Ironbridge Gorge

Geomorphological Mapping

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1 Introduction

1.1 Terms of Reference

1.1.1 Jacobs Engineering UK Ltd have been commissioned by Telford and Wrekin Council (TWC) to undertake geomorphological mapping of the Ironbridge Gorge World Heritage Site. The purpose of the mapping is to provide base data for the formulation of ground instability hazard plans and planning guidance plans. These plans will be used by TWC to assist in development control and to ensure that an appropriate level of geotechnical investigation is provided with planning applications. In addition, the mapping work contributes to the understanding of slope instability within the Gorge, and will also help with prioritising future actions.

1.2 Study Area

1.2.1 The study area comprises the full extent of the World Heritage Site (Drawing 1100100/G), which covers an area of approximately 8 km^2, but it excludes Ironbridge Town, which has already been mapped (see section 1.3 below). The study area includes the following seven districts, which from west to east are:

- Jiggers Bank
- Benthall Edge
- Ladywood
- Lloyds Coppice
- Jackfield
- Blists Hill
- Coalport

1.3 Previous Work

1.3.1 This work follows on from the High-Point Rendel (HPR) Ground Behaviour Study (2005), which looked at instability hazards in Ironbridge Gorge and Coalbrookdale. The study combined desk study work reviewing ground conditions information, the history of past ground movement and the development of the study area, with engineering geomorphological field mapping and structural damage surveys, to produce a planning guidance map. The map classified the study area according to a five point scale of increasing potential instability hazard, and this was related to the level of information required to be submitted with planning applications.

1.3.2 The current study has used the HPR planning guidance zonation scheme (Table 1) in order to ensure that planning guidance remains compatible throughout contiguous areas and across the gorge as a whole.

Table 1 Planning Guidance Zonation Scheme

Zone	Development Plan Policy	Development Plan Proposals	Development Control
1	Area **suitable for development** in accordance with the development plan.	Ground movement **does not impose any constraints** on site development.	**No Stability Report** required.
2	Area **likely to be suitable** for development in accordance with the development plan.	Ground movement **does not impose significant constraints**, although some mitigation/ stabilisation measures may be required to ensure the stability of the site and surrounding land.	An **Outline Stability Report** would normally be required, prepared by a Competent Person.
3	Area **likely to be suitable** for development in accordance with the development plan provided the developer undertakes appropriate mitigation and stabilisation measures.	Ground movement **imposes constraints** that would generally require mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	A **Standard Stability Report** would normally be required which ***may*** include subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
4	Area **unlikely to be suitable** for development in accordance with the development plan unless the developer undertakes appropriate mitigation and stabilisation measures.	Ground movement **imposes *significant* constraints** that would generally require large-scale mitigation/stabilisation measures to ensure the stability of the site and surrounding land.	A **Detailed Stability Report** would normally be required including detailed subsurface investigation and ground movement monitoring and where appropriate details of proposed stabilisation methods, prepared by a Competent Person.
5	Area **very unlikely to be suitable** for built development.	Ground movement **imposes *severe* constraints** that probably could not be overcome by cost-effective and environmentally acceptable mitigation or stabilisation measures to ensure the stability of the site and surrounding land.	A **Detailed Stability Report** would be required including detailed subsurface investigation and long-term ground movement (both surface and sub-surface) monitoring and detailed proposed stabilisation methods, prepared by a Competent Person.

2 Geology

2.1 Solid

2.1.1 The study area is underlain by outcrops of Silurian and Carboniferous strata. The Carboniferous strata crop out mainly in the central and eastern parts of the study area whilst Silurian strata dominate the western area.

2.1.2 The Silurian strata consist of marine sediments including mudstones, siltstones, flaggy sandstones and limestones. Thin beds of bentonite occur at the base of the sequence. The Carboniferous strata, which include the Upper, Middle and Lower Coal Measures, are principally comprised of mudstones and sandstones, although its economic value has been in the subordinate seams of coal, fireclay and ironstone. Stratigraphical details of the Silurian and Carboniferous strata are summarised in Appendix A.

2.1.3 The overall dip of the entire sequence is to the east or south-east, although locally this is more complex, with, for example, some northeasterly dip beneath Lloyds and Coalport. The Silurian and Carboniferous strata at Ironbridge are separated by a major unconformity and the latter strata dip at shallower angles, typically less than 6 degrees.

2.1.4 Faulting follows three distinct trends, which in order of decreasing frequency are: north-easterly, north-westerly and northerly. Most of the faults are normal and are inclined at between 45 and 90 degrees.

2.1.5 Recent exploratory drilling undertaken by TWC has confirmed that the Silurian strata extend approximately 200 m further eastwards along the Severn valley than had originally been thought and indicated on the published geological map. In addition, it is noted that, owing to the argillaceous nature of many of the Silurian and Carboniferous lithologies, rockhead is frequently identified in the boreholes as a stiff clay. The term ‘rockhead’ should therefore be used with care to avoid misinterpretation by different parties in the planning process.

2.1.6 A geological map of the study area is included as Drawing 1100100/01. The drawing is based on 1;10,560 scale British Geological Survey maps, and does not take into account the revisions noted above to the Silurian outcrop.

2.2 Superficial

2.2.1 Glacial deposits, comprising glacial till with isolated pockets and layers of sand and gravel, are found cropping out on some of the plateau areas above the main slopes of the gorge, for example above Lloyds Coppice. Thicker deposits of glacial material have been recorded in boreholes on the south side of the river near Bridge Bank, and these are believed to represent channel infill. They may not therefore be overconsolidated.

2.2.2 Alluvium and River Terrace deposits are restricted to floodplain areas to the west of Ironbridge.

2.2.3 Extensive deposits of colluvium are present within the study area consisting of solifluction deposits and debris from old landslide events. Material in the colluviums may have originated from solid or drift deposits and can accumulate in significant thicknesses. Example areas include Lloyds Coppice, The Birches and Coalport.

