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A geological assessment of the landslides in the Ironbridge Gorge, Shropshire

Prepared for Wardell Armstrong LLP
by the British Geological Survey

Commissioned Report CR/08/157N

BRITISH GEOLOGICAL SURVEY

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A geological assessment of the landslides in the Ironbridge Gorge, Shropshire

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Executive Summary

This report, commissioned by Wardell Armstrong LLP, provides a detailed overview of the geology and landslides of the Ironbridge Gorge, Shropshire. This report presents factual information about the landslides of the Ironbridge Gorge area based on a limited desk study and no fieldwork took place. Many of the reports that it references are more than 30 years old and it must be stressed that this current work and the previous references should not be used to make any decisions about land use or engineering without making a proper assessment of the ground. The unstable nature of the landslide areas mean that the situation on the ground can change considerably over short periods of time.

Acknowledgements

The author would like to thank Professor Martin Culshaw, Dr Anthony Cooper, Dr Claire Foster and Dr Andrew Gibson who have freely given advice, provided local knowledge and helped to review this report.

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1 Introduction

1.1 TERMS OF REFERENCE

This report describes the findings of a desk study carried out by the British Geological Survey (BGS) to provide information on the landslides of the Ironbridge Gorge, Shropshire, and give an overview of the geology for the area. The study area is shown in Figure 1. The work was carried out in response to an enquiry made on the 6th November 2008 by Wardell Armstrong LLP represented by Lindsey Wood, Environmental Scientist. BGS were commissioned under minor repayment IDA 167530. The National Grid and other Ordnance Survey data are used with the permission of the Controller of Her Majesty's Stationery Office Licence No: 100037272. NextMap™ elevation data are from Intermap Technologies.

1.2 METHODOLOGY

The task was undertaken as a desk study. Time and budget constraints meant that background researches were restricted to material that could be readily accessed within BGS report series and geological archives. Searches of the Internet also produced some useful material.

1.3 LOCATION, HISTORY AND TOPOGRAPHY

The Ironbridge Gorge is located to the south of Telford in Shropshire around grid reference [SJ 67284 03396] and is a World Heritage Site. The Gorge is thought to have originated some 10,000 years ago and is deeply incised in rocks of Upper Carboniferous and Silurian age, which are prone to landsliding, and have suffered a number of failures in historical times (e.g. Henkel and Skempton, 1954). The origin of the Severn gorge at Ironbridge has been the subject of much speculation for which the literature attests (e.g. Maw, 1864; Harmer, 1907; Wills, 1924; Hamblin, 1986; Bridge and Hough, 2002). Currently, the most widely accepted interpretation for the formation of the Ironbridge Gorge is that of Hamblin (1986). This proposed that the formation of the gorge began towards the end of the last glaciation either as a subglacial meltwater channel, eroded *beneath* the glacier when erosive flow of meltwater would have been concentrated within a channel and the ground weakened by frost action, or somewhat later as an ice-marginal channel that developed as the main glacier melted.

Topographically, the valley sides rise steeply from 40 m at river level to over 140 m on the plateau above. Figure 2 shows the pattern of topography of Ironbridge Gorge taken from NextMap™ Surface Model. The area can be divided in to three geomorphological units (after Wills, 1924):

a) The Buildwas Strath is a continuation eastwards of the Shropshire Plain and is a broad valley through which, in the west, the Severn meanders on a broad flood-plain. Towards the eastwards, the valley and the floodplain narrows towards the entrance of the Ironbridge Gorge, at which point Coalbrookdale debouches.

b) The Barrow-Brosely and the Madeley Shifnal Plateaux – a high plateau with a north-west facing scarp, which extends from near Much Wenlock, through Barrow and along Benthall Edge to Ironbridge. North of Ironbridge Gorge a similar plateau stretches from Coalbrookdale and the Wrekin towards Madeley and Shifnal. The two plateaux, although separated by the Severn valley, form a single unit. They both slope, in the main, towards the low ground in the south. They are both crossed by small brooks having a south-east direction.

c) The Ironbridge Gorge – diagonally across the sloping plateau runs the trench-like gorge of the Severn. From Ironbridge to Swinney, its direction is from north-west to south-east, parallel to the consequent brooks. The small tributaries to the gorge have very steep gradients and enter it as hanging valleys.

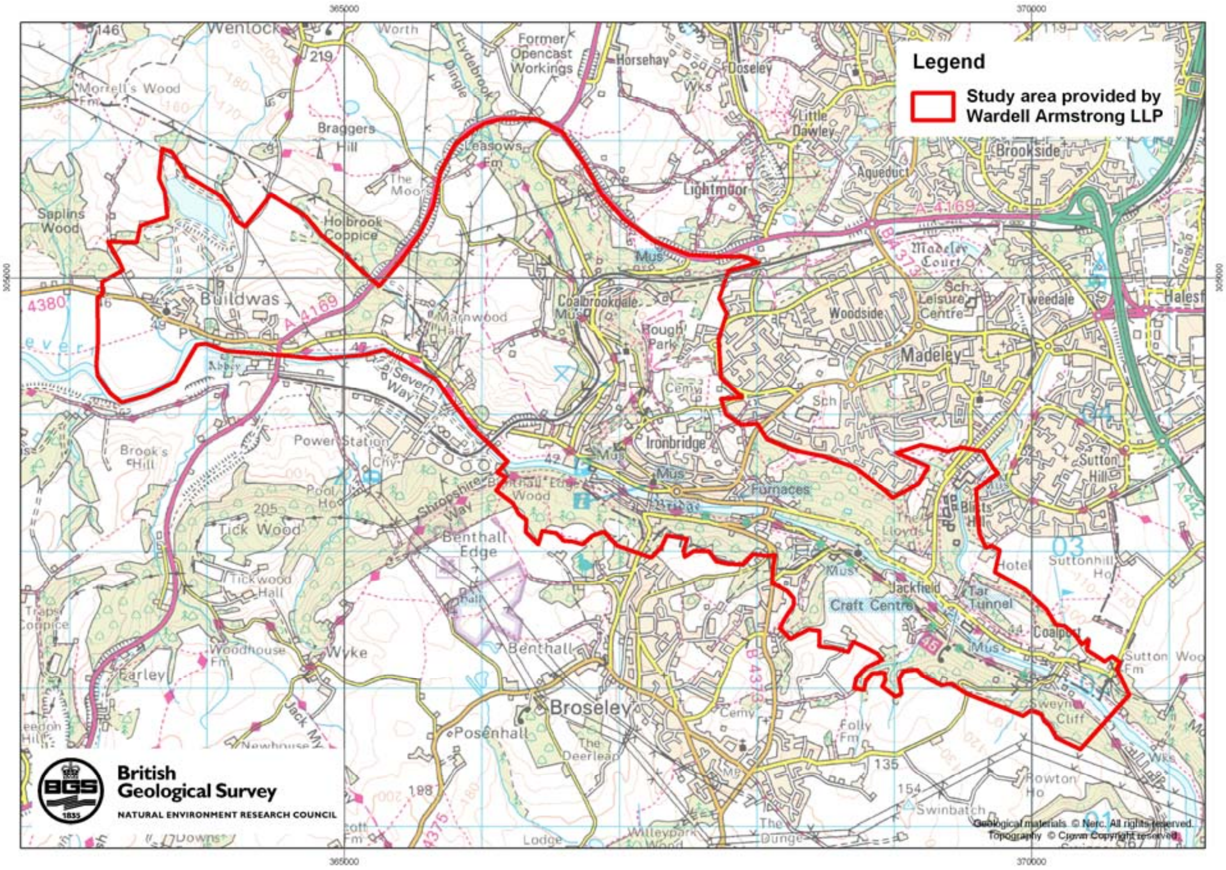

Figure 1 Location map of study area in the Ironbridge Gorge, Shropshire

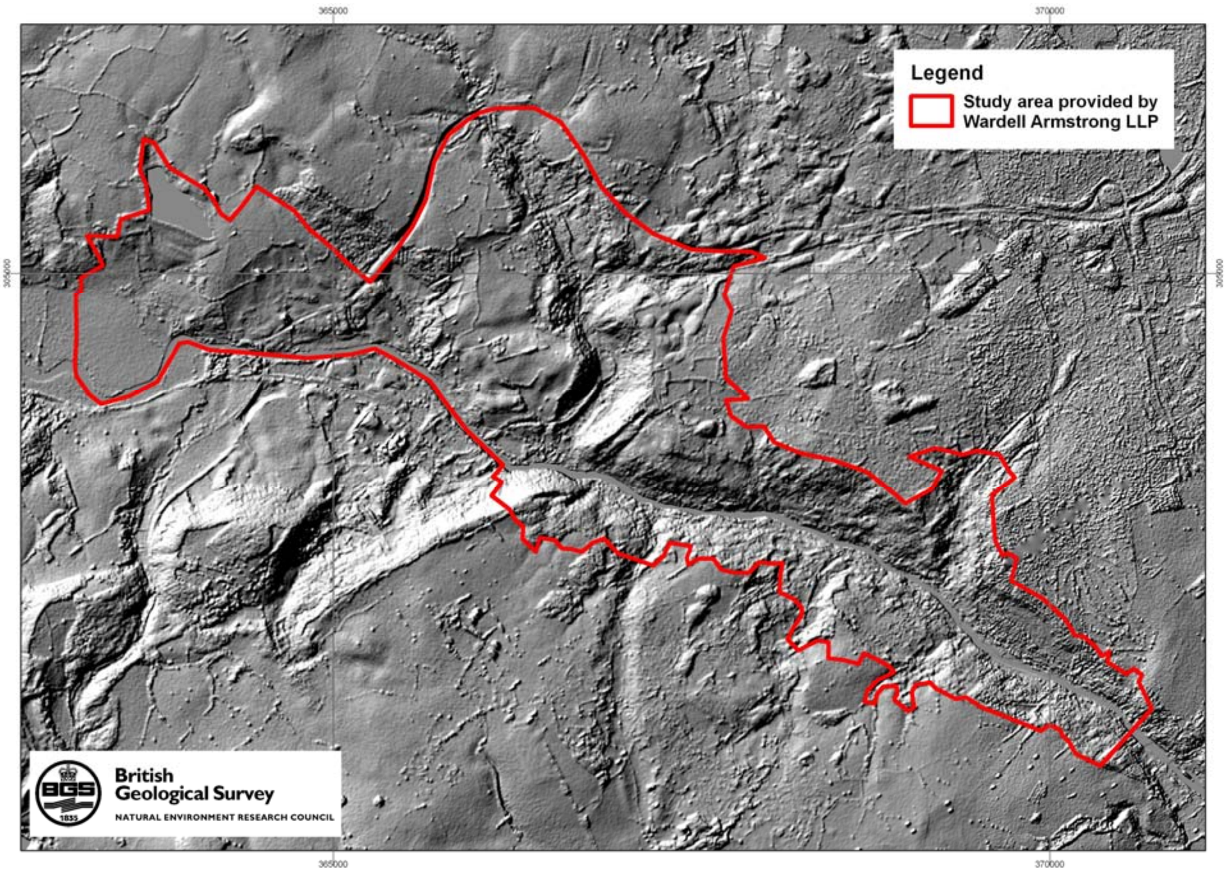

Figure 2 Topographic relief model of Ironbridge Gorge taken from NextMap™

2 Geological Summary

Geological descriptions of each lithostratigraphic unit and geological structure are taken from Hamblin and Coppack (1995), Bridge and Hough (2002) and confidential information held in the BGS archive. Descriptions are limited to those units that are exposed at surface within the area.

2.1 BEDROCK GEOLOGY

The bedrock (solid) geology taken from the BGS 1:50,000 scale digital map (DiGMapGB-50) is shown in Figure 3. A more detailed map of the bedrock geology is taken from the published 1:25 000 Telford Special Sheet (Figure 4) although the stratigraphic names and boundaries have been superseded since this map was published in 1978. For the purposes of this report, the current nomenclature of bedrock geology is used and Table 1 shows the generalised relationships between the mapped rock units.

Period	Stage	Lithostratigraphy	
Carboniferous	Westphalian to Early Permian	Salop Formation	Aveley Member
		Halesowen Formation	
		Etruria Formation	
		Pennine Middle Coal Measures Formation	
		Pennine Lower Coal Measures Formation	
	Mississippian	Sylvan Limestone Formation	Little Wenlock Basalt Member
		Lydebrook Sandstone Formation	
Silurian	Ludlow	Lower Ludlow Shales Group	
	Wenlock	Much Wenlock Limestone Formation	Benthall Member
			Reef Facies
			Limestone
		Coalbrookdale Formation	
	Llandovery	Purple Shales Formation	
		Pentamerus Sandstone Formation	

Table 1 Summary of bedrock geology exposed in the study area

The bedrock geology decreases in age towards the east of the study area with Silurian rocks in the west and Carboniferous in the east as follows:

2.1.1 Silurian

The oldest rocks that crop out in the far west of the study area are the Silurian **Pentamerus Sandstone** and **Purple Shales Formation** which are presumed to underlie most of the district.

The **Pentamerus Sandstone** is approximately 100 m thick and typically comprises blue and blue-grey silty mudstones, with subordinate thinly bedded, orange sandstones and sandy limestones; they generally dip to the south east but local disturbances, such as faults, can result in north or north-eastwards dips.

