Lloyd's Coppice Landslip study
Phase 1: design of site investigation programme

Prepared for Telford and Wrekin Council
by the British Geological Survey

Commissioned Research Report: CR/03/011N

BRITISH GEOLOGICAL SURVEY

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Executive Summary

This report, commissioned by Telford and Wrekin Council, provides a strategy for investigating the instability of the Lloyd's Coppice landslip, near Ironbridge.

Recommendations are given for a drilling programme that will assist in modelling the geological sequence exposed in the sides of the Coppice, and form a basis for a stability assessment.

The recommendations are based on a limited desk study using information provided by the Council, and a one day walkover survey.

Contents

1 Introduction

1.1 Terms of reference

Following a meeting with officers from Telford and Wrekin Council on the 27 November 2002, the British Geological Survey (BGS) was commissioned to design a ground investigation to determine the causes of slope instability at Lloyd's Coppice, an area of active landsliding on the northern side of the Ironbridge Gorge (Figure 1). The project is the first phase of an integrated study to determine possible interactions between slope instability at Lloyd's Coppice and Jackfield on the opposite side of the Gorge.

1.2 Method of approach

The task was undertaken primarily as a desk study. Time and budget constraints meant that background researches were restricted to material that could be readily accessed within BGS or supplied by Telford and Wrekin Council. Searches of the world wide web (WWW) also produced some useful material. A full listing of the information consulted is given in Appendix 1.

A walkover survey was carried out in the company of Council officers on the 3rd January, 2003.

2 Geological summary

The Ironbridge Gorge originated some 10 00 years ago as a meltwater overflow channel cut during the latter stages of the last glaciation. The gorge is deeply incised in rocks of Upper Carboniferous age, which are prone to landslipping, and have suffered a number of catastrophic failures in historic times (e.g. Henkel and Skempton, 1954).

The geological sequence at Lloyd's Coppice (Table 1) is summarised below. Thickness ranges denote uncertainty in the correlation of the Lloyd's Coppice sequence with that of adjacent areas; the implications are discussed in more detail later in this report.

Table 1. Geological sequence at Lloyd's Coppice.

Deposit	Thickness (m)
Man made Deposits	
Glacial till	5.5-17.5
Halesowen Formation (formerly Coalport Formation) *Note: thicknesses are from base of Thick Rock*	Min 38 Max 70
Etruria Formation (formerly Hadley Formation)	Min 18 Max 25
Middle Coal Measures	Min 15 Max 35
Lower Coal Measures	

2.1 Solid geology

The geological setting of Lloyd's Coppice is shown in Figure 2 and a generalised vertical section, taken from the published 1:25 000 Telford special sheet, shows the relationships between the mapped rock units (Figure 3).

The **Lower** and **Middle Coal Measures** crop out in the valley bottom, where the succession is dominated by grey mudstones and seatearths with subordinate sandstones and interbedded coal seams. The sequence was partially proven by a borehole at Lloyd's Head [c. 684 031] (insert 1, back pocket), which penetrated 51m of strata, commencing in coloured mudstones and sandstones possibly representing the basal beds of the Etruria Formation. The coal at 18.6 m depth is taken to be the Big Flint Coal and the odorous seam at 31.40 m is probably the New Mine Coal, marking the base of the Middle Coal Measures. The sequence accords well with the coal outcrops shown on the published 1:10 560 scale map.

The **Etruria (Hadley) Formation** rests unconformably on the Middle Coal Measures. It consists of soft, mudstone which is mainly red, but may also exhibit a wide variety of colours such as brown, green and yellow; this distinctive coloration is due mainly to sub-aerial soil-forming processes prior to sediment burial. Subordinate amounts of sandstone and conglomerate, locally known as espleys, are also present throughout the formation. They are distinctive for being mostly poorly sorted and containing a high proportion of chloritic clays which give them a characteristic green coloration where fresh, or an orange-brown coloration where weathered. The term **Rough Rock** is widely used to describe the espleys. Although the term has been used to imply a single stratigraphical horizon, up to three lenticular sandstones are recorded locally. The Etruria Formation is overlain, apparently conformably, by the Halesowen Formation.

The **Halesowen (Coalport) Formation** crops out in the upper part of Lloyds Coppice. It consists of beds of pale greenish grey, fine- to coarse-grained, micaceous sandstone interbedded with grey or red-mottled mudstone, siltstone and a few thin coals. A persistent sandstone, the **Thick Rock**, forms a mappable unit, intermittently exposed in the rear scarp. It has a recorded thickness of 10.41 m in the Lees Farm No. 1 Borehole but thins and splits eastwards along the Coppice. Named sandstones lower in the sequence include the **Sulphur (Stinking) Rock** and **White Rock**. These overlie two coal seams, the **Little Sulphur Coal** and **Main Sulphur Coal**, respectively. The Main Sulphur Coal is conventionally taken as the base of the Halesowen Formation in the area.

The Lees Farm boreholes (1 and 1A), drilled just to the north of the Gorge, together provide a composite reference section for which the published stratigraphy is as follows:

	Depth (m)	OD (m)
		143.3
Till	5.5	137.8
Thick Rock (top)	23.82	119.5
Thick Rock (base)	34.23	109.1
Main Sulphur Coal	72.6	70.7
Rough Rock (base)	90.8	52.5
Middle Coal Measures to	102.0	41.3

On the basis of this correlation the interpreted thickness of the Halesowen Formation from the base of the Thick

Rock is 38.4 m. For further discussion of this correlation see section 2.5.

2.2 Superficial (Drift) geology

A sheet of glacial till mantles the plateau to the north of the Gorge. The deposit is typically a stiff sandy over-consolidated clay with a variable content of sand and rock fragments. It is most commonly red, chocolate or purple-brown in colour, and has a maximum recorded thickness of 17.5 m (Lees Farm Borehole No. 2).

2.3 Artificial deposits

The lower slopes of Lloyd's Coppice are covered by accumulations of **Made Ground** derived from former clay, ironstone and coal workings.

