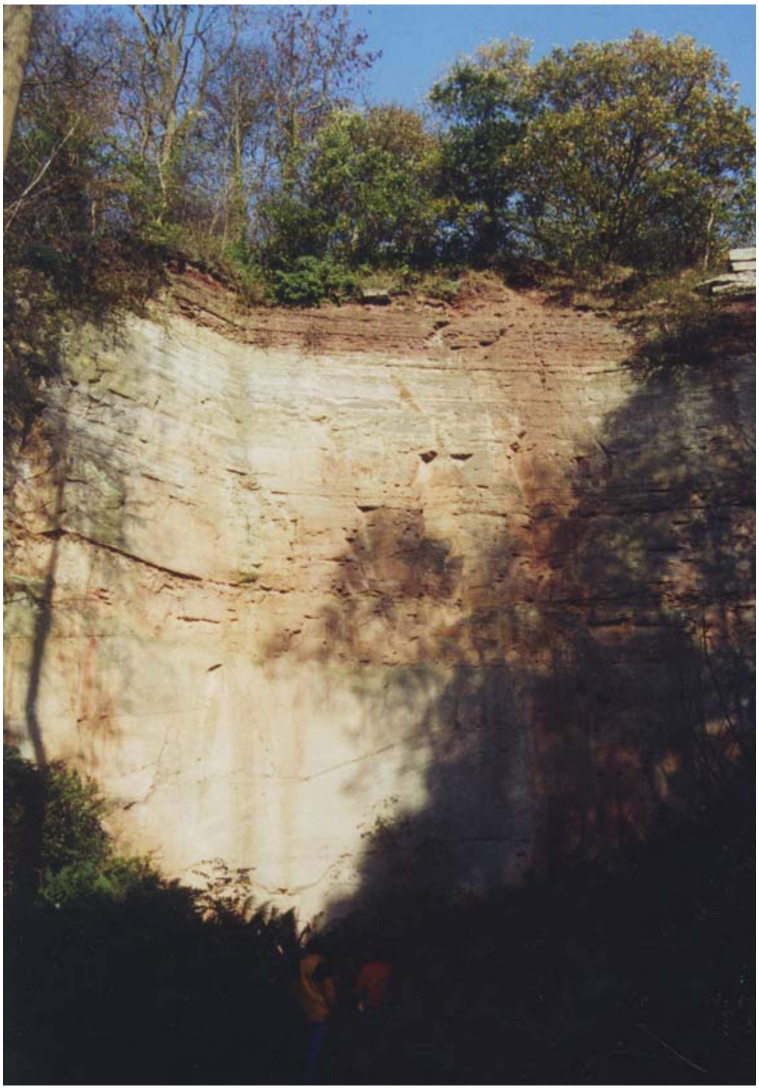
Lowland Catchment Research (LOCAR) Geological framework study River Tern catchment, East Shropshire

Prepared for the LOCAR thematic programme
by the British Geological Survey

Commissioned Research Report: CR/02/183N



BRITISH GEOLOGICAL SURVEY

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BRITISH GEOLOGICAL SURVEY

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Executive Summary

This report describes the geology of the River Tern catchment in East Shropshire, and is one of a series of studies commissioned under the Lowland Catchment Research programme (LOCAR).

The objective of the study was to synthesise existing geological information and to produce a Geographical Information System to underpin hydrogeological research in the catchment.

The report has been compiled from published information, and source material held in the databases of the British Geological Survey (BGS) or provided by the Environment Agency.

It covers 3 major topic areas:

- structure of the Permo-Triassic aquifer system
- description of the Permo-Triassic formations, and
- characterisation of the superficial deposits

The work has been carried out concurrently with a study commissioned by the Environment Agency, and the support provided by the Agency is, here, acknowledged.

An electronic version of this report and digital outputs are included on the accompanying CD.

Contents

1 Introduction

1.1 BACKGROUND

Lowland permeable catchments contain vital groundwater resources and develop important aquatic habitats at the groundwater/surface water interface. Both are becoming increasingly subject to widespread and complex environmental pressures. The scientific understanding to achieve environmental sustainability in lowland catchments is limited by a lack of catchment research facilities and an integrated science base. The Lowland Catchment Research thematic programme (LOCAR) was established to address these deficiencies.

One of the three flagship catchments selected for study is that of the River Tern in Shropshire (Figure 1). This catchment was proposed for inclusion in the LOCAR programme for two main reasons:

- it is a good example of a lowland permeable catchment located on the principal Midlands Permo-Triassic aquifer
- considerable groundwater and hydrological data are available in the middle reaches of the catchment because of the development of the Shropshire Groundwater Scheme (SGS)

The purpose of this report is to describe the geology of the catchment, and to provide researchers with a supporting Geospatial model as layers in a Geographical Information System. The report includes an account of the solid (bedrock) formations and information on the nature and distribution of the superficial (drift) deposits. Cross-sections linking public water supply abstraction boreholes illustrate the geology in key areas of the catchment. Thematic layers for the geological model have been generated by combining digital geological linework with borehole information. The resulting model has been created as an ArcView desktop GIS (ARC3.2), which can be run from the enclosed CD (back pocket). The main components of the model are listed below:

- solid geology
- superficial (drift) geology
- rockhead surface
- drift thickness
- structure contours on the base of the Permo-Triassic formations
- drift domain map

The work has been carried out using published information and databases maintained by the British Geological Survey; no new geological mapping has been undertaken.

The study has benefited from collaboration with the Environment Agency whose research requirements are closely allied to parts of the LOCAR programme, and for whom a better understanding of the geology is an important step towards developing a groundwater model of the catchment.

All tables and figures are placed at the end of the text. Bound maps are produced at 1:200 000 scale. In addition, five maps on a topographic base are included in plastic sleeves at the end of the report. They cover the following themes:

- solid geology
- superficial deposits
- rockhead
- drift thickness
- drift domains

1.2 LOCATION AND TOPOGRAPHY

The area investigated covers 925 km^2 centred on the North Shropshire Plain, and drained by the River Tern and its main tributaries, the Meese, the Roden and the Strine (Figure 1). The catchments of these rivers are predominantly rural but include a number of small towns and villages including Wem, Market Drayton and Newport. The important commercial centres of Telford and Shrewsbury lie just to the south of the area.