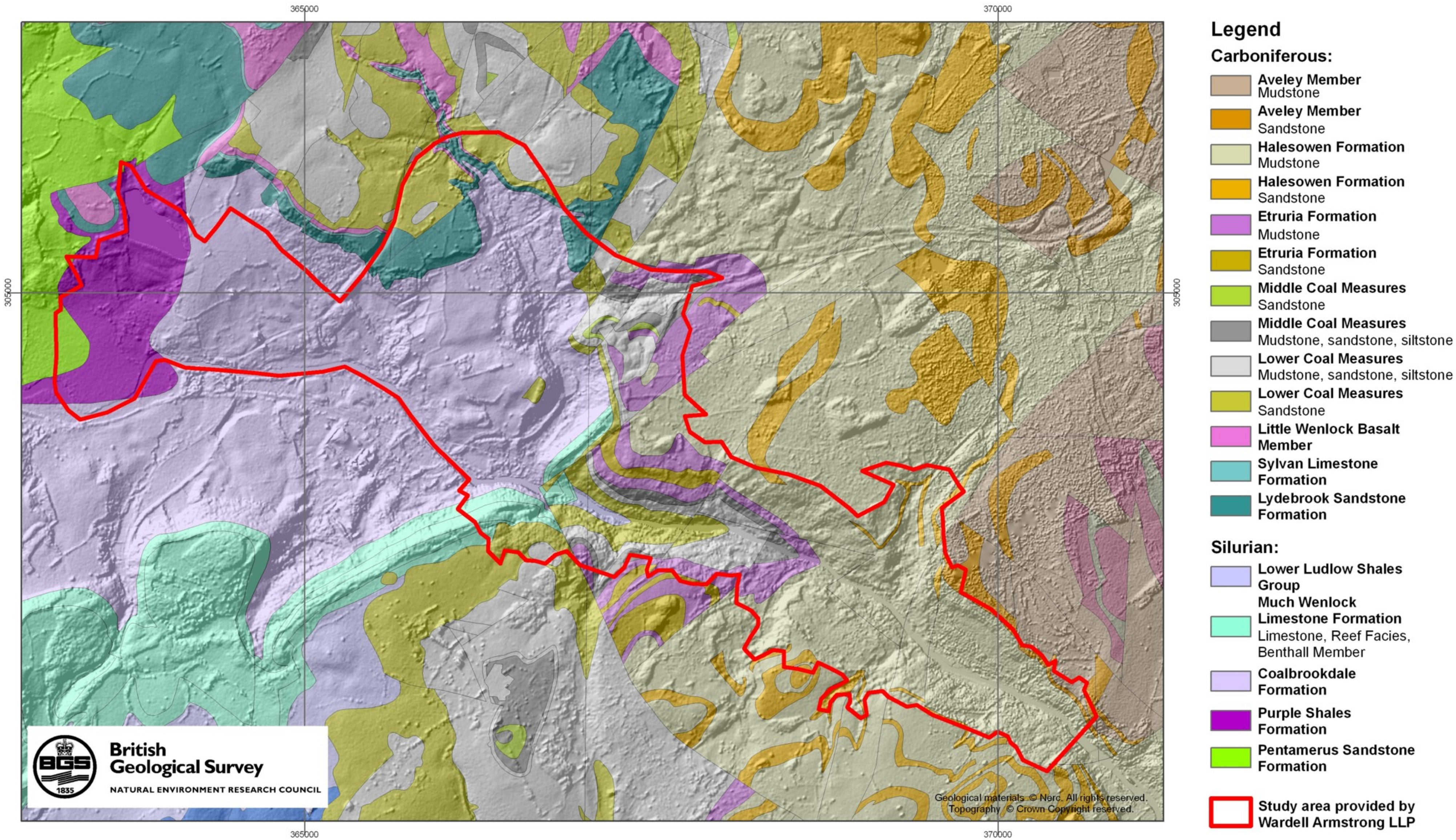

Figure 3 Extract from BGS 1:50,000 scale digital bedrock geology map superimposed on topographic relief Next Map™ model

The **Purple Shales Formation**, previously known as the Hughley Shales, consists of 40 m to 50 m of purple, bluish purple and chocolate brown to grey-brown mudstones and silty mudstone, with some thin units of silty to sandy limestones and calcareous siltstones.

Interbedded thin bentonites in the graptolitic and shelly **Buildwas Formation** (not seen at the surface in the study area) and the **Coalbrookdale Formation** are testimony to distant volcanic eruptions. The Coalbrookdale Formation comprises approximately 160 m of blue-grey mudstones with sporadic calcareous nodules, which become more common in the upper part.

The **Much Wenlock Limestone Formation** dips at 10º to 15º to the south-east, but structural disturbances and sedimentary dips around reef knolls locally give rise to northward and westward dips. Within this formation, the **Wenlock Limestone Reef Facies** consists of up to 30 m of nodular limestones and siltstones, containing large masses of extremely fossiliferous, unbedded ‘ballstones’. These ballstones are thought to be coral banks which formed at the seaward fringe of a reef belt where the sea was probably no more than 30 m deep, but where reefs were not liable to damage by surface wave action. The facies passes laterally into some 20 m of massive flaggy, shelly, crystalline limestones, interbedded with impersistent siltstones in their lower and upper parts forming the **Benthall Member**. The youngest beds of Wenlock age here consist of 4 to 5 m of flaggy to thinly bedded crinoidal limestones referred to as **Wenlock Limestone**.

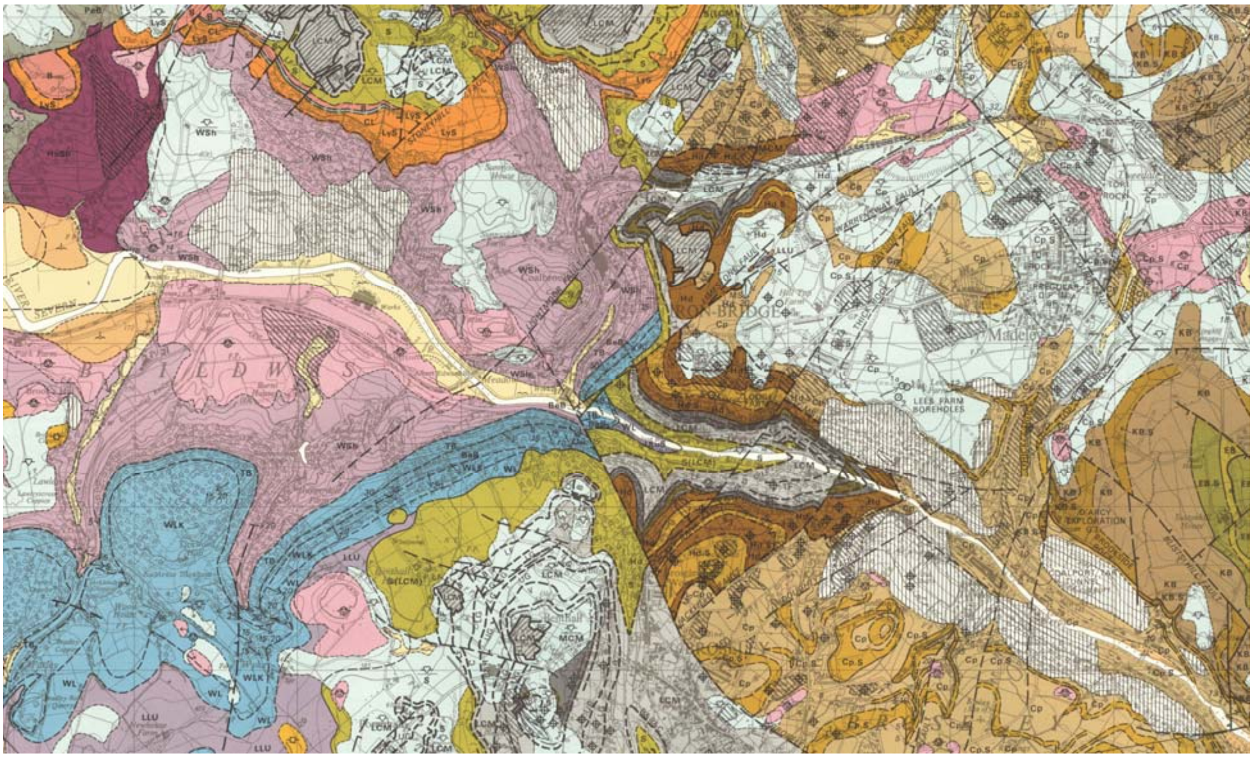

Figure 4 Geological map taken from 1:25 000 Telford Special Sheet BGS © NERC.

The limestone passes transitionally upward into the **Lower Ludlow Shales Group** which has very little exposure across the area. Much of the mapping has been based on topographic features and borehole evidence. It is estimated to be approximately 120 m thick and consists of greenish grey to grey silty mudstones, with calcareous siltstone nodules near the base. The upper limit of this Group is marked by a prominent seepage line, which coincides with a change in slope profile, reflecting the transition into the harder Aymestry Limestone Formation which does not crop out in the study area.

2.1.2 Carboniferous

The oldest unit of Carboniferous age in the study area is the **Lydebrook Sandstone Formation**. This consists of fine- to coarse-grained, gritty to pebbly, yellow to orange-brown sandstones. The sequence maintains a uniform thickness of approximately 30 m except in the south-east at Jiggers Bank where is it overstepped unconformably by the Coal Measures.

The **Sylvan Limestone Formation** of Mississippian age was previously known as the upper part of the 'Carboniferous Limestone Formation'; it comprises nodular or rubbly creamy white or yellow, crystalline limestone with dark grey to black shale bands. Crinoids, corals, brachiopods and other shell debris scattered throughout the sequence. A characteristic gritty texture results from contact metamorphism with the **Little Wenlock Basalt Member**, which is interbedded with the formation. Although only 6 to 8 m thick, the Sylvan Limestone Formation is laterally persistent across the whole area.

The **Pennine Lower and Middle Coal Measures Formations** form a grey, clastic coal-bearing sequence which accumulated in a poorly-drained delta-plain environment. These rocks crop out in the valley bottom in the eastern part of the valley, where the succession is dominated by grey mudstones and seatearths with subordinate beds of sandstones, coal and ironstones. Coal seams which crop out in the study area include (in ascending order) the Lancashire Ladies, Crawstone, Little Flint, Clod, Best, Ganey, Viger and Big Flint coals.

The **Etruria Formation**, previously known as the 'Hadley Formation', rests unconformably on the productive Coal Measures strata. It consists of characteristic mottled purple and grey mudstone 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 within the formation. They are distinctive for being mostly poorly sorted and containing a high proportion of chloritic clays, which where fresh give them a characteristic green coloration that weathers orange-brown. 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 main lenticular sandstones are recorded locally. The Etruria Formation is overlain by the Halesowen Formation.

The **Halesowen Formation**, includes the former 'Coalport Formation' and some of the lowermost beds of the former 'Keele Formation'. It crops out in the eastern part of the study area including the upper part of the Lloyds Coppice landslide discussed later in the report. 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. The Thick Rock is 10.41 m thick in the Lees Farm No. 1 Borehole, but apparently thins and splits eastwards along the Coppice. Named sandstones lower in the sequence include the **White Rock** and the **Sulphur (Stinking) Rock**. These sandstones are named after the coal seams that they respectively overlie, namely the **Little Sulphur Coal** and **Main Sulphur Coal**. In this area, the base of the Formation is taken at the Main Sulphur Coal.

The youngest bedrock lithology in the study area is the **Aveley Member** of the Salop Formation, which gradationally overlies the Halesowen Formation. It consists of red-brown and purple, calcareous mudstone with beds of red-brown, fine-grained sandstone, intraformational mud-flake conglomerates and caliche nodule layers. The Alveley Member comprises strata formerly assigned to the 'Keele Formation'.

2.2 SUPERFICIAL GEOLOGY

There is a noticeable lack of mappable superficial (drift) deposits in Ironbridge Gorge and it is this characteristic, combined with the fresh appearance and steep-sided, rock-bottomed morphology which brought Hamblin (1986) to reach his conclusions about the formation of the Gorge as previously discussed in Section 1.3. The superficial geology taken from BGS 1:50,000 scale digital map (DiGMapGB-50) is shown in Figure 5.

Glacial till in this area is Devensian in age and typically comprises a stiff sandy clay, generally overconsolidated with a variable content of sand and rock fragments. In this area, it is mainly developed in patches on the valley side and extensively on the flatter plateau north of the gorge, with a maximum proven thickness of 17 m at Lees Farm near Madeley It is most commonly brick red, chocolate or purple-brown in colour, through locally pale grey, yellowish of green. The rock fragments are mostly of local origin.

Associated with the till, are spreads of **Glaciofluvial Deposits** in the study area. These are primarily gravels, sands and laminated clays.

To the far west of the study area and downstream of Ironbridge Gorge, a series of **River Terrace Deposits** have been mapped. The main terrace of the Severn does not extend into the area because the Ironbridge Gorge was a later feature (Hamblin, 1986; Section 1.3).

Alluvium exists in the western part of the study area and comprises mainly silty sandy clay, composed of local material derived largely from older superficial deposits.

2.3 ARTIFICIAL DEPOSITS

Worked ground exists where the natural ground surface has been removed; **Infilled ground** results from the part or total backfilling of worked ground with man-made deposits. In this area, large tracts of worked ground are associated with opencast coal and bricklay operations. **Made Ground** is mapped where fill has been deposited on the original ground surface. The lower slopes of Lloyd’s Coppice are covered by accumulations of Made Ground derived from former clay, ironstone and coal workings. Man-made fill and mine waste covers some areas, notably at the western end of the Gorge, on the lower slopes of Jockey Bank and the lower slopes of Lloyds Coppice (Culshaw, 1973a). Figure 6 shows the mapped extent of these deposits. Other smaller areas of artificial deposits may have been mapped at larger scales, but may have not been shown in the map extract due to cartographic generalisation of 1:50,000 scale data.

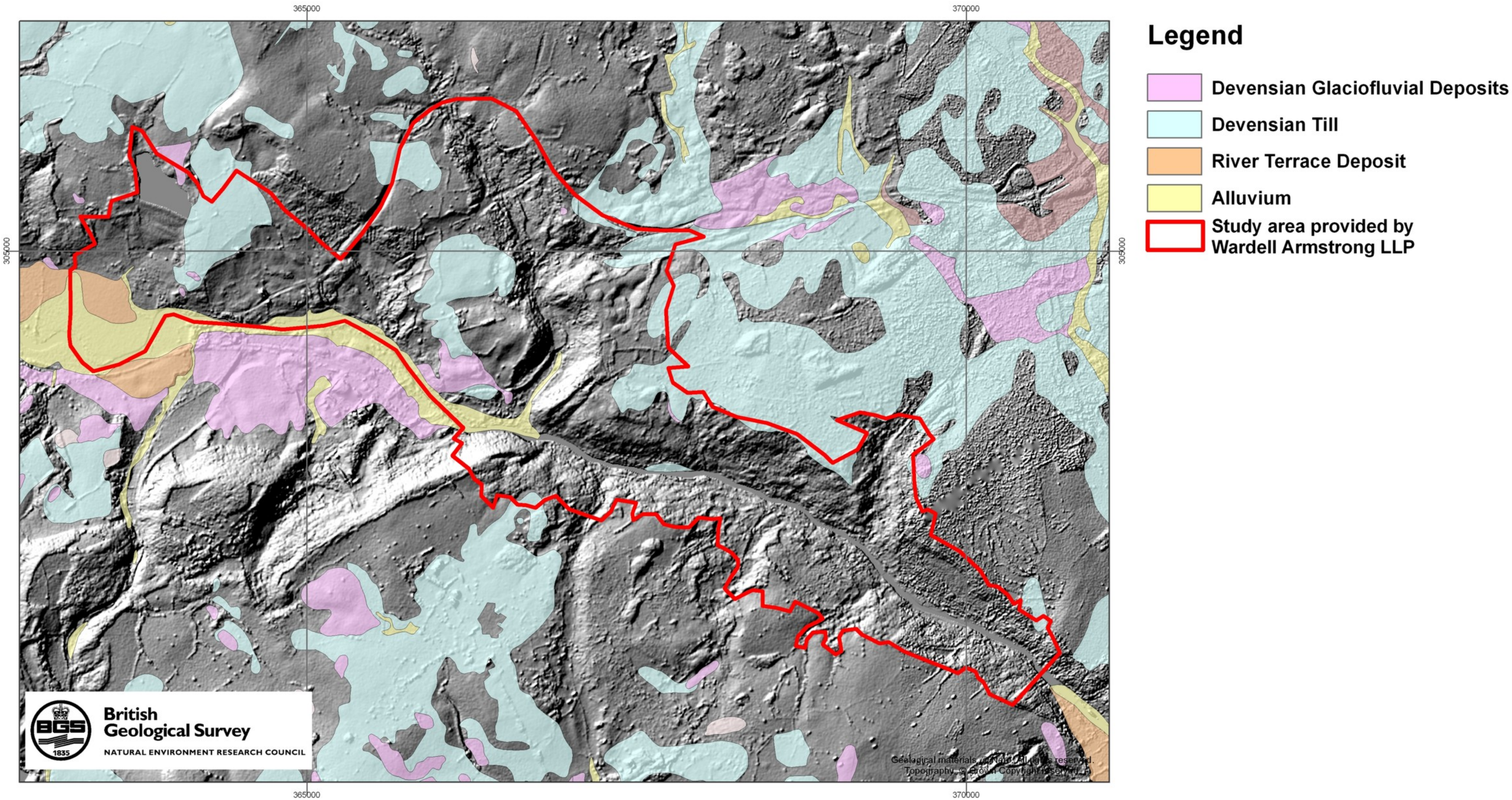

Figure 5 Extract from BGS 1:50,000 scale digital superficial geology map superimposed on Next Map™ topographic relief model

