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A Geological Trail through the landslides of Ironbridge Gorge

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RAYNER, C., RAYNER, M. & ROSENBAUM, M.S. (2007). A Geological Trail through the landslides of Ironbridge Gorge. *Proceedings of the Shropshire Geological Society*, **12**, 39-52. The spectacular nature of the Gorge has led to many studies of the landslides at Ironbridge, the earliest written record being the sermon of John Fletcher concerning Buildwas (1773), followed by the 1853 account of Rookery Wood that disrupted construction of the Severn Valley Railway between Ironbridge and Bridgnorth. The 1952 Jackfield landslide was particularly important, leading to an international revolution in the understanding of clay behaviour.

Slope instability continues, and remains a topic of concern as local people strive to mitigate the consequences of landsliding to their properties and usage of the land. However, other geomorphological processes are active within this steep-sided valley, producing a blanket cover of colluvium, added to which are anthropogenic deposits built up notably during the Industrial Revolution. These cover some landslide deposits; others are disrupted by more recent landslide events, evidence of the on-going slope instability of the Gorge.

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1. INTRODUCTION

Glaciations have taken place a number of times during the past two million years. The last to affect Shropshire was the Devensian: 120,000 to 11,000 yrs BP; its coldest phase ended around 18,000 yrs BP.

During the Devensian the northern part of Shropshire was overrun by a huge glacier moving south from what is now the Irish Sea. The river valleys responded to the onset of a colder climate and consequent drop in sea level (which dropped by many tens of metres as the water worldwide became locked within the glacial ice) and to the influx of meltwater loaded with sediment from the glaciers.

A complex network of river channels and terrace deposits resulted, and some river capture and relocation took place. However, the erosive forces needed to create a gorge as large as that at Ironbridge would be enormous. The popular idea of a huge glacial margin lake (often referred to as Glacial Lake Lapworth) which eventually overtopped the hills and rapidly cut Ironbridge Gorge is discredited. It is now thought more likely that formation of the gorge began as a subglacial meltwater channel, eroded *beneath* the glacier when the water erosion would have been concentrated and the ground weakened by frost action, or somewhat later as an ice-marginal channel which developed as the main glacier melted (Hamblin, 1986).

The spectacular nature of the Gorge has led to many studies, the earliest written record being the sermon of John Fletcher recording the 1773 Buildwas landslide, followed by the 1853 account of the Rookery Wood landslide that disrupted construction of the Severn Valley Railway between Ironbridge and Bridgnorth. The 1952 Jackfield landslide was particularly important, leading to an international revolution in the understanding of clay behaviour (discussed in more detail within the itinerary).

Furthermore, beyond the glaciers the extremely cold climate caused freezing of the groundwater and supported a periglacial environment. Characteristic of this would have been seasonal freeze-thaw producing ice-heave, fracturing of the ground, and pervasive solifluction.

Slope instability continues, and remains a topic of concern as local people strive to mitigate the consequences of landsliding to their properties and usage of the land. However, other geomorphological processes are active within this steep-sided valley, producing a blanket cover of colluvium, added to which are anthropogenic deposits built up notably during the Industrial Revolution. These cover some landslide deposits; others are disrupted by more recent landslide events, evidence of the on-going slope instability of the Gorge.

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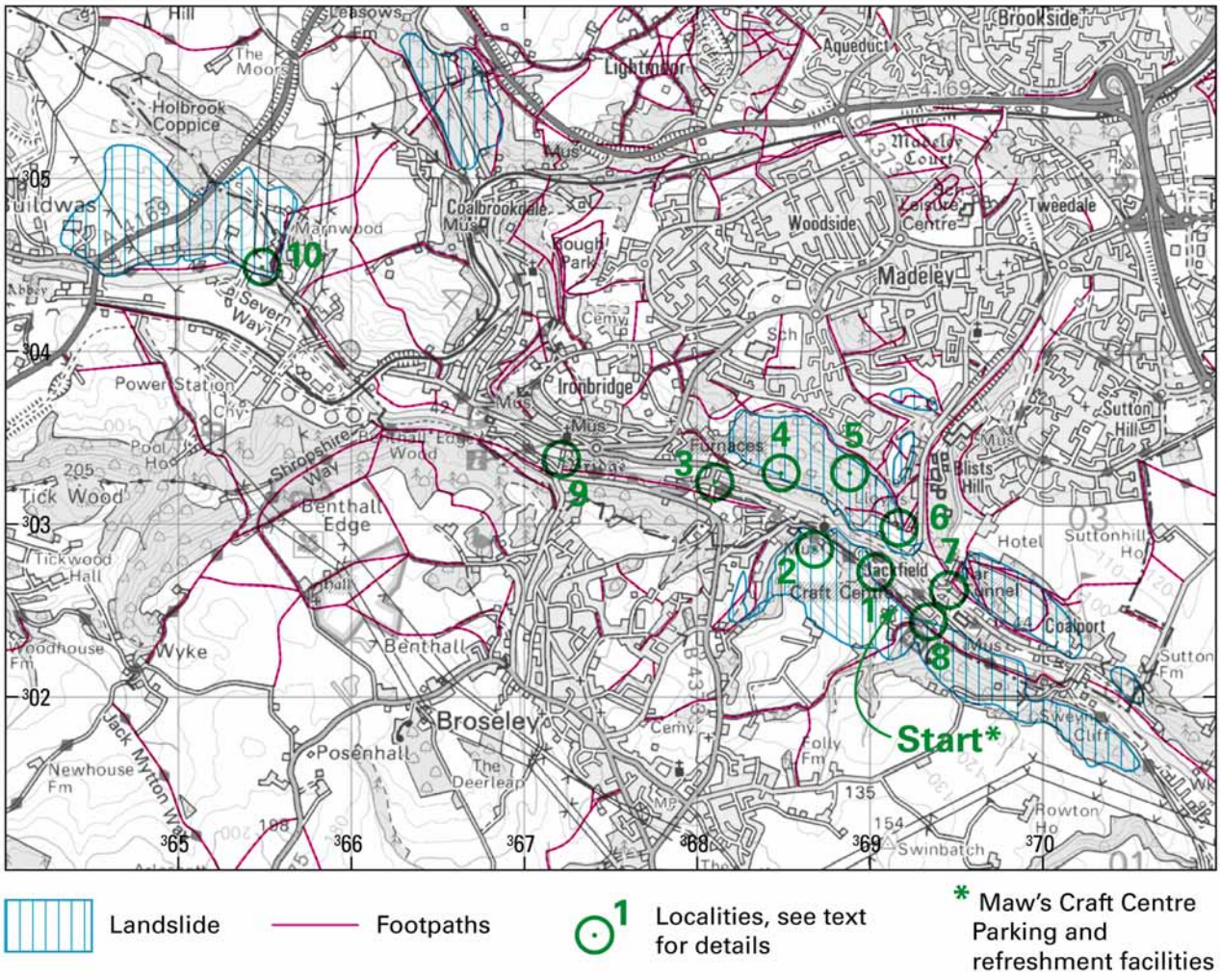