2.4 Structure

Structure contours drawn on the base of the Thick Rock indicate an irregular but generally east-north-easterly dip of between 3 and 4°. Higher dips (up to 10°) are recorded at outcrop, and a value of 6.6°/N78° is calculated from intercepts in the Lees Farm boreholes. The underlying Coal Measures are gently folded by the north-east-trending Madeley Syncline, which bifurcates to the north of the Gorge (Figure 4). Coal seams on the flanks of the fold incrop against the sub-Etruria unconformity.

Two distinct fault orientations are observed (Figure 2). North-east-trending faults dominate but east-south-east orientated structures are also important, particularly in respect of Lloyd's Coppice.

The **Jockey Bank Fault** has a downthrow of about 5 to 10 m to the north-west in the Etruria Formation. Its throw in the Severn Gorge is smaller since the Best Coal Group and the Little Flint Coal are in juxtaposition [6783 0342].

The **Jackfield Fault** commences just north of Broseley, where the Main Sulphur Coal has been mined at 42 m depth on the downthrow side, and is at outcrop on the upthrow side. The throw must reduce north-eastwards to about 15 m in the Etruria Formation around Jackfield.

The **Doughty Fault** has a recorded throw down to the south-east of 40 m on Tile Clay mine plans.

There are no details of the un-named cross-fault which crops beneath the Lloyd's Coppice. This fault, hereafter referred to as the **Lloyd's Coppice Fault,** is poorly known but a throw of 30 m down to the south is conjectured (Halcrow, 1990).

The brief walkover undertaken on the 3rd January 2003 indicated possible additional faulting along a north-east trend. The evidence is mainly to be found in the upper slopes of the Coppice where the Thick Sandstone appears to be downfaulted in a small graben structure (insert map, back pocket). If the interpretation is correct, this structure has important implications on the stability of the Gorge because of its influence on groundwater flow. Currently, water is flowing from the base of the downfaulted sandstone block close to its western end and this is presumably having an impact on the stability of the lower slopes.

2.5 Assessment of the stratigrapical problems of Lloyd's Coppice

The interpretation of the Lees Farm group of boreholes is critical to the understanding of the geology of the Coppice. Section 1A (insert 2), drawn through Lees Farm Borehole 1A, is taken from the Halcrow Report. The correlation lines are based on the premise that the Lees Farm Borehole terminated in Middle Coal Measures.

Viewed in the context of other shafts in the vicinity (insert 1), the Lees Farm Borehole sequence is clearly anomalous. It shows thinning in both the Halesowen and Etruria formations, the coals are not readily correlated, and the descriptions of the Etruria Formation show none of the characteristics expected of this formation. Evidence that the boreholes may have penetrated a fault (or faults) is contained in the written logs, which refer to 'steep dips' and 'sandstone slickensided against mudstone' at depths of about 90 m in both Lees Farm 1 and 1A boreholes. As discussed earlier, the walkover survey has also indicated possible faulting along the line of the boreholes.

An alternative interpretation hinges on the fact that the coal, identified as the Main Sulphur Coal in the published section, is in fact the Little Sulphur Coal. If this is the case, it means that the Lees Farm Borehole terminated at the base of the Halesowen Formation and not within the Middle Coal Measures, as originally believed. This alternative interpretation is illustrated in Section 1B. Note neither section has been re-drawn to take account of the conjectured faulting.

Section 2 (insert 2) shows the geology at the western end of the Coppice. It is based on projected geological linework, and is only constrained by the Lees Farm Borehole (also projected onto the line of section). The correlation lines assume that the Lees Farm Borehole terminated in the Main Sulphur Coal. This results in a north-eastward dip of 9º, which is somewhat steeper than that seen on Section 1. If the published correlation for the Main Sulphur Coal is used instead, the strata dip gently south-westwards towards the River Severn.

The section clearly illustrates the difficulties of interpreting this sector of the Gorge on limited information.

Section 3 is drawn through Lloyd's Engine Pit and uses the revised stratigraphy of the Lees Farm Borehole (projected onto the line of section). There are very few points of reference and depending on the dip used, the outcrop of the various formations on the slopes of the Coppice could shift considerably. For consistency, the strata are shown dipping at the same angle as Section 1.

On this line of section, Shropshire Caving and Mining Club (www.serve.com/scmc/lloydspt.html) note discrepancies in the shaft records for the Air Pit which is 'some 70ft [21 m] higher vertically up the hill than the Engine Pit, yet the various depths to individual seams are usually given to within a foot difference in both shafts'. One of the objectives of the drilling programme must be to resolve the geological uncertainties in this area of the Coppice.

2.6 Sector analysis

For convenience in description the Coppice is divided into six fault-bounded sectors (insert map, back pocket):

- Sector 1 North of Lloyd's Coppice Fault, western end
- Sector 2 North of Lloyd's Coppice Fault, centre
- Sector 3 North of Lloyd's Coppice Fault, eastern end
- Sector 4 South of Lloyd's Coppice Fault, west of Jackfield Fault
- Sector 5 South of Lloyd's Coppice Fault, between Jackfield and Doughty faults
- Sector 6 South of Lloyd's Coppice Fault, east of Doughty Fault

It is recommended that these fault blocks are assessed by a minimum of four borehole transects (see insert map). The positions of the individual boreholes, as given on the insert map, are approximate and take little account of access, but the overall aim for modelling and slope stability assessment should be to provide information along transects that follow lines of maximum slope.

Sector 1
It is essential that any doubts about the stratigraphical position of the Lees Farm Borehole are resolved at the outset. This can only be achieved by drilling one or more continuously cored boreholes to prove the sequence from the base of the Thick Rock to the Middle/Lower Coal Measures

Following discussions on access, it seems that a 60 m borehole (No. 1) linked to a borehole on the top of the gorge (No.2) will serve this purpose. Two additional boreholes (Nos. 3 and 4) on the same line of section but lower down the slope will provide a transect for stability analysis.