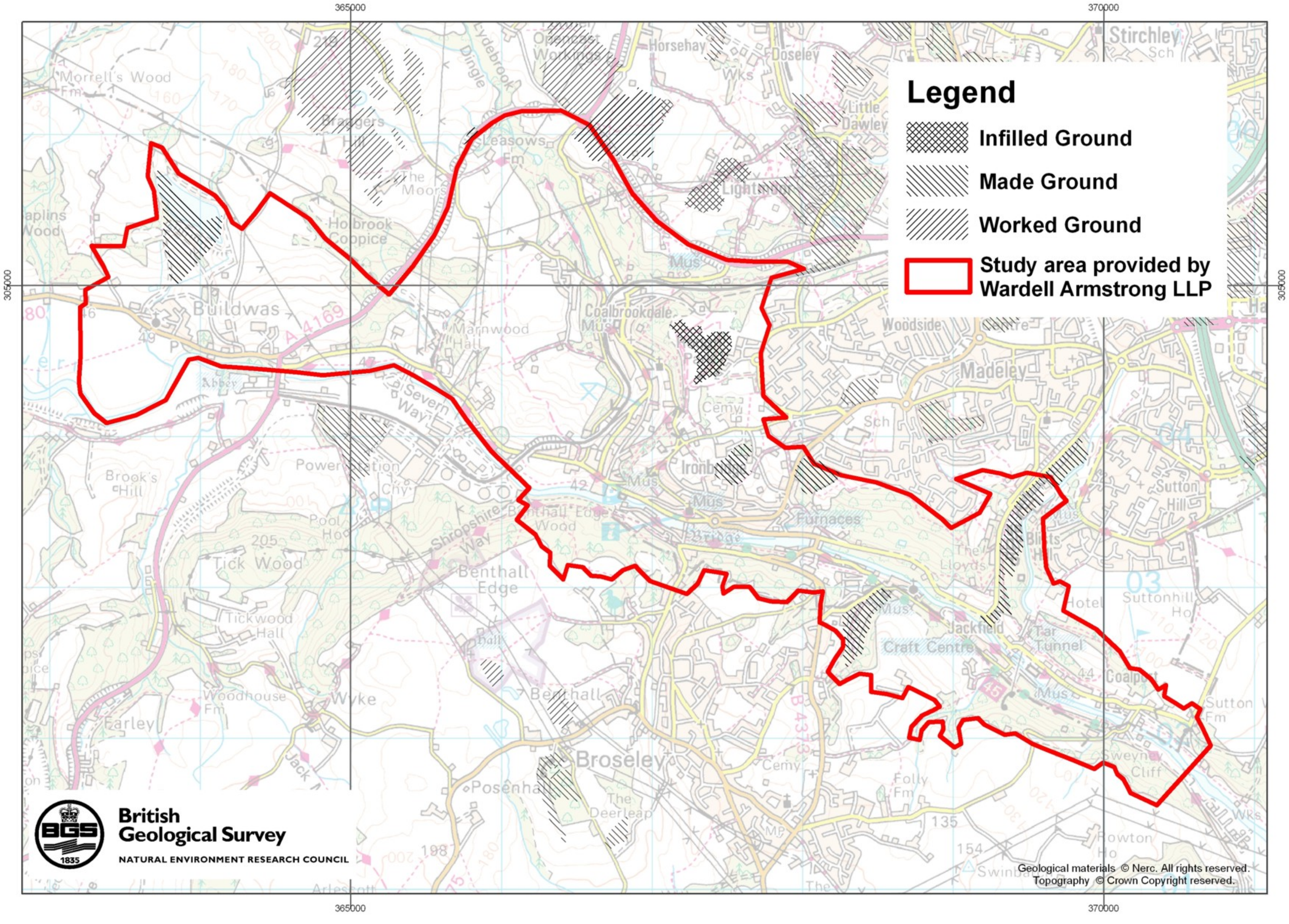

Figure 6 Extract from BGS 1:50,000 scale digital artificial deposits map

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 dip/strike 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 7). Coal seams on the flanks of the fold incrop against the unconformity at the base of the Etruria Formation.

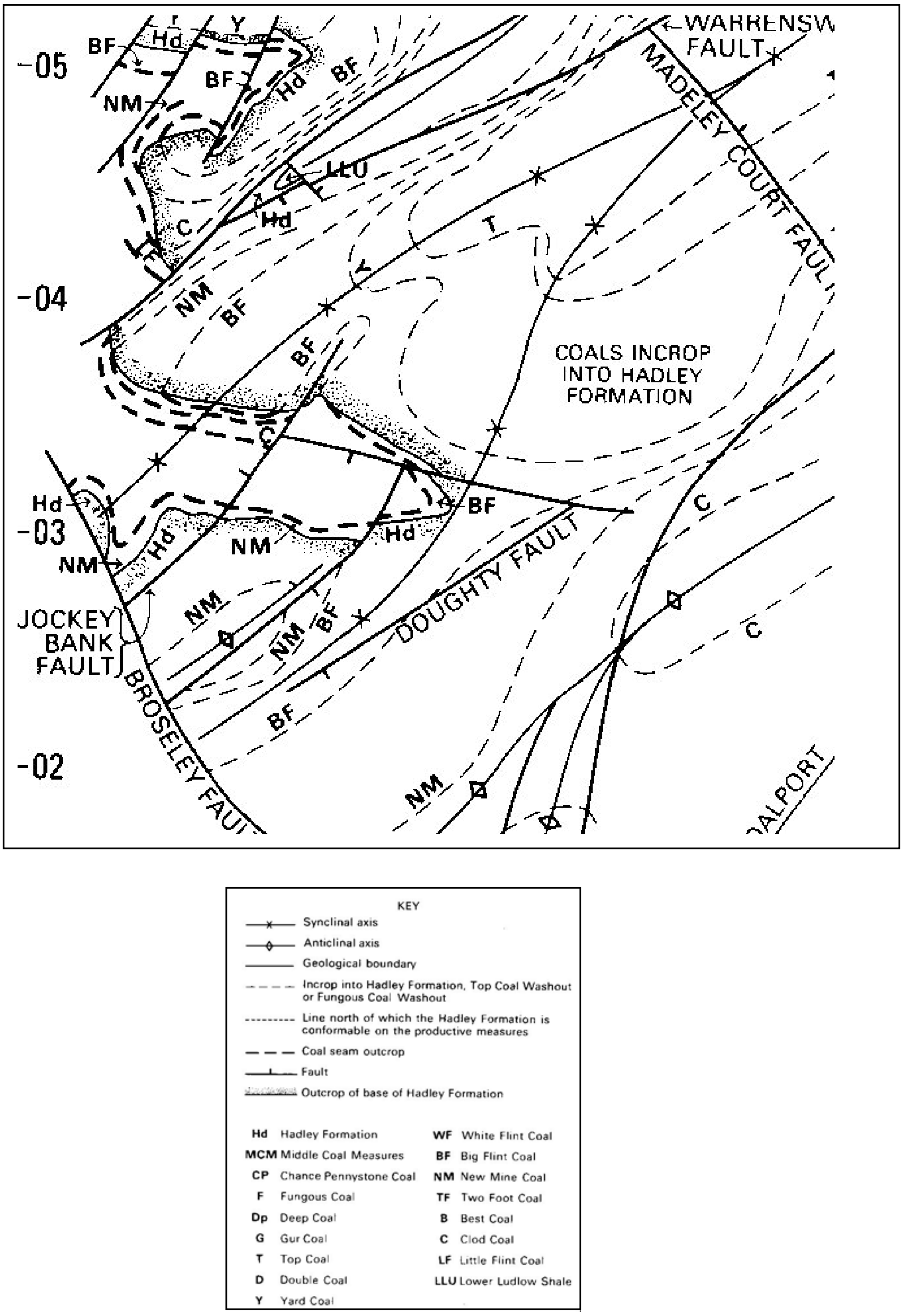

Figure 7 Diagram showing incrop of coal seams into the sub-Etruria Formation unconformity (from Hamblin and Coppack, 1995)

Two distinct fault orientations are identified (Figure 4; Figure 8). North-east-trending faults dominate but subordinate east-south-east orientated structures are also important, particularly in the Lloyd's Coppice area.

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 apparently reduces north-eastwards to about 15 m in the Etruria Formation around Jackfield.

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

There are no details of the un-named cross-fault which crops beneath the Lloyd's Coppice. This fault is poorly known but a throw of 30 m down to the south has been conjectured (confidential information held within the BGS archive). The brief walkover undertaken at Lloyd's Coppice in 2003 as part of this work indicated additional faulting along a north-east trend. The evidence was found in the upper slopes of the Coppice where the Thick Sandstone appears to be downfaulted in a small graben structure. The graben was clearly seen in the upper face of the Coppice, and was considered to be infilled with Glacial Till; it was not known how persistent this structure was (Dr Andrew Gibson pers. comm.). If the interpretation is correct, this structure has important implications on the stability of the Gorge because of its potential influence on groundwater flow. At the time of this survey, in 2003, water was seen flowing as a stream 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.

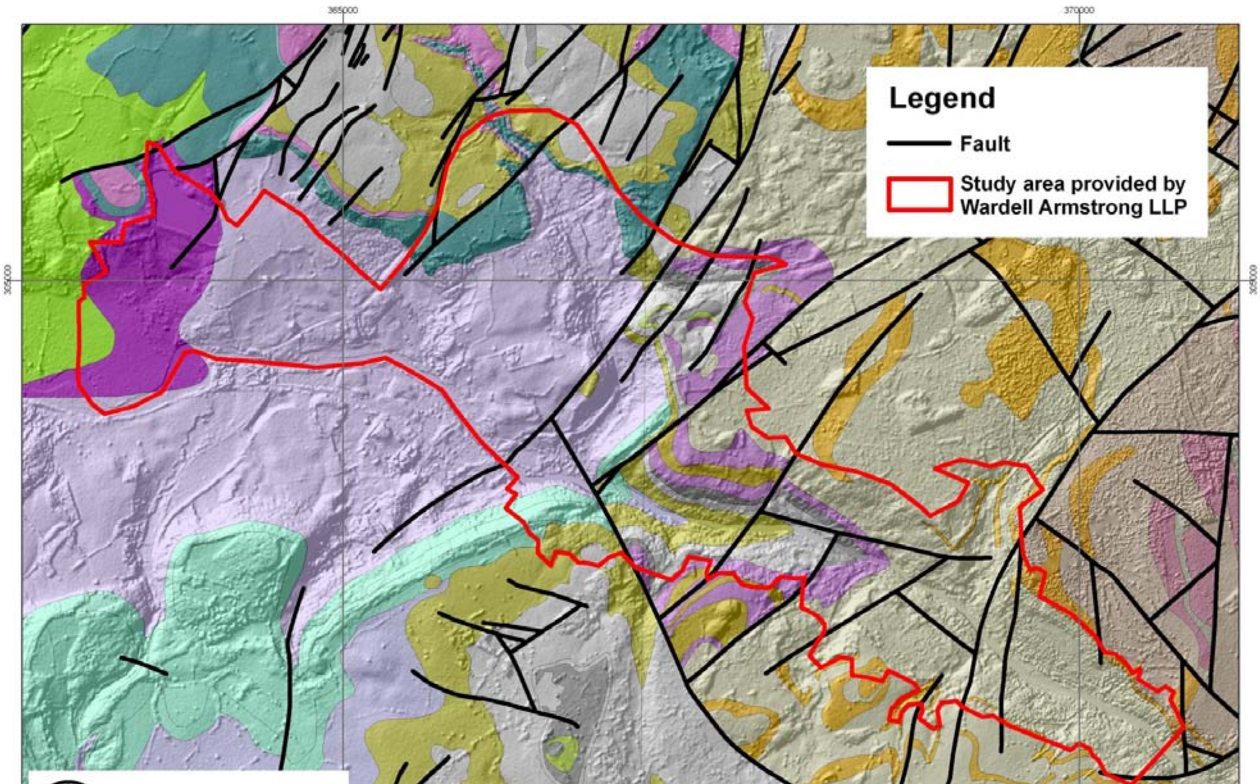

Figure 8 Extract from BGS 1:50, 000 scale digital geology map showing faults superimposed on NextMap^{TM} topographic model. Refer to Figure 3 for bedrock geology.

3 Landslides

The British Geological Survey currently classifies landslides (Appendix 1) according to an adaptation of the original classification of Varnes (1978), Cruden and Varnes (1996) and the World Landslide Inventory (1990; 1993). For more information on landslides work at BGS, see http://www.bgs.ac.uk/science/landUseAndDevelopment/landslides.html

Ironbridge Gorge has experienced a number of failures in historical times. Landslides affect both sides of the Gorge, and some extend into the deeply incised tributary valleys. Unstable or potentially unstable slope deposits extend along the length of the Gorge and the mapped distribution (Figure 9) is a conservative estimate (Bridge and Hough, 2002). As described above, the main valley is thought to have been created relatively rapidly, meaning that the slopes have not yet been able to adopt a stable angle. The valley has also been subject to periglaciation (Hamblin and Coppack, 1995). Characteristic of this would have been seasonal freeze-thaw producing ice-heave, fracturing of the ground and pervasive solifluction and raised groundwater conditions (Rayner *et al.*, 2007).

Shallow-seated downhill movement has affected the village of Ironbridge over a long period, resulting in damage to the buildings and to the Iron Bridge itself (e.g. Shropshire Star, 2008a). The listricated mudstones of the Coal Measures, Etruria Formation and, in particular, the Halesowen Formation are all prone to failure of steep slopes, particularly where they are overlain by water-bearing sandstones. Factors contributing to slope failure along the gorge were documented (Henkel and Skempton, 1954; Skempton, 1964; Denness, 1977; Gostelow *et al.*, 1991). Culshaw (1973b) used a zoning technique to distinguish areas of ‘high’, ‘medium’ and ‘low’ hazard. This type of approach accepts that development is possible in areas of ‘low’ hazard providing precautions are taken to maintain the integrity of the slopes. Not all the landslides documented in the literature appear in the BGS 1:50,000 scale digital mass movement polygons (DiGMapGB-50). This is either because they are too small to be combined into the 1:50,000 scale map or occurred/were discovered after the field mapping took place. However, these landslides are documented in the National Landslide Database (Foster *et al.*, 2008).

3.1 NATIONAL LANDSLIDE DATABASE

The National Landslide Database has been developed by the British Geological Survey as the definitive source of information on landslides in Great Britain. It currently holds over 14,000 records of landslide events with each landslide documented as fully as possible. Each landslide record can hold information on over 35 attributes including location, dimensions, landslide type, trigger, damage caused, slope aspect, material, movement date, vegetation, hydrogeology, age, development and a full bibliographic reference.