Figure 1. Locality map for the Geotrail, showing the distribution of major landslides and locality numbers. Outlines of geological units are shown with permission of the BGS (IPR/81-33c British Geological Survey © NERC 2007).

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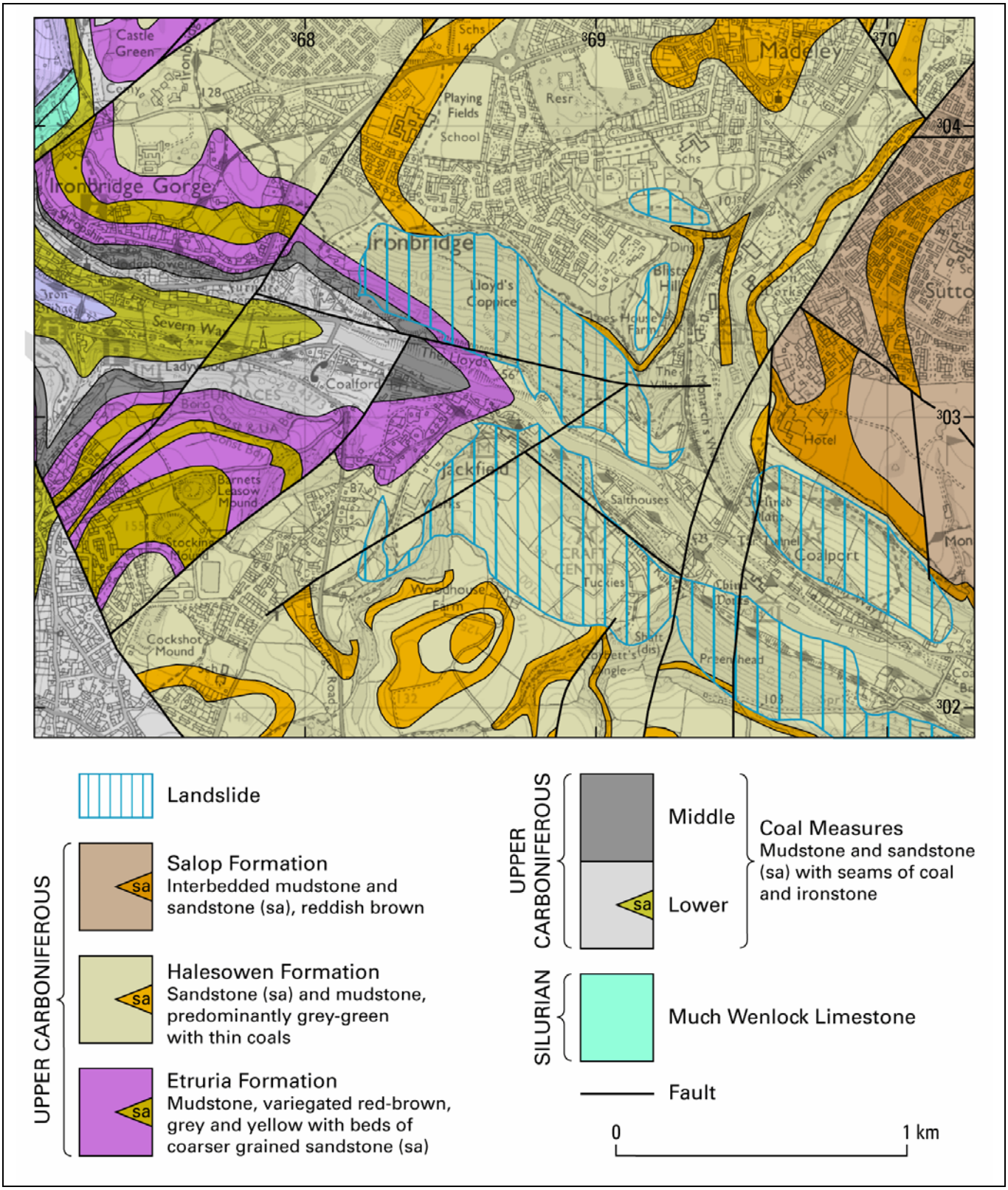

Figure 2. Geology east of Iron Bridge based on BGS mapping. Grey shading indicates landslides (IPR/81-33c British Geological Survey © NERC 2007).

