Technical Report WA/92/33

A geological background for planning and development in the 'Black Country'

J H Powell, B W Glover and C N Waters

BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/92/33
Offshore Geology Series

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J H Powell, B W Glover and C N Waters

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Cover illustrations

Front Cover View of the Dudley Canal and Cobb's Pit, Warrens Hill Park, Dudley.

Back Cover Top; Severn Sister's Cavern, Wren's Nest Nature Reserve (SSSI). Galleries and roof-supporting pillars in workings of the steeply dipping Much Wenlock Limestone (Lower Quarried Limestone).

Bottom; Basal Coal Measures conglomerate resting unconformably on, and overstepping steeply dipping Silurian strata. The Hayes; archival photograph, 1921.

Geographical index

UK, Central England, West Midlands

Subject index

Geology, planning, thematic maps, mineral resources, hydrogeology, mining, engineering geology.

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PREFACE

This report and the accompanying thematic geological maps result from a study, carried out between 1989 and 1992, which was commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey. The principal aim of the study was to produce a synthesis of geological information relevant to the planning of land-use and development in the 'Black Country'.

The study area includes the metropolitan boroughs of Dudley and Sandwell and parts of Wolverhampton MBC, Walsall MBC, South Staffordshire County and Bromsgrove District. The study area is covered by 14 Ordnance Survey 1:10 000 quarter sheets which comprise parts of four 1:50 000 geological sheets, Dudley (167), Birmingham (168), Lichfield (153) and Wolverhampton (154). Primary geological survey of the area at 1:10 560 scale was carried out in the late 19th and early 20th centuries by officers of the Geological Survey, notably J Beete-Jukes, T H Whitehead, T Eastwood and R W Pocock. Revision geological mapping at 1:10 000 scale of those parts of the sheets covering the exposed coalfield was carried out between 1976 and 1979 by R J O Hamblin (SO 99 NW, SW), M R Henson (SO 99 NE, SE, and SP 09 NW, SW) and D Wilson (SO 98 NW and part of SO 99 SE). During the present study these sheets were partially revised as a desk study with limited field checking, but with a complete field survey to delineate areas of made ground and disturbed ground, by the following officers: B W Glover (SO 99 SW, SE), J H Powell (SO 99 NW, NE) and C N Waters (SO 98 NW, SP 09 NW). Revision geological survey at 1:10 000-scale was carried out for the remainder of the study area by B W Glover (SO 89 SE, 98 SE, and SP 08 SW), J H Powell (SO 88 SE, 89 NE, 98 SW, and SP 08 NW) and C N Waters (SO 88 NE, 98 NE, and SP 09 SW). The engineering geology study was carried out by A Forster, and a hydrogeological contribution was provided by S W Fletcher, E L Parry and C A Thomas (National Rivers Authority). B R Marker (Department of the Environment) contributed the planning section. The thematic geological maps were produced by P Turner, using digital methods, at BGS Keyworth. The project leader was J H Powell, the programme managers A J Wadge and J I Chisholm, and the nominated officer for the Department of the Environment, B R Marker.

The willing cooperation of landowners, tenants and quarry companies in allowing access to their lands and undertakings is gratefully acknowledged. We are also grateful to all the holders of data for allowing us to transfer them to the National Geosciences Information Centre, BGS, Keyworth. We are especially grateful to British Coal Technical Services and Research Executive and British Coal Opencast Executive for access to abandoned mine plans and exploration data. We acknowledge the assistance provided by the officers of the various local authorities in the Black Country area, and of many other organisations, including the Severn-Trent Water Authority, National rivers Authority and British Rail, who have readily provided information and advice.

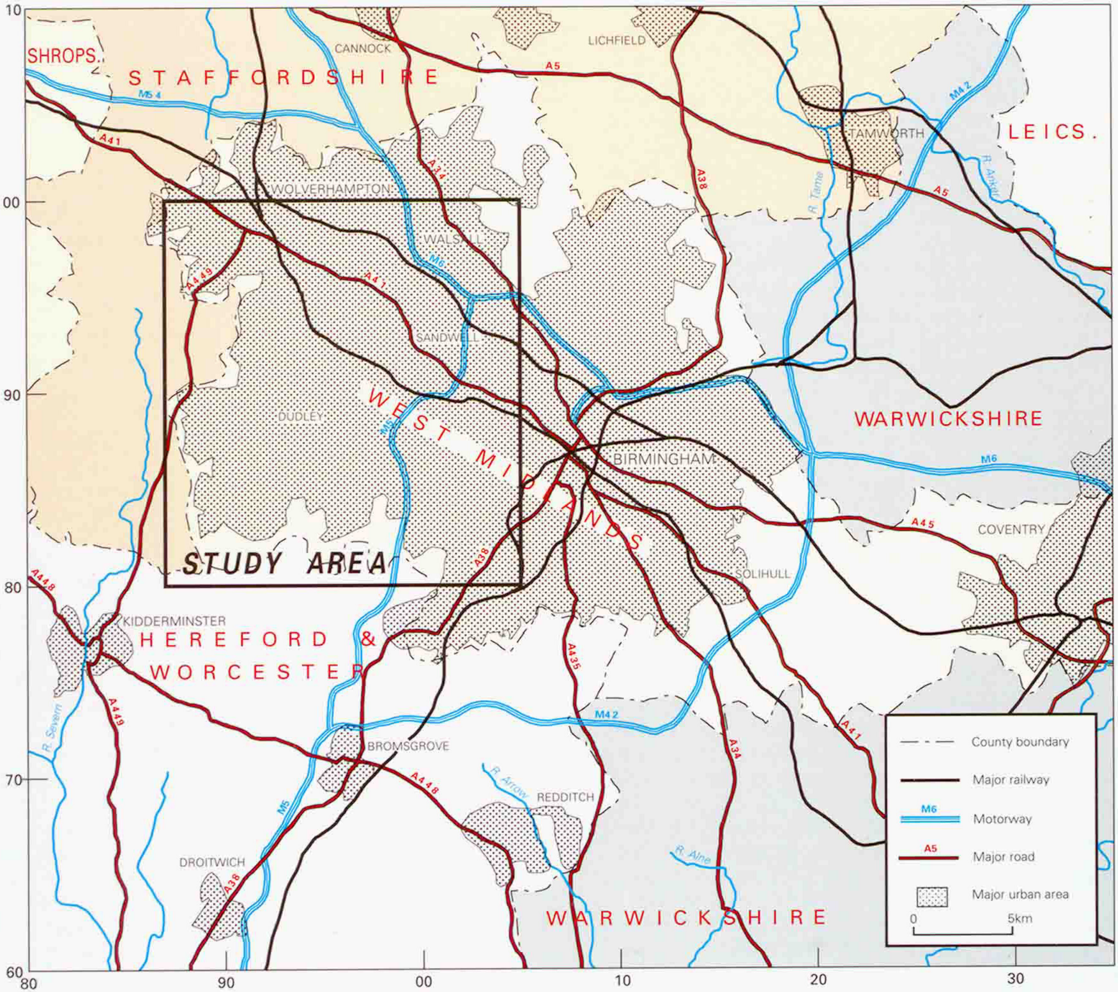


Figure 1 Sketch map showing the regional setting of the study area.

EXECUTIVE SUMMARY

This study, carried out between 1989 and 1992, was commissioned by the Department of the Environment and funded jointly by the Department and the British Geological Survey. Its principal aim was to produce a synthesis of geological information relevant to the planning of land-use and development in that part of the West Midlands conurbation known as the 'Black Country'. This report is aimed at those involved in planning and development. The results are presented in a style which, it is hoped, will meet the needs of both those with and without previous geological knowledge. Much of the information is provided on a series of ten thematic maps, each of which concentrates on a specific aspect of the geology relevant to the use of land. In addition to the information contained in the report, sources of other more detailed data are indicated.

The study area

The study area (Figure 1) comprises that part of the West Midlands conurbation known as the 'Black Country'; it includes the metropolitan boroughs of Dudley and Sandwell and parts of Wolverhampton MBC, Walsall MBC, the City of Birmingham, South Staffordshire County and Bromsgrove District. The study area of 348 km^2 is mostly urban but includes some agricultural land in the south and west; it includes the southern part of the South Staffordshire Coalfield, south of the Bentley Trough faults.

The rapid growth of the Black Country was linked to the development of the Industrial Revolution in the eighteenth and nineteenth centuries, based on exploitation of local mineral resources such as coal, fireclay, ironstone, limestone, foundry sand and aggregates. The pressure of economic growth made the creation of a canal and railway system essential in maintaining the continued growth of the area; communications were more recently improved by the construction of urban motorways. The proximity of the Black Country to the City of Birmingham, to the east of the coalfield, ensured the rapid development and continuing redevelopment of the area. However, the area is now undergoing regeneration following the relative decline of heavy industry which is being replaced by light industry, new high technology manufacturing and warehouse-type service industries.

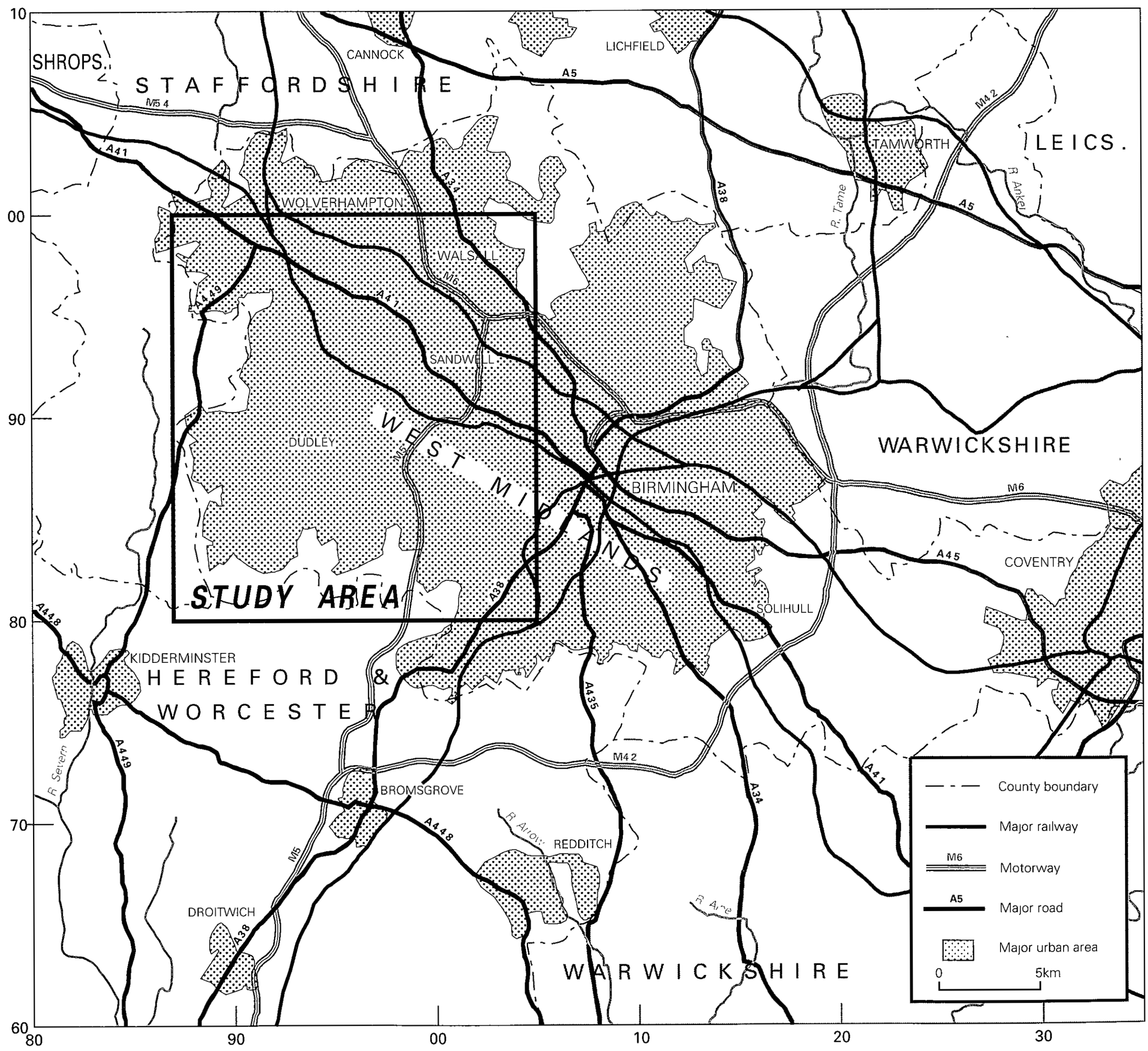


Figure 1 Sketch map showing the regional setting of the study area.

Sources of information

The information used in the report was acquired in two main ways. Firstly, geological data were acquired and compiled from various sources, most notably from the databases and archives of BGS, British Coal, Local Authorities and the NRA/Severn-Trent Water Authority, and from several geotechnical consultants and private companies. These data are mostly in the form of memoirs, maps, underground mine plans, borehole, shaft and trial pit records, and site investigation reports. Secondly, a detailed field geological survey was undertaken by BGS geologists at a scale of 1:10 000. This covered about 55% of the area; the remaining part, having been surveyed in the1970s, was subject to partial revision only.

Geology

The bedrock geology of the'Black Country' area comprises a wide variety of sedimentary rocks including limestone, conglomerate, sandstone, siltstone, mudstone, coal, ironstone and claystone. These rocks were deposited in marine and terrestrial environments spanning the Silurian to Triassic periods, from about 430 to 225 million years ago. Older rocks are known to occur at depth.

Igneous dolerite rock was intruded into the sedimentary pile in late Carboniferous times, about 300 million years ago.

In some parts of the area the bedrock is overlain by poorly consolidated, superficial (drift) deposits which predominantly consist of till (boulder clay), silt, sand and gravel. These deposits include the products of recent downslope movement and river action, and were laid down during Quaternary glacial, interglacial, and postglacial periods. Superficial deposits locally infill deep, pre-glacial, bedrock channels. Large areas of the Black Country are covered by a layer of man-made deposits overlying both the bedrock and superficial deposits; this comprises made ground and fill materials, much of it a product of mining and heavy industries in the area.

The survey has resulted in a considerable improvement to the geological knowledge of the area. Much new detail has been added to the geological map and this has resulted in a new synthesis of the geological structure of the area, with a revision of the stratigraphy and history of sedimentation. This has allowed mineral resources such as brick clay, dolerite, sand and gravel, coal, and groundwater resources to be more clearly defined and constrained.

The revised geological maps also provide a sound basis for development and redevelopment of the area.

Geological Resources

The 'Black Country' area is well endowed with mineral resources and to a lesser extent groundwater; other local resources influenced by ground conditions include soils for agriculture, sound foundation conditions and sites for waste disposal.

For planning purposes, the mineral resources fall into two categories, those that can be extracted by surface working and those that can be mined or recovered at depth. In the area, the former include opencast coal, sand, gravel, dolerite, brick clay, and mine stone, all of which are exploited at present. Areas in which these resources occur are delineated on thematic maps, and the potential resources are discussed fully. Conflicting claims on land from the extractive industry, agriculture or the urban developer have to be resolved by the planner. Any construction will sterilise the resource, and mineral workings may themselves present problems for land uses after extraction has ceased.

Underground mining for coal has a long history in the area, but the last working pit at Baggeridge closed in 1968. Limited coal resources remain in the ground, but only coal lying at shallow depth in the exposed coalfield is considered to be potentially exploitable.

The groundwater resources of the area are reviewed, with particular emphasis on the importance of the Triassic Sherwood Sandstone aquifer. There may be scope for increased abstraction from this source, although high nitrate levels may present a problem locally.

Other resources are discussed in some detail. In the Black Country a unique concentration of nationally important geological sites, close to major urban centers, has potential for tourism, and for educational interest. Geological Sites of Special Scientific Interest (SSSI) are highlighted. Waste disposal sites are provided by areas of past and present mineral extraction. Sound bedrock foundation conditions and the soils of most use to agriculture are related to bedrock types.

Geological Constraints

Potentially adverse ground conditions are the main geological constraint for consideration in planning and development. Assessment of ground conditions includes not only the properties and stability of bedrock and superficial materials, but also the changes to the subsurface brought about by man, such as mining and any consequent subsidence, quarrying and landfill. These two aspects, the natural geological properties and man-made modifications, are considered separately in the report.

The suitability of bedrock and superficial materials for foundations in the Black Country area depends mainly on their geotechnical properties. The various parameters relating to the behaviour of ground materials and to their reaction to engineering structures are reviewed in the report and tables of properties based on data from a total of over 7854 test or sample points are given.

Modification of the land surface and subsurface by human activities takes two forms. Firstly, excavation and removal of material leaving voids or pits, as in mining and quarrying, and, secondly, addition of material as fill either into former excavations or purely as constructed landfill. Many constraints are placed on development by these changes, and particular care must be exercised by developers in the area since many of these activities were carried out before written records were kept.

A long history of shallow and deep mining for coal, ironstone, and fireclay in the area has left a legacy of shafts, adits, shallow workings and backfilled opencast pits which present problems for land use. The outlines of documented workings, and the approximate crop of the coals, at surface or beneath drift deposits, are shown on the thematic maps. Many of the early workings are poorly documented, which means that in the central, exposed coalfield, where mining has a longer history, unrecorded former workings may occur at shallow depths in any area where a coal, or mineral seam thick enough to have been considered workable, lies near the surface. Documented shafts and adits are shown on thematic maps, but responsibility for locating shafts at or close to these sites rests on the site owner or developer. The report contains information on subsidence related to deep mining, particularly the problems posed by geological faults with respect to differential subsidence, and dangerous gas migration.

Underground limestone mining has taken place in many areas where the Silurian limestones are present at depth. An intensive programme involving the investigation, monitoring and treatment of mined limestone cavities is continuing. The problems associated with areas undermined for limestone are outlined and areas known to be affected are shown on the thematic maps.

In view of the poor quality of the early historical records of colliery-based and limestone mining, all development in these areas requires very careful geological investigations to ascertain whether there is any risk of subsidence.

Tabulated information is presented for the former quarries and pits in the area, with notes on the special problems each may present to development.

The increasing use of such pits for waste disposal, and the hazard from toxic leachates and dangerous gases such as methane and carbon dioxide, to which this may give rise, are highlighted. Attention is drawn to the possible presence of unrecorded or poorly documented backfilled excavations in certain parts of the area, and the need for well-planned site investigations in such places. The special problems of fill as a foundation material are also considered.

The constraints imposed by underground water in the area are of two types. Firstly, restrictions are placed on development by the need to protect the Sherwood Sandstone aquifer from pollution. Secondly, rising groundwater levels beneath parts of the City of Birmingham may cause problems for the foundations of buildings. Both aspects are reviewed in the report.

Other geological factors which were examined include local geological structure and slope stability which may give rise to problematical ground conditions and could then act as constraints to development. In addition, possible risks to health from exposure to radioactive radon gas emanating from subsurface materials and, on a regional scale, earthquakes may also have some relevance to land use and development.

Appropriate site investigation should always be carried out prior to development.

References, glossary, appendices and thematic maps

The report concludes with a reference list and glossary of terms used, together with appendices providing information on sources of borehole, trial pit and shaft data and a list of mineral industry operators, and statutory authorities. The thematic maps which accompany this report are as follows:

Map 1. Distribution of records (boreholes, shafts and trial pits); 1:50k
Map 2a. Bedrock geology (south); 1:25k
Map 2b. Bedrock geology (north); 1:25k
Map 3a. Distribution and thickness of superficial (drift) de posits(south); 1:25k
Map 3b. Distribution and thickness of superficial (drift) de posits (north); 1:25k
Map 4a. Distribution of Made and Worked ground (south); 1:25k
Map 4b. Distribution of Made and Worked ground (north); 1:25k
Map 5a. Surface mineral resources and quarrying (south); 1:25k
Map 5b. Surface mineral resources and quarrying (north); 1:25k
Map 6a. Underground mining (south); 1:25k
Map 6b. Underground mining (north); 1:25k
Map 7. Slope steepness and selected geomorphological features; 1:50k
Map 8. Hydrogeology; 1:50k
Map 9a. Engineering geology; superficial (drift) deposits; 1:50k
Map 9b. Engineering geology; bedrock; 1:50k

Copies of this report and its maps can be obtained from the British GeologicalSurvey, Keyworth, Nottingham NG12 5GG. Archival data are held at the same address.

LIMITATIONS

This report has been produced by the collation and interpretation of geological, geotechnical and related data from a wide variety of sources.

The report aims to provide a general introduction to the geological factors relevant to land-use planning and control of development, and as background information for those preparing desk studies on specific development proposals. The data on which it is based are not comprehensive and vary in quality, and this is inevitably reflected in the report. Local features and conditions may not be represented, and many boundaries shown may be only approximate. The dates of the revision geological mapping are shown in Figure 2 and no information subsequent to these dates has been taken into account. For these reasons:-

This report provides only general indications of ground conditions and must not be relied upon as a source of detailed information about specific areas, or as a substitute for site investigations or ground surveys. Users must satisfy themselves, by seeking appropriate professional advice and by carrying out ground surveys and site investigations if necessary, that ground conditions are suitable for any particular land use or development.

Data used in preparing this report and the associated maps are held by the National Geosciences Information Service of the British Geological Survey at Keyworth, and, except for some confidential records, can be consulted thereby prior arrangement.

NOTES

All National Grid references in this report lie in the 100 km squares SO and SP (Figure 2). The majority of Grid References, that is, those located within square SO are given without the letter prefix; those lying within squares SP are preceded by the letters SP. Grid references to specific localities are given to eight figures (accurate to within 10 m); more general locations are given to six figures.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. SO 98 NW 15). The first two elements define the 10 km square (of the National Grid) in which the borehole is situated; the third element defines the quadrant of that square, and the fourth is the accession number of the borehole.

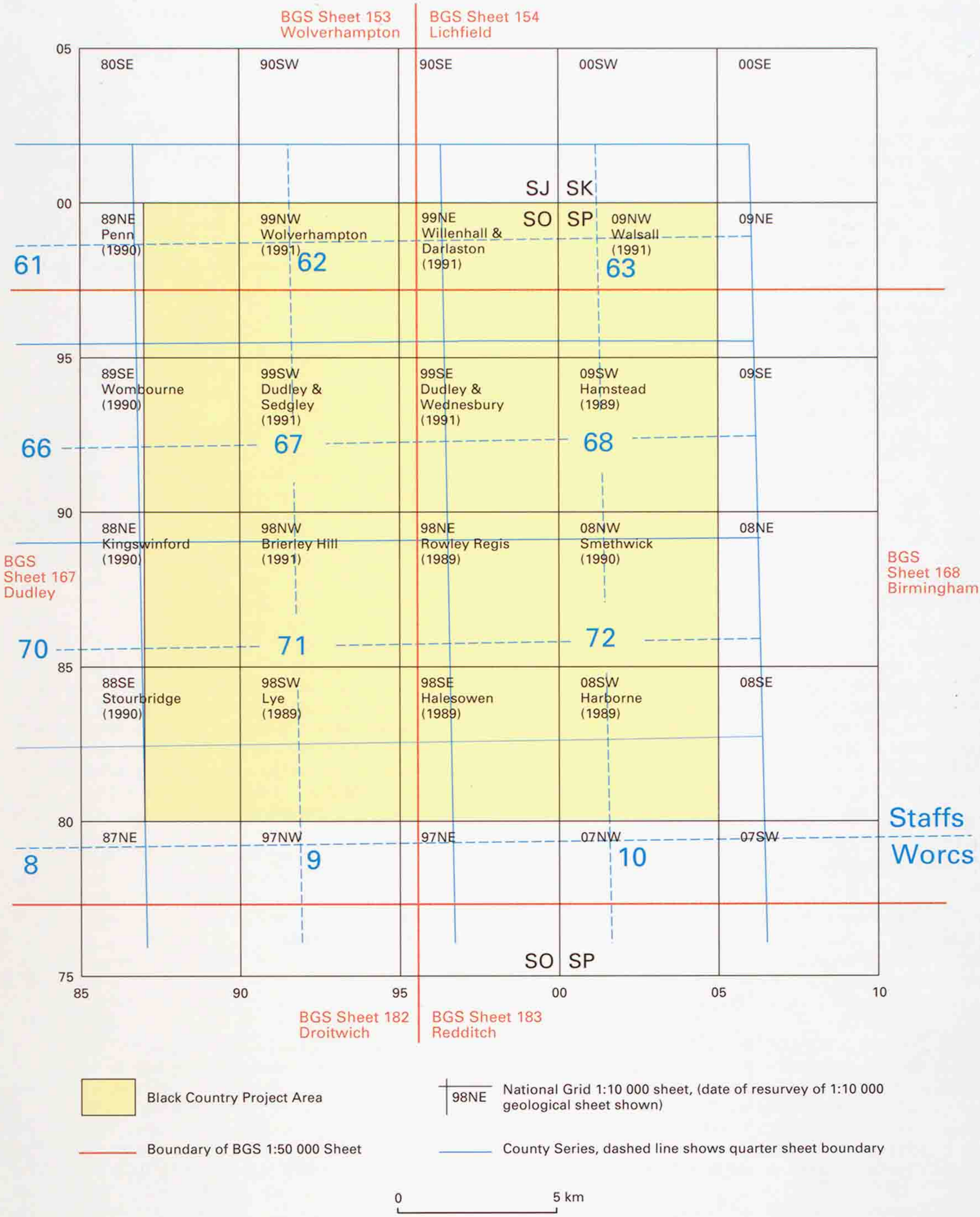


Figure 2 Published BGS geological maps of the Black Country area.

INTRODUCTION

The information in this report was obtained during a three year contract, commissioned by the Department of the Environment in 1989. The work was jointly funded by the British Geological Survey (BGS) and the Department of the Environment.

The report provides geological information as a background for land-use planning and development purposes in the Black Country area. The underlying geological framework is described with special emphasis on aspects relevant to potential land use such as mineral resources, past and present mining and quarrying, foundation conditions and groundwater.

The intention of the report is to provide the geological information in a form which assumes that some readers may have little geological or geotechnical background knowledge. Hence, technical terms are kept to the minimum and a glossary of terms is included to assist the reader. The form of presentation adopted is in line with the recent emphasis placed by the Department of the Environment on producing separate applied geological maps as a way of communicating results to a wider audience than traditional reports constrained by a limited geological approach.

Objectives

The aims of the project were twofold:

1. To produce new geological maps at 1:10 000-scale for that part of the area surveyed at the beginning of the century; that is, all areas except for the exposed coalfield areas which were surveyed in the 1970s (Figure 2). These latter areas were partially revised as a desk study with limited field checking, but with a complete field survey to delineate areas of man-made and disturbed ground.

2. To produce a set of thematic maps at 1:25 000 or 1:50 000 scales, and to collate various geological, geotechnical and other relevant information in a report intended for use primarily by land-use planners and developers. The thematic maps delimit areas and sites with specific geological characteristics relevant to land-use planning and development. Each thematic map highlights a particular aspect of the geology.