The topography is generally low lying and gently undulating along the River Tern but rises to prominent escarpments on the encircling hills. In the south, The Wrekin at 429 m above OD is the highest point in the area.

The catchment can be split into three sectors:

- the Lower Tern, including the River Meese, is flat-lying and dominated by agriculture but has some industry (dairy and sugar beet factory).
- the Middle Tern, including Platt and Potford Brook is influenced by pumping from the Shropshire Groundwater Scheme, so is well gauged, with many observation boreholes and a good monitoring network.
- the Upper Tern is characterised by river corridor springs and seeps, and includes wetland areas.

1.3 PREVIOUS RESEARCH

Geology

Survey publications

The maps covering the district are listed below, together with accompanying memoirs.

1:50 000 and 1:63360

Sheet 122 Nantwich (Solid & Drift, 1967)
(Poole and Whiteman, 1966)
Sheet 123 Stoke (Solid & Drift, 1993)
(Rees and Wilson, 1998)
Sheet 138 Wem (Solid & Drift, 1967)
(Pocock and Wray, 1925)
Sheet 139 Stafford (Solid &Drift, 1974)
(Whitehead et al., 1927)
Sheet 152 Shrewsbury (Solid, 1978; Drift 1932)
(Pocock et al., 1938)
Sheet 153 Wolverhampton (Solid & Drift, 2002)
(Bridge and Hough, 2002)

1:25 000
Telford Special Sheet (Solid & Drift, 1978)
(Hamblin and Coppak, 1995)

Mineral Assessment Reports

Detailed information on the distribution of the Quaternary deposits is contained in a series of mineral assessment reports, dating from a drilling programme undertaken in the 1980s, on behalf of the former Department of the Environment. The results are summarised in four reports:

SJ43 (Welshampton) (Institute of Geological Sciences, 1982)

SJ41, 51 (Shrewsbury) (Cannell, 1982)

SJ42, 52 (Wem) (Cannell and Harries, 1981)

SJ53 (Prees) (James, 1983)

Other publications

Evans, Rees and Holloway (1993)

Hamblin (1986)

Thomas (1989).

Plant et al., (1999)

Geophysics

There are three geophysical reports that are marginal to the investigation area.

Geophysical investigation of the Wem area, north Shropshire (Cornwell et al., 1971)

Geophysical surveys, Telford New Town, Shropshire, (Atitullah and Freeman, 1973)

Geophysical investigations of the Stoke-on-Trent district (Cornwell and Dabek, 1994)

1.4 DIGITAL INFORMATION

The geological information summarised in this report is also available in digital format (ARC3.2) on the enclosed CD (back pocket). The contents of the CD are listed in Appendix 1. The entire project can be opened from the project file *locar_tern.apr.*

2 Geological summary

2.1 GEOLOGICAL SUCCESSION

The succession of rocks and superficial deposits present in the area is shown in Figure 1.

The underlying geology is dominated by Jurassic and Permo-Triassic rocks, preserved in a series of half-grabens, associated with the Wem and Church Stretton Fault systems. The sequence thickens eastwards into the Stafford Basin and north-westwards into the deeper Cheshire Basin. For convenience, the dividing line between the two basins is taken at the Hodnet Fault (Figure 2). Palaeozoic and Precambrian rocks crop out in a number of fault-controlled inliers.

The entire region was glaciated in Quaternary times and the products of this glaciation form a thick cover across the north-western and south-eastern parts of the study area. On the more prominent escarpments, and in the central part of the catchment, the drift cover is more patchy or absent.

2.2 GEOLOGICAL HISTORY

Variscan uplift during the late Carboniferous, associated with the convergence of Laurasia and Gondwana and the ensuing coalescence of Pangea, resulted in the establishment of an arid, aeolian environment across the West Midlands during the Permian and earliest Triassic (Ziegler, 1990). The onset of North Atlantic rifting during the early Permian (Russell, 1976) established a tectonic regime of regional crustal extension and initiated the development of a series of north-south-trending fault-bounded, depositional troughs across the West Midlands (Evans et al., 1993).

The Tern catchment spans a narrow depositional embayment between two such troughs – the Cheshire Basin to the north-west and the Stafford Basin to the east.

One of the difficulties that arises in describing the Permo-Triassic sequences of the area is that rocks of approximately the same age are assigned different names according to whether they are considered to be part of the Cheshire Basin or Stafford Basin sequences. Current BGS practice is to adopt Cheshire Basin nomenclature for the Permo-Triassic rocks cropping out to the west of the Hodnet Fault and to use Stafford Basin names for those to the east (Table 1, Figure 2).

Extensional movement on basement-controlled faults initiated basin development in the region and led initially to the accumulation of predominantly wind-blown dune sands (Bridgnorth Sandstone and Kinnerton Sandstone, Table 1). Deposition continued through the Triassic as northerly flowing braided streams, sourced from the Armorican mountains in what is now the English Channel and Brittany, deposited conglomeratic and pebbly sandstones (Kidderminster Formation and Chester Pebble Beds). With time, as transport gradients into the basin were lowered, the supply of coarse clastic material reduced, and finer grained sandstones of predominantly fluviatile and locally aeolian origin were deposited (Wildmoor Sandstone and Wilmslow Sandstone).

Intra-Triassic regional uplift resulted in the formation of the Hardegsen Unconformity across Britain and much of Northern Europe (Evans et al, 1993; Warrington and Ivimey-Cook, 1992; Ziegler, 1990). In this region, the unconformity is placed beneath the Bromsgrove Sandstone and Helsby Sandstone formations.

Following this erosional event, a change of facies occurred, prompted partly by limited connection to the Tethyan ocean. It began with the development of fluviatile and aeolian sandstones (Bromsgrove/Helsby Sandstone formations) and continued throughout the late Triassic with the deposition of restricted, saline playa lake deposits of the Mercia Mudstone Group (Warrington and Ivimey-Cook, 1992).