The Trail (Figure 1) follows public roads and footpaths and is intended to be followed on foot (other than localities 9 and 10). The use of a large scale Ordnance Survey map is strongly recommended (e.g. Explorer Series Sheet 242 (1:25,000 scale). Ordnance Survey grid references are included to assist location. A compass and GPS will be found useful.

Visitors should refrain from using hammers since the exposures are few in number and small in size; fragments can generally be found in the vicinity. Visitors should also follow both

the Countryside Code (Anon., 2006) and the Geological Fieldwork Code (Geologists' Association, 2006).

The numbers within squared brackets in the text that follow refer to grid references for the stopping points ('Localities') shown on the accompanying sketch map. 6-figure grid references locate each feature to the nearest 100 m; 8-figure grid references to the nearest 10 m.

A convenient starting point is the Maw's Craft Centre at Jackfield, TF8 7LS [GRID SJ 691 027], with a licensed tea room and free car parking. It is generally open every day except Mondays (Tel. 01952 883 030).

Proceed on foot west (upstream) along the road leading from the Craft Centre.

LOCALITY 1: Wooden Road, Jackfield [688 028]

The entire slope to the left of the road is unstable, the result of extensive landsliding over many centuries. The road used to go down to the right and the Severn Valley Railway formerly carried straight on; the old road is now a cul-de-sac but may be traced within the woods towards the river. The current through road, surfaced in the worst section by wooden slats chained together (Figure 3), follows the line of the former railway.

Ongoing movement causes periodic damage to this road and makes necessary frequent repairs to services such as electricity cables, water supply and drains. The services are now located above ground to facilitate repair and have flexible joints. The road surface has been paved with a wooden slatted surface, unique and ideally suited to retaining access whilst the ground creeps beneath.

Further evidence of downslope movement can be seen in cracked and bulging brick walls, for instance the older properties to the west of the Tile Museum (next locality) (Figure 4).

Take the road west from the Tile Museum.

LOCALITY 2: Tile Museum, Jackfield [685 030]

Characteristically hummocky ground of landslipped terrain can be seen behind and uphill from the far (western) side of the Tile Museum buildings. The extensions constructed in 2006 required significant land take and thus a carefully engineered excavation of the landslide took place. This utilised berms to provide a counterbalance with the existing retaining walls to maintain stability (Figure 5). Note the fragmented character of the grey Halesowen mudstones which have been disturbed by the downslope movement from their original *in situ* location higher up the slope, and become a clay soil.

100 m beyond the eastern end of the Jackfield Tile Museum, as the road double-backs to cross the former railway line by the level crossing, note to the right the debris of houses that were damaged by the 1952 Jackfield landslide; most of these have subsequently been demolished (Figures 6 and 7) [684 031]. Their study (Henkel & Skempton, 1955) led to revolutionary theories of clay behaviour which established Skempton (later Sir Alec) as the world leader of soil mechanics.

Figure 3. The unique flexible wooden slatted road across the Jackfield landslide. Note the services carried above ground to the left, to facilitate maintenance. © Ironbridge Geography Exploration Project http://www.taw.org.uk/demo/geography/GeoExpFinal/index.htm

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Figure 4. Evidence of downslope movement from cracked and bulging brick walls, as shown by several of the older properties to the west of the Jackfield Tile Museum.

Figure 5. Western side of the Tile Museum buildings: extensions constructed in 2006 required significant land take and thus a carefully engineered excavation of the landslide has taken place, utilising berms together with the existing retaining walls to maintain stability.

THE MANCHESTER GUARDIAN, THURSDAY, APRIL 10, 1952

Figure 6. Pear Tree Cottage, damaged by the 1952 Jackfield landslide and demolished the following year.

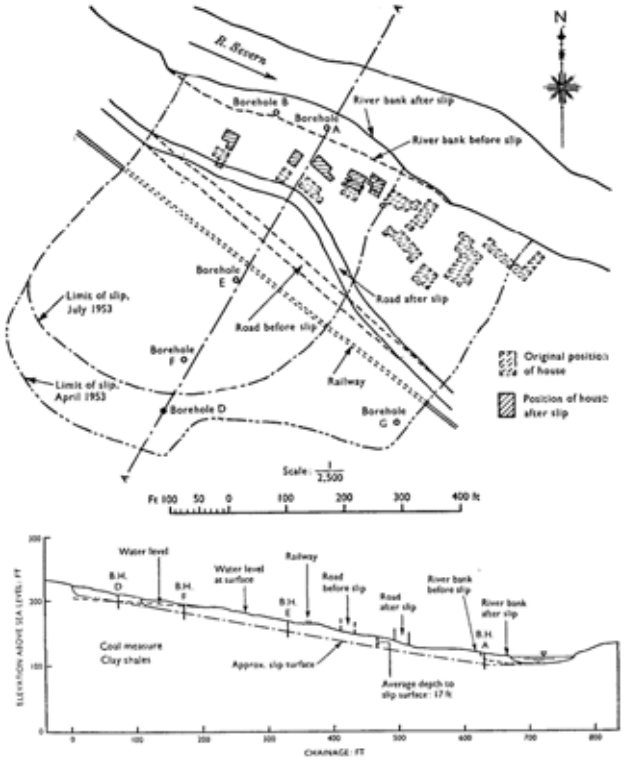

Figure 7. The 1952 Jackfield landslide: site plan and cross-section (A-A) (from Henkel & Skempton, 1955).