Data come from a variety of sources including published BGS geological maps and renewed surveys. Other sources include commissioned and research studies and a number of regional databases inherited or compiled by BGS since the 1970s. The information is corporately maintained and held in digital format that can be adapted and updated so it will be useable for decades to come. The database is linked to a GIS which displays the landslides as point data located at the highest point on the backscarp.

Each record in the dataset provides evidence of a landslide *event* (temporal or survey) of a given landslide, not a landslide *per se* and thereby allows for the storage, manipulation and extraction of landslide events over time. Therefore, multiple movement events and surveys of the same landslide complex can be captured as distinct episodes. To do this, each landslide record is given a unique identifier consisting of *Landslide ID* and *Survey Number*. For example, an initial survey of landslide 12345 would be given the unique identifier of 12345-1. A second survey of the same landslide after another mass movement event or resurvey of the area with additional information would become 12345-2 and so on. Associated surveys are easily searched for in the database and displayed as separate points in the GIS.

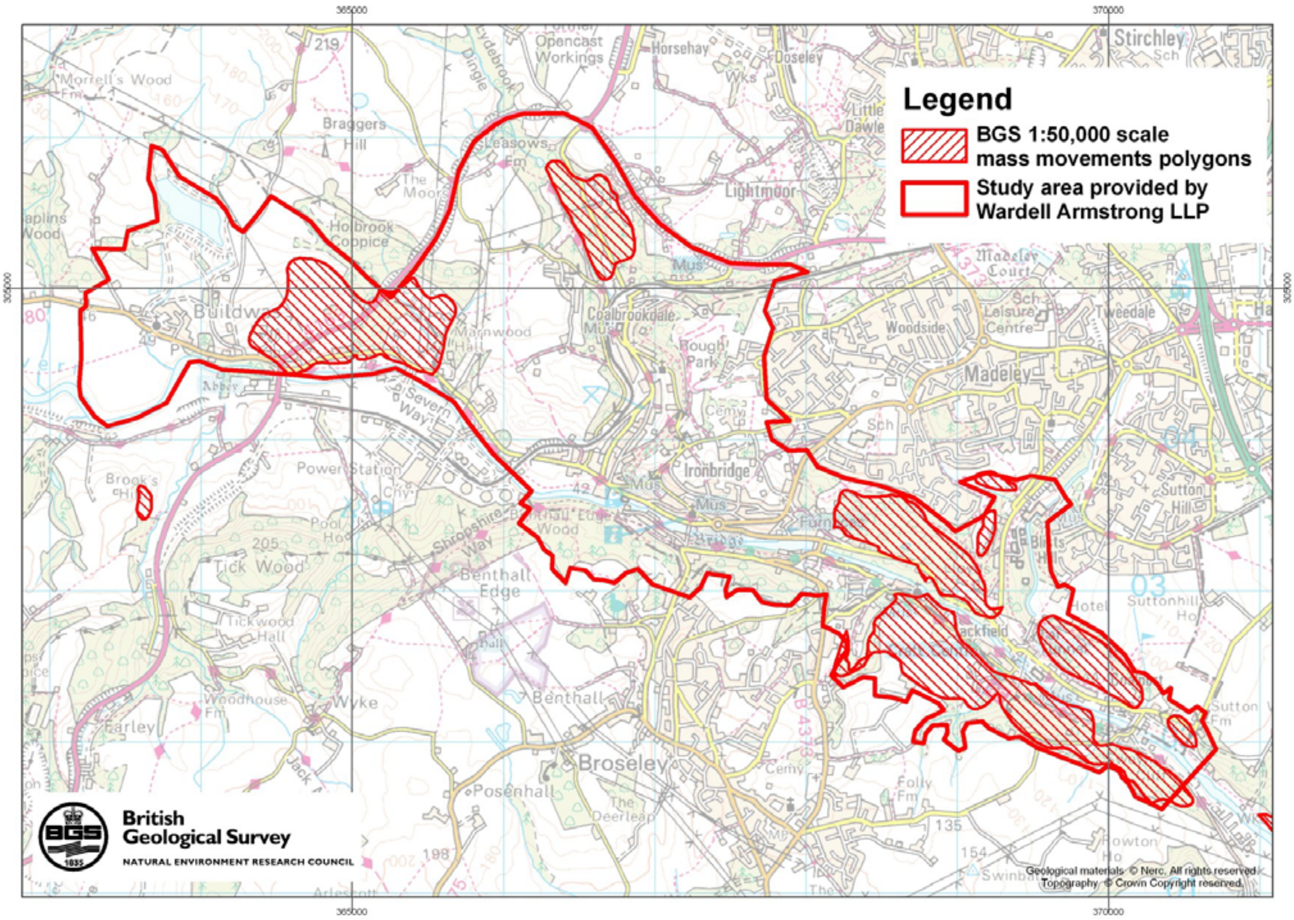

Figure 9 Extent of mapped mass movement polygons from 1:50,000 scale digital mass movement map (DiGMapGB-50)

The landslides held within the National Landslide Database for the study area are listed in Table 2. Figure 10 shows their distribution. These will be dealt with individually and the National Landslide Database Identification (NLDID) numbers included in the description.

3.1.1 Jackfield Landslide

This is an active translational and rotational landslide in the Halesowen Formation that stretches from Jackfield to the Wilds (Figure 11) and includes the famous and active Jackfield landslide described by Henkel and Skempton (1954) and Skempton (1964)[1]. It is thought to have been subject to movement for over 200 years (Carson and Fisher, 1991). This slip forms part of an older slipped complex, which extends 600 m back from the river and is contained within the DiGMapGB-50 mass movement polygon which is approximately 800 m wide.

NLDID 4335/2: In 1952, a landslide occurred at the village of Jackfield, Shropshire, on the River Severn just over 2 km downstream of Iron Bridge, destroying several houses (Figure 12) and causing major dislocations in a railway and road (Skempton, 1964). This landslide event was included in the Fourth Rankine Lecture (Skempton, 1964). The following quotation is taken from this paper:

[1] This report is available at: http://www3.imperial.ac.uk/portal/pls/portallive/docs/1/963905.PDF. See Figures 10 and 11 of this report. Not included in report for copyright reasons.

LANDSLIDE ID	SURVEY NO	Name	LOCATION	Easting	Northing	Accuracy (±m)	Grid ref provenance
4335	1	Jackfield	Ironbridge Gorge, Shropshire, England	368708	302406	10	MAP
4335	2	Jackfield	Ironbridge Gorge, Shropshire, England	368719	302632	100	MAP
4336	1	Ironbridge School	Ironbridge Gorge, Shropshire, England	367453	303507	10	MAP
4338	1	Lloyd's Coppice	Ironbridge Gorge, Shropshire, England	368628	303632	10	REPORT
4338	2	New Buildings	Lloyd's Coppice, Ironbridge Gorge, Shropshire, England	368780	303226	10	MAP
4339	1	Jockey Bank	Ironbridge Gorge, Shropshire, England	367861	303507	100	MAP
4347	1	The Lees	Ironbridge Gorge, Shropshire	369150	303385	10	MAP
4348	1	Lee Dingle	Ironbridge Gorge, Shropshire, England	369288	303672	10	MAP
4350	1	Coalport	Ironbridge Gorge, Shropshire, England	369908	302689	10	MAP
4351	1	Sweyney Cliff	Ironbridge, Shropshire, England	370274	301608	10	MAP
4357	1	South Ironbridge	Ironbridge Gorge, Shropshire, England	369595	301968	10	MAP
4364	1	Hay Farm	Shropshire, England	369568	303128	1000	?
4365	1	Ladywood	Shropshire, England	367315	303174	10	MAP
4366	1	Cherry Tree Hill	Coalbrookdale, Shropshire, England	367368	305004	100	REPORT
4367	1	Rough Park Way	Coalbrookdale, Shropshire, England	368000	305000	100	MAP
4405	1	The Birches	Ironbridge, Buildwas, Shropshire, England	364682	305194	10	MAP
4405	2	Buildwas Bridge 1773	Buildwas, Shropshire, England.	365382	304720	10	MAP
4405	3	Block within The Birches	Shropshire, England	364678	304960	100	MAP
4405	4	Block within The Birches	Shropshire, England	364786	304836	100	MAP
4405	5	Block within The Birches	Shropshire, England	364967	304996	100	MAP
4405	6	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	364979	304836	100	MAP
4405	7	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	364673	304807	100	MAP
4405	8	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	364828	304697	100	MAP
4405	9	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	365082	304749	100	MAP
4405	10	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	364938	304661	100	MAP
4405	11	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	365245	304694	100	MAP
4405	12	Block within The Birches	Ironbridge, Buildwas, Shropshire, England	364626	304628	100	MAP
4405	13	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365574	304928	100	MAP
4405	14	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365622	304864	100	MAP
4405	15	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365677	304831	100	MAP
4405	16	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365638	304902	100	MAP
4405	17	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365704	304860	100	MAP
4405	18	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365683	304906	100	MAP
4405	19	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365640	304946	100	MAP
4405	20	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365762	304868	100	MAP
4405	21	Block within the upper slope of The Birches	Ironbridge, Buildwas, Shropshire, England	365647	304985	100	MAP
4409	1	Jiggers Bank	Coalbrookdale, Shropshire, England	366842	305429	10	MAP
4412	1	Sutton Wood 1	Ironbridge Gorge, Shropshire, England	370470	302166	10	MAP
16340	1	Coalport Road	Ironbridge, Shropshire, England	369383	303169	100	REPORT
16341	1	Holbrook Coppice	Ironbridge, Buildwas, Shropshire, England	365357	305193	100	MAP
16343	1	Darby Road	Coalbrookdale, Shropshire, England	366533	304800	10	MAP

Table 2 Landslides held within the National Landslide Database for the Ironbridge Gorge study area

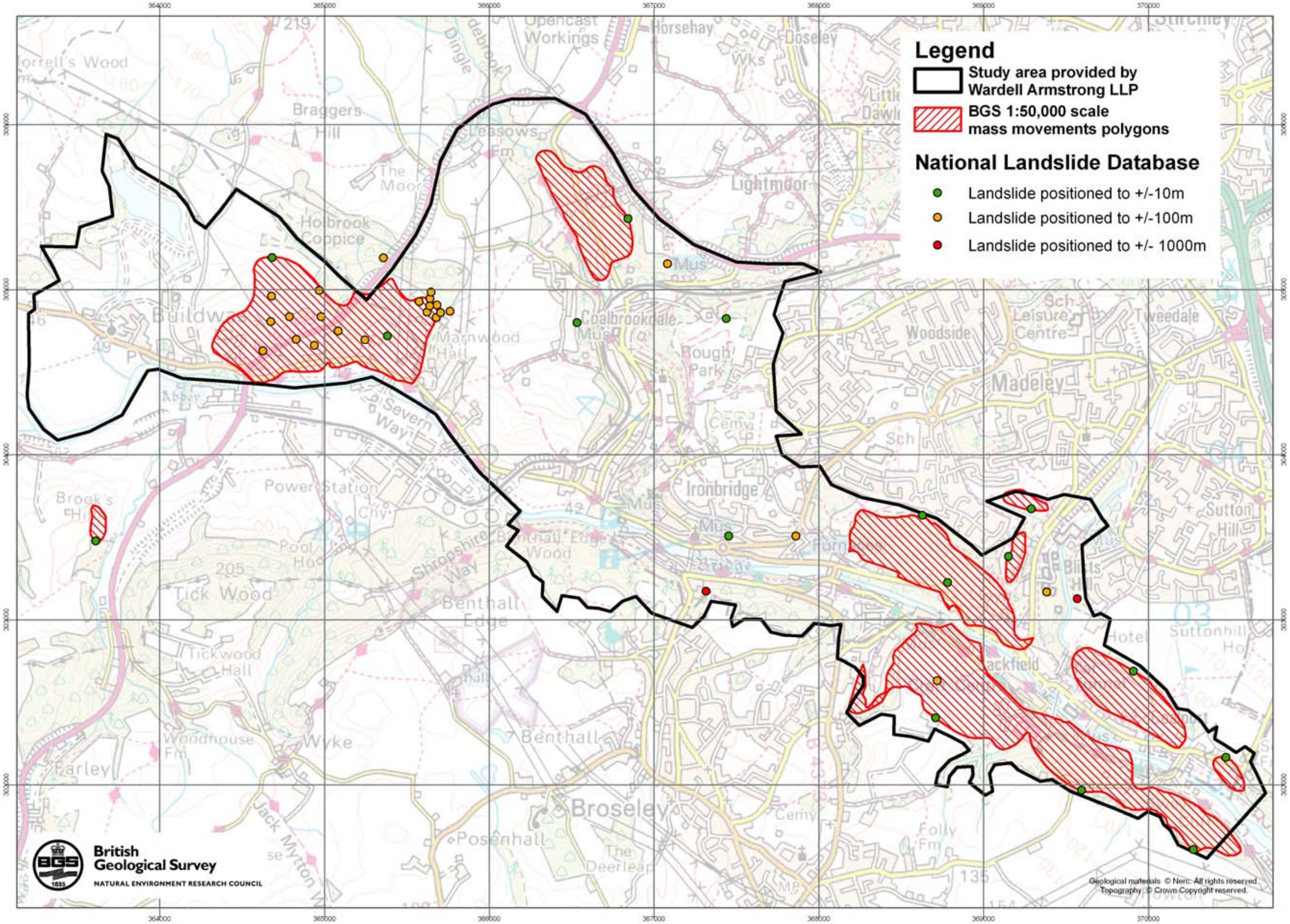

Figure 10 Location of landslides within the National Landslide Database displayed together with the 1:50,000 scale mass movement polygons

"*It is possible that previous landslides may have taken place along at least a part of the present slip surface, but the slope must have been more or less stable for a long time before 1950, when warnings of instability were observed in the form of a broken water main serving cottages near the river bank. Towards the end of 1951 further movement was noted, and by February 1952 the road was becoming dangerous. During the next month or two the landslide developed alarmingly. Six houses were completely broken up, gas mains had to be relaid above ground, the railway could be maintained only by daily adjustments to the track and a minor road along the river had to be closed to traffic. By this time the maximum downhill displacement totalled 60 ft … The strata, consisting of very stiff clays and mudstone, alternating with marl-breccia and occasional coal seams, dip gently in a south-easterly direction with the strike running roughly parallel to the section of the landslide. The slide, however, was confined wholly within the zone of weathered, fissured clay extending to a depth of 20 ft to 25 ft below the surface. The slip surface ran parallel to the slope (which is inclined at 10º), at an average depth of 18 ft. The length of the sliding mass, measured up the slope, amounted to about 550 ft and in the winter 1952-53 ground-water level reached the surface at a number of points, although on average it was located at a depth of 2 ft*".