2.2.4 TWC are currently installing slope monitoring equipment locally around the Iron Bridge and at Jackfield. The colluvium is generally described in these boreholes as a firm or stiff slightly sandy and gravelly clay, and generally extends to depths of between 6 and 10 m below ground level. Slickensides (shear planes) have been identified at a depth of 7.6 m in a borehole (CP 13) close to the north abutment of the Iron Bridge. However, the base of the colluvium can be difficult to identify in the boreholes, and more precise information about landslide geometry and patterns of movement will become available as monitoring proceeds.

2.3 Made Ground

2.3.1 Extensive deposits of Made Ground underlie many parts of the gorge reflecting the long history of mineral extraction and processing. The extra loading imposed on unstable slopes in several areas has been a factor in promoting instability. The Made Ground itself has often been liable to failure, and this can lead to difficulties in distinguishing between Made Ground and colluvium.

2.3.2 Recent investigations by TWC around the Iron Bridge and at Jackfield have identified cohesive and granular deposits of Made Ground typically extending to depths of between 1 and 5 m below ground level (bgl), although in places, especially towards the riverside, this can increase to between 6 and 12 m bgl. The Made Ground deposits are generally composed of re-worked clays with gravel of mudstone, coal, ash, clinker, slag and brick. However, tile waste predominates at Jackfield.

3 Hydrology and Hydrogeology

3.1 Hydrology

3.1.1 The River Severn at Ironbridge responds quickly to rainfall events, including distant events occurring within the headwaters of the catchment in mid-Wales. This gives rise to a highly variable flow regime, and floods are common place. The average flow rate at Ironbridge is 60 m^3/s, and this increases by a factor of ten for the 1% flood event.

3.1.2 The river is a critical trigger in maintaining active movements within the gorge. The three key processes include;

- removal of toe support.
  Erosion or scour of the river bank can cause local oversteepening of the adjacent slope leading to slope instability and initiation of landslide.

- removal of toe debris.
  An existing landslide will eventually reach equilibrium as mass is transferred to the foot of the slope, but if the toe debris is removed, then slope instability is maintained.

- toe failure by rapid drawdown.
  Flood waters in the river channel can recede more rapidly than flood water held within the pore spaces of the soils. This can set up destabilising seepage forces that can halve a slope's factor of safety.

However, in addition to the local consequences of fluvial processes, the river can have a wider impact on the landslide systems as a whole. Two processes in particular are noted;

- linkage of fluvial and landslide systems.
  Sinuosity of flow within the river channel focuses erosive power on the outside bends, leading to enhanced toe erosion of the valley sides at periodic intervals along the valley. The hydraulic characteristics of the river can therefore influence landslide activity. However, the linkage between hydraulics and landslides can also be driven by the landslides; for example, landslide debris can deflect the river flow and modify the downstream flow regime. The linkage between the river and the landslides can therefore lead to long term cyclicity of landslide activity.

- maintenance of creep activity throughout slope.
  Single event landslides are caused by brittle failure, but within the gorge, creep (failure at constant stress) is a significant failure mechanism, and this process is promoted by the river's continual erosion of the slope toe.

3.1.3 The southern sideslopes of the gorge are mostly drained by small unnamed streams that are in many places intermittent or may have been culverted. On the northern sideslopes, misfit streams occupy the tributary valleys of Coalbrookdale and Lea Dingle/Blists Hill. Local blockages of valley sideslope streams by vegetation debris were noted during mapping. These features are noted in order to emphasise the importance of channel maintenance in preventing localised flash flooding.

3.2 Hydrogeology

3.2.1 It is probably impractical to devise a general model of groundwater behaviour within the study area owing to the complexity of features that control groundwater movement. These features include mineworkings, faults, and lithological controls, for example interbedded sandstone aquifers and mudstone aquitards. Mining in particular has severely depressed ground water levels.

3.2.2 The lack of drift cover may enhance re-charge rates to aquifers, making the landslide systems respond more quickly to rainfall events. Rapid drawdown may also feature as a mobilising influence at the toe of the slopes after flood waters have receded.

4 Mining

4.1 Introduction

4.1.1 The primary mineral resources of the area have been extracted from the Carboniferous Coal Measures strata. Surface and underground mining of coal, ironstone and clay, the latter for tile manufacture, has taken place at many localities within the study area including Coalport, Jackfield, Lloyds Coppice and Ladywood. Bitumen deposits from the Coalport Formation were extracted at the Tar Tunnel underground workings near Coalport. Underground mining is a key trigger for ground movement and the reactivation of existing landslides.

4.2 Coal

4.2.1 At least fourteen coal seams have been worked within the district. The stratigraphical succession of the known seams from the Lower and Middle Coal Measures and the Coalport Formation, are included in Appendix A (reproduced from the Geological memoir, Hamblin and Coppack, 1995).

4.2.2 The three main hazards associated with shallow mineworkings are roof collapse (leading to crown hole formation), abandoned shafts, and mine gas.

4.2.3 Roof collapse is the primary closure mechanism applicable to shallow mine workings (floor heave and crushing of pillars are less common). The strata overlying the workings may continue to collapse for many years after mining has ceased. The roof often continues to fail until one of three conditions is met: (i) bulking of the collapsed material fills the voids. (ii) a stratum is reached which is strong enough to span the void. (iii) the void reaches ground surface and forms a crown hole. Collapse at the surface can be sudden. However, as a rule of thumb, further investigation to assess the risks due to shallow mineworkings would normally be required if the workings were within 30 m of rockhead.