Take the road west from the Tile Museum, close to the River Severn.

LOCALITY 3: Jackfield Bridge [681 032]

The present day cable-stay bridge replaced a reinforced concrete structure in 1994, a section of which has been preserved on the right (south) bank.

On the left bank the pub car park reveals significant landslide activity, with displaced brick walls, bulging tarmac due to thrusting, and compressed fences in line with the direction of slope movement (Figure 8) [682 033]. All these are related to the western end of the Lloyd's Coppice landslide. This is very extensive, and the GeoTrail will now trace it for the next kilometre.

Figure 8. North side of Jackfield Bridge: pub car park reveals significant landslide activity with displaced brick walls, bulging tarmac due to thrusting, and compressed fences in line with the direction of slope movement.

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Having crossed the River Severn by Jackfield Bridge, turn right (east) and use the pedestrian footpath to follow the road.

LOCALITY 4: Lloyd's Cottage [687 032]

The pretty setting of the 18th Century Lloyd's Cottage within Lloyd's Coppice belies its dynamic foundations. The road in front frequently moves, and usually there are roadwork signs indicating repairs in progress (Figures 9 and 10). The local authority, Telford & Wrekin Borough Council, have an on-going programme for monitoring movements of the ground hereabouts.

Figure 9. Severe distortion to house frame as a result of landsliding; Lloyd's Cottage. The greenhouse frame is vertical!

Figure 10. Severe subsidence of the main road as a result of movement of the Lloyd's Coppice landslide.

This landslide has been the subject of many investigations aimed at better understanding the mechanisms responsible. Various remedial measures have been applied to restrain the movement, including retaining walls (stone, brick and, more recently, gabion). Effective drainage is important if a build up of pore water pressure is to be prevented, so often the main cause of slope instability.

Unfortunately, the local geological profile (Figure 13) makes groundwater control very difficult. The landsliding higher up the slope within Lloyd's Coppice has intersected a number of separate sandstone aquifers and these feed water into the landslipped ground, maintaining high water pressures throughout the year. Furthermore, the stresses acting on the slope have been exacerbated by the tipping of mine waste excavated from the Lloyd's Colliery that was working here in Victorian times, but now largely obscured by trees and shrubs.

A curiosity that may be noted in passing is the use of iron furnace slag as a walling material by the side of the road.

Continue to proceed east along the road for 300 m beyond Lloyd's Cottage, leaving the roadside by the track that veers left (northeast) up into the wood, marked as a footpath. Proceed uphill into the wood for 200 m and take a minor footpath north into the wood to reach the rock cliff.

LOCALITY 5: Lloyd's Coppice [691 032]

The back scarp of the Lloyd's Coppice landslide is defined by a high wall of rock composed of irregularly bedded sandstone of the Halesowen Formation (Figure 11). The rotational nature of the landsliding hereabouts can be appreciated by the back-tilting of the bedding, which *in situ* is essentially horizontal. The higher vertical scale of Figure 13 exaggerates the dip. Local variations are determined by the locations of faults that cut through and displace the bedrock. The mapped details (Figure 2) are known from the extensive underground mining for coal and, to a lesser extent, fireclay and limestone that took place from the late 18th until the early 20th Centuries.

The map and cross-section through this landslide (Figures 12 and 13) demonstrate the three principal mechanisms of slope movement taking place here, commencing with rotational failure of the *in situ* Halesowen Formation sandstones at the top, especially where thick

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sandstone beds are underlain by mudstones or clays.

As already noted, the intersection of sandstone aquifers by the landsliding maintains high water levels within the slipped ground and keeps pore water pressures high, resulting in frequent renewed slope movements. Hollows often contain water, indicative of the high water table (Figure 14).

Once the rock has collapsed by rotation, it breaks up by stress relief and weathering. The broken material then softens in contact with water and becomes sufficiently weak to slide downhill as a translational slide, even more so if its dip is nearly horizontal or (locally) down towards the river. Further disintegration turns this into a mudslide. This process is aided by removal of debris at the toe by the river. This conforms to the "landslide reservoir principle" put forward by Bruce Denness (1991). This theory helps explain the Lloyd's Coppice situation whereby the landslip complex degenerates more rapidly from its initial relatively solid state to a more viscous or liquid state than would be the case if it was supplied only with run-off water. The contention is that water is being fed into the complex by the sandstone aquifers above, the groundwater being directed along the impermeable contact with the *in situ* mudstones beneath. Perhaps the lateral limit of the landslide coinciding with the location of a major fault reflects a break in the aquifers and thereby limits effective groundwater input to the landslipped complex, beyond which the ground is relatively stable.

The third landsliding mechanism is caused by river erosion, causing collapse of the river banks by toppling and/or rotation and thereby removing support to the landslipped material upslope (eventually causing it to be remobilised). Collapse of the mine waste similarly occurs (Figure 15).