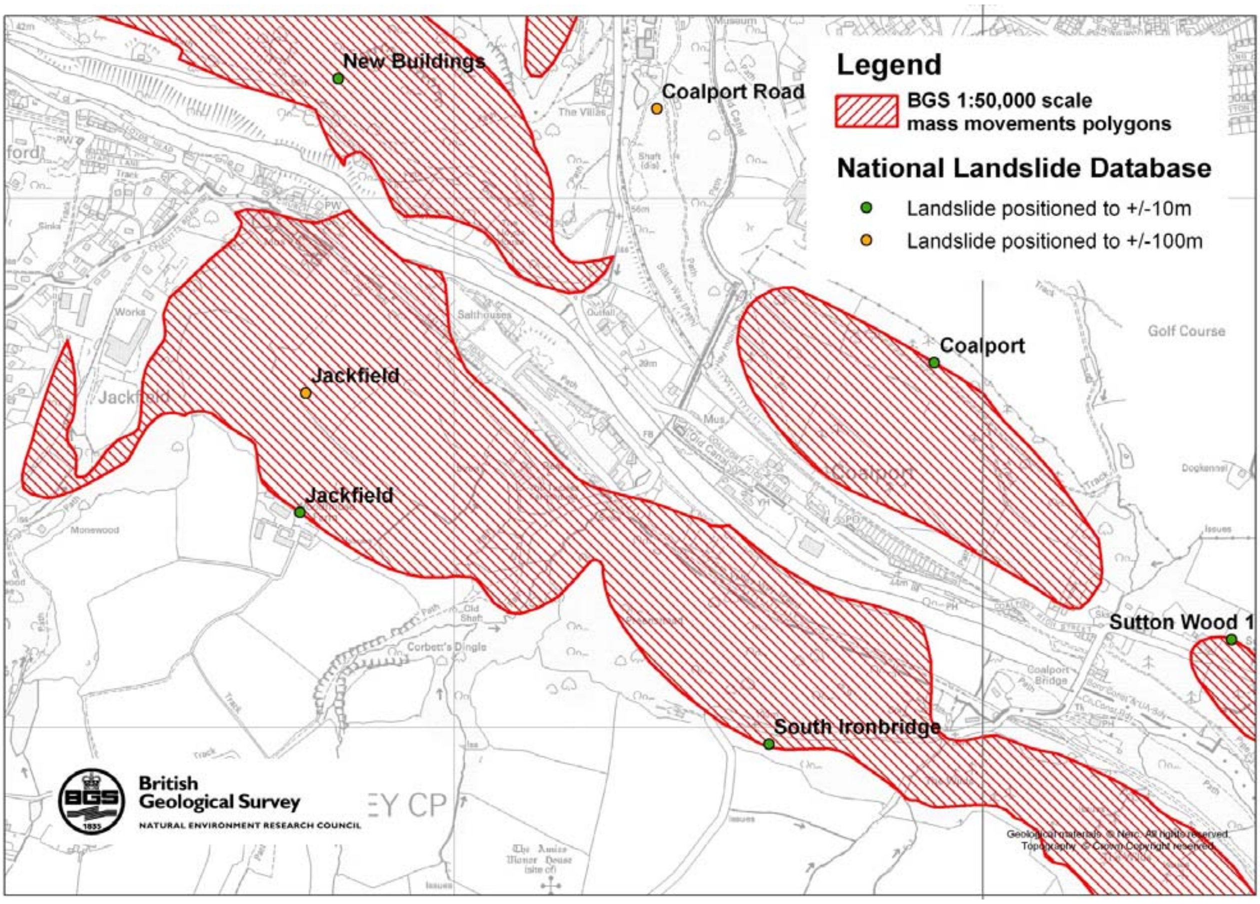

Figure 11 Extract from National Landslide Database showing Jackfield, New Buildings, Coalport, Coalport Road and South Ironbridge Landslides. DiGMapGB-50 mass movement polygons are also included in this map.

Hamblin and Coppack (1995) resurveyed the site (**NLDID 4335/1**) in the 1980s and stated that this slip was clearly not caused primarily by the dip of the strata, which is to the south-east, or by underground workings. It was a translational shear with its base wholly within the weathered zone (at a depth of 5.2 m) and parallel to the slope of the hill. A sheet of material 183 m long moved through 18m at its centre but only 9 m at the river bank, causing bulging and cracking of the surface, with damage to houses, railway and mains services. By April 1953, the length and width of the slide had increased to 213 m and 200 m; the horizontal movement was 24 m at the centre and 14 m at the river bank. The slide had extended uphill by means of minor rotational slips, and the River Severn had been narrowed from 38 m to 24 m.

The geological structure in the form of faulting may be providing conduits for groundwater and backsarps for slope movement, for example The Doughty and Tuckies Faults (High-Point Rendel, 2005a).

This landslide has since been remediated and Carson and Fisher (1991) noted that: "*the approach adopted was to weight the toe of the slide with tile waste and seal the surface cracks with clay won locally by regrading the slope. The regrading was to allow easy drainage and remove humps and hollows which might otherwise trap surface water and trigger local slips. The remedial works were satisfactory for thirty years albeit with higher maintenance costs until a similar slip occurred in 1981/2 closing a section of road which slipped into the river. A similar approach to remedial works was adopted as for the 1951 slip but with additional drainage and the road diverted along the disused Severn Railway track. The road construction however, consists of hinged wooden boards on a granular base. Movement has continued and the road has to be ballasted every few years. A rock toe has been constructed both to add weight and reduce the loss of material to the river in conjunction with counterfort drains. The remedial works have not stabilised the slide completely but appears to have slowed down the rate of movement*".

In 1984, further ground movement occurred to the west of the 1952 area of landslide. Salthouse Road was carried into the river and was replaced by a temporary roadway constructed along the line of the former railway (High-Point Rendel, 2005a). Other movement events for the Jackfield landslide are documented in 1925 and 1931 (Giles, 2008).

High-Point Rendel (2005a)[2] carried out a survey of the Jackfield landslide and made the following observations:

- Currently, river erosion is undercutting the valley sides and removing support at the toe of the slopes near Salthouse Road;
- Valley development has and will continue to initiate a cycle of landsliding activity as slope processes strive to reach equilibrium (i.e. a state of stability);
- Accelerated degradation of the slopes is aided by the relatively incompetent geology comprising interbedded clays, mudstones, sandstones and coals, and the geological dip of the beds;
- The dip of the strata is shallow (~4^{o}) towards the east which could facilitate ground movement towards the river;
- Faults and associated geological structure may be providing conduits for groundwater and backsarps for slope movement;
- The ground movement observed from the geomorphological mapping identified land units of multiple rotational back tilted blocks of various stages of degradation and translational (or debris) failures with secondary rotational failures;

[2] This report is available at http://www.telford.gov.uk/NR/rdonlyres/B28EB2D2-D6E6-4455-9052-9E0DC393AABB/0/GroundInvestigationsatJackfieldandTheLloyds.pdf

- The presently active translational failure in the Salthouse Road sub-unit is a reactivation of the 1952 slip. Ground movement of this area is currently occurring;
- Road drainage appears to discharge directly onto the lower slope;
- The area of the 1952 slip is located on the outside bend of the river where more turbulent water erodes the toe and removes support of the ground upslope;
- The failed area of the lower slope (riverwards of Salthouse Road) contains substantial made ground deposits where the slip plane lies at the interface with the underlying clay and further upslope the slip plane can be observed at ~5m depth within the weathered clay;
- The combined effect of more than one seam being mined may have involved greater bed separation of the overlying strata and subsidence, which has reduced the integrity and strength of the material resulting in the localised instability along the Salthouse Road;
- Borehole instrumentation has identified that the Salthouse Road area is currently active;
- Measured groundwater levels suggest that the Salthouse Road slopes are currently active and slope stability is very sensitive to increases in the groundwater level. The sensitivity of groundwater was analysed using slope stability software and found that areas of the slope are prone to failure with a rising water table. Furthermore, perched water tables may occur above the in situ clay material within the relatively more permeable made ground which will further reduce the strength of the material;
- Slope stability analysis identified that discrete sections of the slope had a factor of safety of less than 1 and that the whole slope was unlikely to fail *en masse*. Analysis identified that the majority of failures were relatively shallow and deep rotational failures could not be realistically modelled;
- Survey monitoring has identified up to 5 m NNW movement since 1994 and almost 850 mm of settlement in the slipped area. The average rate of movement is ~0.5 m/year.

Figure 12 Pear Tree Cottage, damaged by the 1952 Jackfield landslide and demolished the following year (Manchester Guardian, 10th April 1952).

3.1.1.1 Sweyney Cliff and South Ironbridge

The Sweyney Cliff (**NLDID 4351/1**) and South Ironbridge (**NLDID 4357/1**) landslides form the south eastern part of the BGS mapped active translational and rotational landslide that stretches from, and includes, Jackfield to the Wilds in the Halesowen Formation (Figure 16). These three landslides have been combined to form one mass movement polygon on the DiGMapGB-50 digital maps and have the same underlying geology. However, the surface geology, hydrology and presence of faults have divided this polygon into three distinct landslides in National Landslide Database. Corbett's Dingle and a fault divide Jackfield from the South Ironbridge landslide. A stream divides South Ironbridge from Sweyney Cliff at The Wilds.

3.1.2 Ironbridge School

The Ironbridge School landslide (**NLDID 4336/1**; Figure 13) is described in detail by Culshaw (1972a), Hamblin and Coppack (1995) and Denness (1970)[3] as a rotational and translational landslide and was first reported in 1969, when the land between the school and the road below suffered considerable movement. The pavement had frequently been ruptured and soil cleared off the road. The old playground has sunk by about 1.2 m and walls running downhill either side of the school were severely fractured.

The area immediately below the school was the most active part of a larger unstable area. The fill material forming the flat playground behind the school became waterlogged. This loaded the Coal Measures on the steep slope below, and caused a rotational landslide which extended down to the Ironbridge-Madeley road. This was probably exacerbated by the extent of old workings in the Coal Measures and the lack of mains drainage in Ironbridge.

A programme of drilling and testing by the then Telford Development Corporation outlined the area of actual or potential slipping and the landslide was measured, from borehole information, to be between six and ten metres deep, and extending just over one hundred metres along the river and a similar distance away from the river.

A volume of 13,500 m^3 is reported by Giles (2008) and this landslide is part of an area of general slipping. The boundary of the landslide was determined by the disruptive influence of minor renewed movement on manmade structures. Where the landslide occurred immediately below the school, it resulted in the demolition of a house adjacent to the road below (Denness, 1970).

This landslide has been remediated (Culshaw, pers comm.). It is notable that the landslide is located close to the axis of a syncline that channels groundwater into it from the Big Flint Rock, just above the school (Culshaw, 1973a). This is further discussed in Section 4.

[3] Figure 2 of this reference is a map of this landslide. Not included in report for copyright reasons.

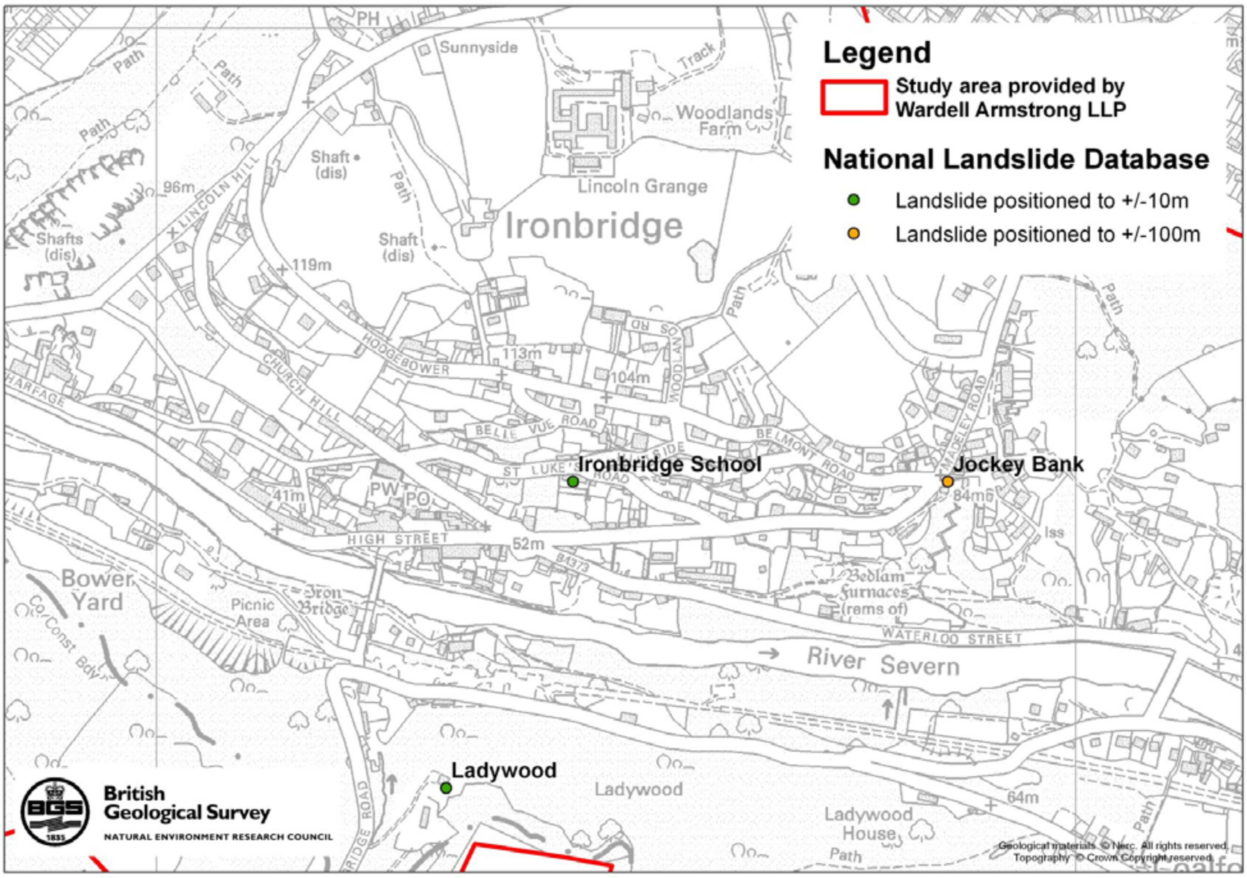

Figure 13 Extract from National Landslide Database Ironbridge School, Jockey Bank and Ladywood Landslides. There are no DiGMapGB-50 polygons in this area.

3.1.3 Lloyd's Coppice

The Lloyd’s Coppice landslide (**NLDID 4338/1**) has attracted considerable study by BGS and others over the last 30 years (Culshaw, 1972a;1973a; Hamblin and Coppack, 1995; High-Point Rendel, 2005a and unpublished confidential information held in the BGS archive):

A large area of the Halesowen Formation is actively moving as a series of rotational slips and surface slides. Crags of Thick Rock sandstone have moved down from their outcrop near the top of the hill, bringing with them the overlying thick till. The Halesowen Formation is particularly susceptible to degradation in this area as it includes more silty strata and less sandstone than elsewhere. Although slipping is thus most active lower on the slopes, it does not appear to extend down to river level.

The current understanding of the landsliding of the Lloyds Coppice area is based upon a survey carried out by BGS (Culshaw, 1972a;1973a) and more recent confidential information held in the BGS archive.

Boreholes sunk upslope from Lloyd’s Coppice at Lees Farm recorded 5.5 to 17 m of till overlying up to 84.8 m of the Halesowen Formation. Up to 11 m of the underlying Middle Coal Measures were also thought to be proven but 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 than the mudrocks above and below. 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. 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 is 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.