Sector 2

Boreholes are required to confirm the conjectured graben and downthrow of the Thick Rock. This could be achieved by a borehole (largely open-holed) on the plateau top (No. 5). In addition, two boreholes (Nos. 6 and 7) below the Thick Rock are proposed. Sites will depend on access.

Sector 3

One or more boreholes (No. 8) are required to provide information on the stratigraphical continuity of the sequence along the upper part of the gorge, and to provide a basis for assessing the throw across the Lloyd's Coppice Fault.

Sector 4

Information on this sector may already be available from bridgework boreholes.

Sector 5.
At least 3 boreholes are required to extend transects from sectors 2 and 3 across the Lloyds Coppice Fault.

The proposed sites are listed as Nos. 9,10 and 11.
Borehole No.9, upslope from Lloyd's Water Engine Air Pit [3690 3031].will serve two purposes:

- help define the throw across the Lloyd's Coppice Fault by comparison with the sequence proved in Sector 3 borehole

- clarify apparent discrepancies between the sequence reported in the Lloyd's Water Engine Air Pit and that of the Lloyd's Engine Pit [3689 3030].

Sector 6
Two boreholes (Nos. 12 and 13) are proposed to assess the stratigraphy and depth to in situ bedrock on the lower slopes.

3 Landslide processes, hydrogeology

The current understanding of the geomorphology of the Lloyds Coppice area is based upon two major studies; the first carried out in 1972/73 by the British Geological Survey (then the Institute of Geological Sciences) and the second by Sir William Halcrow & Partners in 1990. These studies are critically examined and the results synthesised below to develop a landslide model that best fits the available information.

3.1 BGS Ground Model. 1973

3.1.1 Scope

Work was carried out on the request of the Telford Development Corporation to investigate landsliding within Lloyd's Coppice and in land immediately surrounding it. The assessment was required to determine whether areas around Jockey Bank and some areas of Ironbridge Village were suitable for development.

Several boreholes were drilled, including the deep boreholes at Lees Farm (described in Section 2) and a number of shallow holes in the Jackson Field and Ironbridge Village areas.

3.1.2 Results

Two reports (Culshaw, 1972, 1973) describe the geology, topography and engineering geology of the Lloyd's Coppice area and provide a stability classification of the Coppice. The reports include proposals for future investigations and remedial works.

3.1.3 Geology

Boreholes sunk upslope from the Coppice at Lees Farm recorded 5.5 m to 17 m of till overlying up to 84.8 m of the Halesowen Formation (Coalport Beds). Up to 11 m of the underlying Middle Coal Measures were also thought to be proven but, as noted in Section 2, there is some doubt about the classification of these beds. Major sandstones in the Halesowen Formation (the Thick Rock and the Stinking Rock) are considered to be significant geomorphological features, providing structural stability within the slope but also acting as aquifers due to their relatively high permeabilities. The Etruria Formation that underlies the Halesowen Formation was not described by the report, suggesting either that it was not differentiated from the Halesowen Formation at the time of investigation or that it was never penetrated.

Superficial and artificial deposits are not described in detail but it is stated that much of the Coppice is covered in mine waste forming 'elongate flat areas with steep slopes below'. Much of the lower part of the Coppice had been excavated to allow the construction of a road.

No evidence of mining activity was recorded in the borehole records but it was recognised that commercial extraction of coal, ironstone and clay had taken place from within the Coppice area and from adits driven from the nearby Blists Hill Pits and that such extraction (and subsequent deposition of mine-waste) would affect the slope stability and hydrogeology of the slope.

3.1.4 Hydrogeology

Two sets of permeability tests were carried out. The Thick Rock, produced permeabilities around 1.4×10^{-6} m/sec and the 'Stinking Rock' yielded values of 2.2×10^{-7} m/sec. Although not typically thought of as permeable, these sandstones are considerably more permeable than the surrounding mudrocks and, in the Stinking Rock, inflow was sufficient to wash away the sides of the borehole during drilling.

3.1.5 Geomorphological Model

Detailed geomorphological mapping was outside the scope of this study (and was not normal practice at the time) so the landslide zones were proposed based upon a detailed walkover survey of the site, examination of topographic contours and from cross-sections constructed from interpretations of the drilled core.

Topography was used to define two broad slope classes. A near-vertical cliff at the top of the slope, and a second zone with lower gradients (10-15°) downslope from this cliff, considered to be extensively affected by slope instability. The steep cliff was classified as one geomorphological zone, whilst the lower slopes were divided into two further zones based upon the degree of observed landslide activity (Figure 5).

For the purposes of this report, the zones described in the IGS model have been termed a, b and c. Zone 'a' lies above the steep cliff section, formed in relation to the Thick Rock unit.. Zones 'b' and 'c' were considered to be areas of instability

Zone 'c' was confirmed as being unstable ground. It includes the steep cliff which was affected by continuous small falls from within the in-situ material but was not thought to be receding at a significant rate. Below this the upper slopes of the complex were thought to be a result of relict deep-seated landslides, which had become relatively stable since the initial downcutting. The lower slopes within Zone c were interpreted as shallow translational and rotational failures within landslide debris, superficial deposits and mine-waste.

Zone ‘b’ was not described in great detail but was classified as an area of active or potentially active landsliding, probably of shallow rotational and shallow translational nature.

3.1.6 Geomorphological Processes

A process model was proposed to explain the presence of a relatively stable slipped under-cliff, occurring upslope of an area of active landsliding.

1. Flow of the River Severn leads to rapid downcutting of the Halesowen Formation and overlying till
2. At some point the process of down-cutting intercepted the previously confined Thick Rock sandstone aquifer, which then became a source of water to the over-consolidated, moisture-susceptible mudrocks of the Halesowen Formation
3. In response to this influx of water, beds immediately below the sandstone were softened and subject to higher pore-water pressures than before. This, in conjunction with the removal of support and over-steepening of the slope, propagated failure by a process of deep-seated rotational landsliding.
4. After a period of time, the unconfined Thick Rock aquifer drained and became a less significant source of water to the upper slope, curtailing landslide activity.
5. As the Severn continued to down-cut into the Halesowen Formation, a second, confined sandstone (possibly the Stinking Rock) was intercepted.
6. This second sandstone acted as a source of water to the bedrock mudstones downslope of it and led to a second phase of landsliding, which continues to the present day and is observed in the active lower slopes of Lloyds Coppice.

