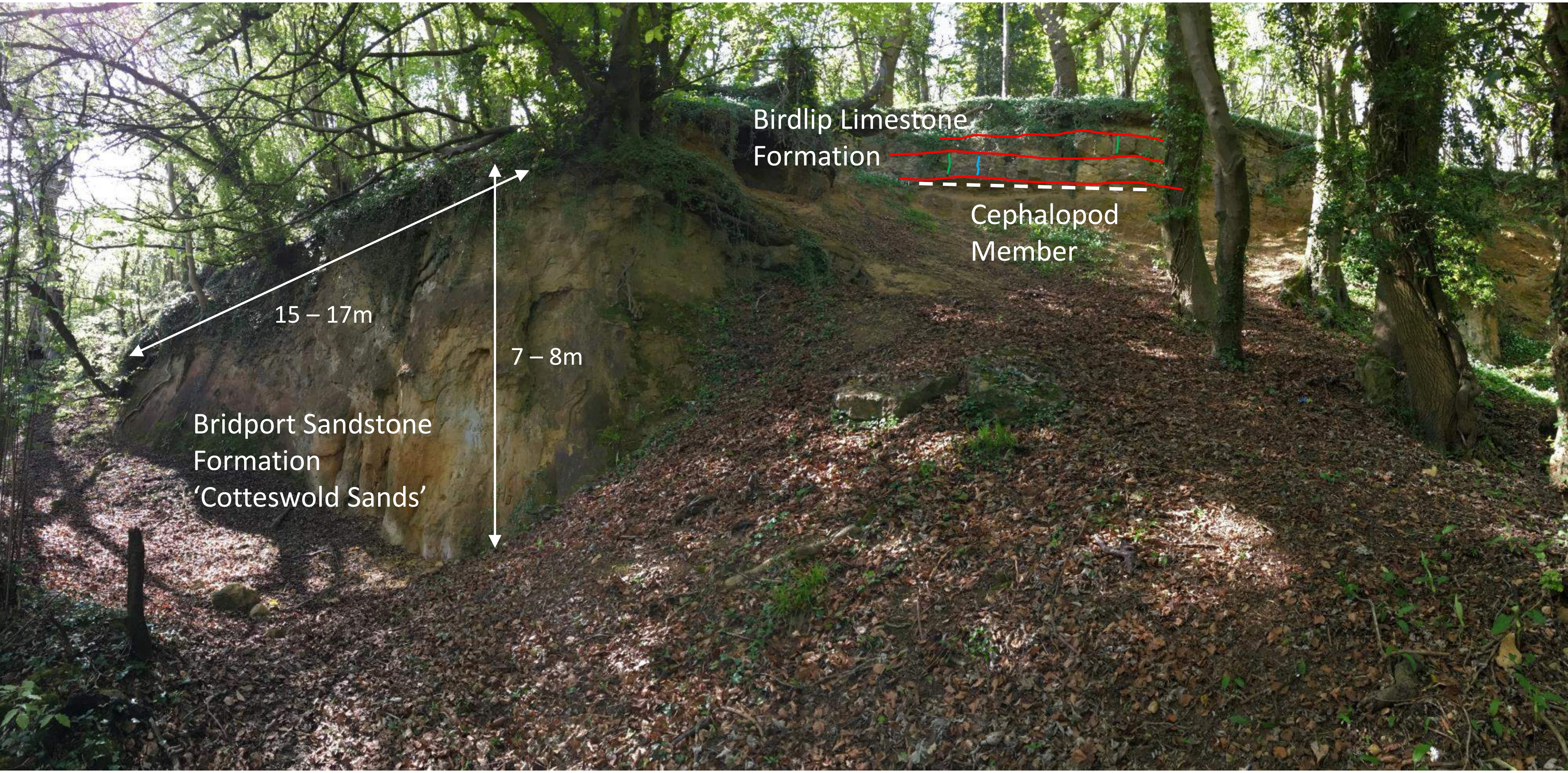


Image Orientation

320º

🟥 Joint Set 1 (Bedding)

🟦 Joint Set 2 (Face of Cliff)

🟩 Joint Set 3 (Into Face)

White dashed line indicative of strata boundary.

Location 4


Bridport
Sandstone
Formation
'Cotteswold Sands'