The onset of the Tethyan transgression during the latest Norian and Rhaetian was marked by the deposition of the calcareous ‘Tea-Green Marls’ of the Blue Anchor Formation, followed by the argillaceous quasi-marine limestones and sandstones of the Penarth Group. Subsequent inundation of the West Midlands resulted in the development of the typical Liassic limestone-shale facies of the basal Jurassic, preserved within the Prees outlier (Evans et al., 1993).

2.3 STRUCTURAL ELEMENTS

The study area is structurally complex, comprising a series of half-grabens developed between the Wem and Church Stretton fault systems. The dominant trend of the main controlling structures is Caledonoid (north-east–south-west), with east-west faults forming a subordinate set (Figure 3).

The *Wem Fault* represents a major plane of crustal weakness extant at least since early Carboniferous times, being a northern continuation of the Pontesford-Linley Fault, which developed in Cambrian times (Chadwick et al., 1999). It forms part of a much larger fracture system (the Wem-Bridgmere-Red Rock Fault System), which represents the southern margin of the Cheshire Basin. The maximum throw on the Wem Fault is estimated at around 2600 m at the base of the Permo-Triassic succession near

Wem. The throw gradually diminishes to the north and south.

East of the Wem Fault, the Brockhurst, Ercall Mill/Ollerton, Brockton and Adbaston faults define a series of shallow half-grabens which generally deepen to the north-west.

The *Brockhurst Fault* is an important structure throwing down to the west an estimated 1200 m at its southern end. Its position in the southern part of the district is purely conjectural, as the solid rocks are buried deeply beneath drift. Northwards, it shifts the outcrop of the Helsby Sandstone north-eastwards about 6 km.

The *Hodnet Fault* is a down-west normal fault, which forms the eastern boundary of the *Ternhill Terrace* (Plant et al., editors, 1999*)*, a structural block lying between the Wem and Hodnet faults. The fault is poorly understood because of sparse seismic coverage, but gravity data suggests that, to the south of Market Drayton, it has a westerly downthrow of around 400 m. Traced northwards, the position of the fault can be inferred from the high dip of the Mercia Mudstone in the hangingwall. The Hodnet Fault is taken as the demarcating structure, separating the Cheshire Basin from the Stafford Basin.

The *Marchamley Fault* is one of a set of east-west-trending faults that links the Brockhurst and Hodnet faults near Hodnet village. The fault throws down the Mercia Mudstone to the north against the Helsby Sandstone. It appears from the digital terrain model that the escarpment formed by the Helsby Sandstone in this vicinity [3585 3288] is repeated southwards, possibly by a strike fault running parallel to the Marchamley Fault. This explanation of the double topograhic feature was proposed by the earliest surveyors and is accepted in this report.

The *Ercall Mill Fault* runs parallel to the Hodnet Fault and defines the eastern margin of a horst block, which brings pre-Permian rocks to crop south of Muckleton [3595 3210]. Northwards, the course of the fault is uncertain but there are grounds for linking it to the *Ollerton Fault* (Pocock and Wray, 1925, p. 60*)*.

Church Stretton Fault System

A set of parallel faults defines the western margin of the Coalbrookdale Coalfield and forms the north-eastward continuation of the Church Stretton Fault System. Most have been active periodically since the Precambrian, and have included normal, reverse and horizontal displacements. Their latest major movements were evidently post-Permian, uplifting the Uriconian horsts of Wrockwardine and The Wrekin. The *Brockton Fault* throws down 60 m to the north-west. It is linked by a north-south structure (the *Wellington Fault)* to the *Boundary Fault* of the Coalbrookdale Coalfield. This latter fault juxtaposes the Bridgnorth Sandstone against Lower and Middle Coal Measures. The fault identified as the *Adbaston Fault* may form part of the same system and has been extended south-westwards from its mapped trace on the Stafford 1:50 000 sheet, to link with the Wappenshall Fault of the Wellington area. The position of this fault is tentatively fixed at Edgmond, where the basal beds of the Kidderminster Formation (exposed in a prominent scarp feature) are juxtaposed against a much thicker Kidderminster sequence (152 m unbottomed), proved in the Puleston Bridge Borehole [37342 32197]. A throw of 190 m to the north-west is quoted (Hamblin and Coppack, 1995) for the southern (Wappenshall section) of this fault. The *Lonco Fault* throws down around 100 m to the east, and marks a major deepening of the Stafford Basin floor, which continues eastwards.

2.4 STRATIGRAPHY OF THE SOLID FORMATIONS

2.4.1 Pre-Permian rocks

Structure contours, drawn on the base Permo-Triassic unconformity (Figure 5), show the form of the pre-Permian surface. The contours are based on deep borehole provings, combined with seismic reflection data.

Except in the immediate vicinity of the Lower Paleozoic and Precambrian inliers, the Permo-Triassic fill rests on folded and faulted rocks of the Upper Carboniferous Warwickshire Group. The latter comprises, in upwards succession, the Etruria, the Halesowen and the Salop formations (Table 1). The nomenclature of the late Carboniferous units has been standardised for the Midlands (Powell, et al., 2000). Local names (now obsolete) are shown in brackets in Table 1.

Apart from the Halesowen Formation, which includes grey measures, the sequence is entirely in red beds. The poor quality of many of the borehole logs has made it impractical to map out the distribution of these formations in the subcrop.

2.4.2 Permo-Triassic Lithostratigraphy

The Permo-Triassic succession is thickest (over 4500 m) in the hangingwall block of the Wem Fault. East of the Wem Fault, thicknesses reduce to between 800 and 1000 m on the Ternhill Terrace, and there is a further reduction to less than 200 m on the margins of the Stafford Basin. Towards the depocentre of the Stafford Basin, the sequence thickens to over 700 m.

The formations present at outcrop or beneath superficial drift cover are listed in Table 1 and their distribution is indicated on the solid geology map (Figure 3).

Structure contours have been drawn on the base of the following units:

- Base Permo-Triassic (Figure 5)
- Base Kidderminster Formation / Chester Pebble Beds (Figure 6)
- Base Wildmoor Sandstone / Wilmslow Sandstone (Figure 7)
- Base Bromsgrove Sandstone/ Helsby Sandstone (Figure 8)
- Base Mercia Mudstone (Figure 9)

The contour interval is typically 50 m but increases to 100 m or more in those areas where there is poor outcrop or borehole control. The locations of the key stratigraphical boreholes used in constructing the surfaces are shown in Figure 4.