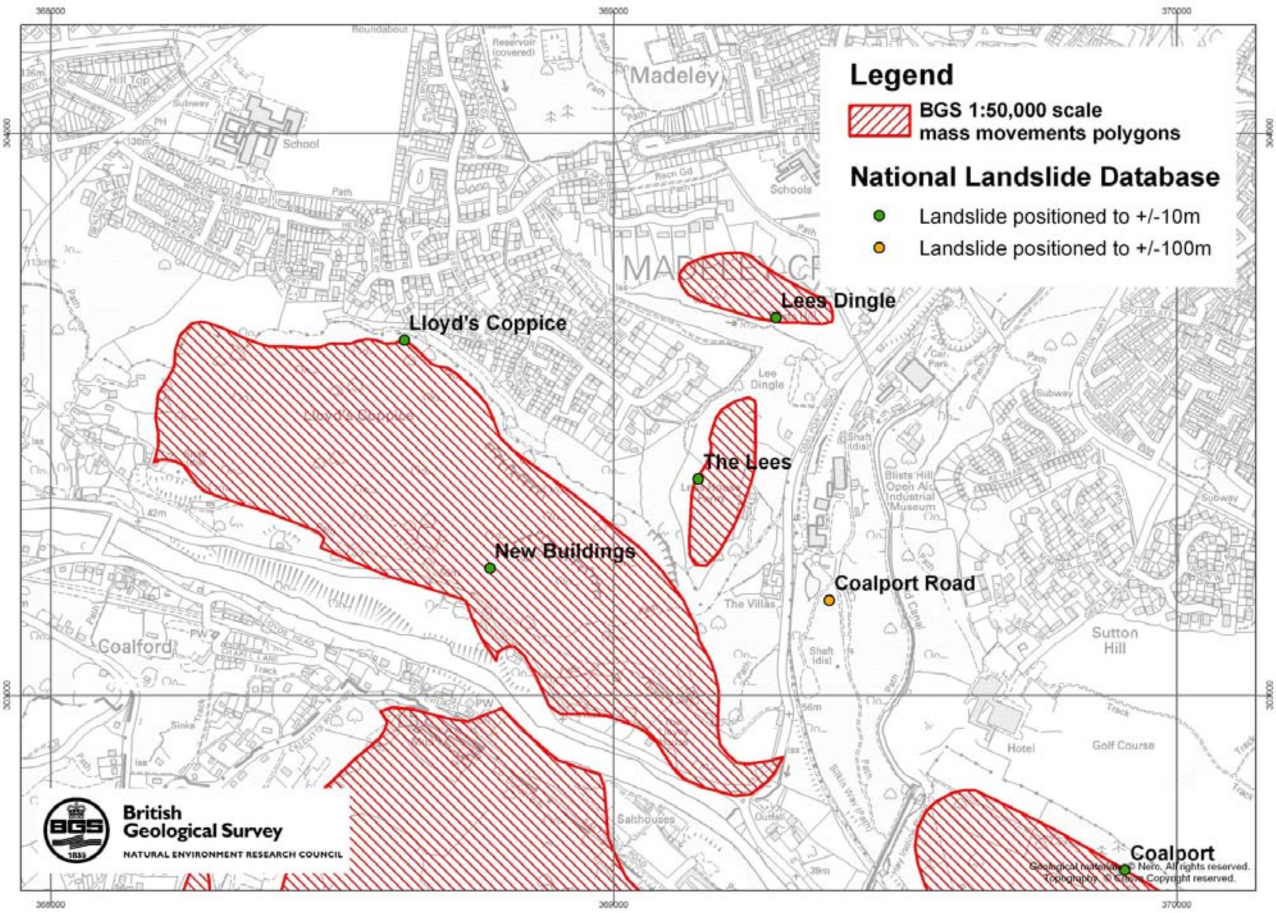

Figure 14 Extract from National Landslide Database including Lloyd's Coppice, New Buildings, The Lees, Lees Dingle and Coalport Road. DiGMapGB-50 mass movement polygons are also included in this map.

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.

In broad terms, the Lloyd's Coppice landslide complex is considered to comprise five main zones:

1) A steep upper cliff formed around the Thick Rock
2) A degraded upper undercliff, which can be sub-divided into:
    a) Western zone where the landslide blocks have largely been destroyed by weathering
    b) Central zone forming a small headland, possibly formed by a degraded block
    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
3) An active undercliff, with landsliding active in debris accumulations and possibly within the solid geology
4) A relatively inactive apron of debris
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.

Unpublished confidential information held in the BGS archives suggest other factors which should be considered in the interpretation of the geomorphology and landslides of Lloyd's Coppice. This includes:

- the existence of unmapped geological faults or other structures within the complex as a significant control on slope stability;
- the importance of coal, as a potential weak/permeable horizon; deep-seated landslide processes that 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.

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

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

It should be noted that considerable further work has been carried out in this area as part of Lloyd’s Phase I (2006-7) and Lloyd’s Phase II (2007-8) for the Borough of Telford and Wrekin Council which the author has not had access to.

3.1.3.1 NEW BUILDINGS

The New Buildings (**NLDID 4338/2**) was identified by Denness (1970)[4] to be a more recent active part of the Lloyd's Coppice landslide (Figure 14):

This is a spasmodically active mudflow which occasionally flows onto the road and blocks the passage of traffic. It is probably several metres deep, though has not been investigated sub-surface and consists of large angular sandstone blocks in a matrix of smaller blocks and remoulded shale and mudstone.

3.1.4 Jockey Bank

The area known as Jockey Bank (**NLDID 4339/1**; Figure 13) is at the eastern end of Ironbridge on the relatively steep north valley side of the Severn. The landslide extends either side of the B4380 road known as Madeley Hill. Culshaw (1972a, b) investigated this area and reported the following:

The whole of the built up area together with the area at Brockholes and the fields to the NW of this were investigated and a number of landslides, probably shallow, were observed. These had moved in a south-westerly direction but the thickness of vegetation growth indicated that this movement took place some time ago. No fresh back scarps, large or small, were observed although there were areas of wetter ground around the sides and toes of the landslides and the surface stream runs through the middle of the field. The actual extent of the landslide was difficult to determine as the upper areas had been obscured by the construction of a sewage works and higher up the slope by the mine waste tips. The lower limits were also uncertain as much building has taken place.

The buildings of Jockey Bank, while being in bad condition structurally (some unoccupied or derelict) did not appear to have suffered any damage near the time of survey due to landslip movement. The cause of slipping in this area follows the pattern of Lloyd's Coppice. The top of the hill around Lodge Farm is composed of sandstone which acts as a primary reservoir. This releases water down slope towards Jockey Bank which reduces soil strength which has caused the slipping.

From this work, Culshaw concluded that the hillside of Jockey bank could be divided into four areas on the basis of stability: two stable areas, a possible stable area and an unstable or disturbed area (Figure 15). The unstable area is that part of the succession below the Best Coal. The area also contains random depositions of man-made fill which Culshaw stated may also be unstable or would be rendered so on the movement of underlying deposits and no building should be considered in this area. The upper stable area covers most of the built up land of Jockey Bank and above the Big Flint Rock. Culshaw considered this area safe for renovation of existing buildings or erection of new buildings providing there was strict control of drainage. If any water were allowed to escape from drains down the hillside, it could create large areas of instability below this area. The area named as 'possibly stable' coincides with the Best Coal outcrop and some building work had already taken place in this area at the time of survey but further building was not recommended due to steepness of slope and drainage issues.

It must be stressed that this work was undertaken 36 years ago and a full reassessment of the area should be undertaken before any recommendations are made.

[4] Figure 2 of this reference is a map of this landslide. Not included in report for copyright reasons.

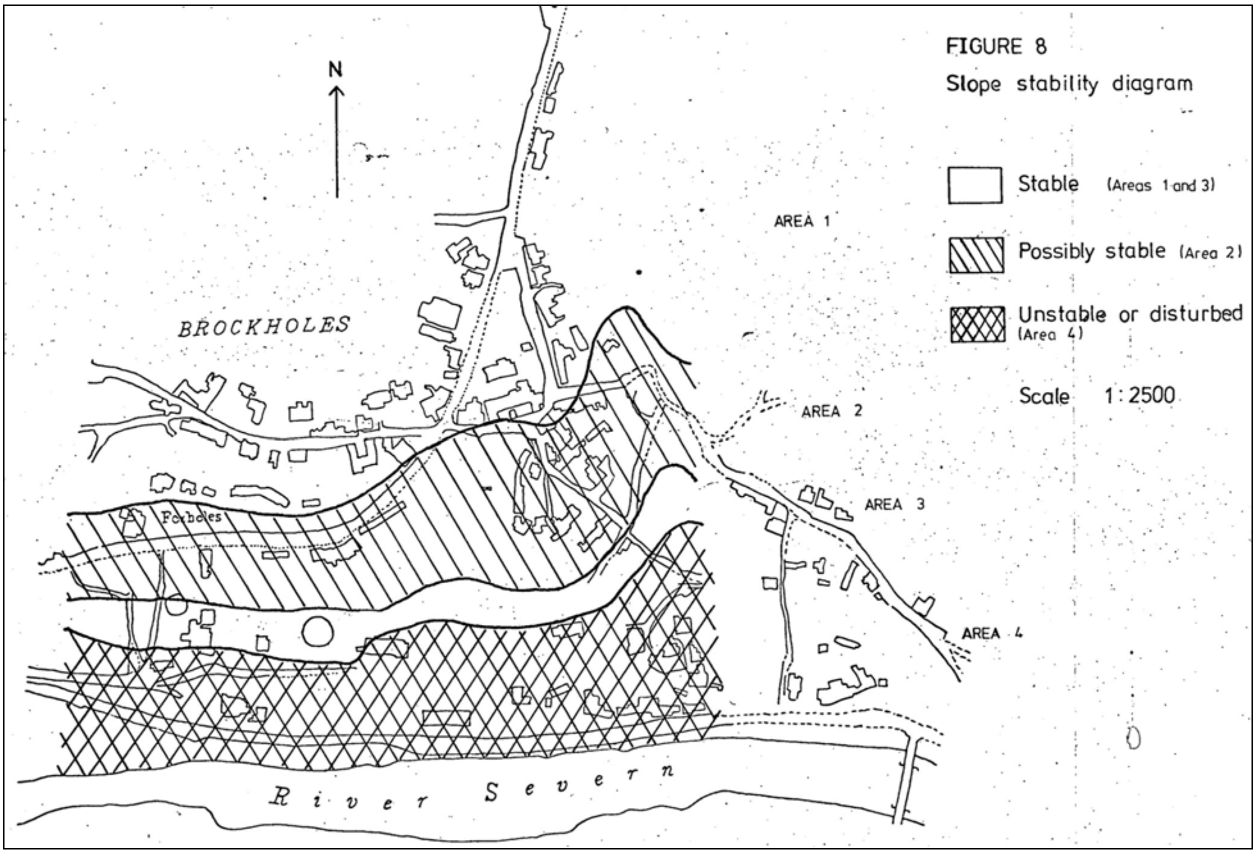

Figure 15 Slope Stability Diagram of Jockey Holes landslide (taken from Culshaw, 1972b).

Reference to landslide activity in 2000 at Jockey Bank Gardens Park is sited on the web although the exact location is not given (Giles, 2008). This landslide is recorded to be a rotational landslide 15 m wide, 14 m long and 5 m deep with a volume of 1500m^3. No building damage was recorded.

3.1.5 The Lees and Lee Dingle

The Lees and Lee Dingle landslides (**NLDID 4347/1** and **NLDID 4348/1** respectively, Figure 14) was investigated by BGS in 1973 (Culshaw, 1973a;b) and in the 1970s (Hamblin and Coppack, 1995) and the following was reported:

The Lees landslide is located to the west of The Lees buildings. At the edge of the plateau is a small steep backscarp some 5 m in height and below that a series of shallow landslides which extend through the superficial geology and into the weathered zone of the Halesowen Formation. The Lees buildings sit at the foot of these landslides and below, the ground falls more steeply to the bottom of the valley.

On the north side of Lees Dingle, south-south-west of Madeley County Infants School, the plateau has been cut back much further than to the south. Extensive rotational landsliding has taken place and the trees are confined to the lowest slopes above the stream, which are undisturbed. The backscarp to this landslide is, in the west, quite recent and there is evidence of continuing activity but at the eastern end, the backscarp is high and old with large, straight trees growing undisturbed upon it. The landslides themselves are thickly grassed and produce the typical hummocky ground, particularly at the western end.

Instability in this area is caused by a combination of factors; the steep sides of the hill, the softness and low permeability of the drift deposits, and the argillaceous nature of the Halesowen Formation. Waterlogging and easy weakening of the strata are the result (Hamblin and Coppack, 1995).

3.1.6 Coalport

The Coalport landslide (**NLDID 4350/1**) was mapped by BGS and its extent can be seen in Figure 11. This landslide comprises a series of shallow structures. The slipping is wholly contained within argillaceous Halesowen Formation above the Top Rock, although it has also brought down large masses of Brookside Rock (Hamblin and Coppack, 1995).

3.1.7 Sutton Wood 1

The Sutton Wood 1 landslide (**NLDID 4412/1**) was mapped by BGS and its extent can be seen in Figure 16. The landslide has the same characteristics as the Coalport landslide (Section 3.1.6; Hamblin and Coppack, 1995).

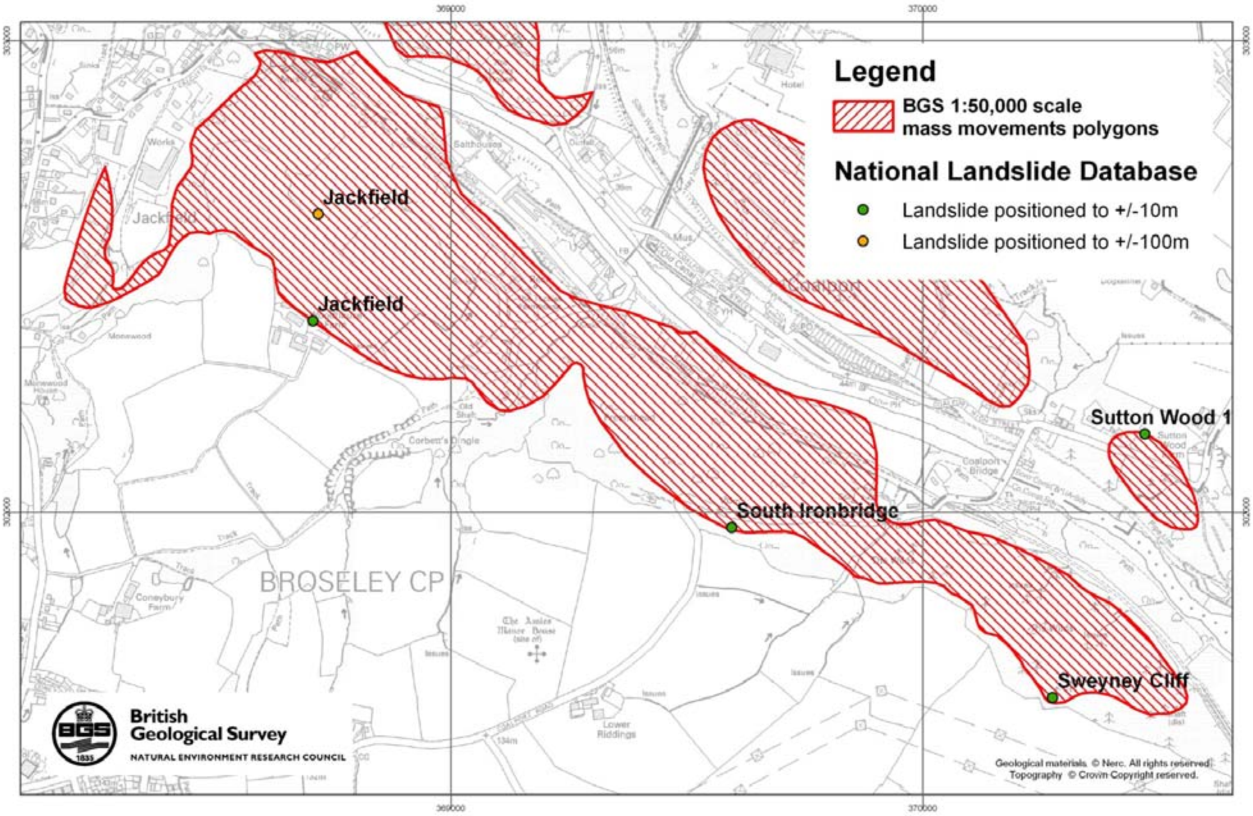

Figure 16 Extract from National Landslide Database including Jackfield, South Iron Bridge, Sweyney Cliff and Sutton Wood. DiGMapGB-50 mass movement polygons are also included in this map.