Random
jointing
Fine grained
micaceous
Sandstone

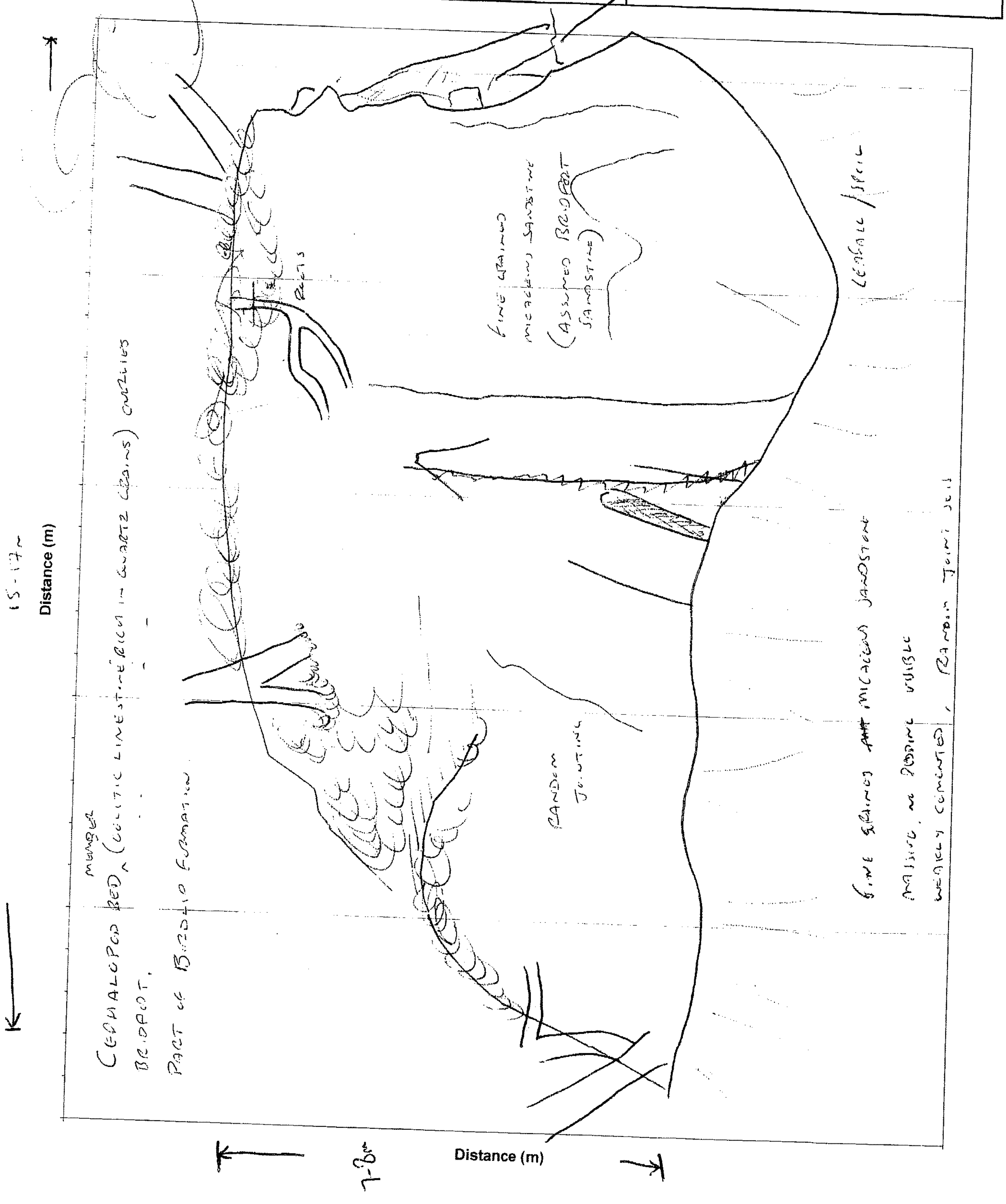
Location 4


Birdlip Limestone
Formation
Cephalopod Member
Bridport Sandstone
Formation 'Cotteswold
Sands'

MOTT MACDONALD

SECTION SKETCH

Client:	Highways England	**GPS Easting:**	N. 51° 38.525
Project:	A417	**GPS Northing:**	W. 002° 21.460
Site Location:	L4 – Wotton hill	**Date:**	25/4/2017
Logged By:	JW	**Time:**	15.00
Checked By:		**Weather:**	Mostly fine with rainy spells
Face Orientation	320°		



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LITHOLOGICAL DESCRIPTION AND DISCONTINUITY SUMMARY

Client:	Highways England	**Site Location:**	L4	**Logged By:**	JW	**GPS Easting:**	N 51° 38.525
Project:	A417			**Checked By:**	CB	**GPS Northing:**	W 002° 21.460

LITHOLOGICAL DESCRIPTION

(BS5930 Strength, Structure, Colour, Texture, Grain Size, Rock Type, minor constituents, weathering (describe state and changes in strength, fracture state, colour, presence of absence of weathering products), number and type of discontinuity sets (describe below)

BRIDPORT SAND. WEAK TO MEDIUM STRONG, MASSIVE, WEAKLY CEMENTED FINE GRAINED MICACEOUS SANDSTONE

RANDOM DISCONTINUITIES, MASSIVE STRUCTURE.

DISCONTINUITIES SUMMARY

Zone	Discontinuity Set	Dip	Dip Direction	Spacing (mm)			P	R	Aperture (mm)	Infilling		Term 1	Term 2	Per (m)	Amplitude (mm)	Wave Length (m)	Weathering	Wall Strength	Water	Comments
				Min	Max	Typ														
-	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	

PLANARITY (7)	ROUGHNESS (8)	INFILLING (10)	INFILLING (11)	TERMINATION (12,13)	WEATHERING (17)	STRENGTH (18)	WATER (19)
P-Planar	K-Slickensided	N-Clean Surface	CL-clay	D-Terminates against another discontinuity	F-Fresh	EW-Extremely Weak	D-Dry
U-Undulating/Curved	S-Smooth	F-Surface Film (<0.5mm)	SI-Silt	R-Terminates within exposure	SW-Slightly Weathered	VW-Very Weak	ST-Stained
S-Stepped	R-Rough	S-Soil	SA-Sand	X-Extends beyond exposure	MW-Moderately weathered	W-Weak	DA-Damp
		C-Cemented (>0.5mm)	I-Iron Oxides		HW-Highly Weathered	MS-Moderately Strong	S-Seepage
		B-Breccia	C-Calcite/Carbonate		CW-Completely Weathered	S-Strong	F-Flow (quantify in comments)
		X-Other	Q-Quartz/Silica		RS-Residual Soil	VS-Very Strong	
			S-Iron Sulphides, pyrite			ES-Extremely Strong	
			X-Other (comment)				

M
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RMR - Rock Mass Classification

Client: Highways England
Project: A417

Site Location: L4 - Bridport Sandstone · Nottle Under Edge
Logged By: JW
Checked By: CS

Chainage: NA

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values					
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred	
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	[✓ 5 - 25 MPa] 1 - 5 MPa < 1 MPa	
	Rating		15	12	7	4	[✓ 2] [✓ 1] 0	1-2
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%	
	Rating		[✓ 20] ⟷	[✓ 17]	13	8	3	17 - 20
3	Spacing of discontinuities		> 2 m	0.6 - 2 m	200 - 600 mm	60 - 200 mm	< 60 mm	
	Rating		[✓ 20] ⟷	[✓ 15]	10	8	5	15 - 20
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous	
	Rating		30	[✓ 25]	20	10	0	25
5	Ground water	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125	
		(Joint water press)/(Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5	
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing	
	Rating		[✓ 15]	10	7	4	0	15

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable	
Ratings	Tunnels & mines	0	-2	[✓ -5]	-10	-12	-5
	Foundations	0	-2	-7	-15	-25	
	Slopes	0	-5	-25	-50		

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	[✓ 80 ← 61]	60 ← 41	40 ← 21	< 21
Class number	I	[✓ II]	III	IV	V
Description	Very good rock	[✓ Good rock]	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence) Rating	< 1 m 6	1 - 3 m 4	3 - 10 m 2	10 - 20 m 1	> 20 m 0
Separation (aperture) Rating	None 6	< 0.1 mm 5	0.1 - 1.0 mm 4	1 - 5 mm 1	> 5 mm 0
Roughness Rating	Very rough 6	Rough 5	Slightly rough 3	Smooth 1	Slickensided 0
Infilling (gouge) Rating	None 6	Hard filling < 5 mm 4	Hard filling > 5 mm 2	Soft filling < 5 mm 2	Soft filling > 5 mm 0
Weathering Ratings	Unweathered 6	Slightly weathered 5	Moderately weathered 3	Highly weathered 1	Decomposed 0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	[✓ Fair]	

* Some conditions are mutually exclusive . For example, if infilling is present, the roughness of the surface will be overshadowed by the influence of the gouge. In such cases use A.4 directly.
** Modified after Wickham et a. (1972).