Cross-sections, based on the structure contour plots, show the solid geology along six transects (Figures 11–16). The lines of sections are shown on Figure 10.

Bridgnorth Sandstone and Kinnerton Sandstone formations

The Bridgnorth Sandstone and its correlative, the Kinnerton Sandstone, crop out in a series of narrow, fault-bounded half-grabens between the Wem Fault and the Boundary Fault. A narrow outcrop of the Bridgnorth Sandstone is also present on the western margins of the Stafford Basin. Both formations are present at depth in the Stafford and Cheshire basins.

Limited thicknesses of pebbly or conglomeratic material occur sporadically at the base of the sequence, particularly west of the Hodnet Fault; these may represent relict juvenile fill material or minor contemporaneous debris-flow deposits (e.g. Rees and Wilson, 1998). However, the bulk of the sequence is represented by red to red-brown, fine- to medium-grained, pebble-free, dune-bedded sandstones. The formation is of aeolian origin, with accumulation considered a consequence of wind-blown, sandflow and grainfall processes within a large dune complex or erg-field (Wild, 1987).

The thickness of both formations is highly variable due to irregularities on the pre-existing topographic surface, and to syndepositional movements on the basin-bounding faults. Over most of the outcrop the formation is in excess of 100 m thick.

West of the Wem Fault, 71 m of strata, assigned to the Kinnerton Sandstone Formation, were proved in the Prees Borehole [35572 33447] from 3032 to 3103 m depth. A further 600 m of Permian strata occur below the Kinnerton Sandstone which are assigned to the Manchester Marl and Collyhurst Sandstone formations. Neither of the last two formations are recognised at outcrop east of the Wem Fault.

Between the Brockhurst and Wem faults, data are very scanty and mapped outcrop lines do not agree well with borehole evidence. The outcropping Kinnerton Sandstone is proved to a depth of 150 m by several boreholes across this half-graben. However, none of the boreholes penetrated the base of the sequence. Seismic reflection lines indicate rapid deepening and thickening northwards into the Wem Fault.

Between the Brockhurst and Hodnet faults, the formation is poorly constrained. Only the Ternhill No. 1 Borehole [36315 33132] partially proves the succession, recording a thickness of some 48 m of beds. Boreholes situated on the outcrop to the south proved a minimum thickness of 76 m. Seismic evidence indicates a rapid deepening of the basal Permo-Triassic surface westward towards the Brockhurst Fault, and eastwards into the hangingwall block of the Hodnet Fault, with consequent thickening of the Kinnerton Sandstone.

East of the Hodnet Fault, the formation thins northwards and is progressively overstepped by the Kidderminster Formation across basement highs bounded by the Ollerton, Child's Ercall and Adbaston faults. The Standford Borehole [370500 323600] drilled on the axis of one of the highs proved only 30 m of Bridgnorth Sandstone. Local thickening occurs in the hangingwall blocks of the bounding faults in this central part of the area. For example, at least 108 m of strata were proved in the Great Bolas abstraction borehole [365050 321660], located in the hangingwall of the Child's Ercall Fault.

A tongue of Bridgnorth Sandstone extends south-westwards from Longdon to Atcham forming the Longdon Groundwater Unit (Figure 2). Recent drilling at Uckington [357790 309260] and at Betton Abbots [35150 30800] has shown that the structure of this unit is more complex than indicated on the published geological map. A borehole drilled by Severn Trent Water at Uckington reportedly proved 200 m of Bridgnorth Sandstone (unbottomed), suggesting that the formation thickens south-eastwards and may be stepped down by antithetic faulting associated with the Brockton Fault. Recent coring in the Betton Abbots landfill site [35150 30800] has proved an extension of the Bridgnorth Sandstone beyond that previously known. Cored boreholes proved typical aeolian Bridgnorth Sandstone lithologies in an area mapped entirely as Salop Formation mudstones. The contact relationships between the two formations are unproven, but may well be faulted.

East of the Coalbrookdale Coalfield, the Bridgnorth Sandstone is largely concealed by younger strata. The formation is only about 50 m thick at outcrop but thickens down-dip into the Stafford Basin, where 121 m of strata were proved by the Ranton Borehole [38441 32362].

Kidderminster Formation and Chester Pebble Beds

The Kidderminster Formation and Chester Pebble Beds are exposed at surface throughout much of the central part of the Tern catchment. The principal outcrops lie between the Hodnet and Boundary Faults, and along the eastern margin of the Coalbrookdale Coalfield.

The formations comprise red-brown sandstones, pebbly sandstones, conglomerates and rare mudstones. The base of both formations is defined by an unconformity. The Kidderminster Formation may be divided into lower, middle and upper members (Rees and Wilson, 1998), although these have not been differentiated for the purpose of this study. The lower and upper members are sand-dominated, whereas the middle member is mainly conglomeratic. Steel and Thompson (1983) recognised several facies associations, including gravel bars, sandwave deposits and subaqueous dunes, which indicate deposition in confined channels of large, braided rivers. Reactivation surfaces, scours and discontinuities suggest a complex depositional architecture (Rees and Wilson, 1998). The junction with the overlying Wildmoor and Wilmslow Sandstone is ill-defined in borehole logs but is drawn conventionally at the point above which the sequence becomes pebble free.

The Chester Pebble Beds in the Prees Borehole are 111m thick.

Between the Wem and Brockhurst faults, the outcrop of the Chester Pebble Beds is not known with any degree of certainty and there are clear disparities between some of the borehole records and the outcrop, as mapped.

Between the Hodnet and Child's Ercall faults, the Kidderminster Formation is only patchily preserved, and trends are difficult to decipher. The formation is around 60 m thick in the west, but little data are available northwards or eastwards. Similarly, thicknesses are extremely uncertain west of the Hodnet Fault, where the only proving is in the Ternhill Borehole of some 135 m of strata.

Between the Boundary Fault and the Child's Ercall Fault, the Kidderminster formation shows variations in thickness similar to those observed in the underlying Bridgnorth Sandstone. Thickening occurs towards the block margins, with around 130 m of beds recorded in the Puleston Bridge Borehole [373420 321970] close to the Adbaston Fault, and approximately 125 m in the Child's Ercall boreholes [36657 32336]. Across the central part of the block, the formation thins to only around 48 m, proved in the Standford Borehole.