3.1.8 Ladywood

This landslide (**NLDID 4365/1**; Figure 13) occurred in 1988/89 and has been documented as a translational landslide where part of a private access road to a house was damaged; it was 24 m wide, 34 m long, 3.5 m deep and with a volume of 2856 m^3 (Giles, 2008).

3.1.9 The Coalbrookdale Landslides

The Coalbrookdale valley has a series of mudslides which form the most northerly valley-side slopes of the study area along Cherry Tree Hill and Jigger's Bank. In 2005, High-Point Rendel carried out a ground behaviour study of the Ironbridge Gorge and Coalbrookdale for Telford and Wrekin Borough Council and the information included in this section (3.1.9.1 to 3.1.9.4) is taken from this report[5] unless stated otherwise: The slopes of the Coalbrookdale valley are formed of

[5]This report is available at the URL below. Drawing B is a map which locates the landslides mentioned in this section. http://www.telford.gov.uk/Business/Land+and+premises/Engineers+Land+Stability.htm .

Wenlock Shales which terminates against the Lightmoor Fault near the Museum of Steel Sculpture; this, coincidently, also forms the easterly boundary of the Cherry Tree Hill Mudslide system. They are characteristically subdued with the benches gently inclined at gradients of 2-12º with intervening scarp slopes typically less than 30º. There are features of slope instability in localised areas, comprising heave, tension cracks and lobate features consistent with shallow transitional mudslides. They are marginally stable and sensitive to reactivation caused by changes to the slope geometry and hydrogeology, either artificially by man or through natural processes such as erosion and extreme rainfall events and are probably seasonally active in response to high groundwater levels during the winter. There is much evidence of widespread seepage, ponding and surface drainage in these areas.

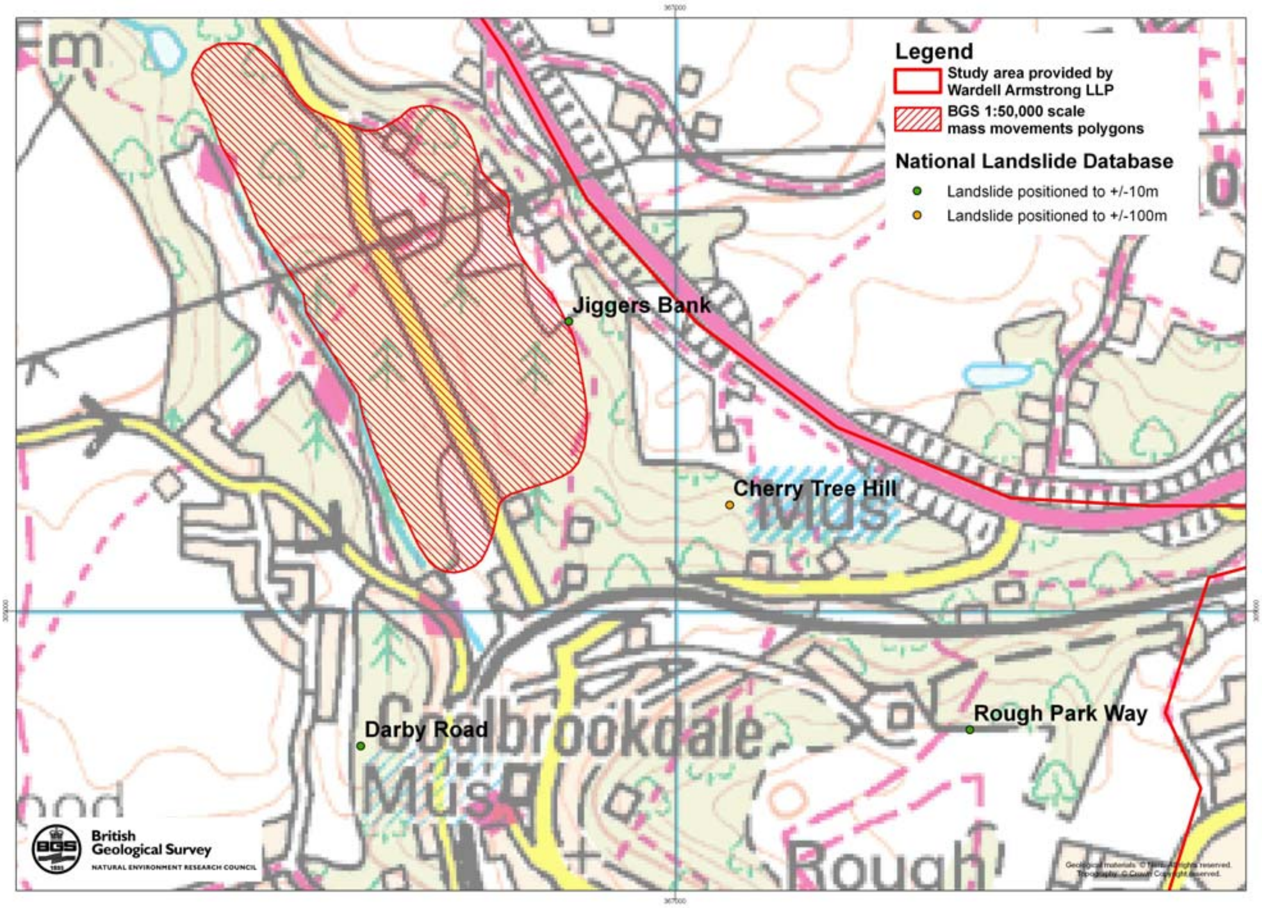

Figure 17 Extract from the National Landslide Database of Cherry Tree Hill, Rough Park Way, Darby Road and Jiggers Bank landslides. DiGMapGB-50 mass movement polygons are also included in this map.

3.1.9.1 CHERRY TREE HILL

Cherry Tree Hill landslide (**NLDID 4366/1;** Figure 17) is in an area affected by seasonal landslide movement and can vary from year to year. Although movement is imperceptible, large-scale events have been recorded and may occur. Instability is typically characterised by differential shear, tension, opening of cracks, settlement and heave. Few properties lie within the zone of ground instability in this area and of the properties inspected are subject to slight to moderate damage. Mudslides present a threat to public safety due to the very soft ground conditions. A gabion wall is located immediately above Cherry Tree Hill at the toe of the mudslide suggesting a former active section of slope.

A further event has been recorded as occurring in 2000 (Giles, 2008): This involved the inundation of railway embankment material and the shoulder of the railway embankment collapsed and blocked a ditch drain. It was 8 m wide, 11 m long, 5 m deep and 440 m^3 in volume.

3.1.9.2 Rough Park Way

The Rough Park Way landslide (**NLDID 4367/1**; Figure 17) is in an area affected by ongoing settlement of deep seated landslide blocks, likely to be situated on pre-existing shear surfaces. The toe of the landslide system has been developed using the benches of the blocks as terraces. The blocks are subject to settlement and creep, and the landslide processes include differential shear, tension, heave and superficial failures. The developed ground shows mainly moderate and significant damage to property. This area is likely to be subject to creep, settlement and toe heave.

3.1.9.3 Darby Road

Deep Seated rotational landslides have been identified along Darby Road (**NLDID 16343/1**; Figure 17). These landslides are contemporary landforms influenced by historic stream erosion and groundwater conditions. They are developed in the Wenlock Shales and failure is possibly up to 15 m below surface. The landslides comprise linear benches with gradients typically less than 5º, separated by scarp slopes with gradients of 15-25º; the benches are locally tilted backwards with ponding and soft ground accumulated to the rear side of the benches, a characteristic of deep-seated rotational and translational landslides. The landslides are probably subject to imperceptible creep, although the cumulative displacement over time can be significant. Such movement causes progressive settlement and shearing of the ground, resulting in cracking, ground heave and associated damage.

3.1.9.4 Jiggers Bank

The Jiggers Bank mudslide (**NLDID 4409/1**) is located near Loamhole Dingle and was mapped by BGS and the extent of this landslide is shown in Figure 17 and Figure 18. The landslide is known to cause problems for the Coalbrookdale-Horsehay road and is a result of the Coalbrookdale Formation moving down-dip (Hamblin and Coppack, 1995; Shropshire Star, 2008b). This landslide has also been mapped by High-Point Rendel (2005b).

Two further events have been recorded as occurring in 2000 (Giles, 2008): both were small rotational landslides and the first was 15 m wide, 20 m long, 3 m deep and 900m^3 in volume; the second was 22 m long, 20 m wide, 3 m deep and 1320 m^3 in volume.

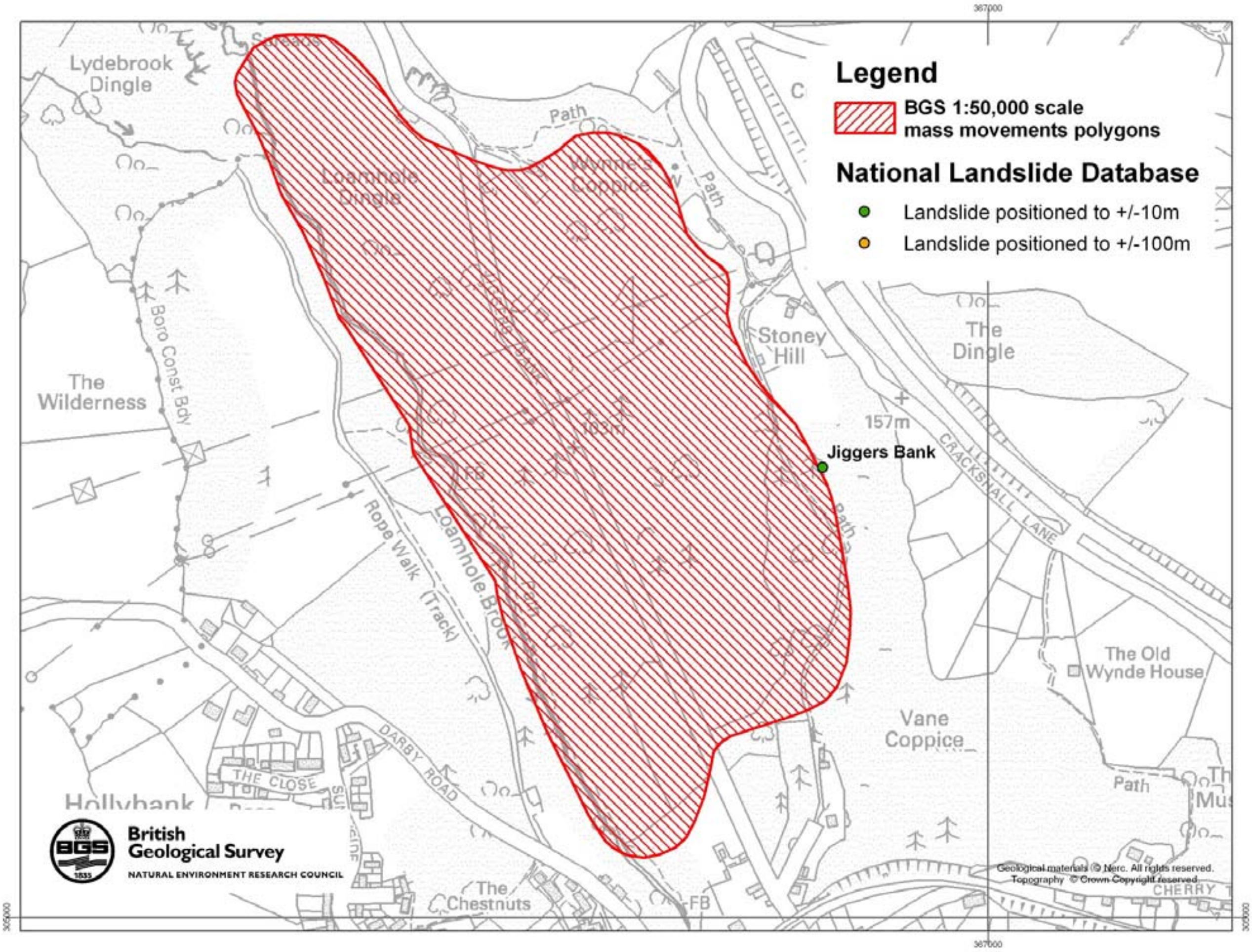

Figure 18 Extract from National Landslide Database for the Jiggers Bank landslide. DiGMapGB-50 mass movement polygons are also included in this map.

3.1.10 The Birches, Buildwas Bridge and Holbrook Coppice

This is a large area of landsliding near Buildwas Bridge (Figure 19). This section describes 21 National Landslide Database Surveys of this landslide (**NLDID 4405/1-21**) plus the Holbrook Coppice landslide (**NLDID 16341/1**). This series of landslides is one of several large mass movements on natural slopes which were recorded in the 1700s; they were probably initiated by the cold wet winters which were experienced towards the end of the Little Ice Age (Gostelow *et al.*, 1991). The large area of slipped Coalbrookdale Formation adjacent to Buildwas (**NLDID 4405/1** as mapped in DiGMapGB-50) appears from its subdued form to be a relatively old slip, and apart from reactivation of its south-western and south-eastern extremities (i.e. in 1773), it has not moved in historical times (Gostelow *et al.*, 1991). The slipped mass is at least 32 m thick and is underlain by up to 450 mm of soft, pebbly bentonitic clay. Bentonites occur as thin layers at many horizons within the Coalbrookdale Formation and render this formation particularly liable to slipping. Up to 200 m north of the River Severn, the slip was found to have overridden the gravel which underlies the alluvium of the river at a level of 31 m above OD (Hamblin and Coppack, 1995).