SUMMARY **RMR = A+B**

Rating: ☐ 68 - 77

M
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Q System - Rock Mass Classification

L4 - Bridport end - Wotton-under-Edge

1. ROCK QUALITY DESIGNATION

	RQD
A. Very poor	0 - 25
B. Poor	25 - 50
C. Fair	50 - 75
D. Good	[✓ 75 - 90]
E. Excellent	[✓ 90 - 100]

2. JOINT SET NUMBER

	J_n
A. Massive, no or few joints	0.5 - 1.0
B. One joint set	2
C. One joint set plus random	[✓ 3]
D. Two joint sets	4
E. Two joint sets plus random	[✓ 6]
F. Three joint sets	9
G. Three joint sets plus random	12
H. Four or more joint sets, random, heavily jointed, 'sugar cube', etc.	15
J. Crushed rock, earthlike	20

3. JOINT ROUGHNESS NUMBER

	J_r
a. Rock wall contact and	
b. Rock wall contact before 10 cm shear	
A. Discontinuous joints	4
B. Rough and irregular, undulating	[✓ 3]
C. Smooth undulating	2
D. Slickensided undulating	1.5
E. Rough or irregular, planar	1.5
F. Smooth, planar	1.0
G. Slickensided, planar	0.5
c. No rock wall contact when sheared	
H. Zones containing clay minerals thick enough to prevent rock wall contact	1.0 (nominal)
J. Sandy, gravely or crushed zone thick enough to prevent rock wall contact	1.0 (nominal)

4. JOINT ALTERATION NUMBER

	J_a
a. Rock wall contact	
A. Tightly healed, hard, non-softening, impermeable filling	0.75
B. Unaltered joint walls, surface staining only	1.0
C. Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc.	[✓ 2.0]
D. Silty-, or sandy-clay coatings, small clay-fraction (non-softening)	3.0
E. Softening or low-friction clay mineral coatings, i.e. kaolinite, mica. Also chlorite, talc, gypsum and graphite etc., and small quantities of swelling clays. (Discontinuous coatings, 1 - 2 mm or less)	4.0

SUMMARY:
RQD
Jn
Jr
Ja
Jw
SRF

Rock Quality Index $Q=\frac{RQD}{J_n}\times\frac{J_r}{J_a}\times\frac{J_w}{SRF}$

4, JOINT ALTERATION NUMBER

	J_a
b. Rock wall contact before 10 cm shear	
F. Sandy particles, clay-free, disintegrating rock etc.	4.0
G. Strongly over-consolidated, non-softening clay mineral fillings (continuous < 5 mm thick)	6.0
H. Medium or low over-consolidation, softening clay mineral fillings (continuous < 5 mm thick)	8.0
J. Swelling clay fillings, i.e. montmorillonite, (continuous < 5 mm thick). Values of J_a depend on percent of swelling clay-size particles, and access to water.	8.0 - 12.0
c. No rock wall contact when sheared	
K. Zones or bands of disintegrated or crushed	6.0
L. rock and clay (see G, H and J for clay	8.0
M. conditions)	8.0 - 12.0
N. Zones or bands of silty- or sandy-clay, small clay fraction, non-softening	5.0
O. Thick continuous zones or bands of clay	10.0 - 13.0
P. & R. (see G.H and J for clay conditions)	6.0 - 24.0

5. JOINT WATER REDUCTION

	J_w
A. Dry excavation or minor inflow i.e. < 5 l/m locally	[✓ 1.0]
B. Medium inflow or pressure, occasional outwash of joint fillings	0.66
C. Large inflow or high pressure in competent rock with unfilled joints	0.5
D. Large inflow or high pressure	0.33
E. Exceptionally high inflow or pressure at blasting, decaying with time	0.2 - 0.1
F. Exceptionally high inflow or pressure	0.1 - 0.05

6. STRESS REDUCTION FACTOR

	SRF
a. Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated	
A. Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock any depth)	10.0
B. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth < 50 m)	5.0
C. Single weakness zones containing clay, or chemically disintegrated rock (excavation depth > 50 m)	2.5
D. Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)	7.5
E. Single shear zone in competent rock (clay free). (depth of excavation < 50 m)	5.0
F. Single shear zone in competent rock (clay free). (depth of excavation > 50 m)	2.5
G. Loose open joints, heavily jointed or 'sugar cube'. (any depth)	5.0

6. STRESS REDUCTION FACTOR

			SRF
b. Competent rock, rock stress problems			
	σ_c/σ_1	$\sigma_t\sigma_1$	
H. Low stress, near surface	> 200	> 13	2.5
J. Medium stress	200 - 10	13 - 0.66	1.0
K. High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)	10 - 5	0.66 - 0.33	0.5 - 2
L. Mild rockburst (massive rock)	5 - 2.5	0.33 - 0.16	5 - 10
M. Heavy rockburst (massive rock)	< 2.5	< 0.16	10 - 20
c. Squeezing rock, plastic flow of incompetent rock under influence of high rock pressure			
N. Mild squeezing rock pressure			5 - 10
O. Heavy squeezing rock pressure			10 - 20
d. Swelling rock, chemical swelling activity depending on presence of water			
P. Mild swelling rock pressure			5 - 10
R. Heavy swelling rock pressure			10 - 15

Q = $\frac{75(90)}{6(3)}$ **x** $\frac{3}{2}$ **x** **=** 18.75 — 45

Annex A

10 Objectives and format of proposed investigation

10.1.1 The purpose of the proposed investigation is to define and manage the key ground related risks to the proposed scheme options. The aspiration is that the investigation is sufficient to develop detailed design, however it is recognised that secondary, minor, investigation works (e.g. pumping tests) may be required once more is known about the ground and groundwater conditions.