3.1.7 Conclusions

Based primarily upon geology, slope and degree of active landsliding, the Coppice area was divided into three zones (Figure 5):

- Stable - Zone a - above the rear cliff
- Unstable – Zone c – upper and central slopes of the Coppice, varying in degree of activity
- Intermediate – Zone b – lower slopes where the degree of landsliding could not be determined

Recommendations for further investigation and remedial procedures were given in the report. It is not known whether any of these recommendations were acted upon.

3.2 Halcrow Ground Model. 1990

(Supplied as SCC (1990) on loan to BGS December 2002)

3.2.1 Scope

Work was carried out on the request of Shropshire County Council (Highways Department) to determine the causes of ground movement at Lloyds Coppice landslide complex and the nearby Jackfield landslide complex, with a remit to identify sections of road most at risk from future landsliding.

Research comprised a desk study, an assessment of existing information sources and the creation of large scale (1:2500) geomorphological maps, interpreted for landslide style.

3.2.2 Results

The report described the findings of a desk study and provided a detailed description of the geomorphological maps presented. A series of photographs, historic maps and a damage survey were also supplied.

The report detailed known sources of information with regards to mining within the Lloyd's Coppice and Jackfield areas and a catalogue of damage attributed to landsliding between 1925 and 1990.

3.2.3 Geology

No new geological investigations were carried out for this investigation; geological cross sections were constructed using information from Culshaw (1973) and from information contained in mine plans.

3.2.4 Hydrogeology

The report states that tests were carried out to determine the permeability of the Thick Rock and the Stinking Rock but the provenance of the results is not given. Permeability values are exactly the same as those of Culshaw (1973), but it is not known whether these are the results of further tests carried out to corroborate earlier findings or whether they have simply re-quoted Culshaw (1973). The importance of the sandstones as potential flow paths was raised. A point was also made that the Halesowen Formation in this area can have high permeabilities.

The presence of secondary reservoirs was also investigated. It was suggested that the landslide debris itself may contain and transmit considerable volumes of water, citing as evidence the presence of shallow water tables in landslide debris found in previous investigations. Although no specific records were found, abandoned mine workings were also thought likely to act as potential reservoirs and conduits for water.

3.2.5 Geomorphological Model

The investigation contains the most detailed geomorphological map of the Coppice to date. Although the mapping method is not stated, it is likely that this was made by a combination of aerial photograph interpretation and field mapping and was reproduced in the report at a nominal scale of 1:2500.

The Halcrow model divides the Coppice area into seven geomorphological units (or Ground Behaviour Units) based upon their geomorphological features and degree of landsliding activity at the time of investigation (Figure 6). These are summarised (with estimate of relative stability):

I. Steep cliff – main scarp

II. Deep-seated rotational landslides in bedrock, moderately degraded, (inactive)

III. Ridge – less degraded remnant of deep-seated rotational landslides in bedrock (inactive)

IV. Deep-seated rotational landslides in bedrock, moderately degraded (inactive)

V. Shallow landsliding in debris and mine-waste, moderately degraded with signs of recent movement (rotational and translational) (active)

VI. Shallow translational failures in landslide debris, mainly degraded (inactive)

VII. Recent failures in made ground and spoil, mainly shallow translational but a number of features which have the appearance of small rotational slips occur on the geomorphological map (active)

No attempt was made to form a process model for the Lloyds Coppice area.

3.3 Summary of Previous Research

Although the scope of each of these major reports was very different, they both reach broadly the same conclusions with respect to the geomorphology of the Lloyd's Coppice landslide.

In broad terms, the Lloyd's Coppice landslide complex is considered to comprise four main zones (Halcrow notation in parenthesis):

1) A steep upper cliff formed around the Thick Rock (I)
2) A degraded upper undercliff, which can be sub-divided:
    a) Western zone where the landslide blocks have largely been destroyed by weathering (II)
    b) Central zone forming a small headland, possibly formed by a degraded block (III)
    c) Eastern zone where deep-seated failures could have been more recent than in the western zone or where failures have been less affected by weathering (IV)
3) An active undercliff, with landsliding active in debris accumulations and possibly within the solid geology (V)
4) A relatively inactive apron of debris (VI)
5) An active apron of debris, where recent landslide activity has been prompted either by undercutting by either construction processes or by loading from mine-waste.

The findings of the recent walkover survey have introduced new information which should be incorporated into any geomorphological interpretation of Lloyd's Coppice.

There are a number of significant omissions in both reports:

- neither report considers the existence of unmapped geological faults or other structures within the complex as a significant control on slope stability, although at Jackfield, faulting is known to be a significant factor.
- there is no discussion of the importance of coal as a potential weak/ permeable horizon
- there is no acknowledgement that deep-seated landslide processes may be operating within the Coppice; the possibility that there may be larger scale landslide activity (i.e. a rotational slide) at the depth of the Etruria Formation or Coal Measures must be considered.

3.4 Assessment of the geomorphological problems of Lloyd’s Coppice

Based upon previous research - the primary controls on the geomorphology and slope instability at Lloyd’s Coppice appear to be:

- Supply, storage and flow of groundwater and surface water
- Elevation, lateral persistence and geotechnical/ hydrogeological properties of sandstones within the Halesowen Formation; these bodies acting as both aquifers and structural supports within the slope
- Elevation, distribution and geotechnical/ hydrogeological properties of mudstones within the outcropping formations
- Geological structure (local dip, faulting)
- Disturbance to bedrock geology and hydrogeological regime by mine-workings
- Disturbance to bedrock geology and hydrogeology by construction
- Presence, thickness and properties of mine-waste

Each of these factors will vary between Ground Behaviour Units and their effects are difficult to assess without a full and detailed ground investigation.