The maps and report should be used, together, as a general introduction to geological factors relevant to land-use planning and control of development, and as background information for those preparing desk studies on specific development proposals. The geological information contained on these maps is highly selective as it is not possible to reproduce at the reduced scales all of the information present on the new 1:10 000 geological standards.

Furthermore, the quality of data on some of the thematic maps is very variable; the variability of data is covered, below, under the discussion of the thematic maps. It must be stressed that the information provided on the thematic maps and in the report is interpretive, of variable quality, and is distributed unevenly. Consequently, the maps and report **are not** a substitute for on-site investigation. Furthermore, the report should act as a guide to other more detailed sources, such as the British Geological Survey archives of non-confidential boreholes and other data, including, most importantly, the 1:10 000 geological standards, and accompanying Technical Reports, and the original field-slips, which are the fundamental sources on which much of the report is based. Attention is drawn also to other sources of advice, including those which should be consulted in terms of water, planning and mining interests. It is strongly recommended that the maps and report should be used in conjunction with one another. Each map has only a limited descriptive key; a fuller detailed description and indications of limitations on the information is contained in the report.

Sources of information

The thematic maps and reports have been produced using archival information and by modern geological mapping. The main sources of archival information are listed in Table 1. Previous geological work carried out by the BGS is summarised in Table 2, and the coverage by published small scale (1 inch to 1 mile and 1:50 000) geological maps is shown in Figure 3 and Table 3.

Geological maps of most of the area of the exposed coalfield were revised in the late 1970's (Figure 3) and published at 1:10 000-scale with accompanying open-file reports listing selected boreholes and shafts. These sheets have been further revised during the present survey to include areas of made ground and worked ground, based mainly on subsurface information and limited field checking. Except for minor amendments and the addition of Made Ground categories, these maps are published as sec-

Table 1 Main sources of archival information

British Geological Survey (formerly the Geological Survey & Institute of Geological Sciences)	Geological maps and memoirs, field slips and notebooks: dating from 1850's. Borehole, well and trial pit logs: locations shown on Ordnance Survey 1:10 560 maps. Historical earthquake records. Geophysical data. Engineering geological data
British Coal	Abandoned mine plans. Opencast Site files
Ove Arup (DoE)	Abandoned limestone mine plans
Aerial photographs	Delineation of mineral workings and major new constructions; historical records.
Severn–Trent Water/National Rivers Authority	Details of underground water supply including hydrographs and analyses. Flood Limits
Local Authorities	Site investigation borehole and trial pit data. Abandoned limestone mine plans and borehole data from remedial investigations

Table 2 Summary of previous Geological Survey/BGS geological mapping

MAP SERIES	AREA	DATE OF SURVEY
Old Series (1 inch to 1 mile)	Black Country area	1852–1898
County sheets (6 inches to 1 mile)	Black Country area	1911–1922 with revisions to Silurian 1946–1953
National Grid Sheets (1:10 000) with open file reports	Mostly the exposed coalfield	1977–1978

Table 3 Publication of small-scale (1 inch to 1 mile) geological maps covering the Black Country

SHEET	BGS NUMBER	1 INCH TO 1 MILE	1:50 000 EDITION
Wolverhampton	153	1929 S,D	
Lichfield	154	1926 S,D	
Dudley	167	1939 D	1975 S–D (RC)
Birmingham	168	1924 S,D	

(RC) Reconstituted at 1:50 000 scale without geological revision
S Solid edition
D Drift edition (includes solid)
S-D Solid and drift edition combined

ond editions without major changes to the geological boundaries. The accompanying Technical Reports are published as second editions with additional details of the geology of the sheet area. The remainder of the project area, comprising the sheets towards the south-east and western margins of the area, for which there were no modern geological maps, were subject to full geological revision including field survey. These sheets are published with the latest O.S. topographical base and are accompanied by Technical Reports describing the geology of the sheet area. The component 1:10 000 sheets are listed in Appendix 4. All the maps and reports are available from BGS, Keyworth.

The thematic maps at 1:25 000 and 1:50 000 scale, accompanying this report, have been compiled using the 1:10 000 geological maps and other data to produce a modern synthesis of the geology of the area.

In urban areas such as the Black Country the ability to update the geological maps is largely dependant on the borehole, shaft and trial pit data. As part of this project BGS actively acquired sub-surface data from a variety of sources such as local authorities, site investigation companies, geotechnical consultants and others. The sites of these registered records is shown on Map 1; at the time of publication this holding for the project area was about 17 000. The cooperation of those providing data (Appendix 1) is gratefully acknowledged. Access to the geological records, including the borehole database, may be made by contacting the Manager, Information Services, British Geological Survey, Keyworth, Nottingham NG 12 5GG (Tel: 0602-363100). Appointments must be made in advance. A consultation fee is usually charged.

The sections of the report on groundwater were contributed by S W Fletcher, E L Parry and C A Thomas of the National Rivers Authority, and is based on their well records.

THE THEMATIC GEOLOGICAL MAPS

The results of this geological survey are presented as a series of thematic geological maps at various scales (see below). Some themes are shown on two sheets, at 1:25 000-scale, covering the south and north of the area. Each thematic map highlights a particular aspect of the geology; they should be used in conjunction with the report.

Map no. and theme	Scale	1:25 000 map number South	North
1. Distribution of records	1:50k		
2. Bedrock geology	1:25k	2A	2B
3. Distribution and thickness of superficial (drift) deposits	1:25k	3A	3B
4. Distribution of Made and Worked Ground	1:25k	4A	4B
5. Surface mineral resources and quarrying	1:25k	5A	5B
6. Underground mining	1:25k	6A	6B
7. Slope steepness and selected geomorphological features	1:50k		
8. Hydrogeology	1:50k		
9A. Engineering geology, superficial (drift) deposits	1:50k		
9B. Engineering geology, bedrock	1:50k		

Distribution of records (Map 1)

This map shows the location of boreholes, trial pits and shafts registered in the BGS database at Keyworth. The shaft records are not as complete as those held by British Coal, Bretby. Summary records of selected boreholes and shafts for each 1:10 000 sheet are included in the relevant Technical Report for that sheet; selected details are also presented on the face of the map.

Individual records vary from simple lithological logs to site investigation reports and detailed lithological descriptions; some of the records are held in confidence and may be consulted only after permission hs been granted by the owner of the information. The original non-confidential records may be examined at BGS, Keyworth, Nottingham NG 12 5GG, by prior appointment, or copies of the records can be sent in response to postal enquiries; in either case a fee is charged.

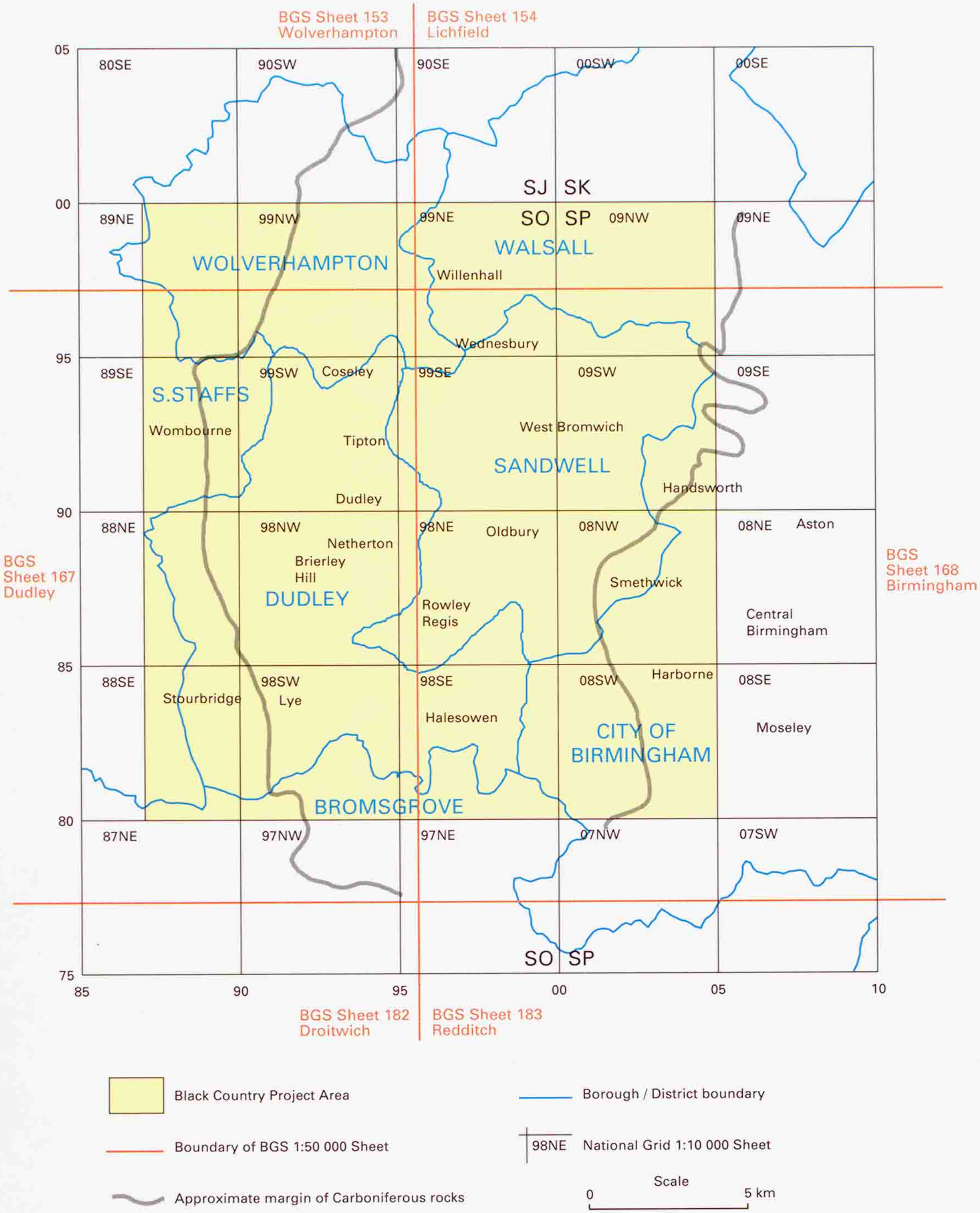


Figure 3 Map of the Black Country study area showing the borough boundaries, component BGS 1:10 00 scale maps and the approximate boundary of the Carboniferous rocks

Bedrock geology (Maps 2A, 2B)

These maps depict the bedrock (solid) geological formations at outcrop; superficial and man-made deposits are not shown. The geological sequence and approximate thickness of the formations is shown in the generalised vertical section. The lithology of the formations is described briefly in this report and in more detail in the relevant Technical Reports for the component 1:10 000-scale sheets. Additional structural information is given in Figures 6 and 9.

Distribution and thickness of superficial (drift) deposits (Maps 3A, 3B)

These maps show the distribution of the drift deposits; bedrock formations are not shown separately. Detailed descriptions of the drift deposits are given in this report, and in more detail in the relevant Technical Reports for the 1:10 000-scale sheets. The boundaries of the deposits are generally conjectural, and many of the drift deposits are characterised by rapid lateral and vertical variations. Only the drift deposit at surface is shown; it may be underlain by, or interdigitate with other drift deposits at depth.

Drift thickness contours (isopachyte lines) show the thickness of drift, contoured in 5 m intervals. The contour data are based largely on borehole data and to a lesser degree on local exposures. Consequently, where sub-surface data are sparse, considerable uncertainty exists as to the thickness of the drift deposits.

Distribution of Made and Worked Ground (Maps 4A, 4B)

Made ground is shown only where the deposit is 2 m thick or over. In some areas this is present as distinctive topographical features which can be easily delineated; in other areas, such as the older parts of the exposed coalfield, the Made Ground has been spread out, more or less evenly, over a wide area as a result of successive periods of redevelopment. Where the deposit does not form a distinctive topographical feature, the boundaries shown on the map are conjectural.

Most Made Ground consists of a heterogeneous mixture of excavated rock and soil, building rubble, and domestic and industrial refuse. The Made Ground, therefore, is not categorised according to its content on these maps. Where these deposits were locally identifiable in the field or from archival sources, such as colliery waste mounds, the nature of the deposit is indicated on the 1:10 000-scale maps.

Surface mineral resources and quarrying (Maps 5A, 5B)

The surface mineral resources are shown as various categories together with the sites of the known quarries. The latter may be open, working, or partially to wholly backfilled (see Maps 4A, 4B). Coal is present throughout much of the Coal Measures outcrop shown on these maps. The approximate location of the principal coal seams at crop, and sub-cropping beneath the drift deposits, is shown in Maps 2A and 2B. The generalised area of near-surface coal resources is shown in Figure 13 as the areas in which coal seams are predicted to come to crop or be found within 50 m of the surface; no assessment or prediction is made as to the the quality, thickness, or extent of former mining of the seams in the area.

Underground mining (Maps 6A, 6B)

These maps show the outline of abandoned colliery-based mines derived from known records held by the Mines Records Office, British Coal, Bretby. In some areas more than one seam may have been mined, at successive levels. The extent of abandoned limestone mines is shown separately; this infomation is derived partly from the records held by British Coal, and partly from the maps and plans accompanying the DoE commissioned report by Ove Arup and Partners (1983). The Index of Known Limestone Mines is that established in the Ove Arup report. The limestone mine data are taken from that report and updated Appendices. An active programme of investigation of the limestone mines is taking place. The outline of the maximum extent of undermined areas is generalised and approximate at this scale and should not be relied upon for site investigation purposes.

The sites of known shafts are indicated; at some locations more than one position is shown for a shaft, where the original record is uncertain (two or more grid references may be given for a particular shaft). The positions are generalised from records held by British Coal, Bretby, and should only be used as a guide to the density of shafts in an area.

For detailed local information about the position of shafts and the delineation of abandoned colliery-based mines the original surveyor's mineplans and shaft register held by British Coal, Bretby, must be consulted. For additional information on past mining activity and abandoned mine shafts, particularly for the limestone mines, the records held by the Building Control Officer of the relevant Metropolitan District Borough Council (Dudley, Sandwell and Wolverhampton) should be consulted.

Slope steepness and selected geomorphological features (Map 7)

This map is intended to highlight areas of steep slope which may present a constraint to development. The slope steepness contours are generated from the 1:50 000-scale Ordnance Survey digital contour data at 10 m contour intervals. The slope steepness categories are those considered by most engineers to represent significant angles of slope. This map should be utilised in conjunction with the Engineering Geology maps (9A, 9B) which outline the geotechnical properties of the materials and show the position of landslips.

Selected geomorphological features are shown in order to highlight the principal landforms in the area, and their relationship to the underlying geology.

Hydrogeology (Map 8)

This map shows the outcrop of the principal aquifers in the region and their summary characteristics, aquifer protection zones surrounding abstracting licensed wells, summary well data, and additional features of hydrogeological and hydrological interest. Further information on the hydrogeology of the Black Country area and abstraction rates is given in this report.

Engineering geology, superficial deposits (Map 9A) and bedrock (Map 9B)

These maps show the distribution of the engineering geological categories of both bedrock and superficial deposits and summaries of their geotechnical properties. The engineering geological categories are cross-referenced to the

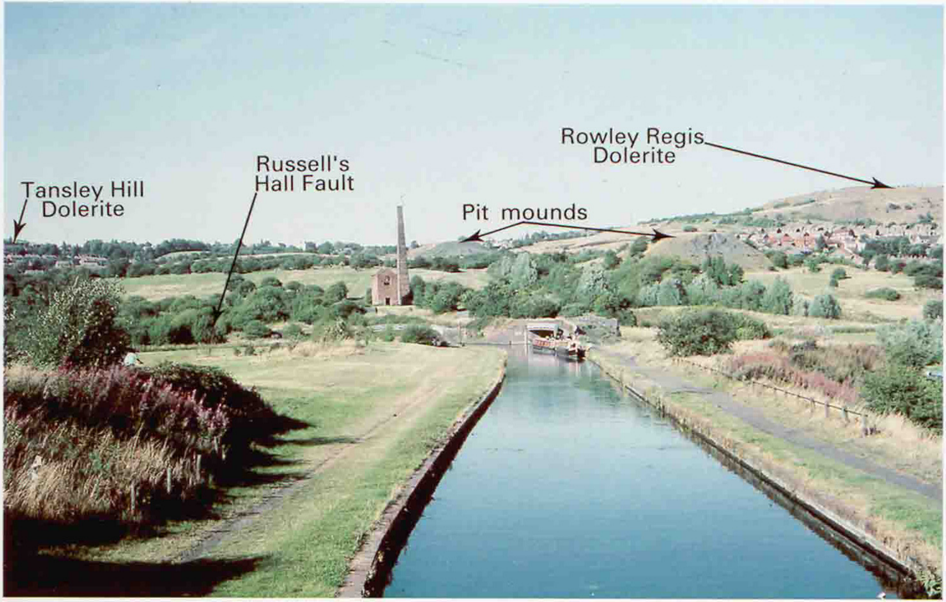


Plate 1 Warren's Hall Park, Dudley. View of the Dudley Canal (looking north-east) near to the entrance of the Netherton Tunnel. Cobb's Engine Pit and two prominent pit mounds are relics of coalworking at Windmill End Colliery. The high ground represents the dolerite outcrops at Rowley Regis and Tansley Hill. The steep slope in the vicinity of Cobb's Engine Pit marks the line of the Russell's Hall Fault.

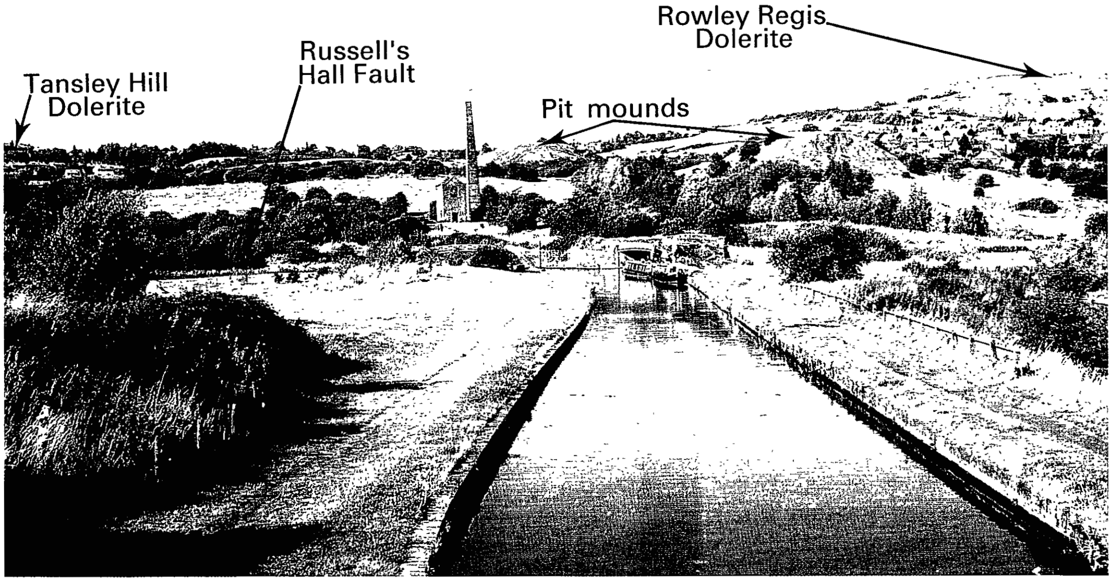


Plate 1 Warren's Hall Park, Dudley. View of the Dudley Canal (looking north-east) near to the entrance of the Netherton Tunnel. Cobb's Engine Pit and two prominent pit mounds are relics of coalworking at Windmill End Colliery. The high ground represents the dolerite outcrops at Rowley Regis and Tansley Hill. The steep slope in the vicinity of Cobb's Engine Pit marks the line of the Russell's Hall Fault.

bedrock formations and superficial deposits shown on Maps 2A, 2B, 3A, and 3B, respectively. Areas of landslip are also shown. These maps should be used in conjunction with Map 7 (Slope steepness). The engineering geology maps are intended for regional feasibility studies and should not be used to supplant detailed site investigation and geotechnical studies of a site.

GEOGRAPHICAL BACKGROUND

Physical setting

The study area (Figure 1) comprises part of the West Midlands conurbation — the Black Country — and a narrow tract of agricultural land to the south and west; it covers an area of 348 km^2. The area is mostly urban and includes the metropolitan boroughs of Dudley and Sandwell and parts of Wolverhampton MBC, Walsall MBC, the City of Birmingham, South Staffordshire County and Bromsgrove District (Figure 3). The component 1:10 000 National Grid Sheets are shown in Figure 3, and listed in Appendix 4.

The rapid growth of the Black Country in the 18th and 19th centuries was linked to the development of the Industrial Revolution, based on the exploitation of abundant, varied local mineral resources such as coal, ironstone, fireclay, brick clay, limestone, foundry sand, and aggregates.

Economic growth necessitated the construction of good communication routes, including a network of canals and railways, and more lately, urban motorways. These factors and the proximity of the Black Country to the City of Birmingham, to the east, ensured the continued development of the area. The major heavy industries, on which the prosperity of the area was based, have been in decline since the 1940's. However, new light manufacturing industry and service industries are replacing many of the traditional industries. Deep coal mining ceased in the 1960's, and many of the sites of former large steel complexes, such as Bilston and Patent Shaft (Plate 8), have been exploited for opencast coal prior to reclamation and regeneration to various urban uses, including industrial and housing estates. Except for localised, short-term opencast coal workings the only extractive industries presently working in the area are brick clay, dolerite (aggregate), and sand and gravel.

The topography of the area reflects the underlying geology (Figures 4, 10). The central part, which largely comprises the coalfield, is defined to the west by the Western Boundary Fault and to the east by both the Eastern Boundary Fault, and the Great Barr Fault. The greater part of the exposed coalfield is topographically higher than the surrounding, downfaulted areas to the east and west which are underlain by Triassic sandstone. Areas of lower elevation are largely confined to the valleys of the Tame, in the north-east, and the Stour in the south-west. Most of the upland area lies above the 100 m contour, with many of the hills rising above 200 m in elevation; the highest point is the Four Stones in the Clent Hills (304 m). Within the coalfield numerous faults and folds bring older rocks to the surface as prominent hills, such as the Silurian limestones of Wrens Nest and Castle Hill. These folds form part of a prominent north-east-trending ridge that extends from Sedgley, in the north-west, through the Silurian limestone ridges, to Rowley Regis (intrusive dolerite) and Frankley Beeches in the south-east. The ridge, which represents the main watershed of the district, and of central England, is defined by the trace of the Russell's Hall Fault (Plate 1), and is largely due to the presence of hard, resistant strata such as intrusive dolerite and Silurian limestone on the north-east side of the fault. In the south of the area, the resistant Clent (Breccia) Formation forms the eponymous hills. The hard Kidderminster conglomerate gives rise to a series of ridge-like escarpments, at Wollaston and Stourbridge, in the west, and at Warley, in the east. In general, however, the Triassic Sherwood Sandstone is typified by gently undulating topography, such as the well drained area between Harborne through Edgbaston to Handsworth. Gently undulating topography is also typical of the drift covered areas, typified by the low-lying region around Darlaston and Wednesbury, and to the east of the coalfield, between Smethwick and Handsworth.

To the south-east of the ridge that forms the major watershed, streams drain to the west via Smestow Brook, the Stour and its tributaries to the Severn; to the east of the ridge, the Tame and its tributaries the Rea and Hockley Brook, flow towards the Trent, and eventually to the North Sea. Parts of these river valleys have been canalised, and together with the railways they formed the principal communication routes until the rise of the urban motorways. The Tame flows south-eastwards along a broad valley which was formerly subjected to flooding. In contrast the streams in the west such as the Stour and Smestow Brook flow along more steeply incised channels.

PLANNING BACKGROUND

Introduction

A principal objective of this study is to present applied geological information, relevant to land use and the development of land, in a form suitable to be taken account of in the planning process. Before discussing the geological characteristics of the area it is pertinent, therefore, to briefly summarise some points about the planning process, the planning context in the Black Country, and the ways in which geological information relates to planning issues.

The Planning System

The town and country planning system was established in 1947 and remains unchanged in its essential requirement that planning permission is required for development to proceed. The legislation is now embodied in the Town and Country Planning Act, 1990, as amended by subsequent Acts. The planning system is administered by the Department of the Environment but is operated by local planning authorities - the district, borough and county councils.

The process aims to regulate the development and use of land in the public interest. It is intended to facilitate much needed development whilst striking an appropriate balance with the need to conserve and protect the environment and the quality of life. This is no easy task since, in these relatively crowded islands and particularly in extensively urbanised areas, there are many potentially competing uses for land and many constraints on particular uses.

The main features of the system are development plans and the control of development.

Development Plans

Development plans are mandatory documents prepared by local authorities. These provide the context for deciding planning applications and identify sites needed to meet demands for various land uses and developments. Preparation takes account of the views expressed in public consultations, and plans are reviewed, and updated if necessary, at appropriate intervals. The plans are based on extensive surveys of social, economic and physical characteristics and trends which planning authorities compile for their areas.

There are four types of development plan:

a) Structure Plans set out strategic policies and certain key proposals for counties and are prepared by the County Councils : these are comprised of a written statement and a key diagram;

b) Local Plans give more detailed policies, indicate proposals and allocate land for various uses within the strategic framework set out in the structure plan: these are prepared by district and borough councils outside the Metropolitan areas: local plan provisions are shown on an Ordnance Survey base map;

c) Subject Plans can be prepared to consider issues which are of particular significance in an area, for instance minerals and waste disposal plans prepared by some shire counties; and

d) Unitary Development Plans which are prepared by Metropolitan Boroughs and consist of a strategic part 1 and a more specific part 2 which mirror the functions of the structure and local plans prepared elsewhere.

Most planning issues are dealt with by district authorities but some , such as minerals and waste disposal, are county matters. In the Metropolitan Authority areas there are no counties; thus the boroughs are responsible for all planning issues.

The Metropolitan Borough Councils within the study area have prepared their Unitary Development Plans, and placed them on deposit (Table 4). In some cases, the public inquiry has been held. In all cases, adopted Unitary Development Plans should be operative by the end of 1993. The remainder includes small parts of the shire counties of Staffordshire and Hereford and Worcester where plans of the other types exist.

Control of Development

The second key element of the planning system is the control of development. For most types of development, the prospective developer must submit a planning application to the relevant local authority for consideration and decision by the Planning Committee. The development plan provides an essential framework for such decisions.

If the planning authority fails to issue a decision within a statutory period or refuses the application, the applicant has the right of appeal to the Secretary of State for decision. Appeals may also be lodged in respect of planning conditions attached to a consent granted by the local authority. In such cases a local planning inquiry may be held before an inspector appointed by the Department of the Environment. In a very small proportion of cases which involve issues of more than local importance, the application may be reserved for decision by the Secretary of State for the Environment.