10.1.2 The investigation aims to:

- confirm the presence and thickness of geological strata beneath the proposed scheme
- obtain geotechnical data to enable detailed design of the preferred option including deep cuttings, embankments and structure foundations
- obtain geotechnical and contamination data to assess suitability of soils and rocks for reuse
- obtain geotechnical and geomorphological data to enable slope stability assessments of Crickley Hill to be undertaken
- obtain groundwater and permeability data to inform groundwater impact assessments and the design of dewatering schemes for cuttings (if necessary)

10.1.3 It is envisaged that the objectives will be achieved through a combination of intrusive (ground investigation) and non-intrusive investigation (e.g. remote sensing, geophysics). Two options (Option 12 and 30) are currently being considered and two separate ground investigations have been scoped to consider the separate routes, as presented by the exploratory hole location plans in Appendix A and B. It is planned that option selection will be made prior to the ground investigation and the appropriate ground investigation scope will be used. As both routes go up Crickley Hill there is some commonality between the investigations in this area.

11 Special problems to be investigated

11.1 Stability of Crickley Hill

11.1.1 Crickley Hill is covered by historic landslide deposits, thought to be in a marginally stable condition. The general conceptual model of formation of landslides on the Cotswolds escarpment is presented in Figure 4.6. Both proposed route options will affect the toe of the slopes. The routes will sit upon Mass Movement Deposits and require realignment and / or culverting of Horsbere Brook, which runs along the valley floor separating the north and south facing slopes of an incised valley.

11.1.2 The issues this presents to the scheme are discussed in sections 4.3 and 6.4.

11.1.3 In order to understand how the works will impact on the stability of the landslide the following requires investigation:

- Thickness of mass movement deposits
- Composition of the underlying Lias Group – particularly the presence (or absence) of the Marlstone Rock
- Presence (or absence) of the Bridport Sand Formation at the boundary between the Inferior Oolite and underlying Lias Group
- Presence of springs and groundwater
- Relict shear surfaces
- Presence of Alluvium (associated with Horsbere Brook)
- Slope movement and groundwater monitoring to inform assessment of the current stability of movement deposits, and form a baseline for longer term monitoring.

11.2 Rock slope stability of proposed deep cut

11.2.1 To achieve an acceptable vertical road alignment profile both route options require that a deep cutting be constructed at the top of Crickley Hill. The cut commences at the top of Crickley Hill, an area of transition from the mudstones of the Lias Group to the more competent limestones of the overlying Inferior Oolite Group.

11.2.2 The issues this presents are discussed in sections 4.3, 6.2, 6.3, 6.5, and 6.6.

11.2.3 In order to design and construct a cutting at an angle that is stable (and by association identify land take), the following requires investigation:

- Presence and thickness of the strata likely to be encountered by the deep cut, including the depth and extent of any superficial materials infilling fissures and including variability and material properties of Lias below the Inferior Oolite rock

- Dip and strike of joints within the limestone and general rock mass properties
- Presence, frequency, geometry and infill of fissures / gulls within the limestone
- Presence, orientation and rock quality adjacent to geological faults.
- Presence and depth of groundwater
- Permeability of the rock mass

11.3 Stability in the Churn Valley Area (Option 30)

11.3.1 Option 30 has a junction on embankment at the head of the Churn Valley (Coldwell Bottom) and area of instability which presents the issues discussed in 4.3 and 6.4.

11.3.2 Investigation in this area needs to identify:

- Presence and thickness of strata underlying the proposed junction
- Presence of relict shear surfaces
- Groundwater level

11.4 Groundwater

11.4.1 Groundwater issues for the scheme are discussed in detail in sections 3.4, 4.4, 4.6, 5.5, 6.3. Currently insufficient information exists to give confidence that the hydrogeological regime of the area is fully understood; and it is not possible to make an appropriate assessment with regards to the potential impact of the proposed scheme on groundwater. The Environment Agency therefore has a holding objection on the scheme.

11.4.2 In order to alleviate the objection and better understand the hydrogeology of the scheme so that an appropriate impact assessment can be carried out, the following information is required:

- The presence, level and inferred direction of flow of groundwater within the Great Oolite, Inferior Oolite, Fuller’s Earth and Lias Group, as well as hydraulic relationship between the different aquifers.
- The location of surface water features
- The potential influence of major geological faults on the groundwater regime
- The permeability of each of the aquifer units and the degree of leakage between them (it is noted that this objective is most likely to be achieved by pumping tests which are best design once base data has been obtained and therefore may form part of a secondary investigation)
- Groundwater within the landslide deposits and its relationship with springs issuing from the escarpment and the bedrock aquifers
- Aquifer response to rainfall and seasonal effects

11.5 Bushley Muzzard (Option 12)

11.5.1 Bushley Muzzard is a SSSI wetland area discussed in sections 4.5, 4.6, 5.5, and 6.3. It is listed as a separate concern specific to Option 12, as this route passes much closer to the SSSI than Option 30 and therefore would require additional focussed investigation of that listed in section 11.4.

12 Proposed investigation

12.1.1 Non-intrusive and intrusive investigation is proposed to address the ground related risks outlined in section 11. Generally, the non-intrusive investigation will inform the intrusive works and therefore should be undertaken first. The envisaged order of work is as follows:

- Topographic survey (including permanent ground marker installation) and LiDAR baseline survey
- Surface geophysics surveys
- Aerial remote sensing (possible, depends upon industry availability)
- UAV photogrammetry
- On the ground geomorphological survey
- On the ground water feature mapping and surveys
- Construction of intrusive exploratory holes with associated insitu and laboratory testing and installation of long term groundwater borehole installations and inclinometers
- on-going monitoring of groundwater installations, inclinometers and permanent ground markers.

12.2 Topography and LIDAR baseline survey

12.2.1 This non-intrusive investigation has been included in the topography specification for the overall scheme (Ref: HE551505-MMSJV-VTO-000-SP-VT-00001) but is included here for completeness. It is recognised that the area of LiDAR technology is fast moving and dependent upon the available equipment. It has therefore been sent to market as an end product specification:

12.2.2 45no. permanent ground markers are proposed for installation on the body of the landslide at Crickley Hill to be surveyed to National Grid coordinates and elevation +/- 0.01m for the purposes of identifying if the landslide is currently moving, and potentially for monitoring use during construction phase. A minimum of 5no. permanent ground markers are to be installed outside the body of the known landslide to be used as control points relative to those on the body of the landslide. It should be noted the majority, if not all permanent ground markers will be located on private land and will therefore be subject to land access arrangements.

12.2.3 Terrestrial and / or airborne LiDAR is proposed to achieve a high resolution digital terrain model on a millimetre scale resolution. The LiDAR survey(s) is to be tied into / checked against the control permanent ground markers. The survey is to be undertaken 4no. times in 12 months, spaced 3 months apart. The first survey will be used as a base map for geomorphological mapping, water feature mapping, and as a baseline to compare the future surveys to. The aspiration is that by subtracting one digital terrain model from another any parts of the landslide moving (if any) and their rate of movement will be identified.