In the south-east of the investigation area, the Kidderminster Formation thickens from around 50 m at outcrop to between 100 and 150 m in the central part of the Stafford Basin.

Wildmoor Sandstone and Wilmslow Sandstone formations

These formations rest conformably on the underlying formations but as noted above the junction is transitional. In the Prees Borehole, the Wilmslow Sandstone, though partly faulted out, is 595 m thick. Between the Wem and Brockhurst faults, the surface geology and seismic evidence are irreconcilable, but it seems likely that as much as 300 m of Wilmslow Sandstone may be preserved in this half-graben. Delineation of the outcrop in this area is hampered by thick drift.

Further east, the Wildmoor Sandstone is only patchily exposed at outcrop, being principally found east of the Lonco Fault.

The Wildmoor Sandstone comprises brown to bright red sandstone with interbedded silty horizons. Pebbles are uncommon, although rip-up intraclasts are occasionally observed (Rees and Wilson, 1998). The unit is characteristically soft and poorly cemented. Outcrops, in general, agree well with borehole and geomorphological evidence. However, an outcrop designated as Bridgnorth Sandstone in the area of Child's Ercall has been shown to be Wildmoor Sandstone on the basis of information provided in a Shropshire Groundwater Study report.

The Wildmoor Sandstone thickens progressively eastwards into the Stafford Basin, from around 50 m at outcrop to over 150 m to the east of Gnosall. The formation is dominated by fluvial facies. Argillaceous beds are thought to represent overbank fines, whilst coarser sandstones represent braided river channel deposits (Thompson, 1985). Aeolian sandstones, with characteristic ‘pin-stripe’ laminae, are also common, particularly within the upper part of the formation.

Bromsgrove Sandstone and Helsby Sandstone formations

The base of the Bromsgrove Sandstone and Helsby Sandstone formations is marked by a local unconformity, the contact representing the brief period of uplift and erosion associated with the Hardegsen earth movements. Both formations are relatively thin (generally around 20 to 50 m) at outcrop.

The sandstones are typically red-brown, yellow and grey, with a pervasive calcareous cement. Interbedded, discontinuous greenish siltstones are observed at outcrop at Grinshill Quarries. The formation is resistant to weathering, and forms prominent scarps and cuestas across the investigation area. Much clastic material is probably reworked from older rocks of the Sherwood Sandstone Group (Rees and Wilson, 1998).

Thickness variations are difficult to assess due to poor borehole data. At outcrop, west of the Hodnet Fault, the Helsby Sandstone is between 20 and 50 m thick. East of the Lonco Fault, the Bromsgrove Sandstone thickens from 50 m on the margins of the Stafford Basin, to around 75 m beneath Mercia Mudstone cover.

The Bromsgrove Sandstone largely represents deposition in low-sinuosity river channels (Rees and Wilson, 1998), although ephemeral drying and occasional aeolian-dominated successions are observed. Siltstones are thought to represent overbank deposits.

Mercia Mudstone Group

The Mercia Mudstone is conformable on the Bromsgrove Sandstone and Helsby Sandstone. The junction is usually transitional and is placed at the base of the sequence where sandstones are replaced upwards by alternations of siltstone, mudstone and fine-grained sandstone of the Tarporley Siltstone Formation. The Mercia Mudstone Group is largely undivided in the Stafford Basin but a formal stratigraphy has been applied to subdivisions recognised in the Cheshire Basin. Above the Tarporley Siltstone, the formation mainly comprises dark reddish brown mudstones and siltstones. However, saliferous formations occur at two well-defined horizons. The Mercia Mudstone is at least 200 to 300 m thick on the Ternhill Terrace. The depositional environment envisaged is of a low-relief continental basin dominated by inland sabkhas or playa lakes.

2.5 SUPERFICIAL DEPOSITS

The superficial deposits within the Tern catchment were mainly laid down under glacial, periglacial and temperate climatic conditions. The majority of the deposits relate to the Late Devensian ice sheet and the post-glacial

Holocene period. The distribution of the superficial deposits is shown in Figure 17; cross-sections drawn along nine transects (Figures 18-26) add a 3-D perspective to the essentially 2-D map.

2.5.1 Late Devensian Glacigenic Deposits

The Late Devensian glacigenic deposits were laid down in an area of coalescence between Irish Sea ice sheet advancing from the north, and the Welsh ice sheet advancing from the west (Thomas, 1989). The resulting deposits show significant spatial variation in both thickness and sediment type, and they commonly grade compositionally and texturally into one another. However, Thomas (1989) has shown that the geometry and lithological characteristics of the glacigenic deposits form predictable patterns of sedimentation that can be linked to sub-glacial and supraglacial deposition at an oscillating ice margin.

The sequence of events is summarised by Thomas as follows:

1. Ice advances from the Irish Sea Basin and from Wales with coalescence of the two streams occurring to the west of Shrewsbury. At its maximum extent (about 22 000 years BP), Irish Sea ice reached just to the south of Wolverhampton (Morgan, 1973). Deposition of a basal lodgement till beneath the ice and subglacial erosion and drainage diversions occurred during ice advance.
2. Deglaciation begins and uncoupling of ice sheets occurs, with meltwaters impounded in temporary lake basins dammed against the retreating ice margin. Ponding of meltwater between the retreating ice front and the proto-Ironbridge Gorge results in extensive glaciolacustrine sedimentation in the River Tern catchment between the modern Severn valley and the Triassic escarpment.
3. Retreat of the ice margin to the west of the Triassic escarpment allows glaciolacustrine conditions to develop north and westwards, with discharge of meltwater southwards through rock channels within the Triassic escarpment at Yorton and Lee Brockhurst. These channels feed extensive, low gradient outwash ribbon sandar to the south. Oscillation of the ice margin in the north-west of the catchment results in the deposition of significant thicknesses of glacigenic deposits and the formation of high morainic ridges.

On the drift map (Figure 17), the glacigenic deposits are classified into three main components; namely, till, glaciofluvial outwash and glaciolacustrine deposits.