4.2.4 Mine shafts are present throughout the district. The sites of all known shafts and adits are shown on the attached mining plans (Appendix B). These plans have been prepared by TWC and form the current output from a continuing appraisal and synthesis of all available records. (An index relating mining desk study maps to Ordnance Survey tiles and geomorphological maps is provided in Table 2.) The positions of many old shafts are inadequately documented and as they were commonly only capped at surface levels, they may remain open below and still present a hazard. Unrecorded shafts may also exist, thus absence of evidence does not constitute absence of hazard.

Table 2 Index of Maps

OS tile	Mining Desk Study Plan	Area
6503 6603	**NA*** **E**	Benthall Edge
6504 6604	**NA*** **D**	Jigger's Bank (south)
6505 6605	**NA*** **C**	Jigger's Bank (north)
6702 6802	**F** **J**	Jackfield
6703 6803	**E** **I**	Ladywood and Lloyds Coppice
6901 7001	**K** **Q**	Coalport (south)
6902 7002	**J** **P**	Coalport (north)
6903	**I**	Blists Hill

* NA no mining desk study plan available, outwith mining hazard area

4.3 Ironstone

4.3.1 Two well developed ironstone horizons are present within the district, with the Crawstone at the base of the Lower Coal Measures, and the Pennystone at the base of the Middle Coal Measures. The Crawstone Ironstone is generally a single layer of large brown irregular ovate nodules usually within a matrix of fine white sandstone or black shale, and reaches a maximum thickness of 2.2 m. The Pennystone, named after the characteristic small flat round nodules, generally has a mudstone matrix and is commonly between 4.5 and 8.0 m thick. The ironstone seams have been worked from adits and by opencast techniques.

4.4 Clay

4.4.1 Fireclays within the Coal Measures were worked, in much the same manner as coal, for the manufacture of decorative tiles. Five named seams were worked , Fire Clay, Ganey Clay, Tile Clay, Dressed Clay and Red Clay, although some records are potentially misleading in cases where the mine plans referred to a higher value product irrespective of what was brought out of the ground.

4.5 Limestone and Sandstone

4.5.1 Extensive quarrying of the limestones on Benthall Edge took place in the 18^{th} and 19^{th} century. The stone was used as a flux to smelt iron and was also burned to make lime. Sandstone has also been extracted for building stone at Ladywood.

5 Geomorphological Mapping

5.1 Methodology

5.1.1 The geomorphological maps that have been produced for this report summarise the surface morphology of the valley-side slopes by identifying key breaks of slope that define landform features related to the extensive slope instability that characterizes the area. The maps are a product of detailed field mapping at 1:1000 and 1:3000 scale and are supported by an interpretation of available aerial photography and geological maps. Fair-copies of the field maps are included as Line Geomorphology Plans in Appendix C.

5.1.2 The geomorphology map identifies the main areas of mass degradation on the upper slopes, the transport mechanisms across the slope, and the eventual accumulation areas at the toe, from which an assessment of the nature and extent of the landslide terrain can be made. Although the fieldwork was led by expert field mappers, the geomorphological maps are necessarily an interpretation of the observed physical features, and therefore alternative interpretations are possible.

5.1.3 It should be noted that the gorge has been the scene of intense industrial activity during the last three hundred years leading to much mining, quarrying, waste infill, landscaping and other slope modifications, which all combine to make interpretation difficult. Mapping problems were also compounded by many slopes being covered in woodland with a dense undercover of brambles and nettles. Furthermore, whilst the geomorphology underpins the conceptual model of slope processes within the Gorge, a more complete understanding will be possible when the results of slope monitoring installations become available (e.g. inclinometer and piezometer records).

5.2 Landslide Landsystems

5.2.1 The study identifies different types of landslide and other types of terrain. In the main, the report follows the same geomorphic designations adopted in the High-Point Rendel Report (2005), but the scheme has been improved by defining the slopes exclusively in terms of key geomorphological elements associated with the different parts of a landslide system. Different areas of slope failure have been categorized with respect to location on the slope. Thus, the upper slopes are characterised by tensional stresses leading to scarp formation and mass loss; the mid-slopes are zones of debris transport and mass transfer and show progressive morphological change as material is moved downslope; and the lower slopes are areas of net accumulation as transported material is deposited and modifies the original slopes.

5.2.2 In this study we have identified three types of landslide system based on the field mapping - with each zoned from upper to lower slope using distinct geomorphological features. These are **rotational landslides** related to listric failure on deep seated shear planes related to distinctive geological situations where a competent higher strength caprock overlies mudstones of low shear strength. These will increasingly fragment and deform downslope by flow towards the lower slopes where the debris accumulates as large irregular mounds or lobes. Many slopes are, however, characterized by much shallower failure planes leading to **translational failures** with less evidence of rotation but with similar forms associated with increasing downslope displacement of material. A third landslide type, **mudslides**, has also been identified where well marked lateral vertical shear planes were identified in the field. The majority of slopes appeared to be formed by translational failures with increased evidence of flow deformation downslope.

(i) Deep seated rotational landslides

Upper slope	Large, high, steep (>45º) scarps with graben structures and multiple blocks of competent bedrock that have been rotated to dip back towards the back scarp.
Mid slope	Increasingly disaggregated blocks moving downslope with the formation of debris lobes in more argillaceous material.
Lower slope	Accumulation zone forming lobes and irregular mounds of slope debris

(ii) Translational landslides

Upper slope	Smaller scarps with landslide blocks displaced along a shear plane with minimal rotational displacement
Mid slope	Disaggregated blocks and abundant debris lobes moving downslope
Lower slope	Accumulation zone forming lobes and irregular mounds of slope debris

(iii) Mudslides

Upper slope	Small head scarps with displaced blocks
Mid slope	Transported debris with well marked basal and lateral shear zones
Lower slope	Accumulation zone forming a series of large lobes of slope debris

5.2.3 Some landslides are likely to be complex, and may involve compound failure mechanisms that cannot always be resolved using surface mapping techniques. For example, detailed analysis at Lloyds Coppice has concluded that movement was initiated with a single large rotational slide, possibly of immediate post-glacial age, superimposed onto which are later secondary and tertiary non-circular failures, which have been initiated by local cyclical triggers. Similarly complex compound slide mechanisms may also be replicated to a lesser or greater degree at other sites.