12.3 Surface geophysics

12.3.1 Geophysics surveys using a range of techniques are proposed with varying objectives. The results of geophysics surveys can be impacted by background ‘noise’ (interference). This often prevents the objectives of the survey being fully achieved; and therefore, geophysics surveys should not be considered as a stand-alone investigatory technique, but complimentary, to aid global interpretation.

12.3.2 The proposals for use of geophysics on the scheme are based upon case studies where geophysics have been used previously with success e.g. (Barron, Uhlemann, Pook, & Oxby, 2016).To further assess the likelihood of a selected geophysics technique achieving the required objectives it is proposed that trials are undertaken prior to executing the full survey extent.

12.3.3 The results of all geophysics survey should be combined with the LiDAR, aerial remote sensing and geomorphological survey, and used to review the locations of the intrusive investigation to confirm their findings.

Gulls, faults and dissolution features

12.3.4 To define the presence, frequency, geometry and area in which gulls (see section 11.2) occur a geophysics survey comprising electrical resistivity tomography (ERT), ground penetrating radar (GPR) and micro-seismicity is required.

12.3.5 Investigating the presence of gulls solely using traditional intrusive techniques (drilling and trenching) may prove inconclusive given the relative size of the fractures in comparison to the area in which they may occur.

Landslide deposits

12.3.6 To assist in defining the extent and geometry of landslide deposits on Crickley Hill a combination of ERT, seismic reflection and refraction techniques are proposed.

12.4 Possible aerial remote sensing

12.4.1 An airborne remote sensing survey may be undertaken, following research regarding industry availability of such equipment e.g. (Whitworth, Giles, & Murphy, 2005). The survey would hopefully comprise:

- Photogrammetry – to obtain high quality aerial images to overlay on the LiDAR survey for geomorphology and water feature mapping use, but also for visualisations.
- Thermal sensor – to aid in water source detection as there is uncertainty regarding location of springs and if all springs have been captured by OS mapping.

- Hyper-spectral sensor – identification of minerals on the landslide, and moisture detection to aid in water feature mapping, identifying landslide failure mechanisms.

Given the specialist nature of this work discussions are required with specialist providers to ascertain the details and practicality of sensing techniques.

12.5 Geomorphological survey

12.5.1 A geomorphology survey is required to characterise the landforms along the route, identify potential hazards and understand how the landscape may have changed from previous studies. By identifying the reason why a change has occurred the route design can take this into consideration, potentially preventing an increase in the rate at which the changes are occurring and / or minimise detrimental impact on maintenance of the route.

12.5.2 Prior to commencing the survey previous geomorphology surveys shall be compiled and aerial photography studied for reference, to identify change and to update.

12.5.3 Geomorphologists in the field will then survey those areas of interest - at this point expected to be primarily Crickley Hill and the Churn valley (where Option 30 proposes a ‘dumbbell’ junction) to identify any further change and confirm observations made during desk top study of past data.

12.6 Water feature mapping and surveys

12.6.1 Water feature mapping undertaken by hydrogeologists walking the proposed route and the wider scheme area is required. The survey will aid in identifying the presence and location of water features that may or may not be present on OS mapping, including springs, streams, ponds, seepages, wetlands, and licensed and unlicensed surface water and groundwater abstractions. This will allow identification of surface water and groundwater receptors in the area, and assist in delineating spring catchments. It is also a requirement of the Environment Agency. Surveys may also include stream and spring flow monitoring, and water sampling and testing.

12.7 Intrusive ground investigation

12.7.1 An intrusive ground investigation is required to provide geotechnical design and groundwater data to design and construct the scheme, and to enable the impact of the scheme upon groundwater to be determined.

Fieldwork

12.7.2 For Option 30, Appendix A provides a ground investigation location plan and a detailed schedule of exploratory holes. A summary of the proposed investigation scope, including selected in-situ tests, is presented in Table 12.1. It is envisaged that following completion of the non-intrusive surveys the location of the proposed exploratory holes will be reviewed prior to being constructed.

Table 12.1: Option 30 summary of intrusive ground investigation

Intrusive ground investigation element	Quantity (no.)	Depth range (m)
Cable percussion borehole (CP)	28	10-35
Dynamic sampling with rotary core follow-on borehole (DS/RC)	34	15-75
Dynamic sampling with rotary core follow-on and subsequent open holing borehole (DS/RC/OH)	14	40-120
Open hole (OH)	6	15-90
Cone Penetration Tests with porewater pressure measurement (CPTu)	16	Varies
Inclined rotary cored hole (Inc RC)	22	42 (length)
Trial pit (TP)	41	4
Downhole geophysics	42	20-120
Inclinometer installation in boreholes	13	20-60
50mm groundwater monitoring installations	68	15-120
In-situ testing – CBRs, SPTs, permeability testing in boreholes and borehole installations		
Soil and rock sampling, geotechnical and chemical laboratory testing Downhole water sampling and surface water body sampling and laboratory testing Geo-environmental sampling and laboratory testing		
Daily reporting, electronic Factual Report and AGS4 data		
Post fieldwork monitoring and reporting		

12.7.3 For Option 12 Appendix B provides a ground investigation location plan and a detailed schedule of exploratory holes. A summary of the proposed investigation scope, including selected in-situ tests, is presented in Table 12.2. It is envisaged that following completion of the non-intrusive surveys the location of the proposed exploratory holes will be reviewed prior to being constructed.