Whilst underground mining was in progress, active dewatering by pumping and maintenance of drainage adits took place (Figure 16). However, with the cessation of mining the pumping and maintenance ceased. This is thought to be allowing water pressure within the groundwater regime to recover, and this would be expected to reduce the stability of the deeper parts of the slopes and to lead to a renewed phase of landsliding. The local Council is actively investigating the potential slope instability and developing appropriate management plans to anticipate and mitigate the effects on the land usage. Various kinds of retaining structure have been erected (Figure 17). The most recent works began in 2006, following the announcement that over £3 million funding had been secured and a contract signed with AMEC Group Ltd to install three rows of 750 mm diameter reinforced concrete tubes up to 30 m deep into the ground and to infill shallow mine workings in the vicinity.

A number of different landsliding mechanisms are operating within the Lloyd's Coppice, each determined by a particular combination of geological profile, slope geometry and pore water pressure. A failure in one part of the slope does not necessarily result in immediate failure elsewhere, but progressively the slope is collapsing and erosion of the valley side is progressing. The cross-section illustrates the relationship of these varied landsliding mechanisms to the geological profile.

Figure 11. Back-tilting of sandstone as a result of rotational failure; Lloyd's Coppice landslide.

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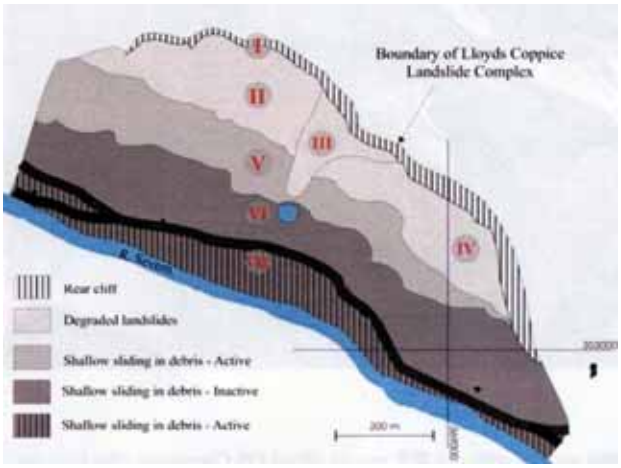

Figure 12. Map illustrating the various landsliding mechanisms; Lloyd's Coppice. Based on Culshaw (1973). © NERC 2007.

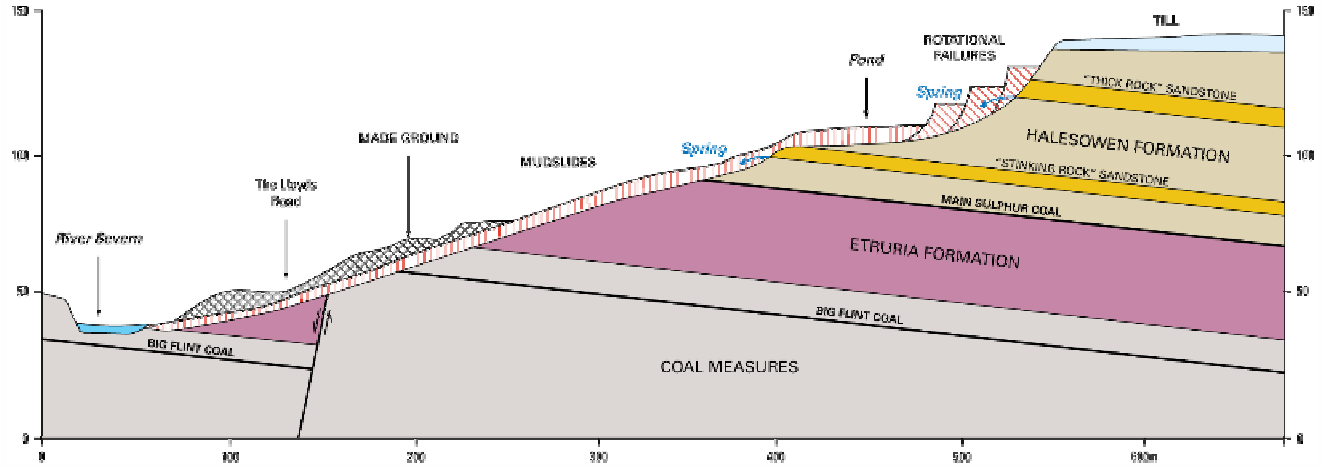

Figure 13. Cross-section illustrating the relationship of the varied landsliding mechanisms to the geological profile; Lloyd's Coppice. Based on Culshaw (1973). © NERC 2007.

Figure 14. Hummocky ground within the Lloyd's Coppice landslide, showing ponded water as a result of the high water level maintained by intersection of sandstone aquifers higher up the landslide.

Figure 15. River erosion causing collapse of the river banks by toppling and/or rotation, thereby removing support to the landslipped material upslope (eventually causing it to be remobilised). Collapse of the mine waste that has been placed on top will be similarly affected. Bank of the River Severn at the foot of the Jackfield landslide, immediately opposite the Lloyd's Coppice landslide.

Figure 16. Distortion of the ground surrounding the shaft for the Engine House, a major pumping station for dewatering the coal mines to the north; Lloyd's Coppice landslide.

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Figure 17. Retaining wall to support the up-slope side of main road; Lloyd's Coppice landslide.

Continue to the eastern extremity of the wood, following the footpath to where the vista opens up to reveal the far side of the valley.