5.2.4 In many areas, the landslide systems are partially relict or dormant, although there is little or no information to date the activity. Many landslides may be postglacial or early Holocene in age, while others may be more recent and related to slope processes occurring in response to industrial activities such as mining or the tipping of waste materials. Furthermore, the River Severn flows through the gorge undercutting the lower accumulation slopes of many landslides and maintaining the slopes in a state of critical stability leading to slope movements at times of flood. This is confirmed by the historical record of on-going slope movement within the gorge and a number of such areas have been highlighted by this mapping exercise, particularly in mid and lower slope localities.

5.2.5 The study also identifies, in addition to landslides, the following landscape elements:

- Valley side slopes over-steepened by fluvial activity with local slope instability
- Steep gradient non-landslide valley slopes in Wenlock Limestones
- Shallow gradient valley slopes in Wenlock Shales (limited landslide activity)
- Plateau
- Plateau margin
- River terrace
- Alluvial fan/Alluvial infill
- Fluvioglacial landforms

5.2.6 The geomorphological interpretations of the study area are presented in a series of eight maps (Landslide Maps), each covering one or two square kilometre Ordnance Survey tiles. The file reference system used by the TWC engineering department is based on OS tile numbers, so these numbers have been used, instead of place names, to identify the maps.

5.3 Structural Defects

5.3.1 Structural defects were mapped and categorised according to the scheme used by HPR in the Ground Behaviour Study (Table 3). Maps showing the structural defects, observations, where recorded, are included as Appendix D.

Table 3 Classification of Structural Defects

Damage intensity	**Description**
Slight	Slight evidence of cracking • Negligible tilting • Multiple slight cracking
Moderate	Moderate evidence of cracking • Moderate cracking • Slight vertical and horizontal displacement • Slight tilting in buildings and garden walls • Slight bowing in walls • Slight deformation of walls.
Significant	Significant evidence of cracking • Significant cracking • Moderate tilting • Moderate vertical and horizontal displacement • Multiple bowed walls • Rotation of structure

6 Descriptive Summaries

6.1 Introduction

6.1.1 The study area has been divided along conventional lines related to key geographical locations, and within each section the main geomorphological features associated with the landslides are described, together with a summary of observed structural defects.

6.2 Jiggers Bank

6.2.1 This area of mapping covers much of the land lying west of Coalbrookdale between Jiggers Bank and the River Severn towards Buildwas. The central plateau in this area lies at 120-140m OD and is composed of Silurian rocks, particularly Wenlock Shales and Sandstones, with patches of glacial deposits (till and sand and gravel). The northern part of this area is characterized by the deeply incised valley of Loamhole Dingle which falls southwards between the plateau to the west and Jiggers Bank to the east. Jiggers Bank is known to be unstable with upslope back scars fronted by midslope lobes above the stream. There is also evidence of quarrying in this area. Although there are some small local block failures in this area, and these slopes appear to be largely translational in form. The lower slopes are characterized by fluvially over-steepened slopes with local undercutting of the stream banks causing multiple small scale rotational failures. These have the potential to dam the stream causing flooding within Coalbrookdale, and are also a key mechanism in keeping the middle and upper slopes active.

6.2.2 The south-western half of the Jiggers Bank region is characterised by undulating plateau topography which gives way to steep stable slopes in Wenlock Shales. These are largely devoid of evidence of landslides or slope instability. However, this is an area of known slope failures with a notable event at Buildwas in 1773. This event appears to have occurred at and beyond the western edge of the mapped area. The lateral graben of the 1773 Buildwas landslide is now occupied by a small stream. However, further landslides appear to have a source area in Timber Wood where large blocks of Lydebrook Sandstone form a number of graben structures which have been modified by quarry activity. Downslope of the large detached blocks, a distinct scarp slope is fronted by local rotational block failures, before giving way to open fields characterized by lobes and subdued hummocky terrain formed in degraded muddy colluvium overlying Wenlock Shales.

6.2.3 Given the general lack of buildings few structural defects were noted. Small scale bowing of a wall along the Rope Walk was noted.

6.3 Benthall Edge

6.3.1 Benthall Edge forms the northern edge of Wenlock Edge and the high ground to the southwest of the gorge. It is underlain by Wenlock Limestone and Shales dipping to the southeast. The limestone forms particularly resistant and stable slopes in excess of 45° and there is little evidence of slope instability on these upper slopes (although there are occasional small failures on the lower slope in the underlying shales). The upper slopes have been extensively quarried for limestone and streams that drain off the plateau to the south are still adjusting to new profiles. This is causing localized rotational failures along the stream valleys and temporary damming of drainage; as elsewhere along the gorge, such small stream-slope interactions have the potential to cause localised floods.

6.3.2 To the east of the Broseley Fault, which separates the Silurian rocks from the Lower Coal Measures, the slopes are composed of less competent rocks and exhibit a sequence of translational failures which are characterized by a series of small upper scarps with well developed lobes occupying mid slope positions and zones of accumulation on the lower slopes close to the river edge. Moving eastwards into the incised valley occupied by Bridge Rd, the western slopes of the valley exhibit small scale upper scars with mid slope lobes, possibly formed in response to fluvial incision. The area adjacent to Bridge Rd has been heavily modified by human activity, as has the nearby riverside terrain, which is predominantly composed of made ground.