Table 12.2: Option 12 summary of intrusive ground investigation

Intrusive ground investigation element	Quantity (no.)	Depth range (m)
Cable percussion borehole (CP)	28	10-35
Dynamic sampling with rotary core follow-on borehole (DS/RC)	47	15-100
Dynamic sampling with rotary core follow-on and subsequent open holing borehole (DS/RC/OH)	10	40-100
Open hole (OH)	3	40-60
Cone Penetration Tests with porewater pressure measurement (CPTu)	17	Varies
Inclined rotary cored hole (Inc RC)	20	42 (length)
Trial pit (TP)	25	4
Downhole geophysics	42	20-100
Inclinometer installation in boreholes	13	20-60
50mm groundwater monitoring installations	74	15-100
In-situ testing – CBRs and SPTs		
Soil and rock sampling, geotechnical and chemical laboratory testing Downhole water sampling and surface water body sampling and laboratory testing Geo-environmental sampling and laboratory testing		
Daily reporting, electronic Factual Report and AGS4 data		
Post fieldwork monitoring and reporting		

12.7.4 For both investigation scopes it should be noted that the proposed exploratory holes have been split into different series (e.g. CP101, DS/RC102, CP401 etc) based upon their primary purpose. While the borehole numbering identifies the primary purpose, it is still used to obtain as much relevant data as possible (a 200 series borehole for embankment design may have a groundwater monitoring installation):

- Series 100 – Located on Crickley Hill, identified geotechnically to be the most challenging part of the scheme.
- Series 200 – For the purpose of Embankment Design and to obtain data on slope stability.
- Series 300 – For design of foundations for structures and vertical holes for the design of cuttings.
- Series 400 – Groundwater data and geological validation.
- Series 500 – Inclined holes to provide data for design of the deep cutting at the top of Crickley Hill.

- Series 600 – Holes located beneath the proposed alignment or on existing road.

12.7.5 A variety of techniques have been selected to be used to construct the exploratory holes as summarised in Table 12.3.

Table 12.3: Summary of proposed exploratory hole techniques

Exploratory hole technique	Reasoning for selection
Cable percussion borehole (CP)	More likely to successfully penetrate mass movement deposits. Method does not use water to lubricate, therefore water strikes and the strata the water strikes are encountered in can be accurately identified. A groundwater monitoring standpipe or inclinometer can be installed. Downhole geophysics can be used if the contractor is confident that the hole can stay open without casing.
Dynamic sampling with rotary core follow-on borehole (DS/RC)	This is expected to be undertaken using a single rig. Dynamic sampling is more successful at obtaining samples of soil compared to rotary core, which is employed to obtain samples of rock. Groundwater monitoring standpipe or inclinometer can be installed. Downhole geophysics can be used in a partially cased hole (to bedrock) or if the contractor is confident that the hole can stay open without casing.
Dynamic sampling with rotary core follow-on and subsequent open holing borehole (DS/RC/OH)	Open hole is a quick drilling technique for which no sample is returned. It is specified when the hole is required to go deeper for the purposes of groundwater installations. Groundwater monitoring standpipe can be installed. Downhole geophysics can be used in a partially cased hole (to bedrock) or if the contractor is confident that the hole can stay open without casing.
Open hole (OH)	Open hole only boreholes have been specified when a groundwater installation is required but the hole is immediately adjacent to another which has been logged. Groundwater monitoring standpipes can be installed. Downhole geophysics can be used in a partially cased hole (to bedrock) or if the contractor is confident that the hole can stay open without casing.
Inclined rotary cored hole (Inc RC)	Specifically to supplement the vertical holes and provide data regarding orientation of fractures in the rock for deep cutting design.
Cone penetration test with piezocone (CPTu)	In-situ test that is quick to undertake to depths equivalent to boreholes. In combination with boreholes, the test can identify stratigraphic changes while the piezocone can be used to measure porewater pressure and undertake dissipation tests.
Machine Excavated Trial Pit (TP)	To enable identification and mapping of relict shear surfaces on Crickley Hill, to confirm geology and undertake insitu CBR tests elsewhere.

12.7.6 All exploratory holes shall commence once the non-intrusive surveys have been completed, and following consultation of statutory utility plans, CAT scanning of the ground surface and hand dug inspection pit with CAT scanning at the base.

Drilling Criteria

12.7.7 All boreholes shall commence at a diameter sufficient to allow for aquifer protection measures (if required and the drilling technique allows), tremie-ing of grout for instrumentation and to obtain rock core (if required) no less than 101mm diameter at the base of its scheduled depth.

12.7.8 Rotary core holes shall utilise drilling techniques that maximise core recovery in the expected ground conditions. Biodegradable polymer flush or other additives may only be used following permission from the Environment Agency. All flushes are to be potable water based and recycled until loss or saturation requires replacement. If agreed with the Environment Agency, flush with polymer and / or suspended sediment will need to be removed and disposed of off site under suitable permits. Surface runoff will need to be very carefully controlled, prevented from travelling outside of the borehole area or running back down the hole.

12.7.9 It is proposed that all rotary cored and open hole drilling shall record drilling parameters – measurement whilst drilling (MWD) - continuously using an automated system. The parameters that shall be monitored, shall include (but not be limited to):

- Penetration rate
- Torque
- Rotational speed
- Flush returns (volume) and characteristics (observations)
- Hole stability
- Inclination of hole
- Groundwater observations (if possible, although this may be masked by use of flush).

12.7.10 MWD shall provide additional data which could provide information on the potential presence of fractures, solution features, and strata boundaries. It shall be undertaken in addition to and does not preclude in-situ testing and core logging.

12.7.11 In cable percussion boreholes it is expected that drilling will pause for 20 minutes to record water strikes.

In-situ testing

12.7.12 A range of in-situ testing is proposed as part of the intrusive ground investigation as presented in the Schedule 2 for each Option (Appendix A and B), and summarised in Table 12.4.

12.7.13 Downhole geophysics will be dependent upon the stability of the boreholes as they require complete or partial removal of the casing. The optical televiewer will require the borehole having been left open, untouched, for a minimum of 24hrs to allow sediment to settle. It is therefore envisaged this technique is undertaken first or last in the suite of tests.

12.7.14 It is expected that the results of the downhole geophysics will be presented side by side at similar scales, with structural analysis of the acoustic and optical televiewers also presented as structure lines, a tadpole plot and a polar plot.