At the south-western corner of the main slip, a catastrophic slide occurred in May 1773 (**NLDID 4405/2**). All movements were completed within 15 minutes (Gostelow *et al.*, 1991). From a contemporary plan held by the Ironbridge Museum Trust, this appears to be a translational failure: the Coalbrookdale Formation dips at about 15º to the south east and a large mass moved along a bedding plane down-dip. The turnpike road was displaced, a bridge destroyed and chasms up to 11 m deep appeared behind the slip; the River Severn was blocked and cut a new course around the toe of the slip (Hamblin and Coppack, 1995). This landslide is also thought to have been controlled by two major vertical joint sets, trending approximately north-south. The toe of the slide emerged from beneath the River Severn and thrust the river bed sideways and vertically upwards (3 m is quoted) creating a new channel to the south. Erosion has continued at the slope base, although no additional major movements have been recorded. Gostelow and Hamblin (1979b) note that “the Severn had for some days overflowed its banks” and that at this particular point on the river the water was 'uncommonly deep'. There is thus also a strong possibility of considerable rainfall and groundwater flow prior to the mass movement taking place.

Gostelow *et al*. (1991) also mapped a series of rotated blocks within the lower and upper slopes of this landslide from aerial photographs (**NLDID 4405/3-21**), including Holbrook Coppice landslide (**NLDID 16431/1**). See Figure 20. Gostelow *et al* state that it is likely that these landslides are translational types and similar to the Buildwas Bridge 1773 landslide. Gostelow and Hamblin (1979a) also describe bands of bentonite up to 45 cm thick associated with landsliding and state that the area of slip immediately north of Buildwas Bridge was still active as the bridge itself and the buildings nearby showed signs of movement. This area probably represents the re-activation of the western end of the Late Glacial solifluction (mudflow) material.

In the late 1970’s/early 1980’s, the Buildwas Link Road (i.e. the Ironbridge by-pass, now the A4169) was constructed through the Birches landslide (Rayner *et al.*, 2007): A huge concrete retaining wall was needed to prevent collapse at the road junction between the Link Road and the road leading onto the bridge over the River Severn and on to Much Wenlock, all part of the same tract of landslipped ground. Construction was hindered by debris falls in the Wenlock Shale and by the reactivation of pre-existing landslides, probably periglacial in origin that had become obscured by erosion subsequently smoothing the uneven ground, and by the vegetation cover. Expensive drainage channels and bank stabilisation were required, and there is an on-going need for monitoring for possible ground movements.

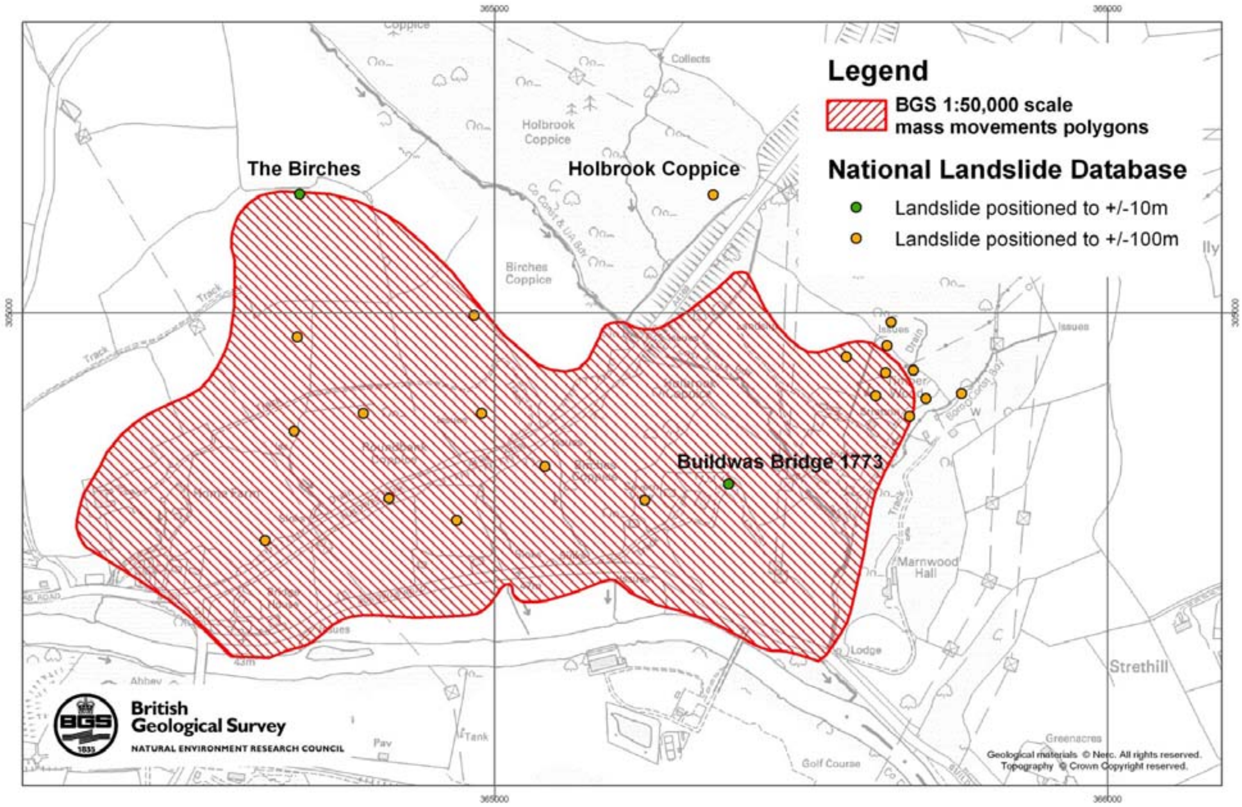

Figure 19 Extract from National Landslide Database for the Birches landslide. The points on this map are for the different National Landslide Database Surveys for this landslide which includes the Buildwas Bridge landslide of 1773 and Holbrook Coppice landslide. DiGMapGB-50 mass movement polygons are also included in this map.

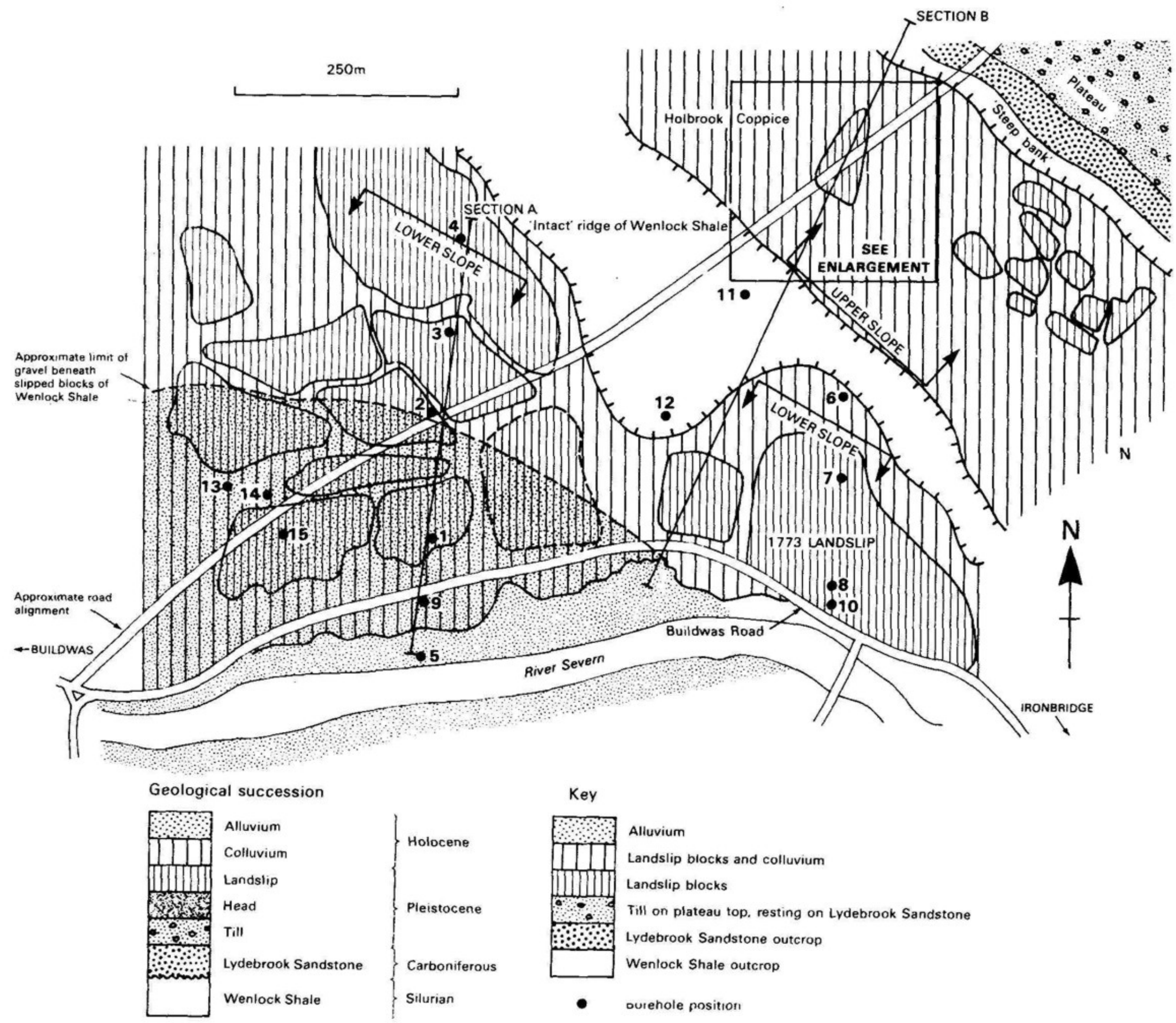

Figure 20 Extent of landslide blocks mapped in the Buildwas area (taken from Gostelow *et al.,* 1991).

3.1.11 Coalport Road

The Coalport Road landslide (**NLDID 16340/1;** Figure 14) was investigated by BGS in 1973 (Culshaw, 1973a) and the following was reported:

"*The whole length of the foot of the hill along the road is very wet. In places, the ground is saturated and water flows over the road. This has resulted in frequent slips of roadside material which stand as a steep bank some 20-30 ft high where it is not retained by walls. The land below the 250 ft contour is also fairly wet and shows evidence of movement. All trees are young saplings and mine shafts have been deformed due to movement. This area seems to be fairly unstable due to the quantity of water it contains and will probably need remedial measures to make it safe*".

3.1.12 Hay Farm

There is an entry in the National Landslide Database for Hay Farm. The original reference is for an unpublished PhD thesis by I. J. Brown (1975) Mineral working and land reclamation in the Coalbrookdale Coalfield, Geology Department, Leicester University, LE1 7RH. The time scale of this desk study did not allow for interlibrary loan to obtain this PhD.

4 Discussion

Culshaw (1973a) presented a hypothesis to explain the lack of landslides in the western part of the north side of the Gorge and relative instability in the eastern part as follows:

The whole of the area of the western end of Ironbridge below the Big Flint Rock and down to the river is very steep (often having a slope of greater than 30º), however observation shows no evidence of disturbance. The reasons for this seem to be closely related to the geology of this side of the Gorge which also controls the stability of the rest of the Gorge. In Ironbridge, the Middle and Lower Coal measures are gently folded into a shallow syncline plunging gently towards the north east. The axis of this fold runs, approximately, just east of the Ironbridge School. Within this succession is the Big Flint Sandstone which is more porous and permeable than the argillaceous rocks above and below. Consequently, water will be more able to pass within the sandstone than the other rocks, and due to the synclinal structure, will tend to move down the fold limbs towards the axis. As the aquifer is confined, the water has to flow out onto the surface at the lowest point of outcrop, namely in the axial area and so the slopes below the axial area of the fold would be expected to be wetter than the slopes either side. Wetting of overconsolidated argillaceous material led to progressive weakening, and in the case of the slope, to failure. Therefore, landsliding and the most gentle slopes are expected near the axis of the syncline. This is the situation with the Ironbridge School landslide being situated close to the fold axis and the groundwater source being the Big Flint Rock, just above the school.

This also explains why the area to the west of Ironbridge shows no evidence of instability despite the steepness of the valley side. This is because this western area is further along the western limit for the fold where little or no water may be seeping onto the surface. However, any change in hydrological conditions, be they natural or artificial, could radically alter the situation by weakening the argillaceous material in the steep slope, possibly to the point of failure.

It might be expected that a similar situation would be found to the west of the school landslide in the region of Jockey Bank. This is not the case as landsliding has taken place. The reason for this instability is the presence of the Best Coal Rock which is a relatively strong sandstone at Jockey Bank but to the west in Ironbridge becomes a series of arenaceous mudstones. Therefore, it is the sandstone that is probably acting as a groundwater source at Jockey Bank the water probably coming from the nearby fault.

Similarly, the distribution of landsliding in the eastern part of the north side of the Gorge was discussed by Culshaw (1973a). This has been presented in detail above in Section 3.1.3. No similar hypotheses have been proposed to explain the distribution of landslides on the south side of the Gorge.

5 Conclusions

A geological summary for the study area, as defined by Wardell Armstrong LLP, has been given and the National Landslide Database has been used to obtain information about landslides in the Ironbridge Gorge. A list of landslides and their locations have been presented with accompanying maps where possible. Resources available to BGS have been consulted and each landslide has been described.

This report presents factual information about the landslides of the Ironbridge Gorge area. Many of the reports that it references are more than 30 years old and it must be stressed that this current work and the previous references should not be used to make any decisions about land use or engineering without making a proper assessment of the ground. The unstable nature of the landslide areas mean that the situation on the ground can change considerably over short periods of time.

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Appendix 1

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CLASSIFICATION OF LANDSLIDES

The classification of landslides by the BGS follows the scheme based on Varnes (1978) and Cruden & Varnes (1996). The scheme terminology is also that suggested by the Unesco Working Party on the 'World Landslide Inventory' (WP/WLI 1990, 1993)

The main classification criteria are:

-type of movement (falls, topples, slides, spreads, flows), and
-type of material involved in the movement (rock, debris, earth)

Combining movement and material type terms enables an appropriately descriptive landslide name to be formulated. Naming can become more detailed with the addition of other descriptive details related to activity state, water content, rate of movement, etc, if known (eg active, complex, extremely rapid, dry rock fall-debris flow)

Only a small selection of the wide spectrum of landslide types that may develop in nature are shown here

FALLS: masses are detached from steep slope/cliff along surfaces with little or no shear displacement (eg joints/fissures) and descend mostly through air by free fall, bouncing or rolling.

TOPPLES: movements of rock, debris or earth masses by forward rotation about a pivot point.

ROTATIONAL SLIDES (SLUMPS): masses slide outwards and downwards on one or more concave-upward failure surfaces that impart a backward tilt to the slipping mass, which sinks at the rear and heaves the toe.

TRANSLATIONAL (PLANAR) SLIDES: movements occur along planar failure surfaces that may run more-or less parallel to the slope.

SPREADS: involve the fracturing and lateral extension of coherent rock or soil masses due to plastic flow or liquefaction of subjacent material.

FLOWS: slow to rapid movements of saturated or dry materials which advance by flowing like a viscous fluid, usually following an initial sliding movement. Some flows may be bounded by basal and marginal shear surfaces but dominant movement of the displaced material is by flowage.

COMPLEX SLIDES: involve a type of movement style that combines two or more of the main movement types (fall, topple, slide, spread, flow) occurring in sequence. Complexity may be indicated by combining the main movement terms, eg complex rotational earth slide-earth flow (or complex slump-earth flow).

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