It is expected that any application should be accompanied by sufficient information on the proposal to allow the planning authority to come to an informed decision. Indeed, the authority has the power to request additional information on issues of importance if this has not been provided at the outset. The planning authority is also obliged to seek the view of various statutory consultees, and may also seek views of members of the public who are likely to be affected by the proposed development, before any decision is reached, and may consult more widely.

Planning permissions may be issued to stated conditions aimed at controlling the way in which the proposed devel-

Table 4 Development Plans

DISTRICT	STRUCTURE PLAN	"OLD STYLE" LOCAL PLANS (THAT HAVE REACHED ADOPTION STAGE ONLY	UNITARY DEVELOPMENT PLANS/DISTRICTWIDE PLAN
Birmingham	West Midlands Country Structure Plan (approved March 1986)	*	UDP on deposit April 1991
Coventry	" "	*	UDP on deposit April 1991
Dudley	"	*	UDP on deposit August 1991
Sandwell	"	*	UDP draft March 1991
Solihull	"	*	UDP on deposit l September 1990
Walsall	"	*	UDP on deposit October 1991
Wolverhampton	"	*	UDP on deposit May 1991
Bromsgrove	Herefore and Worcester County Structure Plan (approved June 1990)	Hagley and Clent Local Plan adopted September 1991	Draft Plan March 1992
South Staffordshire	Staffordshire Structure Plan (approved March 1991)	Southern Area Local Plan adopted January 1982	Draft Plan September 1991

* A number of past District local plans have been adopted. Details can be obtained from the relevant local authority.
UDP–Unitary Development Plan

opment is undertaken and to reduce any affects of the development on the environment or the local population. The local authority is responsible for enforcing such conditions.

Advice issued by the Department of the Environment

In order to facilitate the smooth operation of the planning system, the Department of the Environment issues advice to local planning authorities and developers in the form of Circulars and Guidance Notes. Some of these, which describe the general features of the planning system or relate to specific issues which are relevant in the study area, are listed in Table 5.

Information requirements

Since the system is concerned with the use of land, the nature of the ground may be important. The majority of development proposals involve building or construction and the stability of the ground may be an issue. In other cases, such as the extraction of minerals, the development itself relates to ground material. Implementation of development and the resulting land uses may have adverse effects of the environment and these have to be considered before a decision is made or when drawing up planning conditions. Such environmental effects may also relate to earth resources or to the nature of the ground.

Groundwater resources could, for example, become contaminated or development of a site could cause instability or underground migration of gas. Geological information may be relevant, therefore, to a number of aspects of forward planning of land use and control of development.

Sound information on such issues may be required at several stages in the planning process, for instance:

a) wide-ranging information of the charactersistics of an area required by:
   - the local planning authority for formulation of planing policies and proposals in development plans
   - local interests when assessing draft development plan policies
   - the Department of the Environment when considering the regional and national implications of such policies.

b) site specific information required by:
   - prospective developers, and their consulants, when selecting sites and preparing planning applications
   - local planning authorities when deciding such applications
   - other interests when considering the implications of proposed development prior to any decision being made or at a local planning inquiry.

Table 5 Selected documents giving planning advice and guidance

DOE Circulars

21/87 Development of contaminated land
27/87 Nature Conservation
15/88 Environmental assessment
17/89 Landfill sites: development control

Planning policy guidance

1. General policy and principles (1992)
2. Green Belts (1988)
3. Land for Housing (1988)
4. Industrial and Commercial Development and Small Firms (1988)
12. Development plans and Regional Planning Guidance (1992)
14. Development on Unstable Land (1990)

Minerals Planning guidance

1. General considerations and the development plan system (1988)
2. Applications, permissions and conditions (1988)
3. Opencast coal mining (1988)
6. Guidelines for aggregates provision in England and Wales (1989)
7. The reclamation of mineral workings (1989)

Derelict land grant advice

1. Derelict land grant policy (1991)

(Note: all are published by HMSO)

If a development is likely to have significant environmental effects, the developer may be required to submit an environmental assessment. In general terms, such assessments are needed for major projects which are of more than local importance; some smaller scale projects which are proposed for particularly sensitive or vulnerable locations; and, less commonly, projects with unusually complex and adverse environmental effects (DoE, 1988a).

Results such as those from the present study are a useful source of geological information which can be drawn upon in preparation of environmental assessments. The present study contains information which contributes to the first of these two levels of consideration but the results are general and cannot be used for site specific purposes. They do, however, give a general context which is relevant to the early stages of examination of alternative sites and helps in identification of the range of issues which may need special consideration during any specific site investigation. It is usual for developers and their advisers to seek relevant information from a wide range of sources at this 'desk study' stage. The present results and, more particularly, the database on which they are founded, allow this to be done more quickly and more thoroughly for the issues covered than is otherwise possible.

Strategic planning issues

Strategic planning guidance, resulting from joint consideration by the local planning authorities and the Department of the Environment, was issued for the West Midlands metropolitan area to give a context for preparation of Unitary Developments Plans (DoE, 1988b). This emphasised the need to revitalise the subregional economy and to rejuvenate inner city areas, for instance, by:

— providing housing requirements and improving the housing stock in each Metropolitan District;
— providing high quality industrial sites by both recycling industrial land and releasing greenfield sites;-
— conserving the natural and built environments; and
— improving the environment in the Black Country by 'loosening the existing urban structure' and enhancing the physical and social infrastructure;

The West Midlands Regional Forum of Local Authorities picked up, and expanded upon, these themes in a consultation report on key planning issues in the region (1991) which was a first step in preparing regional planning guidance. This report emphasised that serious problems of dereliction in the Black Country and lack of the service sector growth enjoyed by nearby Birmingham. Particular problems were a deficiency of modern infrastructure and of high quality industrial sites. It was felt, however, that the area is poised to benefit from major infrastructure projects such as the western and northern orbital motorways. Improved access should assist in making the area more commercially desirable and, therefore, rejuvenate the local economy. In planning terms, this would mean increasing demand for good sites for development, part of which might be realised through derelict land reclamation and urban renewal. This accent on development is necessary for economic prosperity but it could have environmental disbenefits. However, the Regional Forum also recognised the great potential in the Black Country for 'greening the urban environment'.

The need to promote development and redevelopment in the Black Country is being addressed by the local authorities and the Black Country Development Corporation and an Enterprise Zones has been created in Dudley.

The Government White Paper 'This Common Inheritance' (Anon, 1990) indicated the need to work towards a more 'sustainable environment' by :

- working towards the resolution of conflict between development and mobility pressures and the conservtion of what is best in both the rural and urban environments;
- maintaining economic growth without making excessive demands on natural resources; and
- combating pollution without jeopardising economic growth.

The aim of planning to strike the best balance between these contrasting aspirations requires an adequate information base. The Regional Forum proposed surveys of the natural environment to identify, amongst other things, mineral and water resources, despoiled or derelict land and landscapes, and ageing landscapes in need of rehabilitation. The present report contributes to these for the part of the Region studied; directly in the case of minerals and water; and indirectly through information, on ground conditions, which relates to both land which is currently derelict and to land which could become derelict in future. Such information will help to inform the debate on options and strategic choices which will aim to:-

- secure the preservation and conservation of the common and collective inheritance;
- ensure the most effective use of built resources;
  aid selective exploitation of natural resources; and
- leave a legacy of natural and built resources to future generations.

KEY ISSUES FOR WHICH GEOLOGICAL INFORMATION IS REQUIRED

The following sections review briefly some of the planning issues in terms of the results of this study.

Housing, construction and infrastructure

The Regional Forum identified that much of the Black Country is urbanised but a significant part of the housing stock and infrastructure needs to be improved. Conversely, limited areas of greenfield sites which could be used for additional development have an environmental value which might sometimes outweigh their use for such purposes. A great deal of this undeveloped land is designated as Green Belt which places strict limitations on the types of development which are likely to be appropriate.

Deterioration of housing stock and other buildings is an inevitable ageing process but this can be exacerbated where existing structures are on ground which is subject to movements such as mining subsidence, shrinking and swelling of clays or shales, or heave due to mineralogical changes. Chemical reactivity of groundwater can also give rise to damage to foundations.

Understanding of the distribution of these factors can give prior warning of where deterioration may be most extensive or, in the case of mining instability, where properties may be severely damaged and land may become derelict.

The selection of sites for new development or re-use needs to proceed on a rational basis whether at the level appropriate to Local Plans and Part 2 of Unitary Development Plans, or the selection of individual sites by prospective developers. The most cost effective sites are those in which the foundation conditions are good. Less expenditure is needed, for example, on ground treatment or remedial measures prior to construction where sound rock or compact granular deposits are close to the ground surface. Similarly the thickness of soft materials may influence the depth to which foundations have to be placed or the ways in which underground development, such as tunnelling, are carried out. Applied geological information helps in identification of areas with good ground properties and, in more extreme cases, the extent of mined ground which could give rise to damage if appropriate measures are not incorporated into foundations and building design.

The Regional Forum also stressed the likely benefits of improved road access to the area both in terms of peripheral motorways and the Black Country link to these. The initial selection of such road lines takes in a variety of economic and social factors but also needs to take account of ground conditions on the various alternative routes since these may have a major impact on construction costs. The ground conditions are rarely overriding in the selection process since engineering solutions to most problems can be found, but they can give some forewarning of expenditure implications.

Derelict Land

The government attaches high priority to the reclamation of derelict land, which has arisen from past industrial and extractive industries. To this end, derelict land grant is made available and is allocated by region. The target expenditure in the West Midlands in 1991/92 was £16.8 million (DOE, 1991a).

A recent survey (DoE, 1991b) indicated that the Black Country contained some 1761 hectares of derelict land, over 44 per cent of which related to past mineral extraction (Table 6).

The whole of the present study area is within an Assisted Area. This qualifies relevant local authorities, the Black Country Development Corporation and English Industrial Estates Corporations for 100 per cent grant, and other bodies for 80 per cent grant in respect of schemes approved by the Department of the Environment. Vigorous derelict land reclamation initiatives from the local authorities and the Black Country Development Corporation are underway. Over 800 hectares of land were reclaimed between April 1982 and March 1988 (Table 7).

These initiatives include a major programme to overcome problems arising from abandoned mines in the Much Wenlock Limestone which is guided by the Black Country Limestone Advisory Panel. About £22 million was spent on this between 1983 and 1987, and a forward programme of investigation, monitoring and remedial action is continuing. However, the Black Country also has a legacy of other extractive sites and land contaminated by industrial processes which may require treatment (Table 6).

The identification of land which has been mined or quarried, of tips, and of made ground and fill which may be contaminated, can contribute to the preparation of registers of land which is being, or has been, put to a contaminative use. Local authorities are charged with compiling and maintaining registers of such land (DOE, 1991c). The information can also help with the preparation of strategies for reclamation of derelict land.

Table 6 Amount of derelict land justifying reclamation at 1 April, 1988, by type, in the Metropolitan Boroughs of the Black Country (hectares)

	Dudley	Sandwell	Walsall	Wolverhampton
Colliery spoil heaps	170	9	58	0
Other spoil heaps	45	20	10	47
Excavations and pits	38	19	56	0
Derelict railway land	20	52	59	25
Mining subsidence	153	77	192	12
General industrial dereliction	91	232	182	42
Other dereliction	4	71	37	40
TOTAL	521	480	594	166

Source: DoE, 1991b

Table 7 Amounts of derelict land reclaimed between April, 1982 and March 1988 in the Metropolitan Boroughs of the Black Country (hectares)

	Dudley	Sandwell	Walsall	Wolverhampton
Colliery spoil heaps	98	5	14	6
Other spoil heaps	38	14	7	9
Excavations & pits	32	65	8	13
Derelict railway land	35	18	28	14
General industrial dereliction	18	55	66	80
Mining subsidence	–	–	122	–
Other forms of dereliction	14	17	5	16
TOTAL	235	174	250	148

Source: DoE, 1991b.

Recent research (R Tym and Partners, 1987) demonstrated that the two commonest causes of delays and additional costs to derelict land reclamation schemes were the presence of unforeseen undermining or contamination by past industrial processes. Thus, early awareness of generalised information relevant to these topics is valuable to help ensure that design of reclamation schemes takes account of all relevant factors.

The reclamation of derelict land has obvious benefits of reducing or removing potential hazards and facilitating productive uses of vacant land. Such uses may be for built development, thus reducing the pressure on greenfield sites, or for amenity uses contributing to the process of 'greening' the urban landscape and so to the opportunities for recreation and improvements to the quality of life.

Tourism and education

The Black Country has a rich industrial archaeology and vernacular architecture heritage which is displayed at the Black Country Museum; itself a reclaimed derelict site. The Dudley Canal Trust has developed visitor access to the original canal which was used to transport stone from the mines beneath Castle Hill in Dudley. Nearby Dudley Zoo takes advantage of the high ground of the Much Wenlock Limestone outcrop.

In addition to these facilities, the Black Country has ten Sites of Special Scientific Interest designated to maintain their availability for research and, in some cases, educational purposes. The best known of these is the Wren's Nest National Nature Reserve which is a focus for many school and student visits, although part is fenced off in order to prevent access to dangerous mine sites.

In addition to such formally designated sites, there are many others of more local value which could contribute to similar purposes. This might be kept in mind when, for example, land formerly worked for minerals is reclaimed for new uses. The results of the present study draw attention to many of the key geological features in the area.

Minerals

Minerals are needed by society for many purposes, for example coal for energy production; sand, gravel and crushed rock for construction; or clay for bricks, pipes and tiles. Minerals can only be extracted from geological sources of the right compositions, thus the options for quarry locations are limited. However, quarrying is a destructive process which may have adverse environmental effects such as noise and dust. Mineral Planning Authorities attempt to guide working to the least harmful locations. Planning conditions are set to limit the environmental effects of working and to secure reclamation of workings to appropriate after-uses. However, information on the mineral resources of an area, interpreted from geological mapping, is needed for the various options to be identified.

In addition, knowledge of the resources allows informed decisions to be taken on whether development which might sterilise them should be allowed. An alternative to sterilisation is extraction of the mineral before the subsequent development is commenced thus securing a double benefit from a site.

A large part of the Black Country is urbanised so a major proportion of the remaining mineral resources have already been sterilised, are in small fragmented sites which are unlikely to be economic to work, or are so close to housing that working would not normally be acceptable. Even so, resources do remain in surrounding Green Belt land and there may be exceptions in the more urbanised areas. Opencast working of coal, for example, has been carried out on land reclamation sites (Grimshaw, 1990), sometimes to excavate shallow mines and infill the land to make it safe, for instance around the Bilston Steelworks and Patent Shaft Steelworks sites. Old mine tips may also be washed to extract fine coal particles before the material is landscaped or transported away for other uses, such as fill. In both cases, the value of the extracted coal may help to defray the costs of the reclamation works.

Water resources

Water resources occur both at the ground surface and within the ground.

Resources in the rivers of the Black Country are limited and much of the local supply is piped from elsewhere. However, there are locally significant sources of groundwater which are extracted from wells, principally within sandstones. Groundwater accumulates in pores, cracks and cavities in rocks over a long period of time. If depleted by excessive extraction, it can take a very long time to be replenished. Equally, it may be vulnerable to pollution from boreholes, mines or the ground surface. For these reasons, groundwater abstraction and safeguarding of water quality are subject to strict regulation by the National Rivers Authority. Such regulations arise from legislation outside the planning system but planning still has a part to play since some land uses give rise to greater risks of contamination. Thus the National Rivers Authority is a statutory consultee on planning applications.

Groundwater is not only vulnerable to contaminants released below the ground surface. Where permeable rocks are present immediately beneath the soil profile, percolating rainwater or water from rivers or drainage systems may carry contaminants down to the groundwater resource. Such vulnerable areas can partly be defined by consideration of the relationships between geological materials present in an area and known water resource horizons (aquifers).

Waste Disposal

Although a greater emphasis is being placed on recycling, modern society produces large quantities of wastes. Some are chemically inert and can be safely used as fill, for instance in construction works or disused quarries, but many others are more difficult to deal with. Most domestic and industrial wastes are disposed of in landfill sites, often in abandoned quarries.

Decomposition and chemical reaction within these give rise to noxious gases and chemical leachates. Fluid wastes are sometimes disposed of down boreholes. All of these can give rise to serious safety or pollution problems unless strict controls are observed. Containment measures are taken to prevent leakage from sites, especially to prevent pollution of water resources. Whilst adequate containment measures can be carried out for a wide range of geological settings, the least expensive tend to be those in fine-grained rocks with few fractures and fissures such as some clays. Again the geological maps can give some guidance on the parts of an area within which suitable sites are most likely to be found.

Conclusion

In summary, the key planning issues in the study area are the rehabilitation of housing, the provision of industrial sites and infrastructure such as roads, reclamation of derelict land and the 'greening' of the urban landscape, safeguarding of water resources, conservation of the natural environment, provision of waste disposal facilities and, where appropriate, the extraction or safeguarding of the remaining mineral resources.

Geological information on ground conditions, land instability and water and mineral resources can help to inform any debate on meeting these objectives.

GEOLOGICAL BACKGROUND

Introduction

The geology of an area influences many fundamental natural resources as well as constraints to land use. An appreciation of the geological background thus has considerable importance, especially in an area of such diverse geological materials as the Black Country. The geology of the area may be considered in three tiers – bedrock, at the base, overlain by generally unconsolidated superficial or drift deposits with a relatively thin further layer of man-made and disturbed material at the surface. In some areas the drift and man-made deposits may be absent, or the man-made deposits may directly overlie the bedrock. These three parts are considered separately in the following description.

Bedrock geology and structure

The Black Country area includes a wide variety of sedimentary rocks and smaller outcrops of intrusive igneous rock (dolerite) (Figure 4). The sedimentary rocks at outcrop range in age from Silurian to Triassic, and consist predominantly of sandstone, siltstone, mudstone, conglomerate and limestone, with seams of coal, ironstone and fireclay (Table 8).

The geological history of the bedrock in the Black Country is outlined below, together with a brief description of the rock units, in upward sequence, in the subsequent section. A simplified geological map of the area is shown in Figure 4, but for details Map 2 and the component 1:10 000-scale sheets should be consulted. The geological succession is shown in the generalised vertical sections (Figure 5), and geological cross-sections (Figure 6) show the disposition of the strata across the area. The main characteristics of the principal bedrock formations are shown in Table 9. The nomenclature of the rock units has evolved over the last century, so for comparison the modern names are compared to previous nomenclature in Table 8.

GEOLOGICAL HISTORY

The oldest rocks, at outcrop, in the Black Country are the Silurian strata which were deposited in a warm, shallow shelf-sea between about 430–410 million years ago. During Llandovery times the sea lapped on to the land surface, to the east, and deposited sandstones and shales with a rich shelly fauna. These beds were succeeded, in Wenlock times, by shallow water mudstones and siltstones, and this type of sedimentation continued throughout most of the Silurian. However, at times the supply of silt and mud diminished, and during slight falls in relative sea-level, limestones were deposited. The limestones are composed of abundant and varied shelly fossils and shell debris; in Wenlock times small patch-reefs developed, rich in corals, calcareous sponges and algae. Regression of the sea in late Silurian to early Devonian times, associated with the Caledonian mountain-building episode, resulted in a change of sedimentation as streams fed sand and silt into the basin during a gradual transition from a marine to a continental environment. The latter include fluvial sediments, deposited on the coastal plain, with some winnowed horizons rich in the remains of fresh-water fish.

The area was subjected to gentle folding, uplift and erosion during the Caledonian mountain-building episode, about 380 million years ago.

Subsequent to the Caledonian earth movements, the Coal Measures were laid down in deltaic and swamp-like environments over the eroded, irregular floor of Silurian and Devonian rocks which, at depth, locally form steep sided highs, (Figure 7). The area lay close to the southern margin of the Pennine Basin which includes all of the presently separate coalfields of central and northern England. The southern margin of the basin approximates to the area around the Clent and Lickey Hills which formed part of the land barrier termed the Wales–Brabant Massif. Sand, silt, and mud, derived mostly from Scandinavia was deposited by the southerly flowing rivers and deltas; thickly vegetated peaty swamps developed on the flood-plain. Occasionally the Pennine Basin was invaded by the sea, resulting in the deposition of marine shales (marine bands) that can be correlated over wide areas.

Fluctuations in the rates of subsidence, and sedimentation, and fluctuations in worldwide (eustatic) sea-levels are reflected in the distinct cyclicity of the Coal Measures. A typical, complete cycle begins with marine or brackish shales (such as the named marine bands) which pass up through lacustrine and deltaic deposits consisting of mudstones, siltstones and sandstones. Colonisation of the delta-top by plants during periods of relatively low subsidence resulted in the formation of thick peats underlain by leached soils (seatearth fireclays); after burial and compaction under sediments of subsequent cycles the peats were eventually converted to coal, at depth.

The delicate balance between subsidence and sedimentation is reflected in the great variation of the thickness of the coal seams and interseam thickness over the area. Compared to the adjacent Cannock Coalfield, however, the Black Country area, south of the Bentley Faults (Figure 9) experienced relatively little subsidence, which resulted in a relatively thin overall sequence and the amalgamation of a number of thin seams to produce thicker seams (Plate 3) such as the Staffordshire Thick Coal (9–11 m thick). However, south of a line between Halesowen and Wollescote, the thickness and quality of the coal seams deteriorates rapidly, and the sequence consists largely of mudstone and fireclay, reflecting the proximity of the southern margin of the basin (Figure 7).

During late Carboniferous times there was a gradual transition to deposition in a well-drained, fluvial environment manifested in the 'red-bed' Etruria Formation. Predominantly red mudstones were deposited in oxidising conditions in a flood-plain environment which was periodically cut by fluvial channels in which coarse-grained sandstone and conglomerate were deposited. Dolerite was intruded into the Carboniferous strata in Westphalian C times when these sediments were buried at shallow depths. It takes the form of dykes (cutting sub-vertically through the rock) and laterally transgressive bodies such as sills and lopoliths which broadly follow pre-existing sub-horizontal bedding discontinuities. Volcanic rocks were erupted, locally, at the surface. Following a phase of uplift and erosion in late Wesphalian C time, the Halesowen Formation marks a brief return to sedimentation in alluvial and lacustrine environments, similar to the Coal Measures.

In late Carboniferous and early Permian times, uplift and faulting of the highlands to the south of the Pennine Basin resulted in rejuvenation of rivers which deposited sand, silt and mud on broad alluvial plains in well-drained, oxidising conditions reflected in the red colour of the sediments (Keele and Enville formations). In early Permian times, subsequent to the deposition of the Enville Formation, a period of erosion occurred which was followed by deposition of coarse-grained breccia, the Clent Formation (Figure 7). The latter was deposited as alluvial fans at the foot of an emergent mountain front, located south and west of the

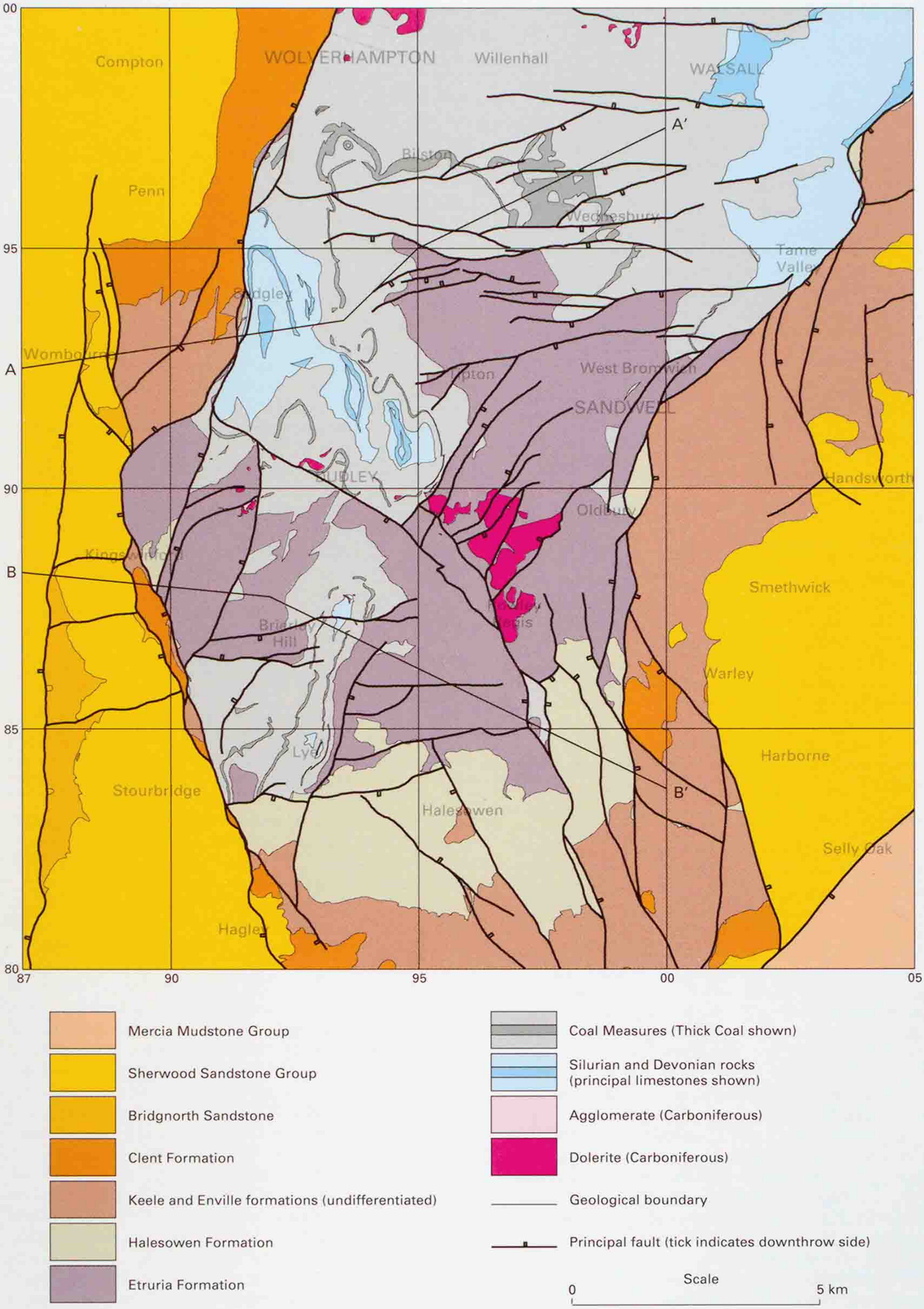


Figure 4 Generalised bedrock geological map of the Black Country

Table 8 Present bedrock geological nomenclature compared to the previous schemes.