Table 12.4: Summary of in-situ testing

Test	Detail	Reason
Standard Penetration Test (SPTs)	To be undertaken at 1m centres in cable percussion and dynamic sample boreholes alternating with UT100s in cohesive material, prior to downhole shear vane.	Test result – *N* value – provides an indicator of the density and compressibility of granular soils and the consistency of cohesive soils. Many empirical correlations using the *N* value making it one of the most widely used parameters in geotechnical design. Contractor must undertake at least 2no. site specific energy ratio tests and provide the results.
Measurement of porewater pressure and dissipation (CPTu)	Porewater pressure to be measured continuously by CPT (see Table 12.3). 2no. dissipation tests to be undertaken in each CPT, 1no. in mass movement deposits and 1no. in undisturbed strata.	To provide data for stratification, slope stability, lateral earth pressures and uplift pressures. Add to knowledge of the groundwater regime in the area.
Downhole geophysics – three arm calliper	To be run first of the suite of down hole geophysics, in those vertical holes identified in schedule 2. Hole to be uncased. Bow springs or 'feelers' that follow the wall of a hole.	To ascertain diameter of the borehole / identify karst features, give certainty as to hole stability for other tests.
Downhole geophysics - resistivity	The voltage drop between electrodes on the sonde is a function of the resistivity of the formation and fluid in the hole.	Formation water saturation, stratigraphic correlation of aquifers.
Downhole geophysics – natural gamma	Detector measures gross gamma activity of naturally occurring and artificial radioisotopes	Identification of lithology and stratigraphic correlation. Increases in clay or shale content tend to equal higher gamma radiation.
Downhole geophysics – gamma gamma	Contains a gamma sources shielded from a detector.	Estimation of bulk density and porosity. Identification of lithology and location of cavities.
Downhole geophysics – acoustic (seismic) televiewer	An acoustic transmitter-receiver, orientated on magnetic north, that is rotated to scan reflection from wall of the borehole.	Location and orientation of fractures and solutions features.
Downhole geophysics – optical televiewer	Rotated, orientated on magnetic north, to provide images of the wall of the borehole. Hole must be left open, for suspended sediment to settle for at least 24hrs in order to obtain clear images.	Location and orientation of fractures and solutions features.
Variable head or constant head permeability testing	Water is removed (rising), added (falling) or maintained at a constant level, with the change of hydraulic head in the test section or flow rate measured.	To determine preliminary hydraulic properties of the strata to enable dewatering design and design of pumping tests.
Packer testing	To undertake lugeon testing.	To determine the average hydraulic conductivity of a specific stratum.
California Bearing Ratio (CBR)	To be undertaken in specified trial pits	To test the strength of the subgrade, commonly used in highways pavement design.

Instrumentation

12.7.15 As identified in Table 12.1 and Table 12.2, installations comprising groundwater monitoring standpipes and inclinometers are proposed.

12.7.16 Particular care will be needed when installing the instrumentation headworks to make them vandal proof, and prevent creating a pathway for surface water inflow into either the strata being monitored or overlying aquifers. All headworks should have the hole ID inscribed to aid in identification during monitoring.

12.7.17 Upon completion all exploratory holes should be surveyed to National Grid and the elevation +/- 0.005m. This is particularly important for holes with instrumentation in, in order to locate them again and accurately identify the hole for monitoring purposes.

Groundwater standpipes

12.7.18 Groundwater monitoring standpipes shall comprise 50mm slotted standpipes with geotextile surround, end cap and clean granular material for the response zone. A minimum 1m grout seal shall be supplied top and, where necessary, bottom of the response zone. No more than 1no. standpipe shall be installed in any borehole.

12.7.19 Each Schedule 2 identifies the target geology of the response zone. Casing should be pulled back prior to standpipe installation so sufficient seal between the grout and borehole wall is achieved and the standpipe is not in danger of being dragged back up the hole with removal of the casing.

12.7.20 Each groundwater standpipe requires installation of a diver. The majority will require non-vented water level data loggers (diver or similar) set to record water levels every 15 minutes. The occasional standpipe will require installation of a Barodiver or similar to allow barometric correction to be made for unvented logger data. More frequent water level readings are likely to be required during permeability testing.

12.7.21 All groundwater monitoring standpipes shall be developed following installation for monitoring and testing.

Inclinometers

12.7.22 Inclinometer casing, wherever possible should be installed 5m below expected movement. Due to ground conditions encountered, it may be necessary to deepen the exploratory hole to achieve this. The primary set of cross-keys / grooves should be installed facing in the direction of expected movement as confirmed with the supervising ground investigation specialist (downhill, north-west to west on the south slope, and south-east to east on the north slope of Crickley Hill).

12.7.23 The casing should be installed within 3 degrees of vertical and fully grouted. The properties of the grout will need to be adjusted to match the surrounding ground. Difficulties achieving verticality arise from holding the casing down from the top to resist uplift pressures during grouting – the compression of the casing causes it to snake. To avoid this method such as suspending a drill rod inside the casing (an inch off the bottom cap) pre-installing an anchor at the bottom of the casing, or grouting in stages (the first 3m allowed to set and act as an anchor).

Rainfall Gauge

12.7.24 A rainfall gauge shall be procured for the project to measure amounts of daily rainfall to aid understanding of groundwater level readings and contribute to understanding of the groundwater regime in the project area. It shall be located in a vandal proof location during and post fieldwork. The gauge shall be capable of storing at least a month's worth of data.

Monitoring

12.7.25 A summary of the frequency and length of time instrumentation monitoring is required for is presented in Table 12.5. It is considered that monitoring shall commence as soon as installation is complete. The monitoring frequency shall be periodically reviewed and if appropriate adjusted.

Table 12.5: Summary of monitoring

Instrument	Min. length of post-fieldwork monitoring period	Frequency
Groundwater standpipe	12 months	Data logger set to measure level every 15 minutes. Collection of data dependent upon capacity of diver, ~ once a month
Inclinometer	12 months	Monthly
Rain gauge	12 months	Monthly

Exploratory hole logging

12.7.26 Accurate logging of exploratory holes is extremely important; once the fieldwork is complete it forms the main representation of the intrusive fieldwork. It is required that all holes will be logged as per industry standard Geotechnical logging – BS EN ISO 14688-1, BS EN ISO 14688-2 and BS EN ISO 14689-1. It is also required that these descriptions be supplemented with lithological details and weathering classification (e.g. (Hobbs, et al., 2012)) to accurately identify the formations within the Great Oolite, Inferior Oolite and Lias Group.

12.7.27 To achieve the requirement for lithological logging, it is proposed that the British Geological Survey (BGS) is engaged to assist with field identification during the initial stages of the deep borehole drilling and then commissioned to undertake selected lithological logs of certain boreholes. It is also required that a BGS specialist in the Great Oolite, Inferior Oolite and Lias Group attend site on a minimum of 5 separate occasions to undertake lithological logs of select holes which will be used as high-quality correlations for the scheme.

Laboratory Work

Geotechnical Laboratory Testing

12.7.28 Comprehensive geotechnical testing is proposed as detailed in the bills of quantities presented in Appendix C (Option 30) and D (Option 12). The testing will obtain parameters for slope stability analysis, cutting design, embankment / earthworks design, highways pavement design and material re-use.