Till is the most widespread superficial deposit, forming sheets and morainic ridges over 30 m thick to the west and north-west of the main Triassic escarpment, although it is much thinner elsewhere. Typically, much of the till is described as a poorly-sorted, unstratified mixture of rock fragments in a matrix of stiff, overconsolidated reddish brown or greyish brown 'sandy clay'. The sand fraction is generally fine to medium grained. Most of the till in the area is a reddish brown diamicton containing northerly-derived clasts and, thus, originated from Irish Sea ice. Deposits of greyish brown till have been recorded locally, but there is no evidence to link them to the Welsh ice sheet. Both lithologies are considered to be lodgement tills laid down beneath the ice sheet. In borehole logs, a distinction can be drawn between stiff lodgement tills and thinner deposits of soft, grey to reddish brown clay or silty clay (usually less than 5 m thick), which occur interstratified with, or capping outwash. These softer clays may represent resedimented ablation tills that were deposited in morainic ridges.

Glaciofluvial outwash deposits occur in a variety of settings; they include ice-contact deposits, outwash fans and valley train deposits, all of which were deposited by meltwater flowing on, in, or under the ice or beyond its margin. These deposits range from coarse gravel, through pebbly sands to clayey sands. The most extensive deposits occur in the north-west of the area in the region of Whitchurch and Prees Heath, around Shawbury north-east of Shrewsbury, and north of Wellington. The sands and gravels of the Shawbury area were probably laid down as alluvial fans or fan deltas in front of an ice-sheet that lay to the north of the Triassic escarpment. Major meltwater channels cut in the Triassic escarpment at Yorton and Lee Brockhurst carried the sediment southwards. The deposits around Shrewsbury itself are probably also outwash deposits and form part of a more extensive body of sand and gravel that fills a buried channel system beneath the River Severn, hereabouts. The proven thickness of sand and gravel is commonly in excess of 20 m. In the east, the superficial deposits are thinner and more dissected. However, isolated ridges and tracts of clean sand and gravel may reflect sub-glacial deposition as narrow, linear eskers.

Glaciolacustrine deposits are commonly recorded in boreholes, particularly in the west of the district, but are not widely mapped. Typically, they consist of soft, brown, pebble-free, laminated clays. Many of the deposits recorded as silty clay in boreholes may have originated in a proglacial, glaciolacustrine environment, suggesting that ponding of meltwater between the ice margin and ice-free higher ground was a frequent occurrence during deglaciation. Significant thicknesses of these clays, such as occur around Petton and Loppington, indicate that glaciolacustrine conditions prevailed for a significant length of time, before the lake was finally drained by the continued development of the Ironbridge Gorge. An extensive area of lake clays has been mapped at the surface in the vicinity of Aqualate Mere, and this may reflect the final development of lacustrine conditions in the study area, although lacustrine deposition may have continued well into the Holocene at this location.

Periglacial deposits have not been mapped extensively in the area of the Tern catchment, although periglacial conditions would have prevailed as the ice sheet retreated. Under these conditions, reworking of the previously deposited glacigenic deposits would occur, leading to the accumulation of solifluction deposits such as head. The latter has only been recorded in small valleys on the flanks of The Wrekin but is likely to be present across much of the area, albeit of limited extent or thickness.

2.5.2 Holocene Post-Glacial Deposits

During the 13 000 years since the ice retreated, silts, sands and gravels, derived in part from the glacigenic deposits have been reworked and incorporated in fluviatile and river terrace deposits and alluvium.

River Terrace Deposits form distinct benched surfaces along the valleys of both the River Tern and River Severn. The terraces reflect former floodplain surfaces of the rivers and are probably all of Holocene age. The composition of the individual terraces varies, although they typically comprise pebbly clayey sands in varying quantities, reflecting the reworking of the glacigenic deposits through which the rivers flow.

Within the upper reaches of the River Tern catchment, only a single terrace is identifiable just above the modern floodplain. Only downstream of Rodington on the River Roden, and downstream of Isombridge on the Tern does a second terrace become apparent.

On the River Severn, in the south-west of the study area, three terrace benches rising 3–6 m, 6–12 m, and 12–18 m above the Severn can be identified. The Third Terrace can only be traced upstream as far as Shrewsbury, although it forms extensive deposits on the eastern outskirts of the County Town. It consists predominantly of fine- and coarse gravel of about 4.5 m thickness. Wroxeter also lies on this terrace.

The Second Severn Terrace ranges from 2 to 5 m in proven thickness. It consists of brown sandy pebbly clay overlying a 'clayey' gravel, and can be observed south of Uffington and south of Wroxeter.

The First Severn Terrace can be traced along the River Severn upstream from Cressage, through Cound, Atcham and Emstrey, and also into the Tern through Attingham Deer Park. It consists of brown silty or sandy clay overlying coarse grained gravel. The deposit is 4 m thick.

Alluvium consists of clay, silt, sand and gravel, locally with lenses of peat or humic deposits. Many deposits have gravel at the base. It is present on the floor of most modern valleys, and is continuous in the valley of the Tern and the Severn, where it ranges up to 8 m but is commonly less than 5 m thick. Elsewhere in the area, isolated basins eroded within the rockhead surface have been infilled with soft alluvial deposits, the composition of which often reflects the immediately local bedrock or superficial drift geology.

Peat commonly fills glacial drainage channels and the silted-up sites of lakes such as Aqualate Mere and Fenn’s Moss, the latter an enclosed lake basin within a thick till sequence north of Wem. There are also extensive tracts of peat along the valleys of the River Strine and its tributaries between Crudgington and Newport. Smaller patches of peat can be found in small basins across much of the area, particularly in the north-west and east of the area. Peat deposits are variable in thickness, reflecting the size and depth of the original depression, although in Fenn’s Moss thicknesses in excess of 3 m have been recorded on the basin margin, suggesting a significant thickness may be present at its centre. Elsewhere, peat thickness is typically of the order of one to two metres.

3 Rockhead relief and drift thickness

3.1 DATA PROCESSING

The rockhead surface (Figure 28) was generated from borehole records held in the National Geosciences Records Centre at BGS, together with additional borehole data supplied by the Environment Agency and Severn Trent Water plc. The distribution of the boreholes is shown in Figure 27.