LOCALITY 6: opposite Blists Hill [692 029]

At the edge of Lloyd's Coppice the open ground of the spur opposite Blists Hill above the minor valley leading south towards the main one provides an excellent vantage point. This provides a clear view of the geomorphology of the south side of the gorge (Figures 18 and 19): Woodhouse Farm is prominent on the skyline; Maw's Craft Centre is within the large industrial building beneath, close to the river.

The hummocky ground extends across virtually the whole of the opposite side of the valley, reflecting the almost total coverage of that ground by landsliding, from the river bank to the crest of the slope. The Jackfield landslide lies to the right (west).

Descend to the road and proceed downstream (east) towards the Hay Incline.

LOCALITY 7: The Hay Incline [695 027]

Although disused since the end of Victorian times, the Hay Incline is a most impressive piece of engineering. Canal boats were raised on two parallel railway tracks, hauled by cables from the Coalport Canal up to the Shropshire Canal above.

From the single-track road bridge, note the alignment of the rails upslope. The eastern track is clearly displaced 50 m above the road (Figure 20), thought to be the result of slope movement consequent upon landsliding. Immediately next to the bridge, to the left (west) may be seen an extensive gabion wall which has recently been constructed to restrain this bank from further collapse. Such failures provide engineering geologists with evidence for the timing and frequency of slope movements, essential for the analysis of landsliding mechanics.

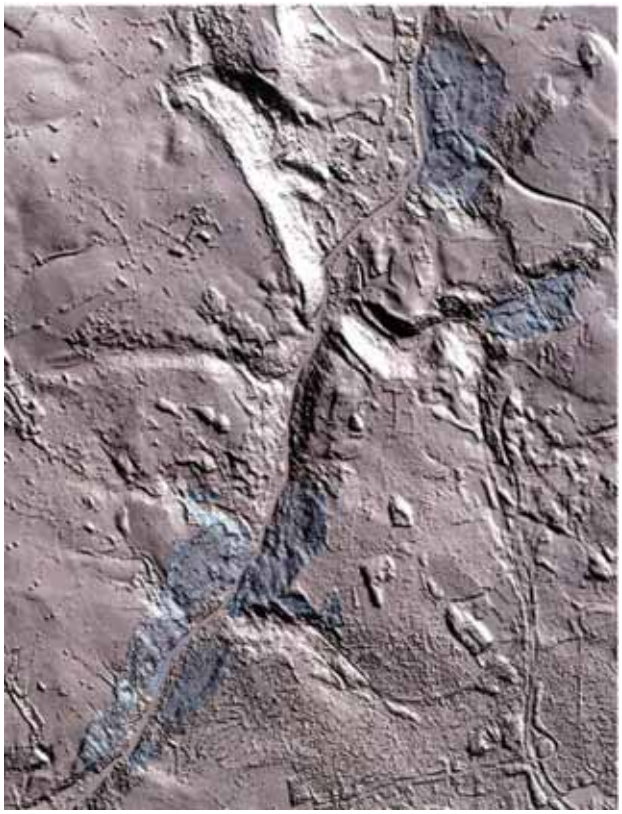

Figure 18. A Nextmap image of the Ironbridge Gorge area looking upstream, showing details of the topographic relief. Note the cutting for the bypass in the top right hand corner, appearing as a prominent notch Superimposed are the areas of known landsliding. © NERC 2006.

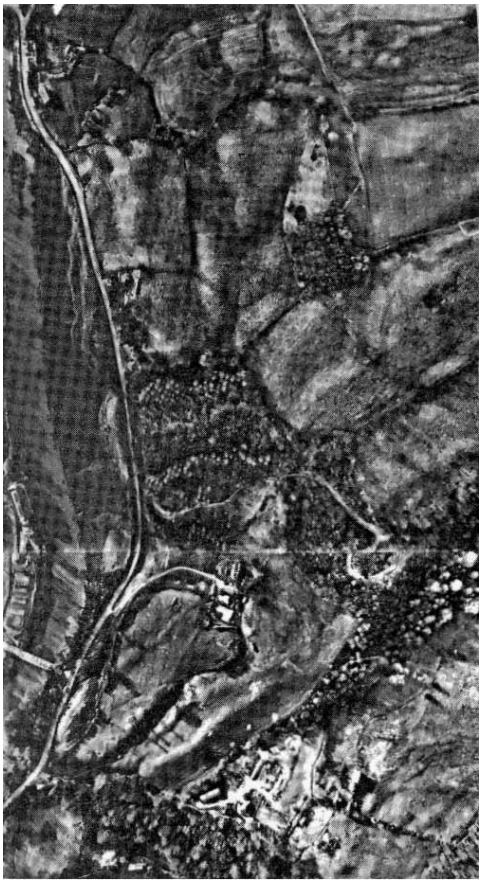

Figure 19. View upstream from the Iron Bridge, towards Buildwas, of the top right hand part of the Nextmap image in Figure 18, prior to construction of the bypass. The hummocky ground reveals the extensive development of landsliding (Figure 3 from Gostelow *et al*., 1991).