6.3.3 The Benthall Edge district is mostly undeveloped, but structural defects were noted in the Bridge Road area, which forms the boundary with the Ladywood area to the east. In particular, moderate wall deformation was noted in walls adjacent to the former railway line, on the north side of Bower Yard, and adjacent to the bridge west of Bower Yard. Significant deformation was identified on a property at Bower Yard (No. 78) and on the bridge west of Bower Yard. Moderate deformation was noted at the Toll House next to the Iron Bridge.

6.4 Ladywood

6.4.1 The upper slopes of Ladywood exhibit multiple upper scarps which are transitional downslope to multiple lobes and lower slope accumulation areas along the river side. The upper and mid slope contain sandstone units that have been quarried as well as numerous mines related to the extraction of coal and clay.

6.4.2 Slight to moderate deformation has been noted at Bridge House, Station Hotel and nearby walls at the bottom of Bridge Road.

6.5 Lloyds Coppice

6.5.1 Lloyds Coppice is underlain by the Coalport Formation (Lower Carboniferous), which is composed predominantly of mudstones with interbedded sandstones. The plateau area to the north reaches 130-150 m OD in elevation and is relatively flat and built upon by houses. No evidence of slope instability, such as tension cracks, was observed along the plateau edge. The upper slopes are characterised by large steep scarps (ca. 30m) which form a series of arcuate scars along the plateau margin, and which are fronted by large rotated, back tilted blocks in the sandstones which make up the upper slopes. Downslope of these are disaggregated blocks forming linear ridges that run west to east through the coppice and grade downslope into the lower slopes which are composed of thick accumulations of colluvial debris forming multiple active lobes and hummocky terrain. Tension cracks and tilted trees are ubiquitous in the mid and lower slope areas, and recent ground investigation work at Lloyds Cottage suggests that this lower slope debris mantle is moving over shallow failure planes approximately 8-10m below the ground surface. There are also significant areas of made ground along the lower slopes which is also unstable and active. Recent drilling works associated with the Lloyds Phase 1 stabilisation scheme have identified Made Ground and colluvium extending to depths of up to 22 m. Adjacent to the river bank the ground is also subject to small scale shallow rotational failures triggered by bank erosion, and which is enhancing upslope instability.

6.5.2 The coding system used on the geomorphological mapping introduces an artificial distinction between the eastern boundary of the Lloyds Coppice system and the adjacent Blists Hill area. The Lloyds has a rotational upper slope zone, whereas Blists has a more translational upper slope, and therefore the two areas are coloured differently on the map. However, the mid-slope sections for both areas display similar landslide mechanisms comprising mid-slope landslide terrain with disaggregated material moving downslope. This area is therefore interpreted as the locus of two landslide systems coalescing along a common boundary.

6.5.3 The lower slopes of Lloyds Coppice are very active and significant infrastructural damage has been previously noted. Old building remains in the coppice (e.g. The Engine House) are distorted and cracked. Lloyds Cottage is significantly back tilted, and the gabion wall behind the Old School House is bowed and laterally displaced, as is the road. The School House and adjacent properties have also been moderately tilted. The ongoing movements of the slope above the river have resulted in the recently completed Lloyds Phases I and II engineering works to stabilize the lower slopes in this area.

6.6 Jackfield

6.6.1 The plateau forms the higher ground above the valley-side slopes, varying in elevation at ca. 125 m OD near Woodhouse Farm, and is generally level with undulating slope gradients of 1 or 2°, before passing into a narrow plateau margin (ca. 125 - 110 m OD) which shows no sign of tension cracks or present movement. The upper limit of the valley slopes is marked by a small scarp (2 - 3 m) that is continuous along the valley side and below which there is evidence of past and present slope instability.

6.6.2 The upper valley-side slopes between Jackfield Tile Museum and Tuckies Farm undulate gently with elongated ridges formed in mudstones of the Coalport Formation (Carboniferous Lower Coal Measures) running southeast to northwest that are a series of degraded shallow translational slides. To the northwest of the Woodhouse Farm, there is a mudslide that extends 200 m downslope, marked by small displaced blocks below the main scarp and a distinct lateral shear extending > 100 m downslope on the western edge. The eastern limit is difficult to discern. Saturated ground was observed across a width of c.100 m within this area of the slope suggesting that this mudslide is an area of active slope movement.

6.6.3 The valley midslope area below Woodhouse Farm is occupied by a series of large superimposed lobes which have been progressively formed by downslope movement of the degraded elongated bedrock ridges. Within the woodlands and pastures that mark the lower slopes to the east of the Tile Museum towards the Maws Craft Centre are a series of small highly active failures marked by back scarps, locally rotated small blocks and tension cracks. Further downslope these translate into a series of lobes and increasingly complex hummocky ground. Clear evidence of on-going slope movement can be most easily observed in the current deformation of Salthouse Road. This is the area of the historical Jackfield landslides and is an area of known on-going instability reflecting reactivation of the lower valley slopes by either, river undercutting, or by increased pore water pressures associated with the cessation of mine drainage.

6.6.4 Further to the east, beyond the end of the road, the upper slopes of Preenshead wood are characterized by a number of scarps up to 20m in height with some evidence, particularly on the eastern side of Corbetts Dingle, for localized rotational block failures, although in most instances distinct displaced blocks are not discernible, the slopes being largely composed of degraded colluvial material and appearing relatively stable. The midslope areas of Preenshead are typified mainly by degraded colluvial slopes, although in areas these slopes appear active, with tension cracks, tilted bank supports, and small scale scarps and lobate, hummocky terrain. The lower slopes are also active in areas with well defined lobes, boggy hummocky ground and tilted trees. Further east, the slopes within the Wilds are similar in form to those in Preenshead, although some areas may have been quarried/mined.