Although the walkover survey carried out as part of this research was brief and covered only part of the Coppice area it has demonstrated that the previously accepted geomorphological model of Lloyd’s Coppice (Halcrow 1990) does not satisfactorily characterize the slopes. The process model of Culshaw (1972) should also be revised. A number of factors are now required to be included in any new slope interpretation:

At least two, previously unknown NNE/SSW trending faults have been speculatively identified in the centre of Lloyd's Coppice (Section 2). If these are proven by borehole investigations a ground model will have to incorporate:

1. A re-interpretation of, the central section of the upper-Coppice. Interpreted by Halcrow (1990) as a degraded rotational block, this may (depending upon further evidence) be re-interpreted as an in-situ fault block, downthrown relative to the eastern and western areas of the Coppice.
2. The presence of a series of rotational slips within the till unit above the down-thrown block.
3. A comprehensive revision of the style, location and boundaries of the existing ground model.
4. A different hydrogeological regime within the Coppice.

The borehole investigation to be carried out in 2003 is an important step in establishing the presence or otherwise of features identified in the walkover survey. The investigation should seek to establish the parameters outlined below:

- The geotechnical and hydrogeological parameters and variability of materials within the complex
- The extent to which slope form and stability is controlled by the presence or otherwise of sandstone units
- The depth of landsliding – in-situ geology will need to be proven throughout the complex

4 Recommendations

The design of the site investigation programme must aim to resolve the geological, geotechnical and hydrological uncertainties described in sections 2 and 3.

It is recommended that drilling should be prioritised as set out in Table 2. Ideally, a minimum of 13 fully cored boreholes is required to provide a framework on which to base the geological modelling and stability analysis.

The key boreholes will aim to resolve:

- local stratigraphy
- fault throw
- presence of any shear zones within near surface layers or at depth

It is essential that one or more stratigraphical boreholes are drilled to provide a reference section for the entire sequence.

- Subsequent boreholes should be assessed on-site to ensure that unforeseen problems can be addressed and, where necessary, adjustments made to the proposed drilling programme.
- Instrumentation will depend on available funds but ideally piezometers should be installed within each of the major lithological units identified on the basis of information obtained from the stratigraphical borehole.
- Inclinometers should be installed above significant shear zones.
- Boreholes should be levelled
- Geophysical logging (gamma logging) should be carried out (BGS may be able to assist)

Our belief is that the existing geomorphological model does not fully explain the geomorphological features observed during the walkover survey. Therefore we strongly recommend that additional field-work is carried out to examine the surface geology and geomorphology of the Coppice to properly define Ground Behaviour Units for the purpose of slope analysis.

This will ensure that the best available information is used for slope assessment and will form an invaluable baseline study for future monitoring work, both within the Coppice area and elsewhere.

Table 2. Suggested borehole schedule (outline) based upon the results of desk study.

Borehole	Location	Depth	Purpose
	Sector 1		
1	[6836 0355]	60m	1 2 and 3, in combination, to provide a definitive stratigraphic section for the entire sequence
2	[68409 0366]	50m	Provide stratigraphical information and the depth and nature of shear zones in Ground Behaviour Unit V
3	[6832 0348]	50m	Provide stratigraphical information and the depth and nature of shear zones in Ground Behaviour Units VI
4	[6828 0341]	40m	
	Sector 2		
5	[6888 0343]	30 m	Prove depth to base of Thick Rock (mainly open-holed)
6	[6881 0335]	60m	Prove stratigraphy and depth and nature of shear zones beneath Ground Behaviour Units II, V, VI
7	[874 0324]	50m	
	Sector 3	40 m	Prove stratigraphy of eastern end of Coppice
8	[904 0318]		Prove depth and nature of shear zones beneath lower slopes of Ground Behaviour Units IV, V and VI
	Sector 4		No boreholes planned; depends on available information
	Sector 5		
9	[6893 0310]	50m	Prove throw on Lloyd's Coppice Fault; resolve stratigraphical problems with Lloyd's Engine House and airpit shafts
10	[884 0306]	30m	Prove depth and nature of shear zones beneath lower slopes (Ground Behaviour Unit VII and VII
11	[868 0318]	30m	
	Sector 6		Prove stratigraphy at eastern end of Coppice. Prove depth and nature of shear zones beneath lower slopes (Ground Behaviour Unit VI and VII
12	[6913 0299]	40 m	
13	[6908 0292]	40 m	

References

CULSHAW, M G C. 1972. *Preliminary Report on a landslide survey on the North Side of the Ironbridge Gorge*. Engineering Geology Report 72/3 British Geological Survey.

CULSHAW, M G C. 1973. *A Stability Assessment of the North Slope of the Ironbridge Gorge, Telford, Shropshire*. Engineering Geology Report 73/1 British Geological Survey.

HAMBLIN, R J O, AND COPPACK, B C. 1995. Geology of Telford and the Coalbrookdale Coalfield. *Memoir of the British Geological Survey*, part of sheets 152 and 153 (England and Wales).

HENKEL, D J. AND SKEMPTON, , A W. 1954. A landslide at Jackfield, Shropshire in heavily over-consolidated clay. *Géotechnique*, Vol. 5, No. 2 ,131-137.

SHROPSHIRE COUNTY COUNCIL, 1990. *Landslides at Ironbridge: Jackfield and Lloyd's Coppice. Report on hazard mapping.* Halcrow Consulting Engineers