GEOLOGY OF SOUTH STAFFORDSHIRE COALFIELD (Whitehead et al., 1927)			GEOLOGICAL SOCIETY SPECIAL REPORT Triassic (Warrington et al., 1980) Permian (Smith et al., 1974) Silesian (Ramsbottom et al., 1978) Silurian (Cocks et al., 1971)		BLACK COUNTRY PROJECT		MAP SYMBOL
TRIASSIC	Keuper	Keuper Marl	TRIASSIC	Mercia Mudstone Group	TRIASSIC	Mercia Mudstone Group	MMG
	Keuper	Lower Keuper Sandstone		Sherwood Sandstone Group: Bromsgrove Formation		Sherwood Sandstone Group: Bromsgrove Sandstone Formation	BgS
	Bunter	Upper Mottled Sandstone		Sherwood Sandstone Group: Wildmoor Sandstone Formation		Sherwood Sandstone Group: Wildmoor Sandstone Formation	WmS
	Bunter	Pebble Beds		Sherwood Sandstone Group: Kidderminster Conglomerate		Sherwood Sandstone Group: Kidderminster Formation	Kdm
	Bunter	Lower Mottled Sandstone	PERMIAN	Bridgnorth Sandstone Formation	PERMIAN	Bridgnorth Sandstone Formation	BnS
		Hopwas Breccia		Hopwas Breccia			
CARBONIFEROUS	COAL MEASURES: Upper Coal Measures	Enville Beds: Breccia Group; Calcareous Conglomerate Group		Clent Breccia Formation (Enville Group)		Clent Formation	Cle
			CARBONIFEROUS: WESTPHALIAN D	Bowhills Formation (Enville Group)	CARBONIFEROUS: STEPHANIAN	Enville Formation	En
	Upper Coal Measures	Keele Beds	WESTPHALIAN D	Keele Formation	WESTPHALIAN D	Keele Formation	Ke
	Upper Coal Measures	Halesowen Beds	WESTPHALIAN D	Halesowen Formation	WESTPHALIAN D	Halesowen Formation	Ha
	Upper Coal Measures	Etruria (Old Hill) Marl	WESTPHALIAN C	Old Hill Marl Formation	WESTPHALIAN C	Etruria Formation	Et
	Middle Coal Measures		WESTPHALIAN B, A	Coal Measures	WESTPHALIAN B, A	Coal Measures	CM
SILURIAN	Downton	Passage Beds		Red Downton Beds	DEVn	Downton Group: Ledbury Formation	Lby
	Downton	Temeside Beds (Temeside Group)		Temeside Shales	SILURIAN	Downton Group: Temeside Shales Formation	Tsh
	Downton	Downton Castle Sandstone (Temeside Group)		Downton Castle Sandstone		Downton Group: Downton Castle Sandstone Formation	DCS
	Ludlow	Upper Ludlow Shales		Whitcliffe Beds		Whitcliffe Formation	Wc
	Ludlow	Aymestry (Sedgley) Limestone		Sedgley Limestone		Aymestry Limestone Formation	AL
	Ludlow	Lower Ludlow Shales		Lower Ludlow Shales		Elton Formation	Elt
	Wenlock	Wenlock (Dudley) Limestone		Dudley Limestone		Much Wenlock Limestone Formation	MWL
	Wenlock	Wenlock Shales		Wenlock Shales		Coalbrookdale Formation	Cbd
	Wenlock	Woolhope (Barr) Limestone		Barr Limestone		Barr Limestone Formation	BL
	Wenlock					Buildwas Formation	Bw
	Llandovery	Upper Llandovery Sandstone		Rubery Shale Rubery Sandstone		Rubery Formation	Rby

Table 9 Principal bedrock geological units in the Black Country area and their economic uses

SYSTEM	FORMATION OR GROUP	PRINCIPAL LITHOLOGY	ECONOMIC USE
Triassic	Mercia Mudstone	Red mudstone with thin sandstones	Brickmaking
	Bromsgrove Sandstone	Fairly compact red sandstones, locally pebbly	Formerly used as building stone; good water supply
	Wildmoor Sandstone	Soft red sandstones	Moulding sand in the foundry industry
	Kidderminster Formation	Pebble beds and red sandstones	Building sand and and gravel
Permian	Bridgnorth Sandstone	Red sandstone	Building sand
	Clent Formation	Breccia, mudstone and sandstone	Brick clay (mudstones in north of area)
Carboniferous*	Enville Formation Keele Formation Halesowen Formation Etruria Formation	Sandstone, mudstone and conglomerate	Brick and tile making (mostly Etruria Fm.) Sandstones used locally as building stone
	Coal Measures	Sandstone, shales, mudstone with coal, ironstone, and fireclay seams	Coal, fireclay and ironstone of former economic importance
	Intrusive igneous	Dolerite	Road metal
Silurian to Devonian	Downton Group	Sandstone, siltstone and mudstone	Sandstone (Gornal) used as building stone
	Chiefly Aymestry Limestone Much Wenlock Limestone** Barr Limestone (intercallated with calcareous mudstone units)	Limestone and and calcareous mudstone	Limestone formerly worked for flux in the production of pig iron; agricultural lime

* see Table 11 for details
** see Table 10 for details

area. The erosional phase stripped off much of the Enville Formation, in the south of the Black Country area, so that the Clent Breccia locally rests unconformably on the Keele Formation. Later in Permian times, downfaulting of the areas to the west of the coalfield led to the development of a basin in which aeolian (dune-bedded) Bridgnorth Sandstone was deposited in an arid desert environment.

A further phase of uplift and erosion resulted in an unconformity at the base of the Triassic Sherwood Sandstone Group, so that it locally overlies rocks ranging in age from the Upper Carboniferous (Keele Formation) to Permian (Bridgnorth Sandstone). The group is characterised by coarse-grained conglomerate, sandstone and less commonly mudstone, which were deposited in fluvial and lacustrine environments, in a semi-arid climate. The characteristic red colouration is due to the presence of iron oxides.

The final phase of deformation, in post-Triassic times, resulted in the downfaulting of the the Triassic strata to the east and west of the boundary faults which define the relatively uplifted block, the coalfield.

The individual bedrock units (groups, formations and members) are briefly described, below, in sequential order. The nomenclature is summarised in Table 8.

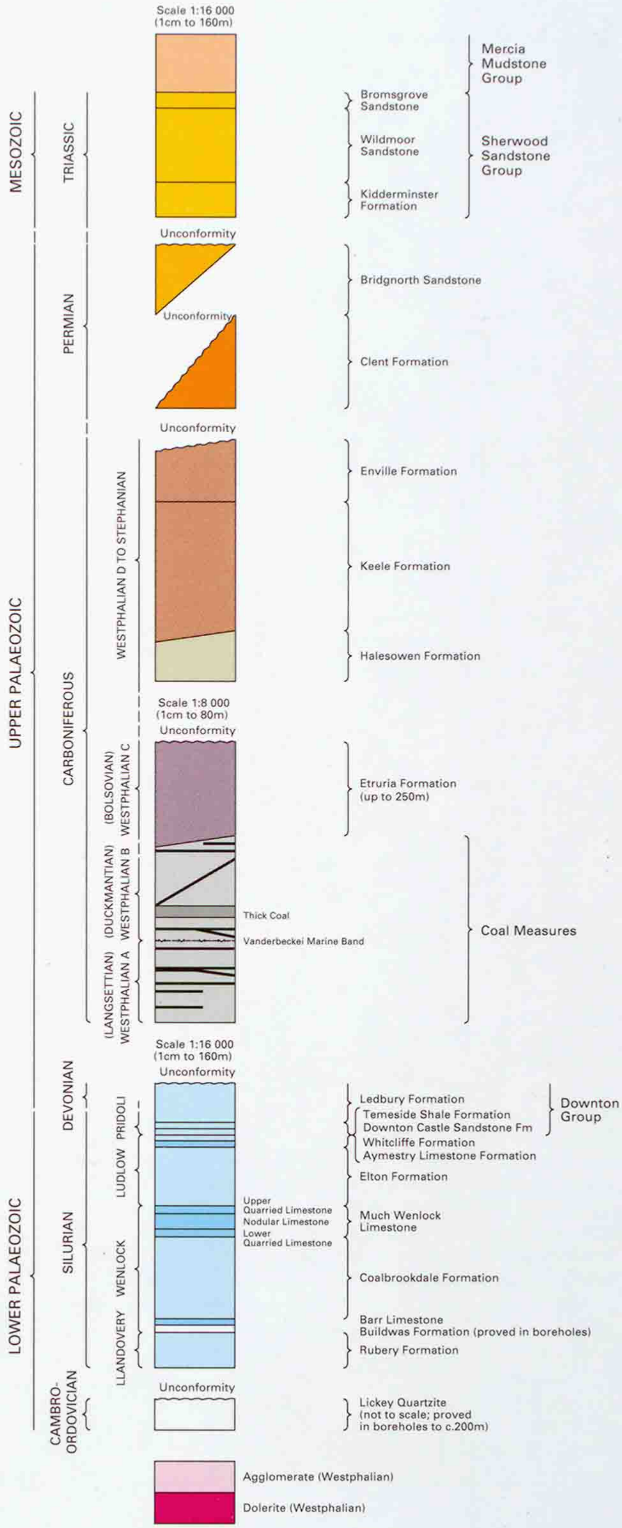
Cambrian–Ordovician

Rocks of this age do not crop out in the area, but have been proved in boreholes in the Walsall area, below the Silurian Rubery Formation. They comprise hard, pale grey quartzite and by analogy with similar rocks exposed in the Lickey Hills, south of the area, they are included in the Lickey Quartzite.

Silurian and Devonian

Rocks of Silurian and Devonian age are the oldest exposed strata in the area. They appear at the surface in two main areas. In the north-east, near Walsall, Silurian shales (calcareous mudstone and siltstone), together with subordinate limestone and sandstone give rise to gently undulating topography. Between Dudley and Sedgley, hard Silurian limestone interbedded with softer shales are folded to form three prominent hills (Dudley Castle Hill, Wren's Nest and

Figure 5 Generalised vertical section of the bedrock strata.



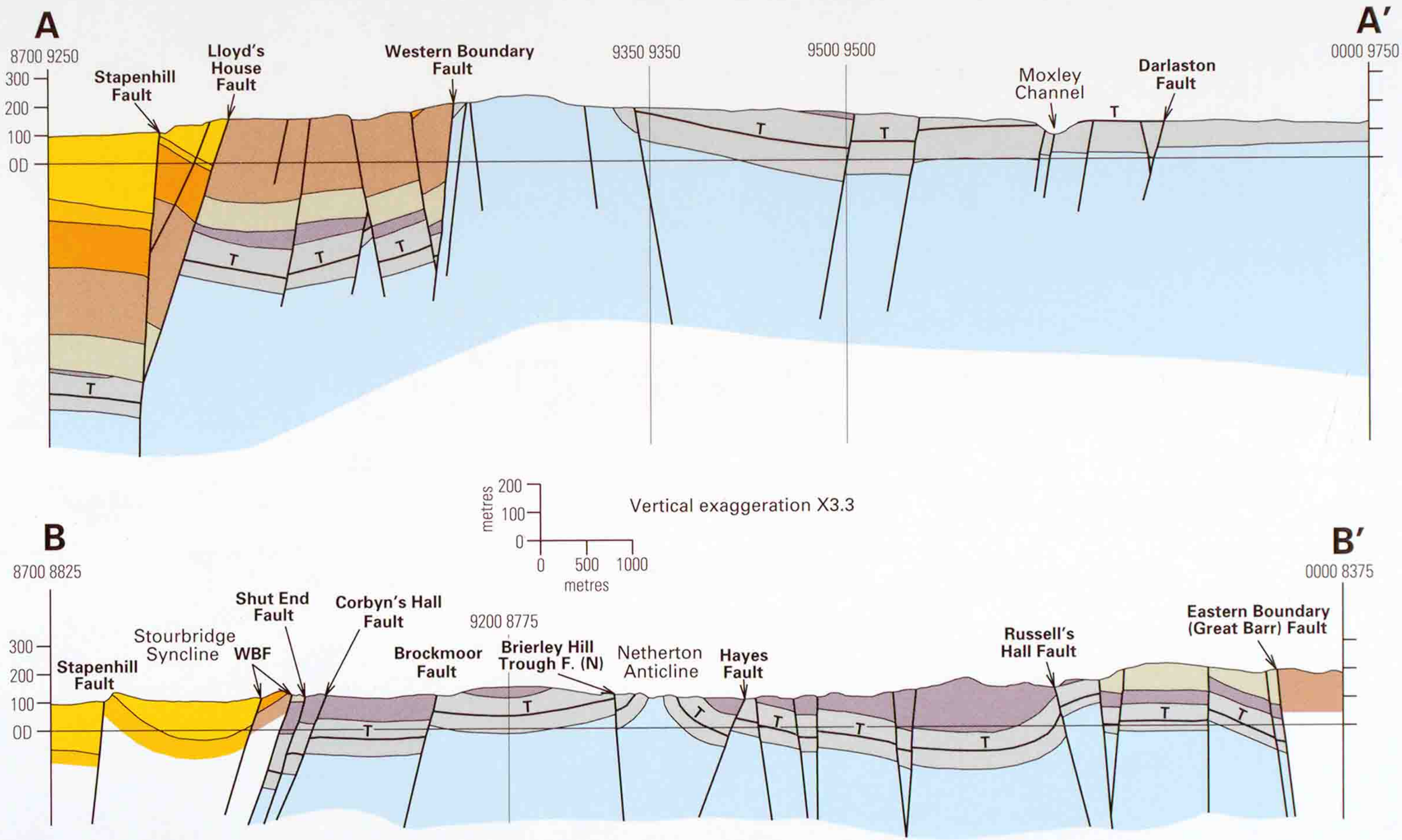


Figure 6 Generalised horizontal cross-sections along lines A–A' and B–B' as shown in Figure 4. See Figure 4 for key.

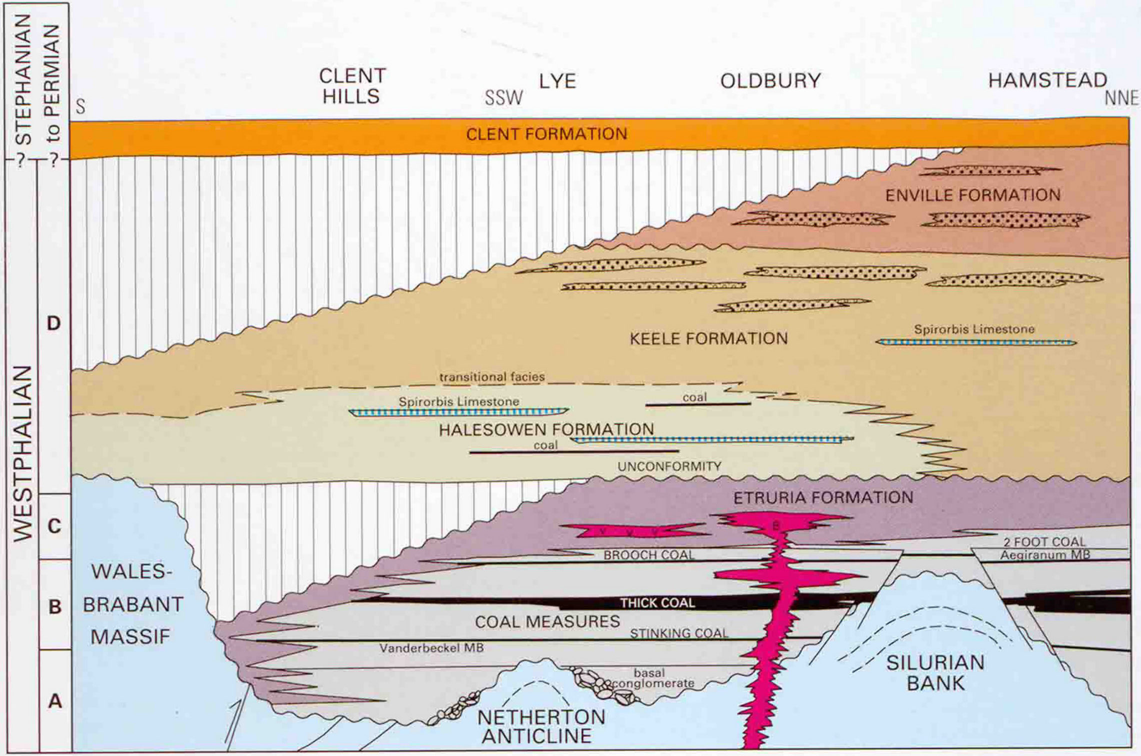


Figure 7 Schematic diagram showing the generalised stratigraphical relationships of the Carboniferous rocks in the Black Country. Not to scale. Vertical lines indicate non-deposition or erosion of strata.

MB– marine band. V– volcanic rocks. B–basaltic intrusion. Sandstones in Keele and Enville formations are shown stippled

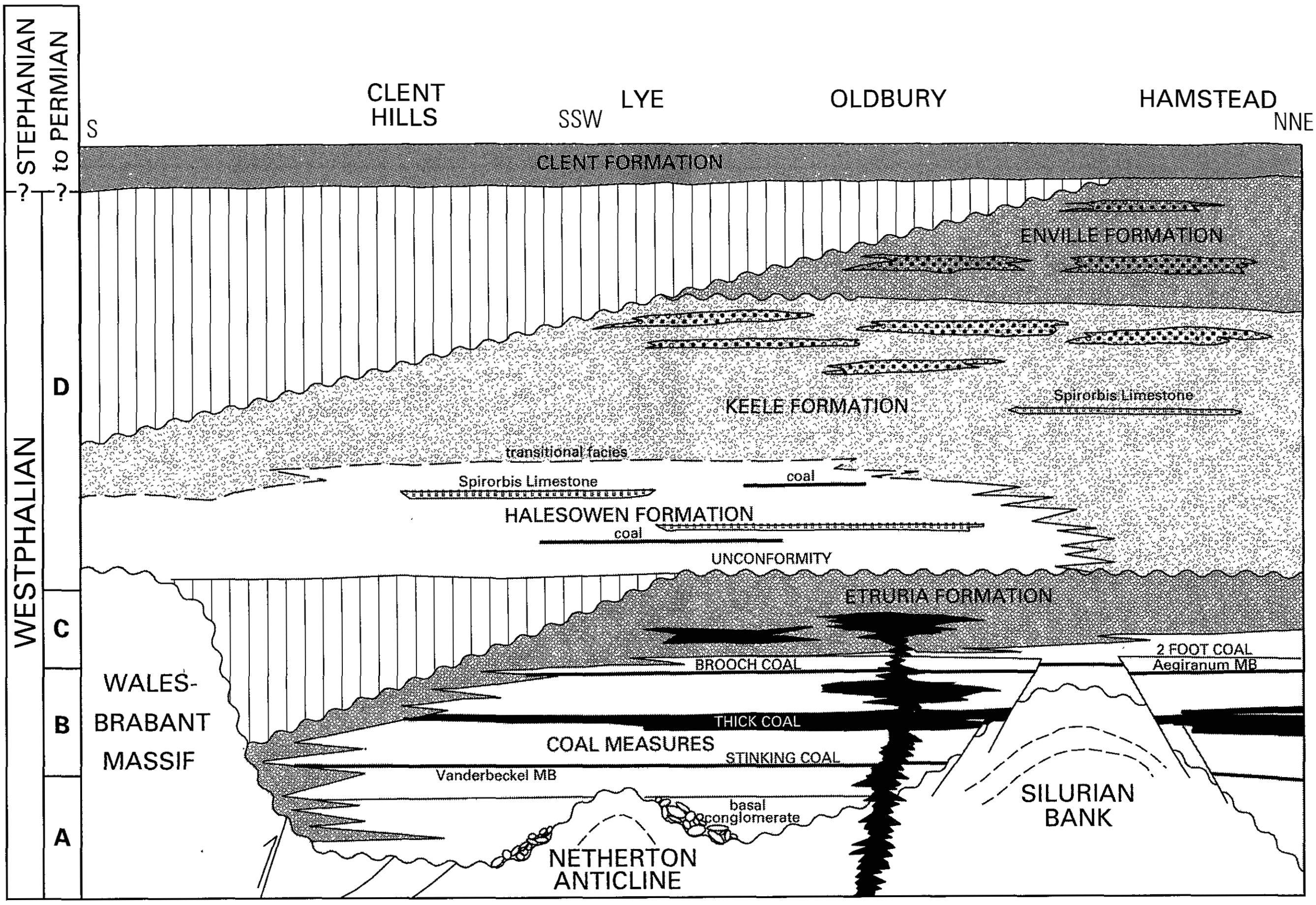


Figure 7 Schematic diagram showing the generalised stratigraphical relationships of the Carboniferous rocks in the Black Country. Not to scale. Vertical lines indicate non-deposition or erosion of strata.
MB– marine band. V– volcanic rocks. B–basaltic intrusion. Sandstones in Keele and Enville formations are shown stippled

Hurst Hill–Sedgley Beacon). Smaller outcrops are present at Netherton, Lye and Wollescote. Silurian and, to a lesser extent, Devonian rocks underlie the Carboniferous Coal Measures, at depth, over most of the area.

Llandovery Series

Rubery Formation

This unit crops out in small fault-bounded inliers along the line of the Eastern Boundary Fault at Great Barr. It is about 90 m thick, and consists of yellow, fine-grained, fossiliferous sandstone intercalated with shaley partings and occasional fossiliferous calcareous beds.

Wenlock Series

Buildwas Formation

The Buildwas Formation forms the basal unit of the Wenlock Series, and consists of about 22 m of greenish-grey shales. It has been proven in boreholes in the Walsall district, but does not crop out.

Barr Limestone

A narrow outcrop of interbedded fossiliferous limestone and shales, the Barr Limestone, is present north of Great Barr. The unit is about 9 m thick and was formerly worked for lime in quarries and shallow adits in the Walsall area. It was also proved, at a depth of -135m OD in a gate road from Springfield Colliery No.1 shaft [958 883], Rowley Regis.

Coalbrookdale Formation

Formerly termed the Wenlock Shales, this unit consists of richly fossiliferous, greyish green shales with thin, nodular limestone beds, ranging in thickness from 152–213m. The formation crops out over a large area to the east of Walsall, and in the cores of the Silurian folds at Castle Hill, Wren's Nest and Hurst Hill. The Coalbrookdale Formation was also proved below the Coal Measures in boreholes in the east of the coalfield at Sandwell, and in the south-east of area between Walsall and Halesowen.

Much Wenlock Limestone Formation

This formation, locally known as the Dudley Limestone, crops out along the northeastern border of the Walsall inlier, and around the periclinal folds at Castle Hill, Wren's Nest and Hurst Hill, and has been proved below the Coal Measures in numerous boreholes between Walsall and Rowley Regis. In this area the formation (Table 10) is sub-divided into an Upper and Lower Quarried Limestone, 10 m and 13 m thick, respectively, separated by the Nodular Limestone (37 m thick); the latter consists of nodular, shelly limestone interbedded with thin partings of grey-green calcareous mudstone and siltstone. The Quarried limestones consist of hard, bioclastic limestone, rich in shelly fossils, and include large, hemispheroidal masses of unbedded limestone rich in fossils which are interpreted as patch-reefs. The names reflect the former importance of the the subdivisions to the quarrying industry, and the upper and lower units were ex-

Table 10 Subdivisions of the Much Wenlock Limestone in the Black Country

Series	Lithostratigraphical Divisions: This Report		Old Terms	Thickness
Ludlow Series	Elton Formation		Lower Ludlow Shale	
Wenlock Series	Much Wenlock Limestone Formation	Upper Quarried Limestone Member	Passage Beds Upper Quarried Limestone	8.6–10.4 m
		Nodular Limestone Member	Nodular Beds	31.1–37.8 m
		Lower Quarried Limestone Member	Lower Quarried Limestone Basement Beds	12.2–16.2 m
	Coalbrookdale Formation		Wenlock Shale	

ploited, down-dip, as shallow adit mines (back cover), and later from shafts as deep mines.

Ludlow Series

Elton Formation

The Elton Formation, formerly known as the Lower Ludlow Shales, crops out around the Silurian inliers of Castle Hill, Wren's Nest, Hurst Hill and to the north and east of Sedgley; a small outcrop occurs at The Hayes, near Lye. It comprises about 152 m of greenish grey, buff-weathering shales and sandy mudstones with thin beds of limestone nodules, similar to the Coalbrookdale Formation. The beds are rich in shelly fossils.

Aymestry Limestone

This formation, known locally as the Sedgley Limestone, is about 8 m thick and occurs around the southward plunging synclinal fold south of Sedgley Beacon, and farther north at Park Hill. South of Sedgley the Aymestry Limestone forms a broad outcrop along the axis of an anticlinal fold. Small outcrops are present at Turner's Hill, Netherton and The Hayes. It consists of about 8 m of nodular limestone with greenish grey shaly calcareous mudstone.

Whitcliffe Formation

Formerly known as the Upper Ludlow Shales, this formation crops out at Sedgley, Turner's Hill, Lye and Saltwells, where it consists of flaggy, silty shales with limestone nodules and thin sandstone. The beds range in thickness from 9–15 m, and have yielded an abundant shelly fauna.

Pridoli Series

Downton Group

The beds above Ludlow strata, in this area, are termed the Downton Group which comprises the Downton Castle Sandstone, Temeside Shales and Ledbury Formation. The Downton Group underlies the unconformable Coal Measures over much of the north-western and southern parts of the coalfield, and is exposed in a number of small inliers (back cover). The top of the Pridoli Series coincides with the boundary between the Silurian and Devonian systems, and in this area is not well defined; it is tentatively taken at a level in the upper part of the Ledbury Formation (White and Lawson, 1989).

Downton Castle Sandstone Formation

The Ludlow Bone Bed, about 0.38 m thick, is present at the base of this formation, and consists of a coarse-grained sandstone rich in winnowed, phosphatised fish remains. It is overlain by buff, silty sandstone and shales, which pass upward to yellow-buff, commonly cross-bedded sandstone, in total about 20 m thick. The lower beds are exposed at Turner's Hill and the sandstone forms a large outcrop at Gornal where it was erroneously shown on previous maps as part of the Coal Measures. Small outcrops are present at Netherton and the Hayes.

Temeside Shales Formation

This unit consists of about 10m of purple mudstone and siltstone with purple and green, micaceous, fine-grained sandstone; locally thin bone beds contain abundant fish remains. The outcrop is restricted to small inliers at Turner's Hill, Netherton, Lye and Wollescote, and has been proved in a number of boreholes in the latter area.

Ledbury Formation

The Ledbury Formation is the stratigraphically highest unit present below the unconformable Coal Measures. It comes to crop in small inliers at Wollescote and Netherton and has been proved in boreholes to underlie the Coal Measures at Baggeridge, and in the Lye area. About 80m of the formation have been proved in boreholes in the Lye area where it consists of red, purple and green micaceous siltstone and sandstone.