6.6.5 Structural defects to buildings, walls and roads are common in the Jackfield area, particularly in the vicinity of Jackfield village. Many buildings and walls have slight to moderate cracking and tilting. Salthouse Rd to the east of the Tile museum is suffering ongoing lateral displacement and has a pronounced hummocky profile. The Tile Museum has some significant cracking at its eastern end. Local utility pipes have also been disturbed, as have roadside signs and trees. Eastward of this, the Maws Craft Centre appears largely undisturbed, although there are some cracked walls around the Half Moon pub. Around Tuckies Farmhouse some of the older buildings have been moderately to significantly cracked, whilst other adjacent properties have been extensively rebuilt in the past (SJ 692 024).

6.6.6 At Preenshead, bank supports and adjacent tension cracks also point to midslope ground movement (SJ 696022), and neighbouring properties such as Lavender Cottage have slight cracking and tilting. There is also some minor evidence of tension cracks on road surfaces on the upper slopes of Preenshead (SJ 696020).

6.6.7 Preliminary results from the BTW ground investigations at Jackfield record depths to rockhead at the base of the slope of typically 4 to 6 m bgl, although in one borehole (BH 103A), rockhead was identified at 12.7 m bgl. Rockhead in this case is defined as the identification of the Coalport Formation, which in engineering terms is initially encountered as a stiff clay. Around the Maws Craft Centre, rockhead depths increase to approximately 10 m bgl owing to the thickness of Made Ground.

6.7 Blists Hill

6.7.1 The western edge of Blists Hill between the Villas and Lee Dingle is characterised by steep slopes formed in Lower Coal Measures (mudstones and sandstones). The slopes show few signs of recent landslide activity, but a distinct upper scarp and shallow failures to the west of the Villas suggest past translational landslide activity

6.7.2 North of this in Lee Dingle there is clear evidence of recent landslide activity. The northern side of the valley is backed by a steep scarp with mid slope areas exhibiting hummocky, lobate terrain. The lower valley floor is undergoing rapid fluvial incision and undercutting which is destabilizing the lower slope triggering localized bank failures, and inducing further upslope instability. Recent upslope failures have required remedial engineering work.

6.7.3 The main valley of Blists Hill was a major industrial centre for coal mining and ironworks and has been severely modified by the dumping of industrial waste. It is now occupied by the Blists Hill Open Air Museum. The upper slopes of the eastern side of the valley above the canal show evidence of former landslide activity showing a similar pattern to that mapped eastwards along the plateau edge towards Coalport.

6.7.4 There was little structural damage noted in the Blists Hill area, although the Open Air museum was not accessed. There is some slight to moderate damage of walls along the Coalport Rd just north of Lee Dingle.

6.8 Coalport

6.8.1 The Coalport area is underlain by the Lower Carboniferous Coalport Formation, which is composed predominantly of mudstones with subordinate thin sandstones. The area is defined by the Hay Incline in the west extending to Sweeney Cliff House in the east. The lower slopes have been severely modified by the Coalport branch railway and the buildings of Coalport pottery and village along the lower slopes. The upper slopes are backed by plateau (now a golf course) at an elevation of ca. 100-120 m OD and characterised by small upper scarps with little evidence of rotational block failures, but with evidence of quarrying of the sandstones. Below this, the mid slope areas exhibit a series of large lobes formed by deformation and flow of the underlying thick mudstones. Within the hay pastures above Coalport village, these lobes are 20-50 m in length and 20-40 m wide and appear to be stacked on top of each other. Along much of the slopes they appear to be relatively stable; however, in the vicinity of the Hay Incline there is evidence of small scale rotational scarps, saturated ground and downslope flow with obvious deformation to the incline. Evidence of instability has also been identified within new works as part of the Blists Hill Museum to the west of the incline. There therefore appears to be an area of on-going instability in the vicinity of the incline above The Shakespeare Inn, although there is no evidence on the lower slopes which have been recently landscaped.

6.8.2 The lower slopes of the Coalport area are composed of thick accumulations of colluvial debris, but these are often masked by made ground and are heavily landscaped. To the west there is also evidence of small scale movement on Sutton Hill, where there are damaged road surfaces, and minor cracks and displacement of walls and buildings. These appear to relate to small scale activity towards the river. There is some evidence of local slope movement nearer the river, particularly along the private drive to Sweeney Cliff House. There is also evidence of active small scale rotational failures (slumps) along The Brook, which is a small stream running off the plateau towards Coalport Bridge at the bottom of Sutton Bank. These small slumps are of note given their ability to temporally dam such small streams with the potential for causing subsequent small floods downslope.

6.8.3 A number of properties on Sutton Bank to the east of Coalport show bowed walls and minor slight cracking and there is minor disturbance to the road surface that climbs the bank. The east end of Coalport High Street also exhibits slightly cracked and displaced garden walls suggesting lower slope movement. Between the Brewery Inn and the Shakespeare Inn, buildings appear largely undamaged, although there are some minor cracks to garden walls and areas in the High Street where ground water seepage is evident. To the west, the lower half on the Hay Incline shows significant horizontal distortion suggesting active slope movement, and this is reinforced by recent ground investigations up slope towards the Blists Hill Open Air museum which have confirmed slope creep.

7 Hazard Zonation

7.1 Application of Hazard Zonation

7.1.1 The Planning Guidance Zone (PGZ) designations for this study follow the categories previously used by High-Point Rendel (2005). The scheme is reproduced in Table 1. In broad terms, active landslides have been designated zone 4 or 5, with zone 3 reserved for inactive landslides. Steep but stable slopes have been designated zone 2. Further details are provided below.

7.1.2 In most instances, areas of plateau or plateau margin have been given a PGZ 1 or 2 classification, as they are relatively stable areas only influenced by very minor ground movements. PGZ 2 has also been used in areas of shallow gradient, stable slopes, and has also been applied to the strip of land behind scarp features to identify a potential zone of active wedge failure.