4647 boreholes penetrated the base of the superficial deposits and an additional 3364 boreholes terminated above rockhead. An initial hand contour-plot was drawn from the posted values. This was subsequently digitised, recombined with the borehole data and outcrop boundary lines, and then gridded. The final surface was generated by re-gridding to take account of those boreholes that terminated above rockhead. The resulting grid is poorly constrained in the west of the catchment where relatively few boreholes proved rockhead. No attempt has been made to modify the grid to create realistic profiles along river sections where the rivers are known to be incised in bedrock.

The drift thickness grid was generated by subtraction of the rockhead grid from the Digital Terrain Model grid. Inspection of the drift cross-sections suggests that in areas of thin, patchy drift the reported drift thickness locally may be an underestimate. This relates to the uneven distribution of data points, and the decision not to force the rockhead grid beneath alluvial tracts along the full length of each river.

3.2 ROCKHEAD SURFACE

The rockhead surface in the central part of the catchment lies mainly between 50 and 75 m above OD. A deep channel system underlies the River Severn, which links westwards with the Mytton-Shrewsbury System, described elsewhere (Bridge, Sumbler and Shepley, 2001). The channel has an uneven floor, and a humped longitudinal profile. Deep scours (to around 0 m OD) occur locally.

The channel system branches at the confluence with the Tern, one arm continuing towards the Ironbridge Gorge, the other continuing north-eastwards as a fairly broad, rather ill-defined depression passing beneath Newport and crossing the watershed at Gnosall, to link into the valley of Church Eaton Brook.

Feeder channels to this system cut the Triassic escarpment near Grinshill [35000 32300] and at Lee Brockhurst [35500 32700]. Further to the north and west, the rockhead elevation falls to below 25 m above OD under the Cheshire Plain. Evidence from outside the catchment suggests that the poorly defined features just beyond the north of the catchment may relate to a buried valley system recorded in the Stoke district.

3.3 DRIFT THICKNESS

The drift thickness map (Figure 29) shows that over most of the central and eastern parts of the catchment, the superficial deposits are less than 5 m thick. Channel-fill deposits, locally up to 50 m thick, are present along the course of the proto-Severn, and thicknesses of 10 to 20 m are recorded along the main drainage diversions through Newport and Gnosall. In the north-west of the catchment, on the outcrops of the Mercia Mudstone, thicknesses are typically in the range 10 to 50 m.

4 Geological domains

4.1 GEOLOGICAL DOMAINS

The concept of domains has been applied successfully elsewhere to characterise the spatial variability of Quaternary sequences (e.g. McMillan et al., 2000) and a modified approach is adopted in this study. Based on borehole information and published maps, ten Quaternary domains are distinguished. The subdivisions are based primarily on lithological criteria, although where information is available on surface morphology, an indication of the associated sediment-landforms is given. The domain classification takes account of the principal lithology mapped at outcrop (interpreted as dominantly sand or clay) together with an estimate of the relative proportions of sand and clay in the sub-surface. The distribution of the domains is shown in Figure 30.

In areas of complex geology, where the relationship between deposits is complex or uncertain, some simplification has been necessary.

Further subdivision could have been achieved, for example, by delineating individual sand bodies sandwiched between clay units. In most cases, however, the quality of the subsurface information precluded a more rigorous approach.

One consequence of adopting a purely lithological classification is that a single domain may include deposits laid down in different environments. For example, Domain 1 comprises both waterlain and ice-contact deposits. Similarly, Domain 2, although predominantly composed of glaciofluvial outwash, also includes fluviatile deposits.

4.2 DOMAIN DESCRIPTIONS

Domain 1 (clay dominated): Till cored-ridges, till plain and glaciolacustrine deposits

Domain 1 mainly comprises till and glaciolacustrine deposits. The till occurs as morainic ridges in the north-west of the area where, in places, it is over 30 m thick (Thomas, 1989,fig 3). Thick sequences of till and associated glacigenic sediment are also present on the northern flanks of the main watershed between the Ironbridge Gorge and Gnosall. Thinner and more discontinuous deposits form flat, subdued or gently undulating sheets, which are widely developed across the central and southern parts of the Tern catchment to the south and east of the Triassic escarpment. Extensive glaciolacustrine deposits occur around Prees, in the Severn valley and between the morainic ridges in the north-west.

Domain 2 (sand and gravel dominated): Glaciofluvial and fluviatile deposits

Domains consisting predominantly of 100% sand and gravel include both glacigenic and fluviatile deposits. Ice-contact sands and gravels occupy troughs in the north-west of the area and sheets of glaciofluvial outwash are distributed around the margins of the till plains, and as isolated bodies resting on bedrock. The recent alluvial and terrace deposits in the present-day river valleys also fall in this category.

Domains 3,4,5,6: Glacial, glaciolacustrine, glacio-fluvial and fluviatile deposits

These are typically interlayered sequences which occur in a variety of settings as described by Thomas (1989):

ribbon sandar deposits (mainly Domain 4) have a characteristic smooth, gently sloping surface morphology. Most tend to comprise thin outwash sands draped across a basal till. The best example, to the north-east of Shrewsbury, is fed by a major rock channel cut through the Triassic escarpment.

ice-front alluvial fans or fan deltas form sloping fans up to 10 km in length and 4 to 5km in width. These comprise thick sequences of lacustrine and outwash sediments resting on till. Good examples (mapped as Domains 3 or 4) slope towards and terminate against the Triassic escarpment near Prees.

heterogeneous ice-contact deposits occur in ridges mounds and hollows between major till cored ridges in the north-west of the area. Their distribution in the central and south-east of the area is not known.

buried valley deposits fill deep channels that formed during ice-advance, and, in places, cut down to below sea-level (section 3.2). These channesl are mainly filled with till or glaciolacustrine sediments but include glaciofluvial sequences.

Domains 7 and 8: Undifferentiated fluviatile deposits

It was not possible to wholly subdivide the fluviatile sequences in some areas north of Telford, and domains 7 and 8 are identified on morphological rather than lithological criteria.