Carboniferous

Coal Measures

The Coal Measures comprise the oldest Carboniferous rocks in the area (Table 11), and rest unconformably on Devonian or Silurian rocks (back cover). The Vanderbeckei Marine Band, which is locally present above the Stinking Coal (Figure 8) has been used to sub-divide the Coal Measures into Lower and Middle divisions, but since the marine band cannot be traced over much of the coalfield, the Coal Measures are considered here, and on the thematic maps, as a single unit.

In the Black Country the Coal Measures range in thickness from 94–152m the thickness diminishing gradually, but irregularly, from north to south. Coal seams (Table 12; Plates 2, 3) comprise only a small part (13–17%) of the total thickness of the Coal Measures; the remainder consists of mudstone and siltstone ('shales'), fireclay, and sandstone with thin beds of ironstone. The complete cycle, described above, is frequently not present due to variations in conditions at the time of deposition. Thus, there may be considerable variation, across the area, in the thickness of the interseam strata, particularly the sandstones. The latter generally represent the deposits of major fluvial channels and their overbank deposits; locally

Plate 2 Exhumed 'pillar and stall' workings in the Stinking Coal exposed at Dibdale Road opencast coal site prior to excavation.

Plate 3 Exposed face of the Thick Coal at the Dibdale Road opencast coal site. Note the collapse of overburden, including redened, burnt shale into old workings on the right.

Plate 2 Exhumed 'pillar and stall' workings in the Stinking Coal exposed at Dibdale Road opencast coal site prior to excavation.

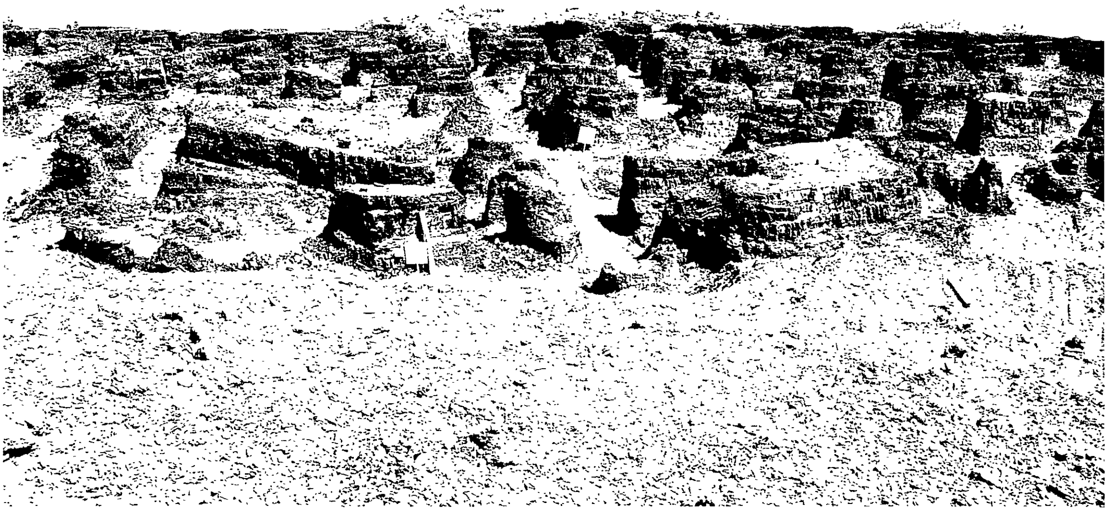


Plate 3 Exposed face of the Thick Coal at the Dibdale Road opencast coal site. Note the collapse of overburden, including redened, burnt shale into old workings on the right.

the channel sandstones may erode all, or part, of the underlying coal seam resulting in a 'washout'.

A generalised section through the Coal Measures showing the principal seams of coal, ironstone and fireclay is shown in Figure 8. Variations in the thickness of the coal seams is shown in Table 12.

Etruria Formation

The Etruria Formation consists of a 'redbed' sequence of mudstone and siltstone characterised by predominantly red colours but with variegations of grey, brown and yellow, together with greenish grey, coarse-grained sandstones and conglomerates, known locally as 'espleys' (Plates 4, 5). Thin, poor quality coals are also present. The boundary with the underling Coal Measures is hard to define since the transition to redbeds is highly gradational and occurs lower down the sequence in the south of the area. The top is marked by an erosional unconformity at the base of the Halesowen Formation (Plate 7). Uplift and subsequent erosion at the end of Etruria Formation times resulted in great variation in the thickness of the formation in the area. Regionally, it ranges in thickness from 61–207 m, but in areas such as Penn it is locally absent, at depth. The formation is the principal brick clay resource in the area.

Halesowen Formation

This formation marks a return to Coal Measures type sedimentation. It ranges in thickness from 76–152 m, and con-

Figure 8 Comparative vertical sections through the Coal Measures in the north-central and south of the coalfield. Datum line is Stinking (Vanderbeckei) Marine Band, above the Stinking Coal.

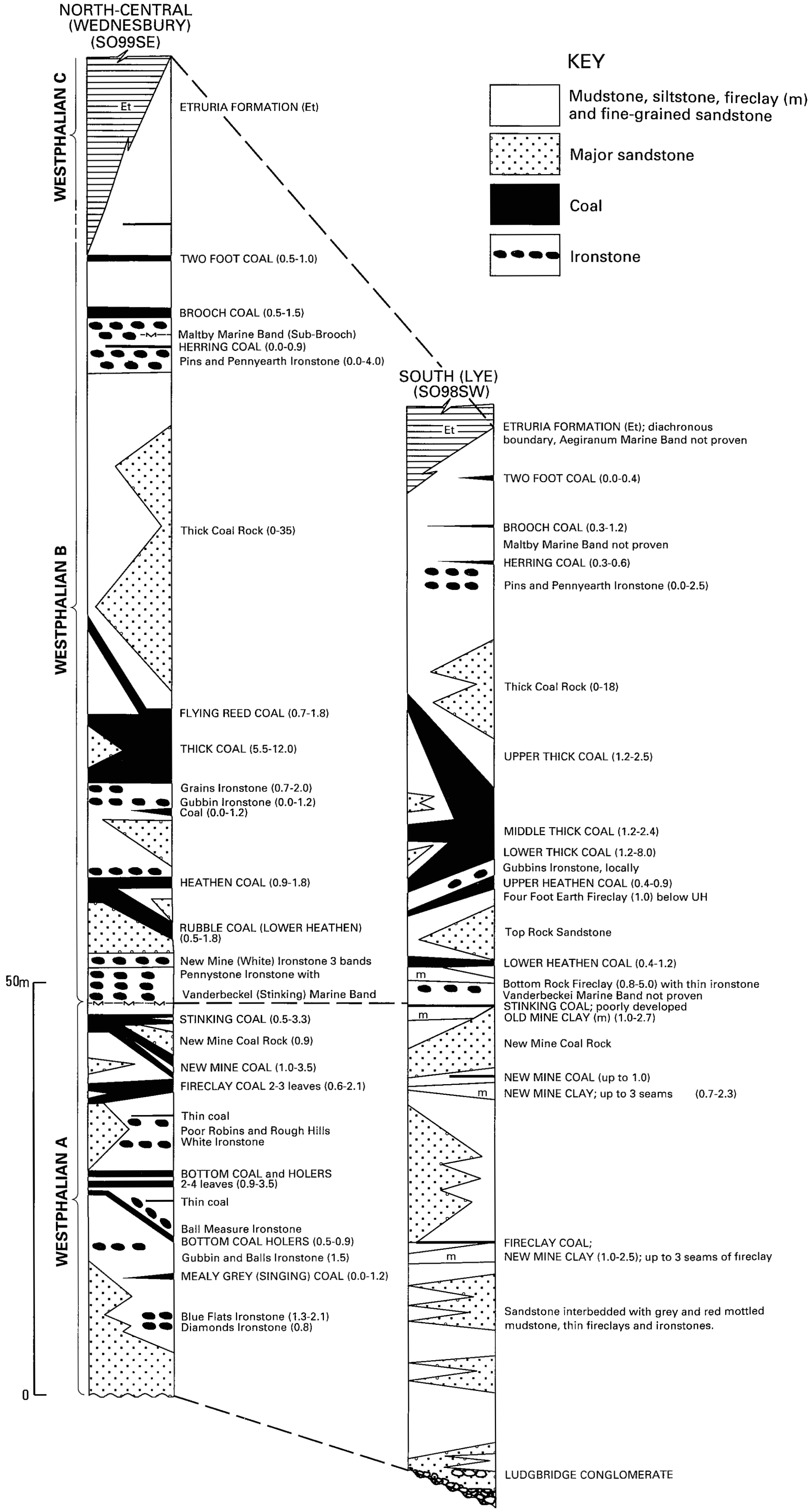


Plate 4
Volcaniclastic tuff bed (dark grey) overlying purple-red mudstones and siltstones, and greenish pebbly sandstones ('espleys'). Etruria Formation, Tansey Green Quarry (brick clay resources).

Plate 5 Purple and yellow-grey palaeosol (fossil soil) horizons and green, pebbly sandstone (left) in the Etruria Formation. Tansey Green Quarry (brick clay resources).

Plate 4 Volcaniclastic tuff bed (dark grey) overlying purple-red mudstones and siltstones, and greenish pebbly sandstones ('espleys'). Etruria Formation, Tansey Green Quarry (brick clay resources).

Plate 5 Purple and yellow-grey palaeosol (fossil soil) horizons and green, pebbly sandstone (left) in the Etruria Formation. Tansey Green Quarry (brick clay resources).

sists of grey-green mudstone and siltstone, and thick beds of yellow weathering, locally pebbly, sandstone. Thin coals (less than 0.5 m thick) underlain by seatearth fireclays are present, but with the exception of workings at Baggeridge Pit, they are too thin to have been worked. Thin beds of pale grey Spirorbis limestone, deposited in fresh-water lakes, occur locally. The formation rests unconformably on the Etruria Formation (Figure 7).

Keele Formation

The boundary between the Keele Formation and Halesowen Formation is gradational and diachronous. It is marked by a mottled zone of purple-red mudstones and sandstones, passing up to orange-red mudstone, siltstone and sandstone typical of the Keele Formation. At depth, in the Hamstead area, the Halesowen Formation passes gradationally and laterally into the Keele Formation (Figure 7). Nodular (caliche) limestone beds and thin Spirorbis limestones are also present. The Keele Formation increases in thickness from about 140 m in the south of the area, to 274 m in the north.

Enville Formation

This formation is lithologically similar to the underlying Keele Formation, but is distinguished by the presence of thick beds of pebble conglomerate, rich in limestone,

Table 11 Carboniferous rocks present within the Black Country and their economic importance

UNIT	LITHOLOGY	ECONOMIC IMPORTANCE
Enville Formation	Red sandstone and marls	Sandstones formerly used locally for building purposes
Keele Formation	Red marls and sandstones	Brickmaking; sandstones formerly used locally for building purposes
Halesowen Formation	Grey marls with clays and sandstones	Sandstones formerly used locally for building purposes
Etruria Formation	Red and purple marls and pebbly sandstones	Brickmaking
Coal Measures	Shales, clays and sandstones with coal, ironstone, and fireclay seams	Former shallow and deep mining of coal, fireclay and ironstone; coal locally exploited in opencast mining

dolomite and chert clasts, and pebbly sandstones. The sandstones are generally red-brown in colour and have a higher proportion of quartz compared to the underlying formation. The formation ranges in thickness from 61–198 m and crops out to the west of the Western Boundary Fault and to the east of the Eastern Boundary Fault.

PERMIAN

Clent (Breccia) Formation

In the type area of the Clent Hills, this formation consists of coarse-grained breccia set in a soft red-mauve mudstone matrix; at depth the rock is stronger due to the presence of a calcite cement. The pebble clasts predominantly consist of sub-angular fragments of volcanic igneous rocks mostly derived from older Precambrian rocks. As the formation is traced northwards from the Clent Hills, the proportion of breccia decreases, with a concomitant increase in the proportion of mudstone and thin beds of sandstone. Thus, in the Baggeridge area the formation is characterised by mudstone and siltstone with thin beds of sandstone, locally with lenses of small pebbles. The boundary with the underlying Enville Formation is difficult to trace in the north of the area, due to the similarity of the non-pebbly strata. In the Clent Hills the formation is 137 m thick; to the north around Baggeridge it is estimated to be 243 m thick.

Bridgnorth Sandstone

The Bridgnorth Sandstone is up to 60 m thick and is restricted in outcrop to a narrow strip in the west of the area, adjacent to Smestow Brook and the Stour valley. It consists of red, fine- to medium-grained sandstone with abundant rounded quartz grains indicative of its aeolian origin. It is characterised by a speckled (mottled) appearance due to the presence of feldspar grains, and by large-scale cross-bedding formed during deposition of the sand as aeolian dunes.

TRIASSIC

Sherwood Sandstone Group

The base of the Triassic Sherwood Sandstone Group is unconformable, so that it overlies rocks ranging in age from the Upper Carboniferous to Permian. The group is subdivided into three formations, in upward sequence, the Kidderminster Formation, Wildmoor Sandstone and Bromsgrove Sandstone. The boundaries between the formations are often difficult to trace due to the similarity of the sandy lithologies. The characteristic red colouration is due to the presence of iron oxides. The Sherwood Sandstone Group outcrop flanks the coalfield to the east and west of the boundary faults and is the best aquifer in the region.

Kidderminster Formation

The lower part (c.20 m thick) of this formation consists of well-rounded pebble conglomerate with a weakly cemented sandstone matrix; the pebbles are composed of hard quartzite, sandstone, vein quartz and, more rarely, igneous rocks; where the conglomerate is locally cemented by calcite it forms a hard rock. The lower conglomerate-dominated part of the formation passes gradationally up to red sandstone with thin beds and lenses of conglomerate, in total about 60 m thick. The formation crops out along the flanks of the coalfield which represented a topographical high during deposition of the basal conglomerate. The junction with the overlying Wildmoor Sandstone is gradational.

Table 12 Approximate thickness of the principal seams in the South Staffordshire coalfield; main worked seams shown thus: *

NAME	APPROXIMATE THICKNESS (in metres)
Two Foot Coal	0.22 — 0.91
*Brooch Coal	0.30 — 1.82
Flying Reed Coal (where separated from the Thick Coal)	0.15 — 0.45
*Thick Coal	5.47 — 9.14
*Upper Heathen Coal	0.61 — 1.52
*Lower Heathen (Rubble) Coal	0.23 — 1.22
Stinking (Sulphur) Coal	0.15 — 1.82
*New Mine Coal	0.45 — 3.96
Fireclay Coals	0.45 — 2.74
*Bottom Coal (including Bottom Hollers Coal)	0.30 — 3.65
Mealy Grey Coal	c.0.70

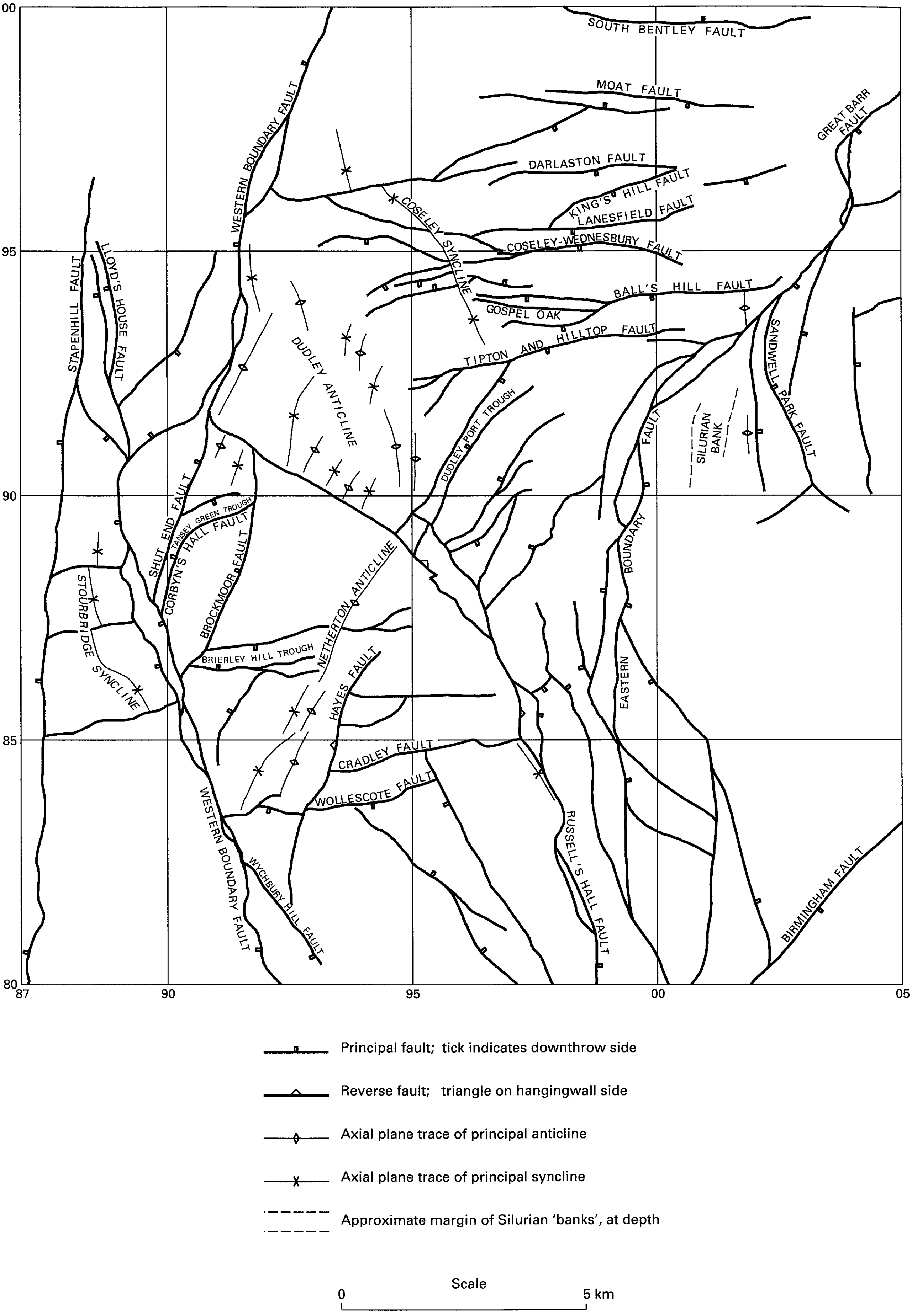


Figure 9 Generalised structural map of the Black Country showing the major faults and folds.

Wildmoor Sandstone

This formation consists of soft, red-orange, fine- to medium-grained sandstone with occasional thin mudstone beds; its speckled (mottled) appearance is due to the presence of weathered feldspar grains. It forms extensive outcrops to the east and west of the coalfield, and ranges in thickness from 61–152 m. The fine grain-size, small clay content and poor cementation made it ideal for exploitation as moulding sand for use in the foundry industry.

Bromsgrove Sandstone

The Bromsgrove Sandstone crops out near Stourbridge and Penn, to the west of the coalfield, and at Selly Oak in the south-east of the area. Red-brown sandstone, pebbly sandstone and pebble conglomerates with a strong calcareous cement are typical. The clasts include rounded quartz pebbles and angular fragments of locally derived mudstone. In the Penn area the formation rests disconformably on the Wildmoor Sandstone, above which it frequently forms a marked escarpment such as at Tettenhall, near Wolverhampton. The Bromsgrove Sandstone was formerly quarried, to a limited extent, for building stone.

Mercia Mudstone Group

The Mercia Mudstone forms a small outcrop to the south-east of the Birmingham fault, in the south-east corner of the area, near Selly Oak. It is about 150 m thick and comprises a monotonous sequence of red and red-brown, calcareous clays and mudstones with occasional thin beds of green siltstone and fine-grained sandstone, known locally as 'skerries'. The calcareous mudstone was formerly exploited for brick manufacture or for agricultural purposes (marling).

Igneous intrusions and Volcanic Rocks of Carboniferous age

Intrusive igneous rocks (dolerite) occur in association with the Coal Measures and Etruria Formation at several localities in the Coalfield. They crop out at Rowley Regis (Plate 8), Pouk Hill (near Walsall), Wednesfield, Barrow Hill (Tansey Green), Netherton, and Gornal Wood. Dolerite sills and dykes have also been proved, at depth, in many boreholes. Dolerite is an intrusive form of basalt and is a hard, dark grey, medium-grained, crystalline rock largely composed of feldspar and ferromagnesian minerals. The dolerite was intruded in Westphalian C times and takes the form of veins, dykes (cutting sub-vertically through the rock) and laterally transgressive bodies such as sills and saucer-shaped bodies (lopoliths) which broadly follow pre-existing sub-horizontal bedding discontinuities. The dolerite was formerly exploited for roadstone and aggregate throughout the area, but there is only one remaining operational quarry, at Rowley Regis.

In the Tansey Green area the dolerite intrusion at Barrow Hill is associated with intrusive agglomerate (composed of sedimentary and igneous fragments) and extrusive airfall tuffs and breccias.

Structural Geology

The disposition of the strata of the Black Country results from the effects of earth movements which can be distinguished as five major phases. The earth movements (phases of deformation and tectonic activity) are manifested as faults and folds (Figure 9) which are described below, in sequential order.

Pre-Coal Measures structures

Most of the principal faults in the Black Country area probably originated as pre-Carboniferous structural lineaments, which have been repeatedly reactivated during subsequent deformation events. Three pre-Carboniferous structural grains are present, namely: north-west-trending (Charnian), north–trending (Malvernian) and north-east–trending (Caledonian). The most distinctive pre-Carboniferous deformation event is the Late Caledonian phase (c. 380 million years ago) of north-west–south-east compression, which resulted in the regional tilting of Silurian to Lower Devonian strata toward the north-west and the formation of north-north-west-trending folds, such as the Netherton Anticline. A number of north-west- to north-north-east-trending faults were active prior to the deposition of the Coal Measures.

Westphalian A to C structures (Coal Measures to Etruria Fm. times)

During the Westphalian A to B the district was located at the southern margin of the regionally subsiding Pennine Basin, which controlled the deposition of the Coal Measures. However, deposition of the Coal Measures and overlying Etruria Formation was also influenced by synsedimentary-faulting, resulting from a phase of north-south extension. North-west- and north-east-trending basement lineaments, such as the Western Boundary Fault, Russell's Hall Fault and Dudley Port Trough, were reactivated. East-west trending grabens, such as the Tansey Green and Brierley Hill Troughs, and half grabens, present in the north of the exposed coalfield, were initiated during this phase of extensional faulting, which was accompanied volcanic activity reflected in the dolerite intrusions such as Rowley Regis and Barrow Hill.

Variscan structures (post Etruria Fm. to Clent Fm. times)

During late Westphalian C to early Westphalian D times (post-Etruria Fm. to pre-Halesowen Fm.) the district was affected by a phase of west-north-west–east-south-east compression, which resulted in uplift and erosion of Carboniferous strata, prior to the deposition of the Halesowen Formation (Figure 7, Plate 7). These earth movements represent part of the Variscan (Hercynian) Orogeny (mountain building episode) which lasted from late Westphalian to early Permian times.

The main front of intensive mountain building movements lay to the south, in South Wales and Cornwall. Major structural lineaments, such as the Russell's Hall Fault, were reactivated and are typified by reverse and strike-slip components of displacement. The compression also produced the series of north-north-west-trending periclines of Castle Hill, Wren's Nest and Hurst Hill and tightened the pre-Carboniferous Netherton Anticline about the same north-north-east-trending fold axis.

Following a phase of relative structural inactivity during the Westphalian D to Stephanian (Halesowen Fm. to Enville Fm.) times the district was affected by a further phase of approximately east-west compression. This resulted in the regional uplift of the coalfield bounded by the Western Boundary Fault (to the west) and Great Barr Fault (to the east), with the greatest uplift occurring to the south. As a result the Permian Clent Formation rests unconformably upon stratigraphically older rocks toward the south of the district.

Plate 6 View along the exhumed Coseley–Wednesbury Fault (looking east). Note the drag of the downthrow strata (left), including two thin coal seams, against the fault. The surface of the lower seam (Two Foot) has been cleaned prior to excavation. Patent Shaft Opencast Site.

Plate 7 Halesowen Formation sandstone (yellow) unconformably overlying mudstones and sandstones of the Etruria Formation (purple-grey). Note the irregular boundary. Ketley Quarry(brick clay resource).

Plate 6 View along the exhumed Coseley–Wednesbury Fault (looking east). Note the drag of the downthrow strata (left), including two thin coal seams, against the fault. The surface of the lower seam (Two Foot) has been cleaned prior to excavation. Patent Shaft Opencast Site.

Plate 7 Halesowen Formation sandstone (yellow) unconformably overlying mudstones and sandstones of the Etruria Formation (purple-grey). Note the irregular boundary. Ketley Quarry(brick clay resource).

Permo-Triassic structures (post-Clent Fm. to pre-Sherwood Sandstone times)

During the Permian, displacement on the Western Boundary Fault formed a topographical high to the east and a basin to the west of the fault, within which the aeolian Bridgnorth Sandstone was deposited. Subsequently, a phase of uplift and erosion occurred prior to the deposition of the Triassic Kidderminster Formation which rests unconformably on older strata.

Post-Triassic structures

The final deformation event comprises a major phase of east-west extensional faulting. This resulted in the juxtaposition of Carboniferous strata within a N-trending horst block (the exposed coalfield), bounded by the Western Boundary Fault (to the west) and Eastern Boundary Fault (to the east), against Permo-Triassic strata (Sherwood Sandstone Group). A number of reverse faults of Variscan age were reactivated as normal faults, such as the Russell's Hall and Hayes faults. Since movement has occurred along many of the faults from Carboniferous to Permian times it is not generally possible to determine the amount of displacement in post-Triassic times.