Figures

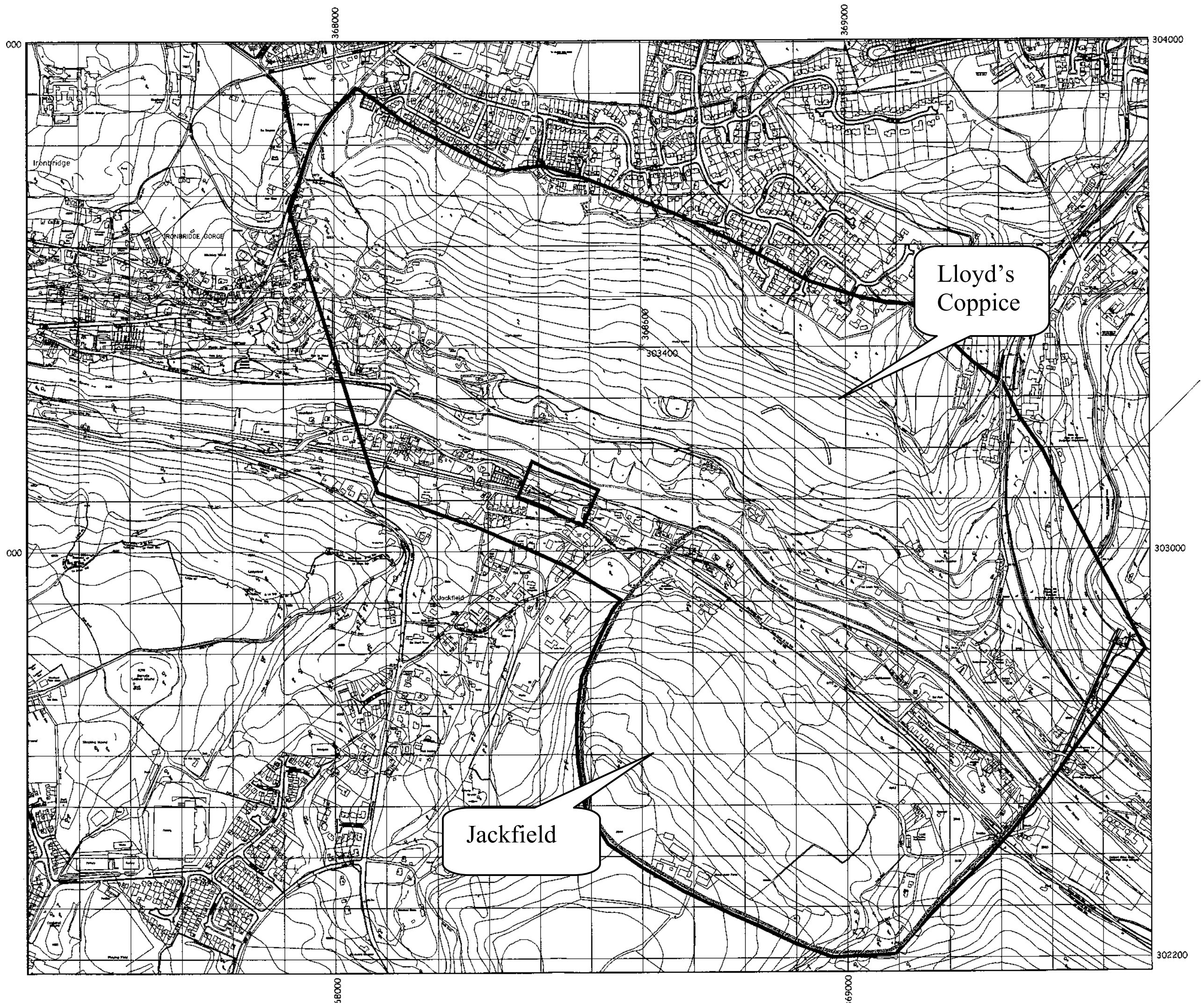


Figure 1. Project area

a)

b)

Figure 2 Geological setting:

a) extract from 1:25 000 geological map b) extract from 1:10 560 geological map

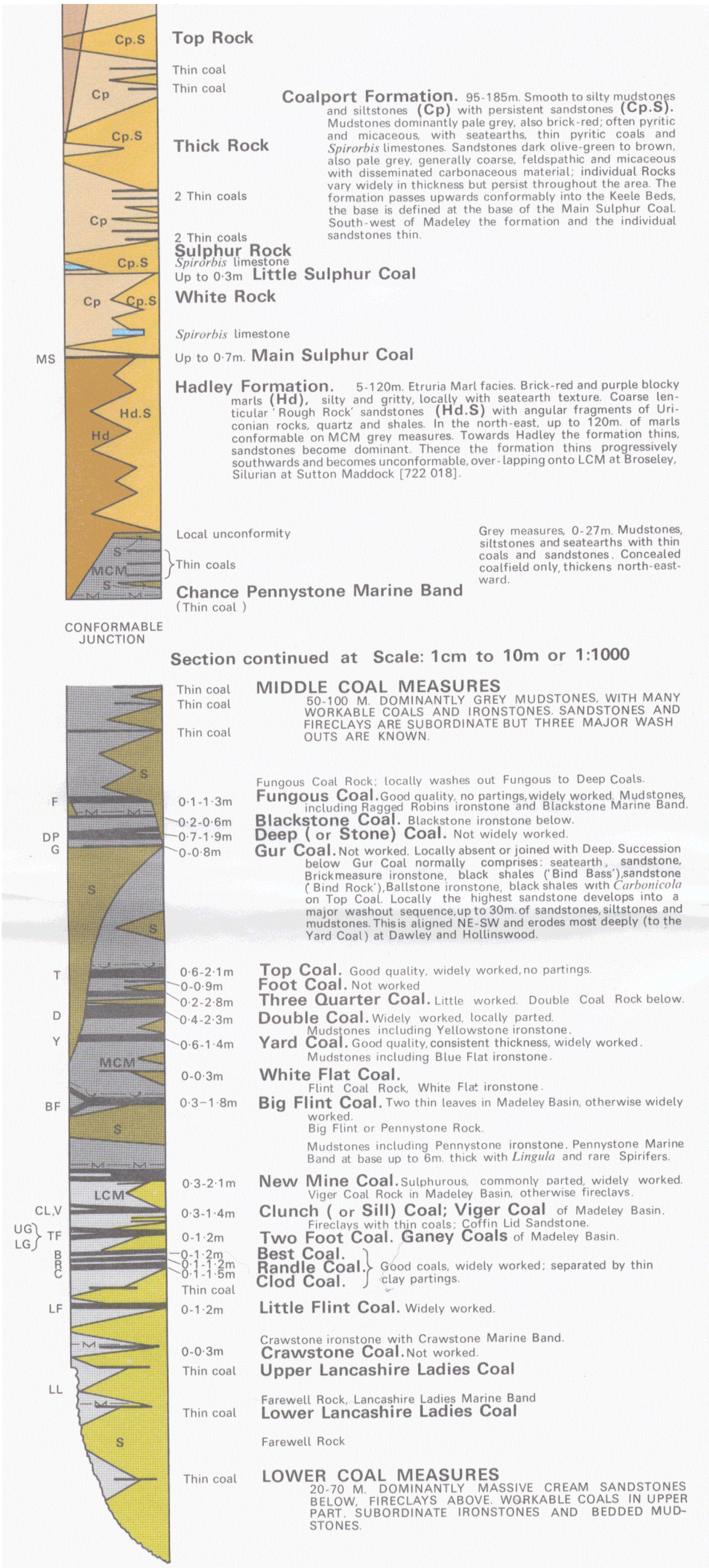
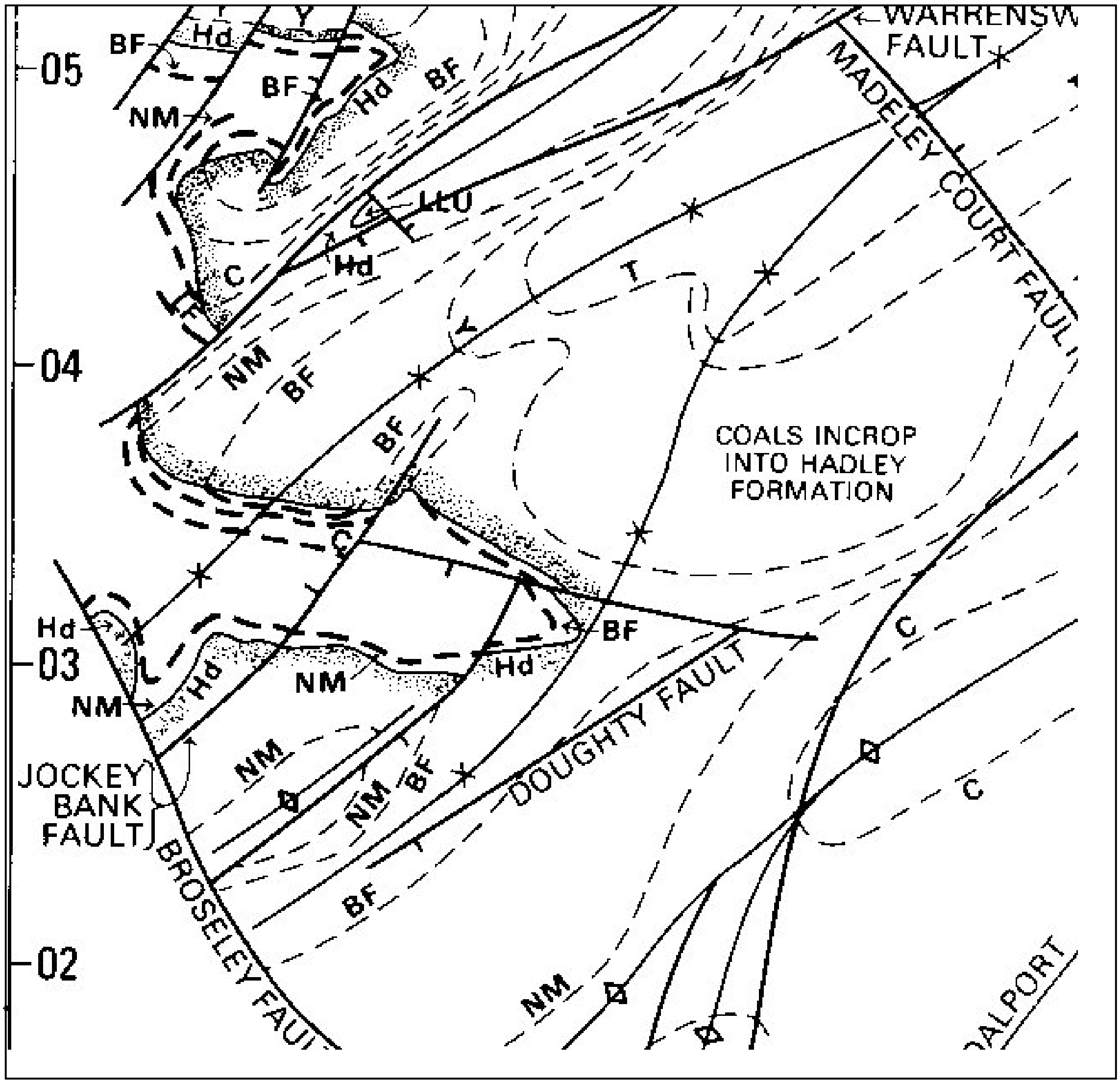


Figure 3 Generalised vertical section of bedrock geology



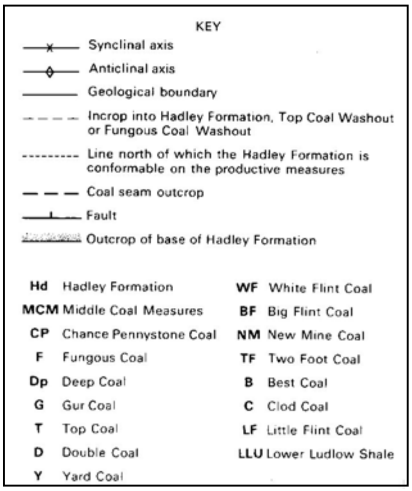


Figure 4. Map showing incrop of coal seams into the sub-Etruria Formation unconformity (from Hamblin and Coppack, 1995)