Domains 9 and 10: Peat

The distribution of peat deposits is discussed in section 2.5.2. A distinction is drawn between peat deposits on bedrock and those that occur above other superficial deposits.

Domain 11: Bedrock at surface

The Permo-Triassic Sandstone is the only significant major aquifer within the project area. The Upper Carboniferous sandstones and mudstones of the Warwickshire Group form a minor aquifer, and the Mercia Mudstone is predominantly a non-aquifer, with groundwater restricted to a few sandstones.

5 Summary

The Permo-Triassic rocks of the Tern catchment are preserved in a series of north-east—south-west-trending half-grabens. Synsedimentary movement on the major faults that define these structures (e.g. Wem Fault, Hodnet Fault) was a major control on deposition and is reflected in the marked thickness variations exhibited by the formations that constitute the lower parts of the aquifer (Bridgnorth Sandstone, Kinnerton Sandstone). Facies variations and unconformities within the sequence are only partially resolved and, in the west of the area, there are clear discrepancies between the geology at outcrop and the interpretations placed on the seismic reflection data.

A review of the shallow boreholes has enabled a complicated Quaternary sequence to be simplified into only ten basic Quaternary domains. These domains have been distinguished on the basis of their principal surface lithology (sand or clay), and on the total contribution such deposits make to the overall drift sequence. The resulting domain map adds a third dimension to the conventional drift map and distinguishes zones within the drift where differing hydrogeological behaviour can be expected.

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Tables and Figures

Period	Stage	Group	Formation Names **Note:** Cheshire Basin nomenclature (applied to formations cropping out to the west of the Hodnet Fault) is identified by change in font	Lithology/Facies
Jurassic	**Hettangian**	**Lias Group**		Calcareous mudstones and limestones /Shallow marine
Triassic	**Rhaetian**	**Penarth Group**		Mudstones, silty limestones and fine-grained sandstones/Quasi-marine
	Ladinian-Norian	**Mercia Mudstone Group**	Including Tarporley Siltstone Formation at base, Northwich Halite and Wilkesley Halite	Hard red marls and siltstones, including two saliferous formations in the Cheshire Basin/Sabkha-playa lake
	Anisian	**Sherwood Sandstone Group**	Bromsgrove Sandstone Formation Helsby Sandstone Formation	Hard, pale grey to reddish-brown micaceous sandstone, locally pebbly; subordinate mudstone/Fluvial facies dominant in the Stafford Basin; fluvial and aeolian facies recognised in the Cheshire Basin
	Induan-Olenekian		Wildmoor Sandstone Formation Wilmslow Sandstone Formation	Friable red sandstone with subordinate siltstones; pebble-free/Wildmoor Sandstone dominantly fluvial;Wilmslow Sandstone dominantly aeolian in the upper part and fluvial in the lower part
			Kidderminster Formation Chester Pebble Beds	Conglomerates and pebbly sandstones, with subordinate sandstones and mudstones/ Fluvial, braided river
Permian	**Undivided**		Bridgnorth Sandstone Formation Kinnerton Sandstone Formation	Red, fine-grained sandstones, generally pebble free/ Dominantly aeolian
Carboniferous		**Warwickshire Group**	Salop Formation(formerly Enville Formation and Keele Formation)	Red-brown mudstone and sandstone with minor conglomerate and sparse thin limestones/Proximal and distal alluvial plain
			Halesowen Formation (Coed-yr-Allt Beds)	Grey-green and red sandstone and mudstone with thin coals and sparse thin limestones/Alluvial plain, swamp,
			Etruria Formation	Variegated mudstone with subordinate pebbly sandstones/Alluvial floodplain

Table 1. Lithostratigraphy

Domain	Lithological nature of surface deposit	Estimated composition of total drift thickness	Occurrence
1	Clay	100% clay	Till and glaciolacustrine deposits
2	Sand and gravel	100% sand and gravel	Glaciofluvial and some fluviatile deposits
3	Sand and gravel	>50% sand and gravel	Glacial, glaciolacustrine, glaciofluvial and fluviatile deposits
4	Sand and gravel	>50% clay	Glacial, glacio-lacustrine, glaciofluvial and fluviatile deposits
5	Clay	>50% clay	Glacial, glaciolacustrine, glaciofluvial and fluviatile deposits
6	Clay	>50% sand and gravel	Glacial, glaciolacustrine, glaciofluvial and fluviatile deposits
7	Undifferentiated fluviatile deposits on bedrock		Fluvial terrace deposits and alluvium. .Category used when lack of data prevents subdivision into domains 1-6
8	Undifferentiated fluviatile deposits on other drift		Fluvial terrace deposits and alluvium. Category used when lack of data prevents subdivision into domains 1-6
9	Peat on bedrock		Significant peat thickness (>1m) mapped at surface
10	Peat on other drift		Significant peat thickness (>1m) mapped at surface
11	Bedrock at surface		Exposed bedrock

Table 2. Domain classification

Appendix 1 Contents of CD

Folder Name	Subfolder/File	File description
BoreholeGriddingdatarh	Drift_TD_boreholes	Boreholes terminating above rockhead
	Rockhead_boreholes	Boreholes proving rockhead
Drift_rockheadgrids	Driftthick10 Driftthickness50 Driftthickness_5mcont_polyline Rockhead20 Rockhead50 Rockhead_5mcont_polyline	Drift thickness 10m grid Drift thickness 50m grid Drift thickness contours (5m intervals) Rockhead 20m grid Rockhead 50m grid Rockhead contours (relative to OD)
DriftDomains	Drift_Domains	Domain map
DriftGeology	Drift_geology	Superficial deposits based on 1:50k Digmap linework
Driftsections	Drift_sections_lines_polyline	Cross-section lines (superficial deposits)
Geographicalfeatures		Rivers and towns
ProjecData	Tern_Catchment Modeldom	Catchment boundary EA groundwater units
Solidgeology	SolidRegions Solid_Geology Fault_Geology_Lines	Formation polygons Solid geology based on 1:50k Digmap linework Geological faults
Solidsections	Solid_section_lines_polyline	Cross-section lines (solid geology)
Structurecontourssolid		Structure contours on base of solid formations
Report and figures		Figures in pdf format Large scale maps in postscript format