Seismicity

Seismic activity, reflected in earth tremors in the Black Country, is relatively slight. Not all the historically record-

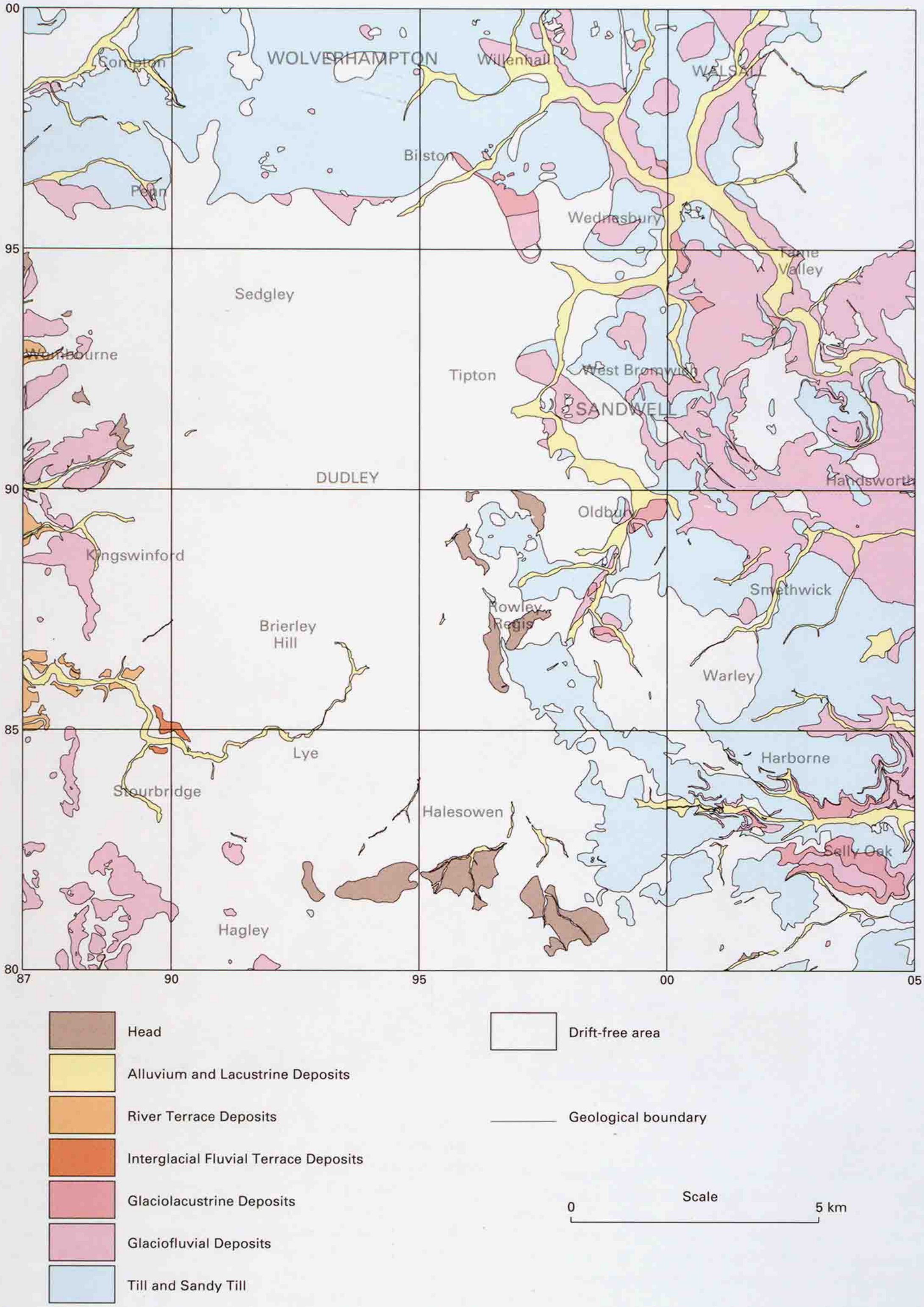


Figure 10 Generalised distribution of superficial (drift) deposits.

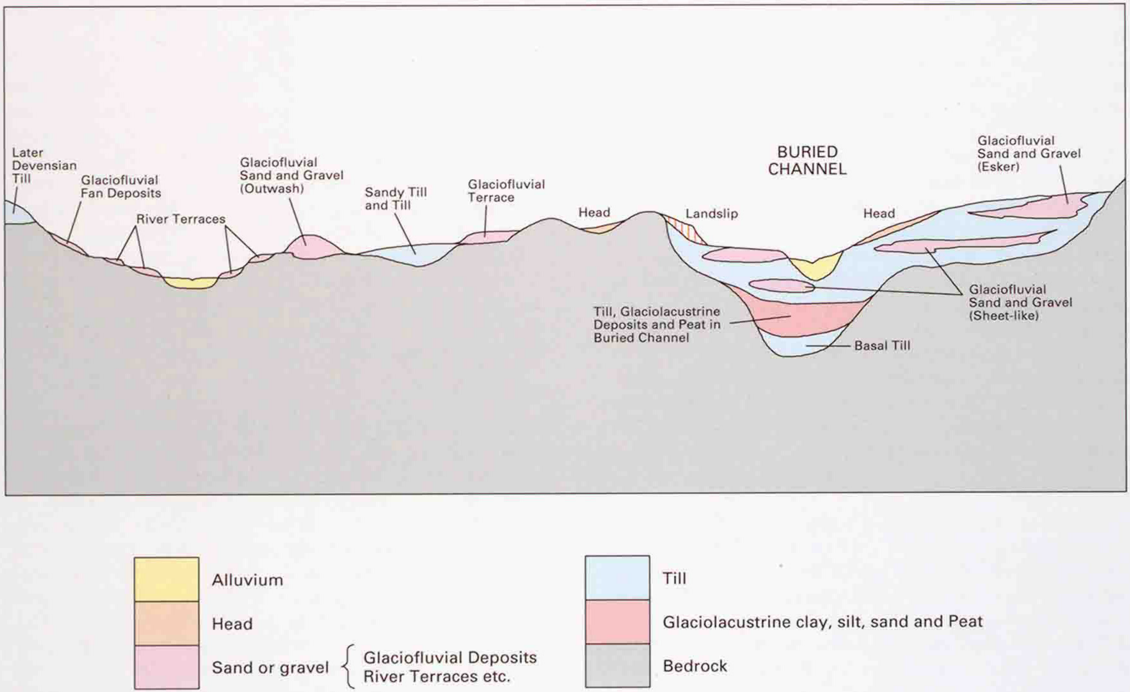


Figure 11 Cartoon showing the relationships of the Drift deposits in the Black Country area. Not to scale.

ed tremors are related to movement along major faults; some of the smaller earthquake records are probably due to the sudden collapse of old mine workings. Earthquakes are discussed further in the section on Geological Constraints to Development.

Superficial (drift) deposits

Superficial (drift) deposits comprise all the sediments laid down during Quaternary and Recent times (the last 2 million years), and largely consist of the unstratified or poorly stratified deposits of the ice ages, interglacial periods and postglacial times (Table 13). The deposits of the Anglian glaciation are mostly restricted to the north and east of the area, and those of the later Devensian glaciation to the north around Wolverhampton. Locally the drift deposits infill deep, pre-existing channels cut into the bedrock, such as the Moxley channel (Figure 11). The temporal relationships of the drift deposits are shown in Table 13 and Figure 11, and their distribution is generalised in Figure 10 (see also Maps 3A, 3B).

The drift deposits overlie bedrock of various ages, and in general are sub-divided on the basis of their lithology, depositional environment, landform, or a combination of all these characteristics, often with a reference to the age of the deposit (Table 13). The principal lithologies are till (boulder clay), sand and gravel, silt, and clay. They were deposited in environments ranging from glacial, periglacial, and fluvial to lacustrine, during climatic periods which fluctuated from glacial (very cold) to interglacial (warm, temperate). The superficial deposits are described briefly below. The form and origin of the steep-sided, drift-filled bedrock channels are dealt with separately.

Till and Sandy Till

Till, also known as boulder clay, occurs as broad spreads in the north-east and east of the area (Figure 10) where it commonly interdigitates with Glaciofluvial Sand and Gravel and other glacial deposits. Till consists of brown or orange stiff clay with well-rounded to sub-angular pebbles, cobbles and boulders (erratics) of various bedrock lithologies that have been incorporated into the ice-sheet and transported to its depositional site. Consequently, the erratics are composed of a wide range of lithologies ranging from far-travelled, exotic clasts, such as Welsh igneous rocks, to those plucked or eroded from the local bedrock, such as Sherwood Sandstone and Coal Measures. Where the sand content of the matrix is high, the deposit is termed Sandy Till, but the latter is only distinguished on the map by a symbol since it is difficult to draw a line between the two types. Generally, the Till deposits are thin (less than 10 m) but locally the Till, intercalated with other glacial deposits, reaches up to 35 m in drift-filled, bedrock channels such as the Millfield and Moxley channels (see p.35).

In the West Bromwich area Tills deposited during the Anglian glaciation, comprising an upper and lower Till, separated by sand-dominated Glaciofluvial Deposits and clay-dominated Glaciolacustrine Deposits, have been described (Pickering, 1957; Horton, 1974; Keen 1989). These Tills are not distinguished separately in this report. Similarly, the Tills of the Anglian glaciation are not distinguished, here, from those of the later Devensian glaciation.

Glaciofluvial Deposits (Sand and Gravel)

These deposits are less extensive than the Till (Figure 10) with which they are commonly associated. They consist of red-brown, fine- to medium-grained sand, and pebbly

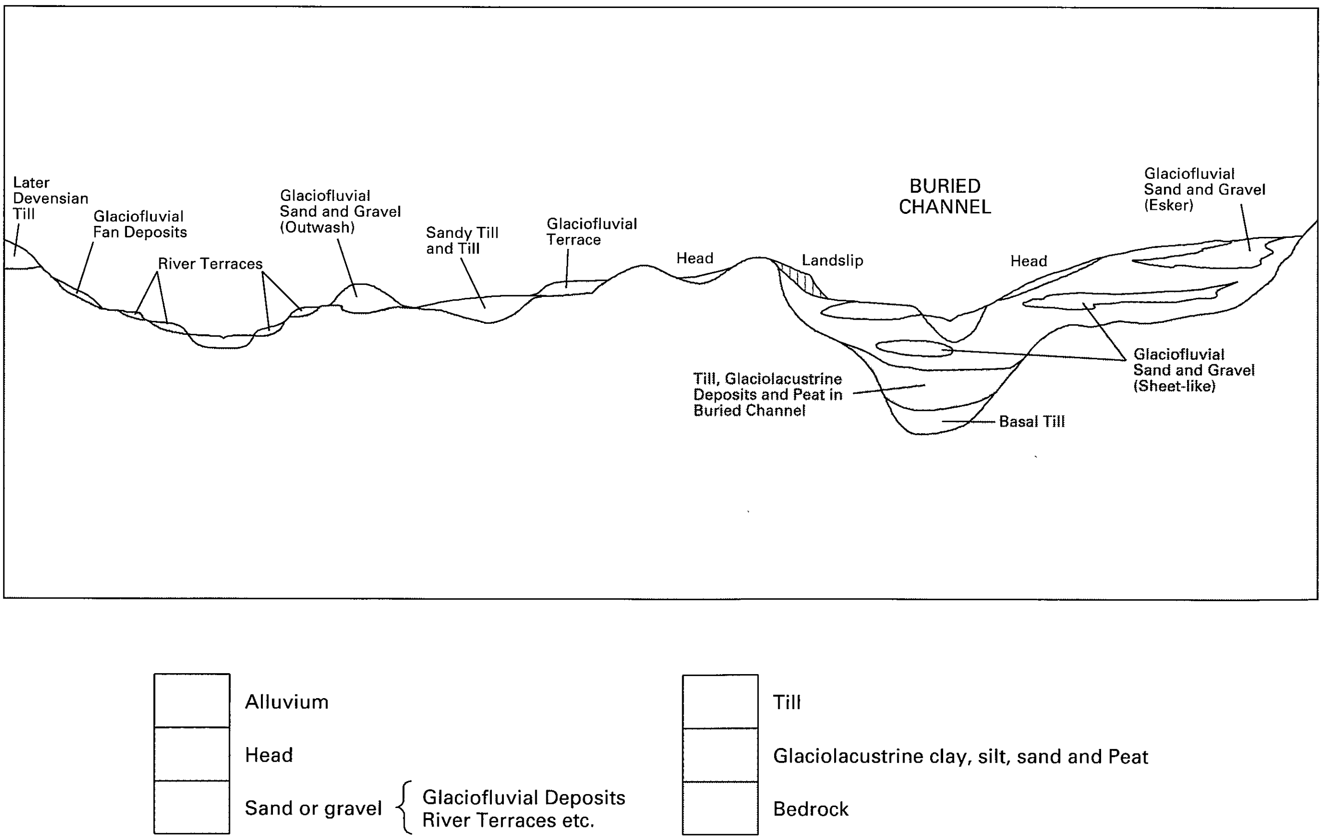


Figure 11 Cartoon showing the relationships of the Drift deposits in the Black Country area. Not to scale.

Table 13 Details of the Superficial (Drift) Deposits in Black Country

Period	Epoch	Stage	Deposit referred to in Text	Environment	Climate
Quaternary	Recent	Flandrian	Alluvium (silt, clay, sand, gravel.) River Terrace Deposits.	Fluvial	warm to cool
			Peat; Lacustrine Deposits (clay and silt)	Mainly lacustrine	
		c.10 000 years BP			
	Pleistocene	Devensian	Till in Tettenhall area Glaciofluvial Terrace Deposits.	Glacial, glaciofluvial & periglacial	glacial, mainly cold
		?	Glaciofluvial Deposits Interglacial Fluvial Terrace Deposits Glaciolacustrine Deposits	Periglacial and fluvial possibly glacio-fluvial or glacio-lacustrine	mainly cold with temper-ate phases
		Anglian (or Wolstonian)	Till, Glaciolacustrine & Glaciofluvial Deposits in buried channels	Glacial, glacio-fluvial and glacio-lacustrine	very cold to cold

sand with beds and lenses of pebbly gravel. The glaciofluvial sand and gravel was deposited by streams flowing on top of, within, and at the base of the ice-sheet. Hence, the deposits frequently occur as lenses interbedded with the Till (Figure 11). In some areas, around Hamstead and Sandwell, the deposits are subdivided on the basis of distinctive landform into Glaciofluvial Sheet or Glaciofluvial Terrace deposits. The Glaciofluvial sand and gravel deposits found to the west of the coalfield, around Iverley, Kingswinford and Wombourne are not associated with till, and are thought to represent the product of glacial outwash streams which flowed south of the limit of the ice-front.

Glaciolacustrine Deposits (sand, silt and clay)

These deposits were laid down in lakes associated with the ice-sheet, where water was temporarily ponded. They are characterised by fine grain-size and fine lamination, the latter resulting from the settling of grains through suspension in quiet-water conditions. Often the sand, silt and clay are interlaminated, reflecting fluctuations (possibly seasonal) in the supply of sediment. 'Rubbery' clays occur in the glaciolacustrine sequence around Harborne. Silt and fine-grained sand is associated with the deposits present in the Moxley Channel, near Darlaston. In the latter area, and in the Proto-Ford and Millfield channels the Glaciolacustrine deposits, intercalated with Till and Glaciofluvial deposits, reach up to 35 m thick (Maps 3A and 3B).

At Quinton, younger Glaciolacustrine deposits are associated, at depth, with organic peat deposits (Horton, 1974; Keen, 1989); the presence of organic peats and Glaciolacustrine deposits may signify an amelioration of the climate typical of an interglacial phase.

Glaciofluvial fan deposits

Small patches of brown sandy loam with quartz pebbles and sub-angular fragments of the local Clent Breccia, occur immediately west of the Western Boundary Fault in the Stourbridge-Hagley area. The deposit is less than 5m thick and is considered to represent the eroded remnants of alluvial fans which deposited local material, derived from the higher ground to the west, at the foot of the scarp.

Interglacial terrace deposit

This deposit is about 3m thick and consists of sand, and pebbly sand with gravel lenses. It forms two small, isolated patches with a terrace-like topography, adjacent to the Stour, near Stourbridge. The deposit has yielded a varied fauna of mammalian bones including mammoth, hippopotamus and wooly rhinoceros. The deposit represents the highest terrace of the Stour valley and was probably deposited in interglacial or immediately post-glacial times during a phase of rapid fluvial discharge.

River Terrace Deposits

This category includes the four river terraces of the Stour, the fourth being the topographically highest and earliest formed; it also includes undifferentiated river terrace deposits the age of which is not determinable. The fourth and third river terraces were probably formed during, or immediately after, the last (Devensian) glacial phase.

The terrace deposits occur at various elevations above the present-day level of the alluvial flood-plain; they probably represent the eroded remnants of formerly extensive alluvial plains that were sequentially deposited as the river eroded down to its present level. The deposits consist of yellow-brown and red-brown sand and gravel. In some areas the individual terrace deposits are typified by a particular suite of pebble clasts; the fourth terrace is devoid of pebbles derived from the Glaciofluvial deposits and may predate the latter; the third terrace, however, contains abundant exotic igneous clasts, similar to the clasts in the Glaciofluvial deposits. The second and first terraces are considered to be post-glacial in age.

Head (solifluction deposits)

Head is a term used for deposits derived by the mass wasting of the bedrock or superficial deposits, usually in periglacial conditions such as those subsequent to the last ice age. When seasonally thawed, these water-saturated deposits tend to move downslope, under gravity, over impermeable frozen ground (permafrost) below. Head is thus typified by the unsorted debris of the local bedrock or drift deposits. Since a veneer of Head or similar weathered material is present in most areas that were formerly glaciated, the deposit is only shown where it is more than 1m thick. Typical of the deposit is the orange-red clay (up to 2 m thick) overlying the Halesowen Formation, near the Hagley Road, which represents downslope movement of the Keele Formation mudstone. Head also occurs on the slopes of the Rowley Regis ridge as an admixture of clay and dolerite fragments.

Because it represents a downslope mass wasting deposit, Head may contain relic shear surfaces, of importance to slope stability and foundation design (Hutchinson et al, 1973).

Lacustrine deposits (including peat)

Small patches of lacustrine alluvium occur in areas where streams have flooded broad areas of the flood plain in post-glacial times. The deposits are generally less than 5 m thick and predominantly comprise silt and clay with lenses of sand. In some areas thin beds of peat or organic clay are present, resulting from the establishment of swampy conditions on the lake flat.

Alluvium

Most of the streams and rivers in the area are flanked by alluvial floodplain deposits. The alluvium generally consists of silt and clay overlying coarser beds of sand and gravel, although these lithologies are often found interbedded. In places the alluvium resembles the lacustrine deposits described above, and in places the two deposits merge both laterally and vertically. The thickness of the deposit is unpredictable because of local irregularities in the floor of river valley. The alluvium of the Stour valley forms a tract about 200 m wide, and is about 5 m thick; the alluvial floodplain of the Tame is up to 300 m wide and, in the past, was was prone to flooding.

The extent and frequency of flooding has been reduced by the construction of artificial levees and canalisation of the Stour and Tame; the reduced risk of flooding has enabled the alluvial floodplain to be built on in places.

Pleistocene mass movement (landslip)

Landslips resulting from rotational or planar shear of bedrock and superficial (Drift) deposits are present on, or below, some of the steeper slopes, notably within the Etruria Formation, below the scarp at the base of the overlying Halesowen Formation (Maps 7, 9A & 9B). Landslips may date from the period immediately after the last ice-age (Devensian) but some are still active at the present day.

BURIED BEDROCK CHANNELS

The pre-glacial topography of the east and north-east parts of the Black Country is characterised by a number of buried bedrock channels; the form of the channels is generally reflected in the thickness contours of the infilling drift deposits. The best defined of these are the NW-trending Moxley Channel, near Darlaston, the Proto–Tame and the Millfield Channel, located in the Walsall/Hamstead area (Figure 10; Maps 3A, 3B). They comprise steep sided channels cut into the bedrock prior to the deposition of the drift deposits, and subsequently infilled with various drift deposits such as Till, Glaciofluvial sand and gravel, Glaciolacustrine deposits, and less commonly interglacial deposits such as organic peat (Horton, 1974). In places the drift deposits infilling the channels are 35 m thick. In some areas the present-day streams, such as the Tame and the Ford, partly follow the trend of the low ground occupied by the channels.

The precise sub-drift form of the channels has been the subject of much debate (Pickering, 1957; Kelly, 1964; Horton, 1974; Waters 1991b). Borehole data collected during the present survey have enabled better definition of the form of the channels. It appears that the Proto-Tame Channel was less extensive than previously thought and is separated from the more southerly Millfield Channel by a bedrock ridge (Map 3B).

The deposits infilling the channels have been locally worked for sand and gravel and brick clay. Where the channel-fill deposits overlie Coal Measures, the drift deposits were often encountered in mine workings; ingress of water at the boundary ('sand-fault') was a hazard to mine operations.

Made ground, fill and worked ground

Human influence on the ground in the heavily urbanised Black Country has been substantial. Figure 12 and Maps 4A, 4B indicate the wide extent of man-made deposits, such as Made Ground, backfill and colliery waste. Disturbance of the original ground surface has much wider ramifications, however, and includes all built-up and landscaped areas. The constraints imposed on planning and development by these deposits are dealt with fully later (p.48). The various deposits and categories of disturbed ground are defined and described below. The Made Ground shown on the maps represents the deposits that were identifiable at the time of the survey. The deposits were delineated by recognition in the field and by examination of documentary sources, including aerial photographs and topographical maps. Made Ground covers much of the urban area to some extent, but deposits can only be shown on maps of the chosen scales where they are over 2 m thick. Thus, only the more obvious Made Ground can be mapped by these methods and the boundaries shown are, in places, conjectural.

Made Ground

This category comprises areas where the ground is known to have been deposited by man on top of the original land surface though, in some cases, the topsoil and subsoil have been removed first. It includes embankments, colliery spoil tips, landscaped ground, and other significant constructional areas. In the historically older parts of the coalfield, such as Bilston, Wolverhampton and Darlaston, the original hummocky made ground (predominantly colliery spoil) has been smoothed over prior to urban development. Consequently the Made Ground does not form topographical features, and the extent of the deposit is, here, based largely on shallow borehole and trial pit data.

Made Ground in the Black Country is a heterogeneous deposit, and includes a variety of rock waste such as shale, sandstone, and poor quality coal, and a wide variety of man-made deposits such as building rubble, pulverised fuel ash (PFA), and industrial, chemical and domestic waste. The last two of the types listed represent a small proportion of the whole, but are significant since they may produce hazardous toxic leachates or gases such as potentially explosive methane.

No categorisation of Made Ground type has been made in this study since records of the type of deposit are sketchy and inadequate for a deposit that can vary greatly both laterally and vertically. Individual records of a site could give rise to spurious assumptions on the nature of the deposit as a whole, and of the safety of the site. Where the Made Ground was exposed in cuttings and excavations during the survey, the nature of the deposit is indicated on the component 1:10 000-scale geological maps.

The most extensive areas of Made Ground are located in the historically oldest parts of the exposed coalfield where the thicker more easily mined seams, such as the Thick Coal, crop out (Wednesbury, Darlaston, Willenhall, Tipton, Bilston). In some of these areas borehole evidence indi-

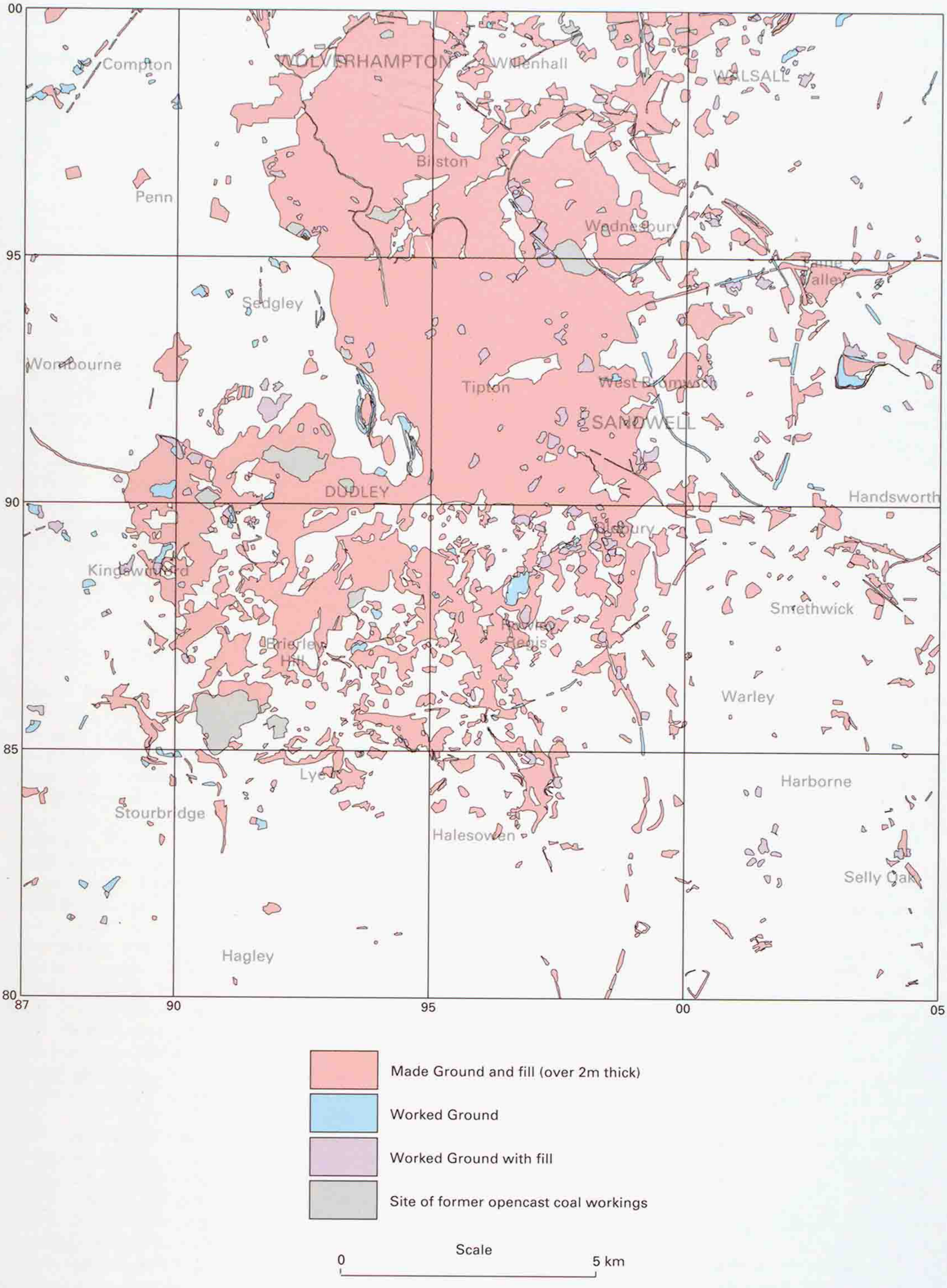


Figure 12 Generalised distribution of Made Ground and Worked Ground.

cates that there is a continuous smoothed spread of colliery spoil more than 2 m thick, and locally about 10 m thick, overlying bedrock or drift. This is a consequence of the haphazard, small-scale mining techniques which generated much waste material. Although much of the spoil was smoothed over prior to the urbanisation of the coalfield area, the more prominent pit mounds, usually built up adjacent to the colliery, are still evident.

Some of the colliery mounds have been excavated for 'mine stone', essentially the shaley, non-coaly part of the spoil, which is used for fill material. Areas known to have been worked are Oldnall, Cradley Park and Sandwell Park collieries.