Figure 20. The Hay Incline. The right-hand (eastern) track is clearly displaced, the result of slope movement consequent upon landsliding. To the left (west) may be seen an extensive gabion wall which has been constructed to restrain this bank from further collapse. © Ironbridge Geography Exploration Project http://www.taw.org.uk/demo/geography/GeoExpFinal/index.htm

The Tar Tunnel just to the east is a geological curiosity: bitumen seeps from the Coal Measures into an adit originally driven in 1786 by William Reynolds to serve as an underground canal carrying the produce of the Blists Hill mines. However, the discovery of bitumen, which was then exploited, meant the tunnel was not used to carry coal until a railway was laid through it, in 1796. Further detail is in the 1971 book by Brown & Trinder "The Coalport Tar Tunnel".

Cross the River Severn by the Memorial Footbridge.

LOCALITY 8: The Boat Inn [694 025]

Note the tremendous depth that the river can reach during peak floods by looking at the

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marks on the side of the pub (Figures 21 and 22).

Turn upstream and follow the footpath to return to the Maw's Craft Centre. This is the end of the Geological Trail to be followed on foot.

There are a number of other sites within the Gorge which may be of interest from a slope instability point of view. The first is the Iron Bridge itself. There is a Pay & Display car park to the southeast of the bridge.

Figure 21. A history of flooding. High water marks on the Boat Inn.

Figure 22. The Boat Inn during the Nov 2000 flood. © Broseley Local History SocietyR0010679.

LOCALITY 9: The Iron Bridge [672 033]

The geomorphology of the Gorge at Ironbridge demonstrates the rapidity with which it has been cut, by virtue of the steep valley sides and fast water flow (Figure 23).

Figure 23. The gorge at Iron Bridge. Photograph by P Witney of BGS, © NERC 2006I

The river is bridged by the notable structure that gives the town its name, forming the centrepiece of the World Heritage Site and an iconic figure for the birth of the Industrial Revolution.

However, the bridge nearly collapsed in the early 1970's as a result of renewed landsliding on the right (south) bank, threatening to destroy the abutment and thus undermine the bridge. The engineering solution has been to construct an inverted arch, effectively mirroring the surface iron structure, to support both abutments (Cossons & Trinder, 1979). As a result, the Iron Bridge is now protected, and sufficient support has been provided to restrain the slopes from further movement (Figures 24 to 26).

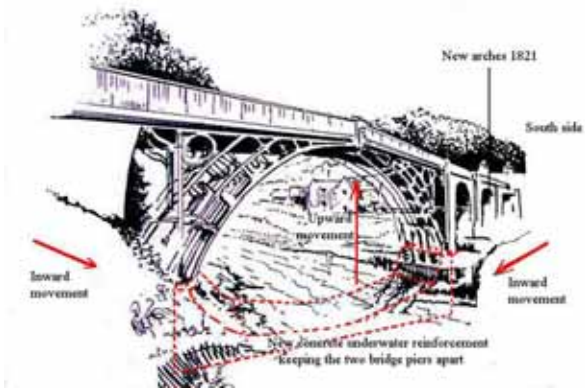

Figure 24. The reinforced support for the abutments of the Iron Bridge. © Ironbridge Geography Exploration Project http://www.taw.org.uk/demo/geography/GeoExpFinal/index.htm

The Ironbridge Geography Exploration Project initiated by Telford & Wrekin Council developed this aspect as a case study. The impressive cast iron bridge was constructed in 1779. Cracks soon started to appear in the stonework on the south side. Repair work was undertaken in 1802 and again in 1821 when two new cast iron arches replaced the crumbling south side stonework. Further repairs followed but the bridge, for a while, was threatened with demolition.

The 1972 repairs addressed the problems caused by the gorge sides slowly moving inwards that had caused the centre of the bridge, once fairly level, to bend upwards.

Figure 25. The Iron Bridge during restoration in September 1973, a year after the northern abutment was emptied of rubble and strengthened with concrete. A concrete strut to keep the abutments apart was built below water level, within the safety of a coffer. © Ironbridge Gorge Museum Acc No 1987:597

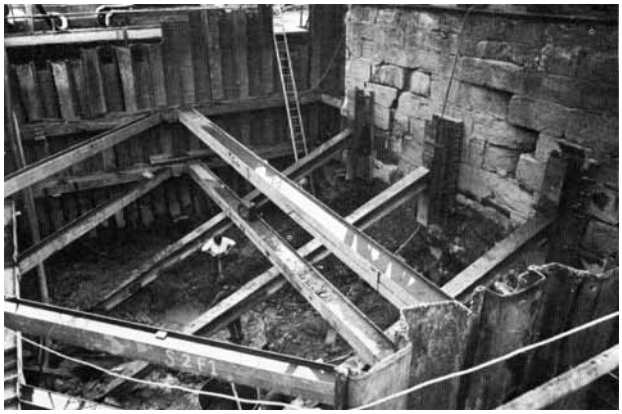

Figure 26. Detail of the Iron Bridge during restoration in 1973, showing the stonework of the southern abutment prior to strengthening with concrete (Figure 76 from Cossons & Trinder, 1979).

A box-like structure called a cofferdam was built across half of the river. Inside the cofferdam the river level was kept low to permit access to the bridge foundations. Outside the cofferdam, in the other half of the river, the water was much higher and allowed to flow as normal. A new, anchored, reinforced concrete foundation was constructed to strengthen the stream bed at this point. Then the whole process was repeated for the other half of the river forming a sort of underwater buttress. The arch shape of the concrete buttress also helped to keep the two sides of the bridge from moving towards each other.

Travel west to Buildwas by the minor road on the left (north) bank of the River Severn, to just beyond the railway overbridge.