Groundwater Laboratory Testing

12.7.29 Suites of groundwater testing presented in the bill of quantities (Appendix C and D) are aimed at identifying groundwater quality.

Contamination Laboratory Testing

12.7.30 The PSSR (Preliminary Sources Study Report - A417 Air Balloon Missing Link, 2018) did not identify any areas of particular historic contaminative land use beyond agricultural farming. General pesticide suites are therefore proposed and testing of the fill material identified by previous geomorphology mapping at the farm on Crickley Hill shall be undertaken. Otherwise, at this stage, contamination testing shall be undertaken only on samples where visual or olfactory evidence of contamination exists.

Factual Data

12.7.31 Factual data shall be required in pdf format as a single coherent report. AGS4 data with files attached as necessary shall be supplied at draft and final reporting stage. Photographs, CPTu, geophysical logs and monitoring data shall also be required in their native file format, uncompressed.

13 Site and Working Restrictions

13.1.1 The exploratory hole location plans are presented in Appendix A and Appendix B. They are located predominantly on land which is owned by Highways England (existing A417 and verges) and private land owners (farmers' fields).

13.1.2 Upon confirmation of the exploratory hole locations, those holes located on private land will require careful programming by the ground investigation contractor and access to be negotiated by the Highways England project land access team. The majority of these holes will be located in fields which may be waterlogged and / or recently ploughed. Those holes on Crickley Hill are likely to require navigation of sloping hummocky ground to reach position. The ground investigation contractor will be required to visit each exploratory hole location to identify a suitable access route and ground protection required.

13.1.3 Those holes located on the existing A417 or on its verge – predominantly the 600 series, but the occasional 200 series holes - are likely to require traffic management. It is proposed that traffic management will be the responsibility of an organisation with appropriate traffic management skills, such as the Highways England survey framework contractor or the A417 maintainer, RMS (Gloucester) Ltd.

14 Specialist Consultation

14.1 Environment Agency

14.1.1 Consultation with the Environment Agency is ongoing for those reasons set out in Section 11.4. The non-intrusive and intrusive ground investigations have been designed to provide data that will enable a better understanding of the groundwater regime in the area of the scheme.

14.1.2 Following agreement of the scope of work with Highways England, the investigation proposals will then be presented to the Environment Agency for peer review.

14.2 Heritage / Archaeology

14.2.1 The scheme area has records of numerous prehistoric and roman finds / settlements. A review of the final intrusive exploratory hole locations will be required by the Design Organisation’s Heritage Consultants prior to commencing the fieldwork phase to identify if any of the locations require watching brief or further study.

14.3 Ecology

14.3.1 Any de-vegetation at the exploratory hole locations or to facilitate access to the locations shall need to be undertaken under an ecological watching brief.

15 Programme, cost and contract arrangements

15.1 Indicative programme

15.1.1 Table 15.1 presents an indicative programme showing the preferred order of works and is based upon the aspirations of Highways England for the intrusive works to commence onsite as soon as possible. The programme presented should be considered as representative of either the work scope included in Option 12 investigation or the Option 30 investigation.

15.1.2 The programme assumes that land access is available and has made assumptions about the number of drilling rigs used in the intrusive fieldwork phase of the ground investigation (2no. cable percussion rigs, 2no. vertical rotary rigs, 1no. inclined rotary rig, 1no. cone penetration rig and 1no. excavator).

15.2 Cost and Contract Arrangements

15.2.1 It is understood that it is intended to procure the ground investigation through Highways England Ground Investigation Framework. The Design Organisation does not have access to these rates and therefore a cost estimate cannot be provided at the time of writing.

15.2.2 Bills of quantities using the Highways England Ground Investigation Framework have been put together for each option and are presented in Appendix C and D.

Table 15.1: Indicative programme

Task	Timeframe (months)																								Comments
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
EA Consultation	■	■																							
Topographical and Lidar Survey		■	■																						Required in useable format prior to starting other surveys
Geophysics surveys			■	■																					
(Possible) Aerial remote sensing			■	■																					
Geomorphological Mapping				■	■																				
Water feature and water flow survey				■	■																				
Review period						■	■																		Hole locations, heritage team, ecology team
GI Contract Award and mobilisation							■	■	▨	▨															Including RAMs, programme, land access (pale blue), setting up site compound and logging facilities.
Ground investigation fieldwork								■	■	■	■	■													Including BGS workshop, daily reporting, check logging, ongoing test scheduling and draft results
Draft Factual Report Issue (with AGS)												■													
Final Factual Report Issue (with AGS)													■												
Ongoing monitoring									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	12 months post fieldwork

16 Reporting

16.1.1 Table 16.1 summarises reporting requirements envisaged as part of the work proposed in this Annex A.

Table 16.1: Deliverables

Title	Responsibility	Deliverable
Topographical and LiDAR survey	Topographic Contractor	High resolution DTM of landslide area.
Geophysics survey for Cambering and dissolution features Report	Geophysics Contractor	Report detailing the extent of the survey, techniques used, limitations encountered and interpretation of the results in graphical form identifying the presence of fissures and dissolution features. Digital version of the model to be provided in a format agreed between the Contractor and Design Organisation..
Geophysics survey for the landslide Report	Geophysics Contractor	Report detailing the extent of the survey, techniques used, limitations encountered and interpretation of the results in graphical form identifying the geometry and slip surfaces (if identified) of the landslide. Digital version of the model to be provided in a format agreed between the Contractor and Design Organisation.
Possible remote sensing data for the A417 project.	Aerial Remote Sensing Contractor – if capability exists outside of the research community	Report detailing the extent of the survey, techniques used, limitations encountered and interpretation of the results in graphical form aimed at achieving the objectives of identifying the presence of water features, difference in mineralogy, high resolution photogrammetry of the project area. Data to be provided in a digital format agreed between the Contractor and Design Organisation.
Geomorphological Mapping	Design Organisation	Report presenting a series of geomorphological maps with an interpretation of what was viewed in the field.
Water Feature mapping	Design Organisation	Report presenting a series of maps validating the presence of water features and indicating the direction and rate of flow.
Ground investigation	Contractor	As detailed in Table 7.1. Final deliverable to comprise a pdf Factual Report with associated AGS data.
Monitoring report	Ground investigation contractor	A summary report of the 12 months of groundwater installations, rain gauge and inclinometers.
Ground Investigation Report	Design Organisation	A report with a global view summarising and interpreting the data collected.
Hydrogeological Report	Design organisation	A report detailing interpretation of the groundwater regime in the area of the scheme.