Worked and Made Ground (principally backfilled quarries, pits and other excavations)

This category comprises areas where the natural ground has been cut away and then partly or wholly backfilled with Made Ground. The Black Country area is dotted with backfilled excavations for opencast coal, sand and gravel, sandrock, brick clay, dolerite, limestone and marl. The types of former quarries and pits and the special problems they present to development are listed in Table 14, and are discussed further in the section on constraints to development. In some cases there is no surface indication of the pit or quarry, where the backfill is landscaped or the area built on. The location of these sites is taken from documentary sources such as archival topographical and geological maps. In general there is no information available on the nature of the fill material, although in some cases boreholes penetrating the fill provide a partial record. Boreholes must be closely spaced in order to give a true picture over an individual site.

Where excavations have been used as waste disposal sites they may contain a mixture of material, the nature of which is often unreliably recorded; they may contain organic and chemical wastes which can produce hazardous toxic leachates or gases, including potentially explosive methane. The nature of the material in backfilled pits and quarries is similar to Made Ground, discussed above. However, there is the added risk of poor drainage in the excavations which may also lie close to the water-table. Furthermore, toxic leachates and gases, including methane, both generated within the fill, may migrate through permeable strata, and/or along faults and joints, to emerge at some distance from the site.

Sites of opencast coal extraction are a special category of backfilled excavations. At more recently excavated sites, the nature of the fill material is carefully monitored. These sites, such as Amblecote, Bilston and Patent Shaft, are also compacted during backfilling to provide useful ground for development.

Worked ground

Worked ground includes areas where the ground is known to have been cut away in, for example, unfilled quarries and pits. As noted above many of the sites of former quarries are wholly or partly backfilled, and as more urban and industrial waste is disposed of by burial rather than incineration, the pressure to use the remaining open sites becomes greater. However, some of the disused, unfilled pits and quarries, such as Dalton's Clay Pit [936 870] have, by virtue of their unique geological and/or biological features, been designated as urban parks, nature reserves or Sites of Special Scientific Interest (Table 16).

GEOLOGICAL RESOURCES AND CONSTRAINTS RELEVANT TO PLANNING AND DEVELOPMENT

Introduction

The general geological and geographical characteristics of an area represent the bones on which the main body of land use planning and development decisions have to be made. The geological framework dictates the mineral and water resource potential and the suitability of foundation conditions in an area, including the factors which lead to instability. One of the main purposes of land-use planning is to ensure the best use of land in the public interest by, for example, avoiding the sterilisation of valuable mineral deposits or high grade agricultural land. Planners may also be faced with decisions regarding the suitability of land for various purposes; many constraints, of varying severity, may be imposed by the underlying geology.

The following section identifies and describes geological resources and constraints so that they may be placed alongside other factors which are under consideration by the planner, such as existing and proposed land use, demand for housing and industrial development, communications, conservation and amenity areas, archaeological interest and agricultural land potential.

Geological Resources

Mineral deposits and groundwater are the principal geological resources, but other resources, influenced by ground conditions, include soils, areas with sound bedrock foundation conditions, and land suitable for waste disposal sites.

The Black Country is well endowed with minerals, principally coal, ironstone, fireclay, brick clay, limestone, dolerite, sand and gravel, and water resources. To a large extent, the historical prosperity of the area was founded on their local availability. Water was useful both for surface communications and for industrial and domestic supply from aquifers.

Much of the area has been built upon, but production of opencast coal, brick clay, dolerite aggregate, gravel and sand still takes place (Harris et al., 1991). In addition, groundwater obtained from the Sherwood Sandstone aquifer makes an important contribution to the water supply of the Black Country and its environs, although domestic water is mostly supplied from outside of the study area.

MINERAL RESOURCES

For the purpose of this report mineral resources cover those minerals and other geological deposits which have a potential for economic exploitation.

Mineral reserves, those quantified deposits which could be economically extracted, are not considered here because many factors such as land values, extraction costs and proximity to markets have to be considered before reserves can be identified; this requires comprehensive evaluation and is well beyond the scope of the present study. The mineral resource potential of the area is almost entirely confined to those materials which are presently worked e.g. opencast coal, dolerite aggregate, brick clay, sand and gravel, but is limited by the extent of existing surface development. Other minerals not presently extracted but of possible, though limited, economic potential are also briefly discussed.

With regard to planning, mineral resources fall into two categories, those that can be extracted by surface workings and those that can be mined or recovered at depth. In the former case, the planner may be presented with conflicting claims on the land from the extractive industry, agriculture or the urban developer; any construction will, of course, sterilise the resource for the foreseeable future. The workings themselves may present problems as to post-extraction land use, which are likely to be resolved only by resorting to geotechnical or hydrogeological advice. For instance, if backfilling and reinstatement is the aim, then a decision must be made as to which infilling material can be used, bearing in mind ground conditions, to ensure the least environmental damage.

Underground mining may involve local subsidence damage and produces waste material, the disposal of which commonly creates a demand for tip sites. The area tipped over becomes sterilised for shallow mineral extraction, and presents the planner with problems regarding land use of the new artificial landforms. In addition, information on ground conditions can be used to ensure that informed decisions are made prior to land allocation for tipping. Whilst further underground mining in the Black Country is unlikely in the near future, the legacy of old mine voids, shafts and tips occurs extensively.

The mineral resources of the area (Maps 5A, 5B) are described in detail in the following sections, and their distribution is summarised in Figure 13.

Coal and associated fireclay and ironstone

The South Staffordshire Coalfield has a total area of about 175 square kilometres and can conveniently be divided in to the 'exposed' and 'concealed' coalfields (Figure 4). The former represents that area where the coal seams are present at or near the surface, and is delimited on its east and west sides by the major boundary faults. Although in parts of this area, the Coal Measures are overlain by the non-coaly Etruria Formation, these areas are traditionally included within the 'exposed' coalfield. The 'concealed' coalfield includes those areas to the east and west of the major boundary faults where the Coal Measures are overlain by a considerable thickness of barren Upper Carboniferous rocks.

The principal worked seams and their thickness are shown in Figure 8 and Table 12. In the southern part of the coalfield, south of a line between Lye and Halesowen, the Coal Measures thin out below the overlying Upper Carboniferous rocks. North of the Bentley Faults, in the Cannock Coalfield, the thick, coalesced coal seams, typical of the South Staffordshire Coalfield, split into numerous thinner seams.

Coal and associated ironstone seams have been mined in the Black Country since medieval times to supply the local iron industries. All the worked coals are of the bituminous variety. In the northern part of the coalfield (Wolverhampton, Tipton, Wednesbury) the seams below the Thick Coal such as the New Mine, Fireclay, and Bottom coals, are both thicker and of a better quality than elsewhere in the area, although the Bottom Holers and Mealy Grey coals are generally of poor quality. The Stinking (Sulphur) Coal (Plate 2) is impure and rich in pyrite and was mined in only a few places. The Heathen Coal (locally split into an upper and lower seam) and the Brooch Coal are of good quality, and the Two Foot Coal was worked for household coal in the northern part of the coalfield. The famous Thick Coal (Plate 3), up to 10 m thick, was subdivided by miners into named partings, each with its distinctive mining and burning characteristics. North of the Bentley Faults, which separate the South Staffordshire Coalfield from the Cannock Coalfield, the Thick Coal splits into about 12 separate seams interbedded with non-coal bearing strata. In the far south of the coalfield, around Lye and Halesowen, the lowermost coal seams fail and are replaced by fireclays.

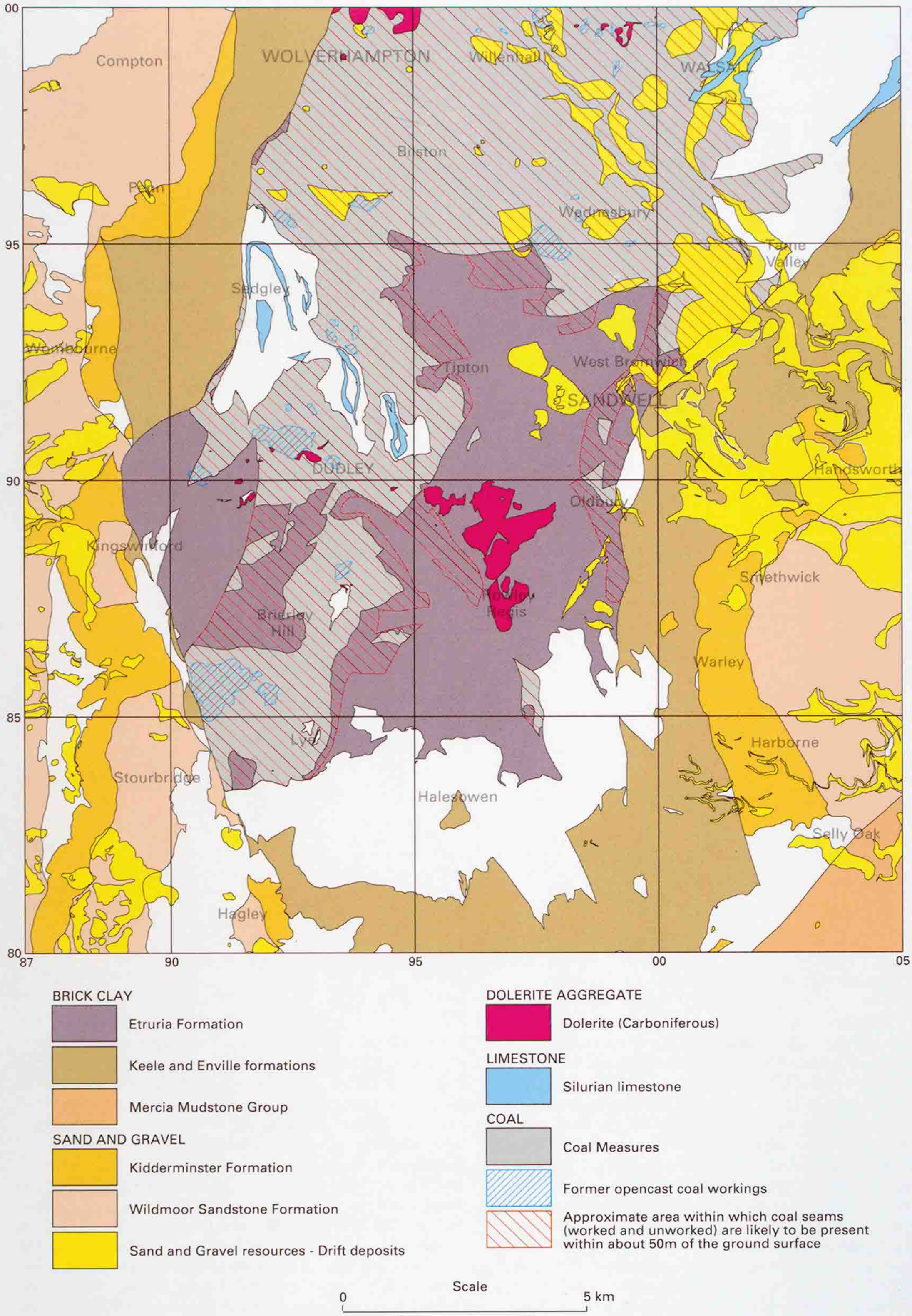


Figure 13 Mineral resources of the Black Country.

Figure 14 Historical trends of mining reflected in the distribution of working mines. A, 1861; B, 1902; C, 1945. After Wise (1948, Figs. 56–58).

Mining methods are described in the section on Constraints to Development: Mining Subsidence, and are summarised in Table 25 and Figure 15. The historical development of coal mining in the Black Country is illustrated in Figure 14. In the middle of the 19th century, the peak period of production, the exposed coalfield was dotted with many small pits, particularly in the north around Wolverhampton, Bilston, Tipton and Wednesbury, where the Thick Coal comes to crop, and to a lesser extent to the south-west of the Russell's Hall Fault, around Netherton. In 1860 the coalfield produced about 8 million tons of coal and about 0.75 million tons of ironstone from 410 collieries. By 1900, exhaustion of the seams and poor drainage in the northern part of the coalfield, led to an expansion of the southern and south-western areas of the exposed coalfield where coal-bearing strata lie at greater depth, overlain by the Etruria Formation (Brierley Hill, Netherton, Lye, Cradley, Old Hill). Dwindling production from the older parts of the coalfield during the later part of the 19th century resulted in exploration in the concealed coalfield. To the east of the Eastern Boundary (Great Barr) fault, coal was mined from Heath Pits, Sandwell Park and Hamstead collieries where the Thick Coal was mined at depths of between 386 m and 572 m. In the south of the exposed coalfield, pits at Beech Tree, Oldnall, and Cradley Park worked coal from shallower depths (c.150 m), but the southern margin of the coalfield was limited by the the rapid thinning and poor quality of the seams south of a line between Wollescote and Halesowen. In the west of the coalfield mining concentrated on Himley Colliery, the largest mine at the turn of the century, but after exploration borings in the concealed coalfield, to the west of the West-

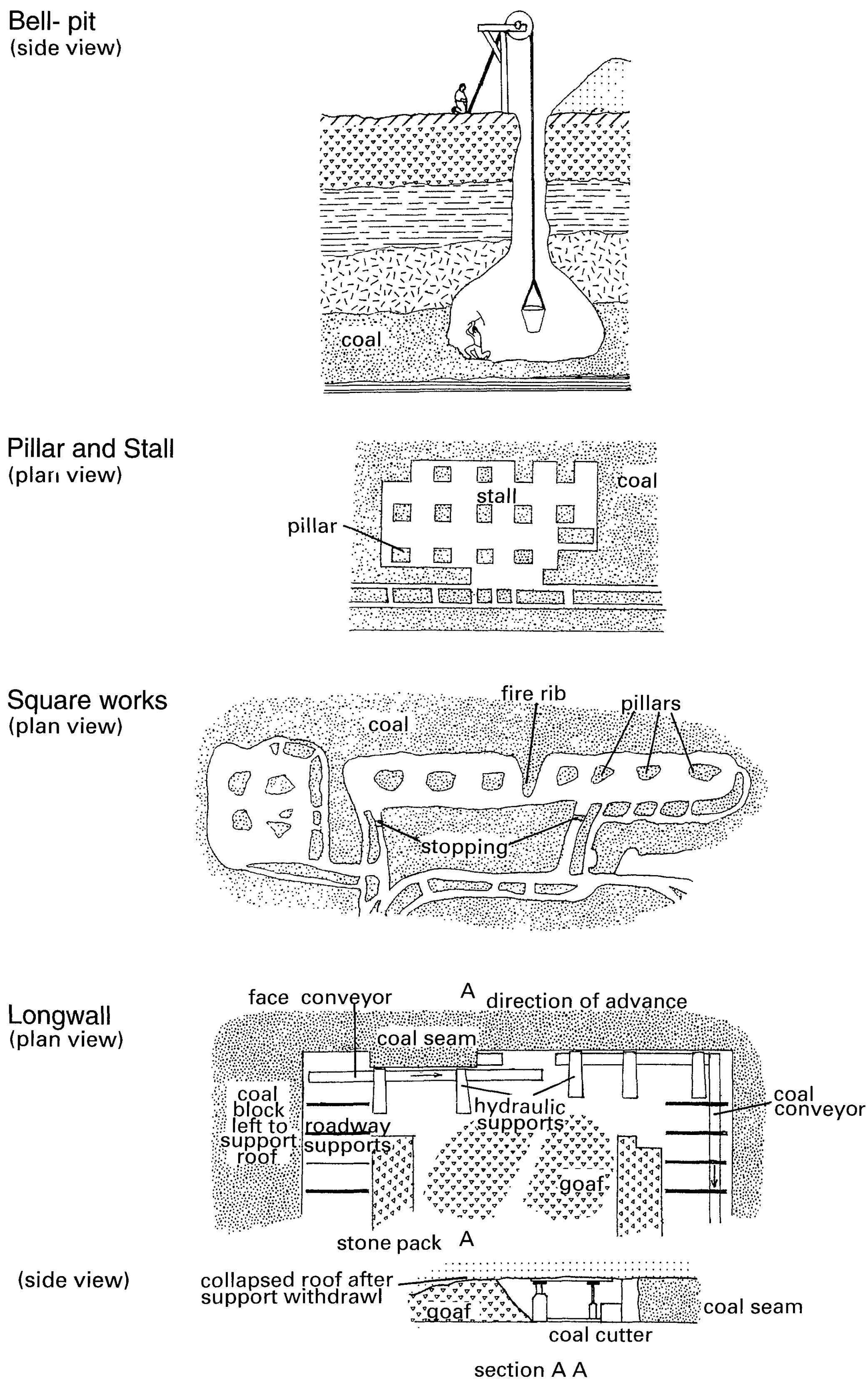


Figure 15 Summary of various types of mining methods (after Littlejohn, 1979 and Healy and Head, 1984)

ern Boundary Fault, revealed large reserves, the focus moved to Baggeridge Colliery which operated from 1912 to 1968 at depths of about 520 m.

Between the wars most of the pits in the exposed coalfield closed and in the 1950's the only viable pits were Sandwell Park and Hamstead, to the east of the exposed coalfield, and Baggeridge to the west. The last deep mined coal was won in 1968 when Baggeridge Colliery closed. The focus of coal mining had by then moved north of the Bentley Faults (Wolverhampton-Walsall area) to the Cannock Coalfield, outside of the present study area.

Opencast mining was carried out by the early miners where the seams, particularly the Thick Coal, came to crop. There are few records of the extent of the workings, but in most areas where the Thick Coal crops out it was worked in 'openworkings'. Large scale, opencast operations have developed since 1940. Much of the area had by then been sterilised due to urban and industrial development, but a number of small sites in the north of the coalfield, northeast of Willenhall, worked the seams below the Thick Coal such as the Bottom, Fireclay, and New Mine coals. De-industrialisation, changes in land use and redevelopment freed a number of sites that were formerly sterilised such as Amblecote railway sidings, Bilston Steel Works, Patent Shaft Steel Works, and Milking Bank. These sites have mostly worked the Thick Coal and/or higher seams such as the Brooch, Flying Reed and Two Foot coals; controlled excavation and backfilling together with remedial work on extant mine shafts has allowed these sites to be redeveloped subsequent to coal extraction.

Since the relatively thick coal seams of the Black Country lie at relatively shallow depths (generally less than 35 m), the potential area for opencast coal mining is great (Figure 13). However, much of the area remains sterilised by urban and industrial development, and in many areas the shallow seams have been worked out by past mining. In some areas the pillars left by the older mining methods may provide sufficient mineral to justify extraction, as at the Dibdale Road site (Plate 2, 3). Spontaneous combustion of some of the shallow, thick seams has reduced them to burnt shale of no economic worth. As with most resources the economics of extraction will depend on access restrictions, proximity to local markets, the volume of extractable coal, land values, the cost of remedial work, and of course the market value of the coal. The most promising areas are in the central part of the exposed coalfield where the gently-dipping, thick seams, particularly the Thick Coal, lie at shallow depth with little or no overburden and coal could be extracted from opencast workings. Much of this area is covered by existing surface development, but there could still be potential for extraction during development of medium- to large-scale industrial sites.

It is unlikely that the economics of the coal industry in the UK will make further deep mining viable in the Black Country.

Ironstone production ceased in the early part of this century, although the nodular sideritic (iron carbonate) seams were an important local source of supply in the 17th, 18th and 19th centuries. Ironstone was generally worked in conjunction with associated coals. The last workings for ironstone, in the 1920's, were in the White Ironstone (below the Heathen Coal) at Gornal Wood and Baggeridge Colliery. Chemical analysis of this seam gave an iron content of 27–36% metallic iron (Whitehead et al., 1927). The Gubbin Ironstones (above the Heathen Coal) were also an important source (32–39% metallic iron) and were principally worked at Himley and Shut End collieries.

The principal **fireclay** district extended northwards from Lye, Stourbridge and Wollescote to Shut End (Oak Farm) and Gornal; in the southern part of the coalfield the main workings extended eastwards as far as Whitley Colliery, near Cradley. The fireclay seams are thickest and greatest in number in the lower part of the Coal Measures sequence, and, geographically, near the southern margin of the coalfield where the associated coal seams deteriorate rapidly and, in places, are replaced by seatearth fireclays. Below the level of the Thick Coal, the Bottom Rock Clay, Old Mine Clay and New Mine Clay (up to five separate seams) were of the best quality and longest worked. Analyses of the Old Mine Clay (Whitehead et al., 1927) gave 77% silica and 13% alumina, for the puresest white clay. In addition, fireclays were worked just below the Heathen Coal. Above the level of the Thick Coal, the Brooch Clay was worked near Saltwells Wood, Brierley Hill, and near Merry Hill; clays above the Flying Reed Coal were also worked near Deepfields and at Oak Farm. The refactory and semi-refactory clays were utilised in the manufacture of fire-bricks, sanitary ware, drain pipes and pottery. Pits at Ettingshall Park Farm worked clays associated with the Bottom Coal for coarse pottery goods.

Fireclay production in the Black Country declined along with deep coal mining in the early part of this century, and has now ceased.

Dolerite (aggregate and coated stone)

The chief sources of road aggregate and coated stone (tarmac) in the area are the dolerite bodies intruded into the Carboniferous rocks (see p.30). The largest of these intrusions and the only one presently worked is at Rowley Regis where it is locally known as the Rowley 'rag'. Dolerite was formerly worked from smaller intrusions at Pouk Hill (near Walsall), Barrow Hill, Cooper's Bank, and to a limited extent near Wolverhampton. The lateral and vertical extent of these igneous bodies is difficult to predict since they vary rapidly in thickness and may pass over a short distance to a lower or higher level in the rock sequence.

The Rowley Regis dolerite represents a saucer shaped body (lopolith) which is thickest in its central part (c. 100 m), wedging out rapidly towards the margins. No evidence of a vertical feeder pipe was found when the area below the intrusion was largely undermined for coal. At Rowley Regis the dolerite is characterised by the presence of three distinctive joint patterns and small faults which have partly controlled the quarrying operations.

The dolerite was formerly used to make paving blocks, and admixed with concrete to make concrete slabs, but most of the past and all of the present output is used in the production of crushed aggregate or coated stone.

Most of the quarries in the main area of production around Rowley Regis, such as Rough Hill [962 889], Yewtree Lane [967 869] and Bury Hill Park [977 891], have been partly or wholly backfilled (Map 5A). The working quarries (Appendix 2) at Hailstone and Edwin Richards ((Plate 8) [965 884], formerly separated by a narrow roadway, are about 100 m deep.

The potential for future exploitation of the Rowley Regis dolerite is limited by planning considerations such as sterilisation by urban and industrial development of the area adjacent to the existing working quarries, and geological factors such as the lensoid shape of the intrusion and the nature of the associated bounding faults. A programme of closely spaced boreholes would be required to determine the precise lateral extent and thickness of the dolerite body, and also the thickness of any overburden (Etruria Formation and Made Ground). Outside of this area other planning considerations and the small size of the intrusions limit their potential as a major source of dolerite.

Brick Clay

Bricks have been manufactured from a variety of geological formations in the Black Country, but the industry was, and still is, mainly based on the workings in the Etruria Formation (locally termed the Etruria or Old Hill Marl). Operators are listed in Appendix 2.

The outcrop of the **Etruria Formation** generally forms a broad strip surrounding the Coal Measures which it overlies. It is particularly suited to brick manufacture because the clays, mudstones and siltstones have a high content of iron oxide (Fe^{3+}) which gives the characteristic red colouration (Holdridge, 1959). Furthermore, the heterogeneous nature of the formation which ranges from red, purple, yellow and green mudstone to green and yellow sandstone, makes it possible to blend the raw material to produce high quality bricks of various colours and hues. The high iron oxide content facilitates the production of the valuable engineering (blue) brick of great strength and durability, which is produced at very high temperatures and in reducing conditions so that the ferric iron is reduced to a ferrous state and combines with the silica to form a vitreous material that infills the pore spaces in the brick. The presence of thin coaly beds, locally, within the lower part of the formation has the additional advantage of increasing the furnace temperature through combustion, thereby reducing the amount of fuel required to heat the furnace. Brick works in the Etruria Formation were concentrated in the south, south-east and south-west of the exposed coalfield, around Old Hill, Cradley, Lye, Brierley Hill and Kingswinford. Present day workings are restricted to the latter area, at Tansey Green [912 898] (Plates 4, 5), Himley [897 889], Ketley [897 889] and Baggeridge [900 914]. Much of the resource area has been sterilised by urban and industrial development, and many of the former pits are wholly or partly backfilled.

Sterilisation of much of the traditional resource, described above, and economic pressures favouring proximity to the market, led to exploitation of other brick clay resources in the area. Weathered surface clays of the **Coalbrookdale Formation** were worked for brick clay near Walsall and near Beacon Hill, Sedgley. However, this source is too calcareous for the manufacture of bricks unless the calcium carbonate has been removed by weathering. The clays of the **Keele Formation** are generally unsuitable because they are also too calcareous and have a low iron content; they were worked together with the overlying **Glaciolacustrine clay** with which they were mixed, at California, near Harborne [SP 036 834]. Glaciolacustrine clay was also worked for brick clay at Baggots Bridge Brick Works [971 857], near Moxley.

Clays of the **Clent Formation** were worked to a limited extent in the north-west of the area, near Penn [905 995]. The **Enville Formation** was exploited for brick clay in the north-east of the area at Springfield [928 992], where it was mixed with Till, and further south at [916 973]. In the exposed coalfield the **Coal Measures** (at around the level of the Thick Coal and New Mine Coal) and the overlying **Till** were exploited in small pits [919 867], [989 995], [961 997] for brick and tile clay, in the Willenhall and Wolverhamton areas. At some of the latter sites colliery spoil tips were utilised; spoil from the Diamonds Ironstone workings between Willenhall and Walsall were also used in brick manufacture. Southeast of the Birmingham Fault, the **Mercia Mudstone Group** was worked in small pits [SP 026 830; SP 049 817], but the main centre for production from this source lay outside of the area, around Kings Norton.

None of the minor resources described above is currently worked for brick clay, and the relatively poor quality of the clays, in comparison with the Etruria Formation, makes their exploitation in the future unlikely.

Sand and gravel

Glacial deposits

Sand and gravel for use as aggregate and building sand were formerly worked from superficial (drift) deposits such as the **Glaciofluvial sand and gravel** and **Glaciolacustrine sand.** The former deposit was worked in a number of scattered, small pits such as those at Smethwick [SP 013 892], Stone Cross [SP 009 945] and Bustleholm [SP 015 945], to the east of the coalfield, and at Norton [887 822], Kingswinford [883 876], Compton [876 983] and Wall Heath [873 980] to the west. Only the pits at Wall Heath and Stewpony [865 845] (immediately west of the area) are presently active, although the resource area is relatively small. There is, however, potential for small-scale operations in the deposits of the Kingswinford and Norton–Hagley areas.

Glaciolacustrine sand was formerly worked near Moxley [971 952; 971 955; 966 965] where its fine grain-size and low clay content made it ideal for use as moulding sand in the local foundries: most of the pits at Moxley have either been wholly or partly backfilled, others are being utilised as nature reserves, urban parks or fishing lakes. The extent of former workings, small outcrop area, and sterilisation by urban development leave little resource potential in the Glaciofluvial sand.