7.1.3 PGZ 3 has been used in areas of steep slopes where there is little evidence of previous ground movement or where relict landslide slopes appear stable, but have the potential to be reactivated if disturbed.

7.1.4 PGZ 4 has been used extensively in areas where there has been clear landslide activity, often on steep slopes, which may be on-going, or that may be re-activated by present or future downslope trigger mechanisms.

7.1.5 PGZ 5 has been used where there is clear on-going evidence of active slope movement and failure, and where the necessary mitigation measures could require significant engineering works including the stabilization of additional areas beyond a development site boundary.

7.1.6 The planning guidance zones for the study area are presented on Drawings series Planning 1100100G SJ6503 to 6903. The drawing format follows the same scheme as that used for the geomorphological maps (OS tiles, presented west to east through the study area). A description of the major ‘hotspots’ of present or potential slope instability is provided in Section 7.2.

7.2 Specific Areas of Instability

Jiggers Bank

7.2.1 Jiggers Bank is a known area of on-going slope instability. This area has been designated a PGZ 5 given recent instabilities triggered by stream undercutting by the head of Loamhole Brook and subsequent upslope ground movement. These processes are likely to continue given the severity of small scale bank failures. Stream damming by slope failures, potentially leading to high impact erosion events when dams burst, should also be investigated. A significant factor in applying the PGZ 5 designation is the identification of upslope ground movement in response to local toe failures, which indicates that comprehensive stabilization for a development site may not be cost-effective.

7.2.2 PGZ 4 and PGZ 5 classifications have been adopted for the west and east sides respectively of Loamhole Dingle. Further south, where the valley was mapped by HPR, less onerous designations of PGZ 3 to the west and PGZ 4 to the east were recorded. The discrepancy stems from a difference of interpretation regarding the intensity of slope processes, and serves to reinforce the point that the maps are intended for planning guidance and do not constitute a specification.

Lloyds Coppice

7.2.3 With the exception of the area recently stabilised during the Lloyds Phases I and II engineering work, the whole of Lloyds Coppice has been given a PGZ 5 designation. The upper slopes are extremely steep, and fronted by large unstable rotated landslide blocks. The mid slopes are also highly unstable with disaggregating sandstone blocks and degrading mudstones forming highly uneven terrain. The lower slopes are undergoing rapid downslope translocation with the debris lobes moving over shallow failures and localized riverside bank collapses triggering upslope instabilities. This evidence of active slope movement automatically places the site within a zone 4 or 5 classification. However, a zone 5 classification has been adopted because it is likely that significant engineering works would be required to stabilize a development site. In addition, owing to the interconnectedness between various elements of the landslip system, stabilization measures may need to extend beyond the development area in order to be effective, leading to potentially prohibitive costs.

Jackfield

7.2.4 Much of the slopes between Jackfield village and The Wilds to the east are characterised by upper slopes with distinct scarps with localized rotational or translational block failures. For the most part they are much degraded and are relatively inactive. However, mid and lower slope areas appear active with debris lobes, tension cracks, ponded areas and tilted trees suggesting ongoing ground instability, which may be triggering upslope drawdown. For these reasons most of the Jackfield slopes have been given a Planning Guidance Zone 4 (PGZ 4) designation.

7.2.5 In the vicinity of the Tile museum, however, the lower slopes have received a PGZ 5 designation as the area is currently extremely active with shallow scarps, locally rotated blocks and active tension cracks characterizing the ground to the south of the distorted Salthouse Rd. The PGZ 5 designation has been applied because significant engineering work would be required to stabilize a development site in this area, and the impact of development on the stability of adjacent areas would also need to be considered. A PGZ 5 has also been applied to the mudslide area to the northwest of Woodhouse Farm. This area is clearly very unstable with disturbed ground from mining activity and waste tipping, sitting on degraded colluvial slopes, and now prone to failure. The area is actively unstable and stabilization would be costly.

7.2.6 The mid to lower slopes of Preenshead woods are currently showing signs of ongoing movement with tension cracks and hummocky, lobate terrain developing along the lower edge of the woods. A PGZ 4 designation has been applied in accordance with the identification of active movement. The constraints are judged to be ***significant*** but not ***severe.***

Coalport

7.2.7 The area around the Hay incline has been given a PGZ 5 designation due to ongoing slope instability. The mid slope terrain to the immediate east of the incline is extremely lobate and saturated and undergoing active downslope movement. This is supported by evidence for ground disturbance along the incline where the rail tracks are deformed. Ground movement is considered to impose ***severe*** development constraints requiring a PGZ 5 designation.

Local stream valleys

7.2.8 In a number of localities around the Gorge (Corbetts Dingle, Lee Dingle, Bridge Rd, Loamhole Dingle; Coalport/Sutton Bank, Benthall Edge Wood) small stream valleys have dissected the local slopes. These fluvial systems are causing slope oversteepening and undercutting, leading to rapid rates of local slope failure and ground instability. This is especially prevalent where streams are trying to regain equilibrium in areas that have recently been quarried (e.g. Benthall Edge) and in areas that are continually adjusting to slope failure (eg. Corbetts Dingle). For this reason these areas have often been given PGZ 5 designations.

7.3 Review of Existing Information

7.3.1 Since the publication of the HPR Planning Guidance Zonation for Ironbridge and Coalbrookdale in January 2005, site investigation data has become available both from the planning process and from BTW's own investigations, which permits an assessment to be made of the application of the zonation scheme.