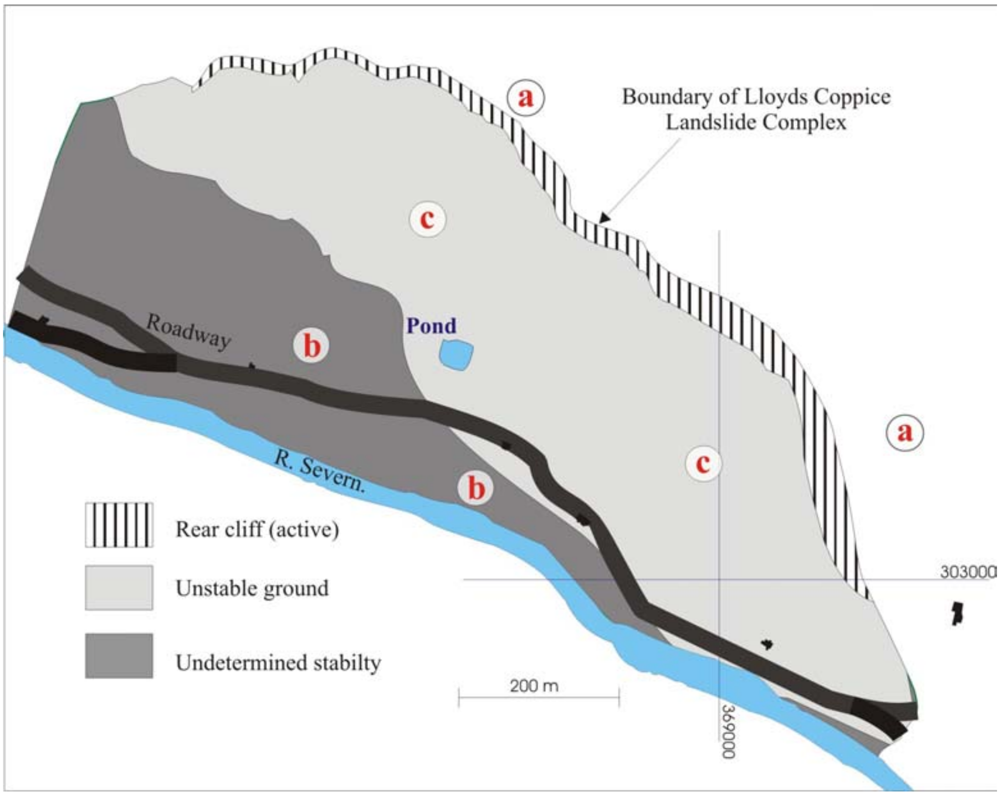


Figure 5. Simplified interpretation of the IGS Slope model for Lloyds Coppice. Outline from SCC (1990).

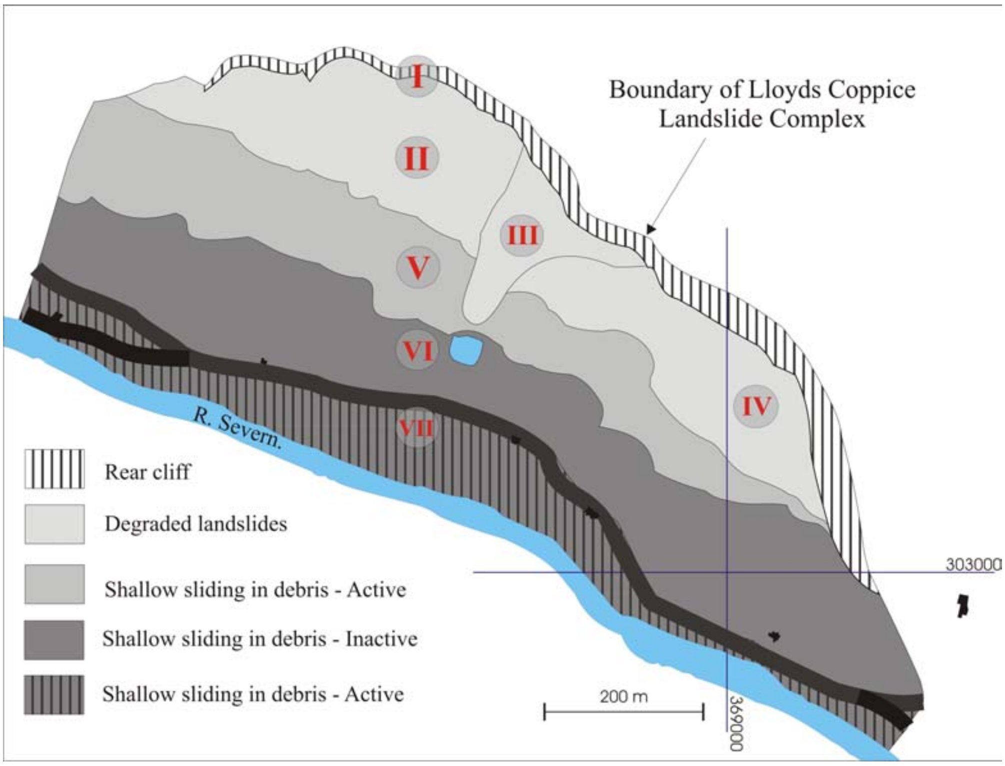


Figure 6. Simplified interpretation of the Halcrow Slope model for Lloyds Coppice, zones summaries in the main text.

5 Appendix 1: Information consulted

Maps and plans

1:10560 Geological map SJ60SE (1972)
1:25 000 Geological Telford Special Sheet

Geomorphological map (Telford and Wrekin Council)

Reports

Geology of the Telford and the Coalbrookdale Coalfield (Hamblin and Coppack, 1995)

Landslides at Ironbridge: Jackfield and Lloyd's Coppice. Report on hazard mapping. Halcrow Consulting Engineers (Shropshire County Council, 1990.

Preliminary Report on a landslide survey on the North Side of the Ironbridge Gorge. Engineering Geology Report 72/3 British Geological Survey. (Culshaw, M G C. 1972).

A Stability Assessment of the North Slope of the Ironbridge Gorge, Telford, Shropshire. Engineering Geology Report 73/1 British Geological Survey. (Culshaw, M G C. 1973).

Borehole and shaft records held in BGS archives

Web sites

www.serve.com/scmc/lloydspt.html