LOCALITY 10: Marnwood Hall, Buildwas [655 052]

In 1773 a huge landslide occurred on the left bank of the Ironbridge Gorge below Buildwas, opposite where the large power station is now sited (Figures 27 and 28). The event was noted in a sermon delivered by John Fletcher, vicar of Madeley, which he later published (Bacon & Krause, 1989). The landslip occurred on Thursday morning May 27th, 1773, and was so extensive that the River Severn itself was temporarily blocked!

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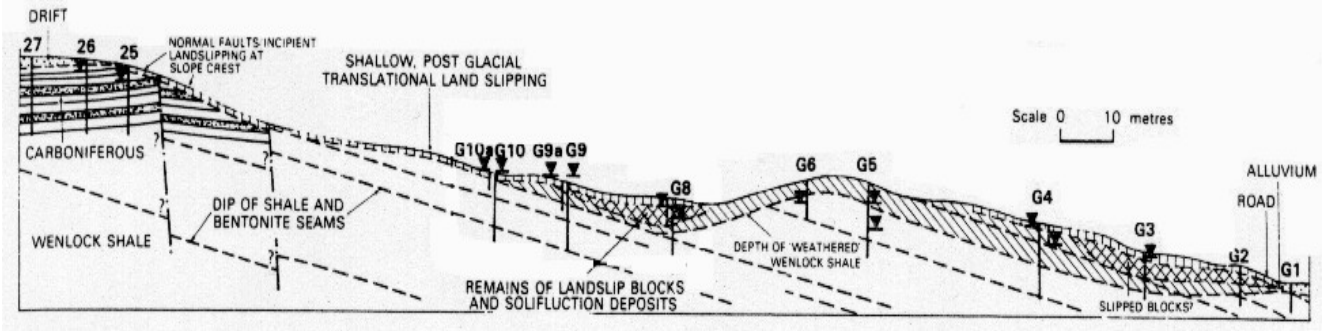

Figure 27. Cross-section illustrating the relationship of the varied landsliding mechanisms to the geological profile; Buildwas (Figure 4 from Gostelow *et al*., 1991). Location of section shown on Figure 28.

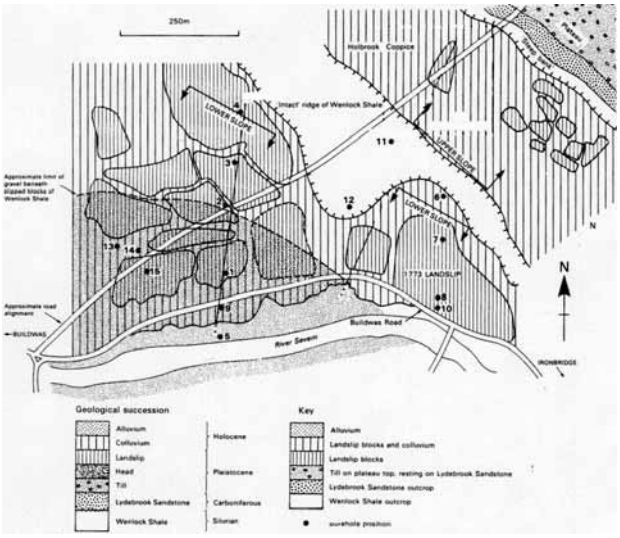

Figure 28. Landsliding in the Buildwas area (Figure 2 from Gostelow *et al*., 1991).

Looking uphill from the foot of the slope near the entrance to Marnwood Hall [656 045] enables the scale if this landslide to be appreciated. Note the woodland of Birches Coppice to the northwest; the landslide occurred across the whole extent of the open ground in front and was some 500 m across and of similar extent from top to bottom. The depth to the plane of sliding was about 9 m and moved horizontally about 11 m, taking about 15 minutes to do so.

The back scarp had to be avoided as much as possible during construction of the Buildwas Link Road (i.e. the Ironbridge by-pass, now the A4169) in the late 1970's. A glimpse of the geological profile may be gleaned as one drives up the new road, at the point where the large embankment leads into the major cutting and the electricity pylons carry their supply lines overhead [656 053]. The predominant bedrock is the Silurian Wenlock Shale dipping southeast at 5-15°. This comprises mudstones containing occasional thin beds of montmorillonite-rich clay, the diagenetic product of volcanic ash layers within the otherwise sedimentary sequence. These are greyish green when fresh but weather to a cream colour, described in the literature as unctuous, i.e. having a 'soapy' feel. They are particularly weak and, where they dip downslope in combination with high groundwater pressure, as after prolonged heavy rain or interception of aquifers extending back to higher ground, can initiate slope failures on a large scale. This was anticipated by the design team for the road, which illustrates how difficult it is to construct such a project (Gostelow *et al*., 1991).

Note also the huge concrete retaining wall 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 [645 047], all part of the same tract of landslipped ground. Nevertheless, slope failures did take place during construction (Figure 29), thought to be due to reactivation of pre-existing landslide slip surfaces, probably periglacial in origin, that had become obscured by erosion subsequently smoothing the uneven ground, and by the vegetation cover.

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Figure 29. Ironbridge Link Road in the early 1980's, just before opening. Construction was hindered by rock falls in the Wenlock Shale, and by re-activation of a pre-existing landslide (to the right of the vehicles). Expensive drainage channels and bank stabilisation were required, and there is an on-going need for monitoring for possible ground movements. © Ironbridge Geography Exploration Project http://www.taw.org.uk/demo/geography/GeoExpFinal/index.htm

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