7.3.2 Planning applications submitted since the implementation of the planning guidance zones have been examined to determine if any evidence of ground movement had been identified that would warrant local changes to the PGZ classification. The information was obtained from scanned records held at BTW's offices. A listing of applications falling within the area of the planning guidance zone that were submitted after 2004 is included in Appendix E. However, only 25 of these records (including records yet to be scanned to the database) were likely to provide information relevant to ground movement, and these are listed in Table E1 in Appendix E. It is concluded that no strong evidence of instability was identified that would require the PGZ to be changed at any of the particular subject sites. To some extent, this is a reflection of the type of information available. Monitoring information, of which none was seen, would be required to show that a zone three should be increased to a zone 4, and the identification of zone 5 conditions depends largely on the context of the site rather than on particular borehole details. Furthermore, the lack of evidence of ground movement from a single investigation is unlikely to be a defensible reason for reducing the local zone classification.

7.3.3 TWC have recently (December 2008) completed a limited drilling programme within the Ironbridge Gorge. Windowless sampling, cable percussive and rotary drilling techniques were used to sink boreholes in 44 locations local to the Iron Bridge and at Jackfield. Standpipes and inclinometers have been installed in selected boreholes to monitor groundwater levels and to provide ground movement information. The reporting and monitoring is still ongoing. Draft logs have been inspected, all of which have been drilled in areas designated as planning guidance zones (PGZ) 3 or 4. Most of the geotechnical data is consistent with the PGZ classification, although some boreholes drilled in zone 3 areas provide information that, on its own, would be compatible with a zone 4 classification. However, in such situations, it is concluded that revisions to the guidance should be based on the additional evidence of ground movement from ongoing slope monitoring information, and an example is given below.

7.3.4 In Ironbridge Town, zones 3 and 4 are interdigitated, and the correct demarcation of these zones is critical in areas where development space is at a premium and where there is close public scrutiny of the planning system. One criterion for distinguishing between zone 3 and 4 is on the basis of landslide activity, with zone 3 for dormant areas, and zone 4 for active landslides. Therefore, whilst landslip material can be identified from the borehole log, slope monitoring information would be required to determine the level of activity. An example of this is Borehole CP13, which was drilled close to the north abutment of the Ironbridge. The PGZ classification is zone 3, but the borehole identifies Made Ground to 4.5 m and head deposits to 9.4 m bgl with slickensides from 7.6 m to 8.0 m. This information would be consistent with a zone 4 classification, but evidence of movement would also be required to justify a change of category.

8 Summary and Conclusions

8.1 The Planning Guidance for Ironbridge and Coalbrookdale that was developed by High Point Rendel in 2005, has been extended by Jacobs Engineering UK Ltd to include the remainder of the World Heritage Site. This encompasses Jiggers Bank, Benthall Edge, Ladywood, Lloyds Coppice, Jackfield, Blists Hill and Coalport.

8.2 The planning guidance has been based on the results of geomorphological field mapping at 1:1,000 and 1:3,000 scale. Three types of landslide system have been identified, with each zoned from upper slope to lower slope using distinct geomorphological features.

(i) **Rotational landslides** comprise listric failures on deep seated shear planes that are related to distinctive geological situations where a competent higher strength caprock overlies mudstones of low shear strength.

(ii) **Translational failures** are characterized by much shallower failure planes with less evidence of rotation but with similar forms associated with increasing downslope displacement of material.

(ii) **Mudslides** have also been identified where well marked lateral vertical shear planes were identified in the field.

The majority of slopes appeared to be formed by translational failures with increased evidence of flow deformation downslope.

8.3 The geomorphological interpretations of the study area are presented in a series of eight Landslide Maps, each covering one or two square kilometre Ordnance Survey tiles. Mapping areas have been defined by the OS tiles, rather than by geographical features, in order to be compatible with the file reference system used by the planning department. Fair-copies of the original field sheets are included in Appendix C.

8.4 Structural defects were mapped and categorised according to the scheme used by HPR in the Ground Behaviour Study. Maps showing the structural defects observations are included as Appendix D.

8.5 Descriptive summaries of each of the seven study areas are provided in Chapter 6.

8.6 The planning guidance zones (PGZ) for the study area are presented on a series of eight Planning Guidance maps. The PGZ designations for this study follow the categories previously used by High-Point Rendel (2005), and are reproduced in Table 1. In broad terms, active landslides have been designated zone 4 or 5, with zone 3 reserved for inactive landslides. Steep but stable slopes have been designated zone 2. A description of the major ‘hotspots’ of present or potential slope instability including Jigger’s Bank, Lloyds Coppice, Jackfield and Coalport is provided in Section 7.2.

Drawings

- **Study Area Key Plan**
- **Geology and Geological Structure**
- **Landslide Maps**
- **Planning Guidance Maps**

Appendix A

Summary of Geological Sequence

Appendix B

Ironbridge Gorge Mining Desk Study Drawings

Mining Desk Study Map	OS Tiles	Drawing
C	6605	C040
D	6604	D040
E	6703	E040
F	6702	F040
I	6803	I040
J	6902	J040
K	6901	K040
P	7002	P040
Q	7001	Q040

Appendix C

Geomorphological Mapping Field Sheets

Appendix D

Structural Defects Mapping

Study Area SJ 6503 - SJ 6603
Study Area SJ 6504 - SJ 6604 no defects recorded
Study Area SJ 6505 - SJ 6605 no defects recorded
Study Area SJ 6702 - SJ 6802
Study Area SJ 6703 - SJ 6803
Study Area SJ 6901 - SJ 7001 no defects recorded
Study Area SJ 6902 - SJ 7002
Study Area SJ 6903

Appendix E

Listing of Recent Planning Applications

Study Area SJ 6503 - **SJ 6603**
Study Area SJ 6504 - **SJ 6604**
Study Area SJ 6505 - **SJ 6605**
Study Area SJ 6702 - SJ 6802
Study Area **SJ 6703** - **SJ 6803**
Study Area SJ 6901 - SJ 7001
Study Area SJ 6902 - SJ 7002
Study Area SJ 6903

planning applications only submitted
for study areas in bold type

Appendix F

Photographs