Bedrock deposits

The soft, poorly cemented nature of the lower part of the **Sherwood Sandstone Group** and, to a lesser extent, the **Bridgnorth Sandstone** led to their exploitation for both moulding sand, and building sand and aggregate. This category is sometimes referred to as 'sand-rock'.

The **Wildmoor Sandstone** was extensively worked for moulding sand in the Compton (Wolverhampton) [88 98], Amblecote [89 94], Wombourne [875 938] and [872 942], Kingswinford [890 887], Cot Lane [886 877] and Stourbridge [90 94] areas, but production has now ceased. These sites were favoured by their proximity to either the Stourbridge canal or the Staffordshire and Worcestershire Canal, which ensured low transport costs. The only working quarry (at the time of the survey) was at Wall Heath [873 980], where the overlying Glaciofluvial sand and gravels is also extracted. The quarry in the Wildmoor Sandstone at Iverley [886 815] is recorded as supplying silica sand for use in the fireclay industry. Because the Wildmoor Sandstone is mostly drift-covered in the east of the area, it was only exploited for local use in scattered, small pits such as those near Smethwick [021 874] and [037 891], and at Selly Oak [042 829]. Many of the large quarries in the Stourbridge area have been built in, since they offer level, dry sites; the majority of those in the Compton area are unfilled, but are now fringed by urban development.

The demand for moulding sand sharply decreased in the later part of this century, in line with the nationwide decline in output of the iron and steel industries, and particularly the closure of many of the foundries in the Black Country. However, the potential resource area to the west of the coalfield is large. The Wildmoor Sandstone is considered to be too fine-grained, insufficiently 'sharp' and with too high a clay content for use as cement-mix sand, although it could be mixed with higher grade sand to produce an acceptable product. It could also be utilised as a general building sand.

The lower, pebbly part of the **Kidderminster Formation** was formerly worked as a source of sand and gravel for aggregate. Because the pebble-rich beds are generally present only in the lower part of the formation, the quarries are restricted to that part of the outcrop. Principal sites in the west of the area are the scattered small pits and quarries along the ridge-like outcrop between Iverley [875 810] and Ridgehill Wood [878 884]; the most extensive of these is along The Ridge [88 84], near Wollaston, at New Wood [882 855] and Ridgehill Wood. The formation was also worked for aggregate in small pits near Himley, at [891 910], [889 937], and farther north near Penn [886 952], [888 951]. In the south of the area, small pits were excavated in Hagley Park [924 804] and south of Wychbury Hill [920 814]. In the east of the Black Country the workings are restricted to small pits near Warley [SP 008 859], [SP 001 869] and [SP 014 866], Hamstead [SP 046 949] and Harborne [SP 002 842] and [SP 014 842].

Although the resource potential of the Kidderminster Formation for aggregate is small, the upper non-pebbly part of the formation is presently quarried for building sand at Highdown Quarry [879 815]. This quarry was formerly backfilled in part, and the fill material had to be removed to temporary store in order to exploit the sandstone at the deeper levels of the quarry.

Glaciofluvial sand and gravel was formerly extracted from the upper part of the quarry, but all the present production comes from the sandrock. The site clearly illustrates the need for foresight in planning for mineral resources before existing quarries are backfilled. It also suggests that the upper non-pebbly part of the Kidderminster Formation, where the outcrop is not sterilised by urban development, has significant potential for exploitation as building sand in the Stourbridge-Iverley area.

The **Bridgnorth Sandstone** was formerly worked to a limited extent in small pits such as those near Wollaston [880 804], and to the north at Checkhill [853 881]. The characteristic rounded grains make it unsuitable for sharp cement-mix sand; this factor, together with its small outcrop area, limit its resource potential, although it could be used as a general building sand.

Mine Stone (colliery waste)

Large quantities of waste were produced as a by-product of underground mining in the Black Country. This material, known as mine stone, consists of shale, mudstone, siltstone, sandstone, ironstone, waste coal and seatearth. All of the former collieries and pits have extensive areas of mine stone adjacent to their shafts. However, in the older parts of the exposed coalfield where there were many small working pits, such as the Tipton, Wednesbury and Darlaston areas, the waste material was spread out, or landscaped prior to urban development in the latter part of the last century and the early part of this century. Landscaping of the waste has also taken place at some of the more recently worked collieries (Sandwell Park, Baggeridge), either for urban redevelopment or parkland. Consequently most of this resource is sterilised, or represents existing foundation material. However, some of the collieries in the south of the Black Country have mound-like resources of mine stone that could be utilised as fill material. These include the waste tips adjacent to Cradley Park [936 842], Oldnall [932 838], Wassell Grove [934 820] and Old Hawn [962 849]; other resources are present north-west of Willenhall [956 994]. Use of mine stone is limited to some extent by its mineralogy since it may contain disseminated pyrite, which could decompose causing foundation problems, and waste coal or carbonaceous material which can undergo combustion after burial if proper precautions (such as compaction) are not taken to exclude air.

Limestone

Limestone was formerly worked from the Silurian strata, namely, in descending sequence, the Aymestry Limestone, the Much Wenlock (Dudley) Limestone and the Barr Limestone, but none is regarded as having a present-day economic potential. The limestone was used as a flux in the iron industry, and was calcined for agricultural lime and cement lime. The close proximity of limestone, coal and ironstone was one of the factors that established the preeminence of the Black Country in the iron industry. Limestone also occurs as thin beds in the Upper Carboniferous strata as the *Spirorbis* limestones, but these were never of any economic importance.

The most important limestone resource was the **Much Wenlock Limestone** which was worked in the 17th, 18th, 19th and 20th centuries initially in quarries and later, as the surface resources became depleted, as shallow adit mines and deep mines (back cover). The history, development and extent of the mining, and remedial measures to be taken to reduce the risk of collapse of old workings, is considered in detail in a report commissioned by the Department of the Environment, and carried out by Ove Arup & Partners: *A Study of Limestone Workings in the West Midlands, 1983*. Consequently, only a summary is given here. The Much Wenlock Limestone is subdivided into an Upper Quarried Limestone Member, about 10 m thick, and a Lower Quarried Limestone Member, about 13 m thick, separated by the Nodular (Limestone) Member, about 35 m thick (Table 10); only the upper and lower members were worked. These last consist of strong, blue-grey, thin- to medium-bedded, bioclastic limestone with thin partings of grey-green shale; the intervening nodular member consists of blue-grey, thinly bedded, nodular clayey limestone, and calcareous mudstone. Large, irregular ovoid masses of unbedded limestone within the Lower and Nodular members, known locally as 'crog balls', represent the remains of fossil patch reefs. Their massive nature made quarrying difficult. The limestone is cut by a set of joints which, in some areas, controlled the layout of the mines.

The mines were generally worked by similar methods to the local coal mines, that is by pillar and stall methods (Figure 15) although the worked stall areas were typically larger than in the coal mines. Where the beds dipped steeply, as on the limbs of the folds at Wren's Nest and Castle Hill, the earliest method of working was on one horizontal level as elongate galleries parallel to the strike of the beds; this method generated large, unsupported voids with occasional pillars orientated at right-angles to the dip of the beds (back cover). The depth of mining ranged from extensions from surface quarries to 260 m, but the majority were within 20 to 70 m depth. Some of the mines were extensions from existing coal mines. An estimated 19 million tons (7 million cubic metres) of limestone was extracted by quarrying and mining, the majority of it from the Much Wenlock Limestone, between 1750 and 1900. This has resulted in about 220 acres (0.9 km2) of quarries and over 390 acres (1.6 km2) of abandoned mines.

The principal areas of quarrying and mining (Maps 5, 6; Table 14) are generally located adjacent to the outcrops of the Silurian inliers, such as Wren's Nest, Castle Hill, and Hurst Hill, and the the area north-east of Walsall where the Silurian strata crop out. Deep mines, worked below the Coal Measures, are also present in the area between Walsall, Darlaston and Wednesbury, and in the Rowley Regis area.

The extent of former workings has exhausted the limestone resource at outcrop, and the deep mines are no longer economically viable. The workings around the inliers at Dudley, however, have potential as attractions for scientific study, tourism and recreational areas (see page 48).

Constraints on development posed by the abandoned limestone mines are considered further in a later part of this report.

Groundwater Resources

Contributed by the National Rivers Authority

Water is an important resource without which development is impossible. The study area lies wholly in the Severn-Trent region of the National Rivers Authority (NRA) who monitor and protect groundwater resources. The major aquifer in the area is the Sherwood Sandstone Group (Map 8) which crops out along the western and eastern margins of the coalfield. Most of the study area is, however, underlain by Carboniferous strata which are not considered to be a major aquifer as far as abstraction of water is concerned. The NRA aquifer protection policy applies to both major and minor aquifers throughout the area. The locations of all licenced groundwater abstraction boreholes and observation boreholes, which monitor long term changes in the groundwater levels, are shown in Map 8. Specific details of the individual licences and groundwater levels are available from the National Rivers Authority, Solihull, West Midlands.

The area is drained by the Rivers Stour and Tame and their tributaries such as Hockley Brook. Together with an extensive canal network these waterways contributed historically to water supply, drainage (particularly mines) and communications (Map 8). The hydrology of the surface water and drainage is beyond the scope of this report, and for further information on resources and planning matters the reader is referred to the National Rivers Authority.

Sherwood Sandstone Aquifer

The Sherwood Sandstone aquifer, which crops out over the eastern and western margins of the Black Country, supplies large quantities of water to Stourbridge, Wombourne and Wolverhampton, in the west of the study area. Within the area which could be affected by future developments in the western part of the study area there are six public water supply boreholes (Churchill, Hagley, Norton, Mill Meadow, Coalbourne Brook, and Tack Lane) located within the boundary. However, the hydrogeological importance of the western outcrop should not be minimised since the aquifer protection zones of a number of public supply wells, located outside of the study area, impinge on the western margin of the area.

The outcrop of the Sherwood Sandstone Group has been divided into three discrete groundwater management units. The western aquifer outcrop is divided into the Stourbridge and Wombourne units, and the eastern outcrop is represented by the Birmingham unit. The groundwater resources for these units are:

Aquifer Unit	Assessed Resource	Licenced Abstractions	Actual Abstractions
Stourbridge	23.95	56.17 (55.39)	45.69 (45.03)
Wombourne	60.68	69.14 (63.75)	51.72 (50.40)
Birmingham	34.98	40.19 (—)	14.89 (—)

(Figures are in megalitres per day; 1 megalitre = 1 million litres. Public water supply abstractions are bracketed)

Both units of the western aquifer are over-licenced, and the Stourbridge unit is grossly over-abstracted. With the exception of the Wolverhampton urban area (see later), no consideration would be given to new abstraction licences in either unit. This may pose an obstacle to development in the area. The hydrogeology of the western aquifer area is complex, with at least two aquifers being present in the Sherwood Sandstone unit. Groundwater quality is generally good but the upper aquifer has a tendency for high nitrates to be present, derived mostly from agricultural application of nitrate-based fertilisers. The lower aquifer generally has a low nitrate content so water of a reasonable quality can be abstracted by designing the borehole to abstract a proportion of its water from the lower aquifer.

The Birmingham aquifer unit is not utilised for public supply; the hydrogeology of this unit in relation to rising groundwater levels is considered further in the section 'Geological Constraints'. Although the Sherwood Sandstone in the south-east of the area forms part of a major aquifer centered on the City of Birmingham, the area around Smethwick/ Handsworth has witnessed a long history of industrial development which has resulted in contaminated land and deterioration in the groundwater quality.

Other strata

There are no major public water supply boreholes in either the Carboniferous strata or the Silurian and Devonian strata, which together crop out over most of the central coalfield area. Since these strata are not consdered to be major aquifers, the NRA does not monitor levels in them and few data are available. However, these strata have yielded good local supplies of groundwater predominantly for industrial purposes. Borehole yields are generally poor due the generally impermeable nature of the strata; the best yields are derived from the thicker permeable sandstone beds in the Carboniferous strata. Licenced abstraction rates for the wells in this area are shown in Map 8.

The natural quality of the groundwater is generally poor due to the metals and sulphate and chloride minerals present within the rocks. Much of the coalfield area has a long history of heavy industry and consequently much of the land is contaminated. The groundwater quality has also been affected in many places. Indeed, there have been direct discharges of liquid industrial waste into old mine workings in parts of the area, although these practices have now largely ceased.

The Silurian shales and limestones locally contain small quantities of groundwater, particularly where the old limestone mines are flooded. These old workings are progressively being infilled with a rock paste for stability purposes (see section on Underground Limestone Workings in Geological Constraints).

The rocks of the Mercia Mudstone Group represent an aquiclude confining the groundwater in the the underlying Sherwood Sandstone, in the south-east corner of the study area. The sandstone aquifer is not utilised for groundwater in this area.

The Carboniferous dolerite of which the Rowley Regis intrusion has the largest outcrop is generally impermeable, although there may be some fissure flow in highly fractured, jointed rock. It is not utilised for groundwater.

Additional resources

Areas with sound foundation conditions

Areas with good bearing capacity and foundation conditions are an important resource, particularly in areas like the Black Country that have been considerably undermined. Most of the bedrock materials provide sound foundation conditions, but local factors, considered in the section on Geological Constraints, may pose particular problems to ground stability.

Table 14 Types of former quarries and pits in the Black Country area and the constraints that they may present to development.

MINERAL	GEOGRAPHICAL DISTRIBUTION	TYPE OF WORKING	PRESENT STATE	POSSIBLE CONSTRAINTS TO DEVELOPMENT
Coal (opencast)	Central, exposed coalfield	Opencast pit	Complete backfill	Differential settlement. Drainage problems
Sand and Gravel	Stour and Smestow Brook valleys	Shallow gravel pits	Partially or completely backfilled	Drainage problems where backfilled. Risk of migration of leachate, and pollution risk
Sand	Eastern and western margins of area (mostly outcrop of Wildmoor Sst.)	Small to large quarries, above the watertable	Partially or completely backfilled	Waste disposal poses pollution risk to underlying Sherwood Sst. aquifer. Porous rock surrounds quarry (risk of gas or leachate migration)
Brick Clay	South and west (mostly outcrop of Etruria Fm.)	Cut into hillslopes or deep pits	Limited backfill of many larger pits. Small pits: partial to complete backfill	Slope failure of steep backwall or talus on side slopes. Drainage problems of clay fill in base and sides; possible leachate migration in 'espley' sst.
Dolerite	Rowley Regis	Quarries	Small quarries partially to completely backfilled; deep quarries open or partially to completely backfilled.	Slope failure of steep backwall or talus on side slopes; possible leachate migration along joints
Silurian limestone	Dudley–Sedgley, Walsall	Small quarries and larger sub-surface caverns	Open to partially backfilled	Sudden collapse of caverns; instability of faces; leachate migration in permeable 1st.

These include the presence of:
(a) mine shafts and adits
(b) undermined areas
(c) former excavations
(d) steep slopes
(e) running sand in foundations
(f) peat deposits
(g) poorly compacted Made Ground deposits

Unexpected factors contributing to ground instability may occur such as the presence of Head with relic shear planes or unconsolidated material with pockets of loose sand. Preliminary site investigations should always be carried out following the guidelines set out in BS 5930: 'Code of Practice for Site Investigations'. Areas of known undermining are shown on Map 6, although this may not represent all areas undermined from colliery-based and limestone mines, since historical records are not complete. Many of the problems associated with ground conditions in these areas can be mitigated by good foundation engineering practice. As a general rule, the area within the exposed coalfield, and the marginal areas of the concealed coalfield, where mining has taken place, have less favourable foundation conditions than the rest of the Black Country. Sites on the Sherwood Sandstone, despite local problems associated with running sand during the excavation for foundations, present the most favourable sites for development.

Waste Disposal Sites

The geology of a site considered for waste disposal is of prime importance since the nature of the bedrock or superficial material, and the geological structure, such as faults and joints, influence the potential for migration of any toxic or explosive substances, including gases, out of the site and in to the atmosphere or the groundwater (Table 14). The economics of exploitation of a mineral at a particular site may be influenced by the potential for utilisation of the void as a landfill site (Table 15). In addition, backfilling and restoration of a site may be an important factor in planning considerations.

The ideal site is a large excavation in impermeable, dry strata which can be backfilled with inert waste and compacted to the former ground level, for use as open recreational space, construction or agriculture. Unfavourable geological

Table 15 Mineral extraction and waste disposal possibilities in the Black Country.

MINERAL EXTRACTION	VOLUME CREATED	BEDROCK CHARACTER	SPECIAL FACTORS IN WASTE MANAGEMENT
Brick Clay	Large	Generally impermeable	Deep excavation
Dolerite	Moderate	Generally impermeable	Deep excavation
Coal	Small (after backfill of spoil	Limited permeability	May be deep and narrow excavation
Sand and Gravel	Small	Permeable	Possible high water levels
Sand (Sherwood Sandstone)	Moderate	Permeable	Bedrock is major aquifer

sites, such as those in permeable sand and gravel, or highly jointed porous bedrock, may be converted into useful sites by the construction of sealed cells for the waste and the controlled venting of any gases such as methane and carbon dioxide. This is a costly operation and the best plan may be not to use these sites for waste disposal. Careful consideration should be given to proposals for backfilling of quarries since the mineral deposit in the existing quarry may provide a valuable local resource in the future; removal of backfill material could make extraction of the mineral uneconomic.

There are few large-scale mineral extraction sites presently in operation in the Black Country; sites are limited to small-scale extraction of dolerite, brick clay and sand and gravel (Table 15). Opencast coal excavations do not generate large voids because the volume of extracted mineral is small and the waste materials generally produce a larger volume than the in situ bedrock. Former sites, not presently backfilled, include those worked for sand and gravel, sand (bedrock), sandstone, dolerite and brick clay (Table 15). However, some of these sites are designated Sites of Special Scientific Interest (SSSI), (Table 16); others have potential for this status or for use as recreational areas.

In some parts of the Black Country waste material has been spread on derelict, unused or low-lying waterlogged land. These include the flood-plain of the Tame Valley [98 98 and 96 96] and reclamation sites such as those near Neachells, to the east of Wolverhampton [93 99] (Maps 4A, 4B). Such spreads of Made Ground over a wide area may have the disadvantage of sterilising mineral deposits, such as sand and gravel, opencast coal or brick clay.

Soils

Classification of the quality of agricultural land is, in part, dependant upon the underlying geology, which influe[illegible]es and drainage. The rural areas to the we[illegible] of the Black Country vary in land quality fro[illegible] Grade 4 with Grade [illegible] being the most com[illegible] better quality Grade 3 land is developed on the outcrops of the Sherwood Sandstone Group, while the poorer Grade 4 land is on the the Upper Carboniferous strata, such as the Halesowen, Enville and Keele formations (Maps 2A, 2B). Thin soils developed on the Clent Formation are suitable only for park and heathland with limited pastoral application. Where superficial deposits (Maps 3A, 3B), particularly 'veneers' of poorly-drained, clayey till are present, these influence the local soil and drainage conditions which, therefore, differ from those that might be predicted from the nature of the bedrock.

Geological sites of scientific and educational interest

In a conurbation such as the Black Country, exposures of rocks and their included fossils, and superficial deposits, which demonstrate the geology and geomorphology of the area are an important resource for education, research and recreation. This is particularly so in the Black Country, because its scientifically important sites reflect not only the development of the geological sciences, but also the industrial archaeological history of the area, which was based on the exploitation of the mineral resources. Some sites serve the dual purpose of preserving the indigenous flora and fauna as well as the geological features. The Wren's Nest site is world renowned for its exposures of Silurian strata and the limestone caverns.

Sites can be protected by their designation as a Site of Special Scientific Interest (SSSI) or as a Regionally Important Geological/Geomorphological Site (RIGS) both administered by English Nature. Geological and biological SSSI's in the Black Country are listed in Table 16. The National Scheme for Geological Site Documentation (NSGSD), initiated in 1977 and administered by English Nature (then the Nature Conservancy Council), provides a source of information on sites for planners, researchers, educationalists and others. In the Black Country this scheme is organised by volunteers from the Black Country Geological Society together with local museums such as Dudley Museum, who keep up-to-date records of the various sites.

Planners and developers need to be aware that, given suitable treatment such as landscaping, clearing and stabilising rock faces, the presence of a rock section of geological interest may enhance the amenity value of a site. Information on the geology of a particular site can be found in the NSGSD listings held by Dudley Museum, and further advice can be obtained from English Nature (see Appendix 4).

Landfill operations can totally obscure important or unique geological features; where backfilling is deemed necessary, the most valuable features may be preserved by leaving part of the quarry face clear.

Some of the sites designated RIGS in the NSGSD may deserve elevation to SSSI status. Sites for consideration are:

Table 16 Geological and biological Sites of Special Scientific Interest (SSSI) in the Black Country area.

Geological Sites

SITE NAME	GRID REFERENCE	GEOLOGICAL INTEREST
Brewin's Canal Section	SO 936 876	Exposure of Coal Measures, unconformably overlying Downton Castle Sandstone (Silurian)
Bromsgrove Road Cutting	SO 971 835	Exposures of Halesowen Formation sandstones
Doulton's Clay Pit	SO 936 870	Exposures of Coal Measures (Westphalian A and B), including the Stinking Coal
Hay Head Quarries	SP 048 987	Former workings in the Barr Limestone
Ketley Clay Pit	SO 898 888	Exposures of the Halesowen Formation unconformably overlying the Etruria Formation
Turner's Hill	SO 909 918	Exposures of Ludlow rocks, Downton Group and Coal Measures
Wollaston Ridge Quarry	SO 883 848	Kidderminster Formation unconformably overlying Bridgnorth Sandstone
Wren's Nest National	SO 937 920	Excellent exposures of Wenlock and Ludlow rocks, including the Much Wenlock Limestone; limestone mines

In addition, the following Geological SSSI is situated just outside of the study area:

Draw End Railway Cutting	SK 035 002	Wenclock rocks

Biological Sites

Fens Pools	SO 920 866
Illey Pastures	SO 977 812

(a) exposures of the Silurian strata, Downton Group and unconformable Coal Measures at the Hayes [9294 8449 to 9302 8446] (back cover)
(b) exposures of the Keele and Enville formations, and the unconformable Kidderminster Formation, along the railway cutting between Halford's Lane Bridge and Watville Road Bridge [SP 0251 8977 to 0257 8974] and [SP 0291 8956]
(c) quarries at Barrow Hill in the Carboniferous dolerite and agglomerate, and the Etruria Formation [915 896].

Geological Constraints

Potentially adverse ground conditions are the main geological constraint for consideration in planning and development. Appropriate site investigations (Anon, 1981b) utilising drilling, trial pitting and soil sampling, together with geotechnical and geochemical testing of fill, superficial and bedrock materials at a site, are important in assessing the suitability of a site for development or redevelopment. Although most ground problems can be overcome by appropriate engineering or construction works, the early recognition of problems which may arise is of great importance, because unforeseen problems lead to additional costs and delays, and, in some cases, solutions may be prohibitively expensive. Assessment of ground conditions includes not only the properties and stability of bedrock and superficial materials, but also the changes to the subsurface brought about by man, such as mining and any consequent subsidence, quarrying and landfill. These two aspects, the natural geological properties and man-made modifications (Table 17), are considered separately below.

Properties and stability of bedrock and superficial materials

The suitability of bedrock and superficial materials for foundations depends mainly on their geotechnical properties. The various parameters relating to the bearing strength of natural materials and to their reaction to engineering structures are reviewed below. Consideration is also given to fill treated as a geologically significant deposit. Large-scale landfill operations are a relatively recent development, made necessary by a massive increase in industrial

Table 17 Major geological constraints to development and their possible risks

MAJOR CONSTRAINTS		POSSIBLE RISKS
A NATURAL		
	Behaviour of ground materials	Low bearing capacity; variable compressibility; swelling/shrinkage of clays; frost heave; sulphate attack on concrete; asphyxiating and explosive gases from natural sources.
	Stability of natural and excavated slopes	Slope failure; landslip; solifluction (creep); rockfall.
	Groundwater	Rising groundwater levels causing flooding of basements and swelling below foundations; contamination of groundwater aquifers. Fluctuations in groundwater may affect mine stability
B MAN-MADE		
	Abandoned coal mines	Explosive and asphyxiating gases (methane and carbon dioxide) emanating from abandoned mines.
	Mining subsidence (coal and limestone)	Crown hole development due to roof failure and general subsidence due to pillar collapse.
	Quarries and Pits	Low bearing capacity and variable compressibility of fill; drainage problems; explosive and asphyxiating gases in fill materials (methane and carbon dioxide), and migration of gases to surrounding areas; leachates polluting soil, groundwater and surface water; toxic residues in soil; slope failure; rockfall.
	Constructional	Variable compressibility of fill*; toxic and explosive gases in fill material; leachate migration; swelling; sulphate attack on concrete.

* Only if fill unsuitable, or badly compacted.

and domestic waste. Fill commonly includes chemical and organic wastes, each of which may provide difficult or, sometimes, hazardous conditions locally.

In considering the stability of engineering structures several geological factors, in addition to geotechnical properties, must be examined. These include local geological structure and slope stability, and the possible presence of mining cavities. Any of these may give rise to difficult ground conditions which can then act as a constraint to development. Site specific investigations should always be carried out prior to development. Further aspects to be considered are the possibility of risks to health from exposure to radioactive radon gas emanating from subsurface materials and from methane and carbon dioxide emanating from methane-bearing strata, abandoned mines or landfill sites. On the regional scale, earthquakes may present problems for some types of development.

These factors are reviewed in detail in the following section.

Behaviour of Ground Materials

Contributed by A Forster

The engineering geological assessment of the superficial and bedrock units in the area was based on information abstracted from published scientific papers and 559 site investigation reports. Data from a total of 7854 test or sample points were used. The data are summarised in Tables 22 and 23. Categories of compressibility, consolidation and sulphate levels are given in Tables 19, 20, and 21, respectively. No new sampling or testing was undertaken so that data points are, to a large extent, concentrated in areas where development has taken place. Sample coverage of geological units is generally good. The chemical tests (ph and sulphate) quoted are those most commonly listed in routine site investigations; at some sites, particularly those where contaminated ground is suspected, additional tests for chemical and biological contamination should be carried out. Full details of the coverage and quality of data, the methodology used in processing the data, the limitations of results and analysis of geotechnical properties are provided in a separate report (Forster, 1991); simplified descriptions of the geotechnical tests and parameters are given in the Glossary. Lithological descriptions in this section are based on engineering geological terminology; the principal lithological component is shown in capitals in accordance with BS 5930: Code of Practice for Site Investigation. Due to the sampling limitations of the dataset some of the less common lithologies within each formation are not represented in the summary data. Geotechnical data are not available for some formations with small outcrop areas, such as the Rubery Formation, Barr Limestone, Aymestry Limestone, Whitcliffe Formation and Downton Group. The engineering geological category of these bedrock units, as shown on Maps 9A and 9B, is inferred from their principal lithological characteristics.

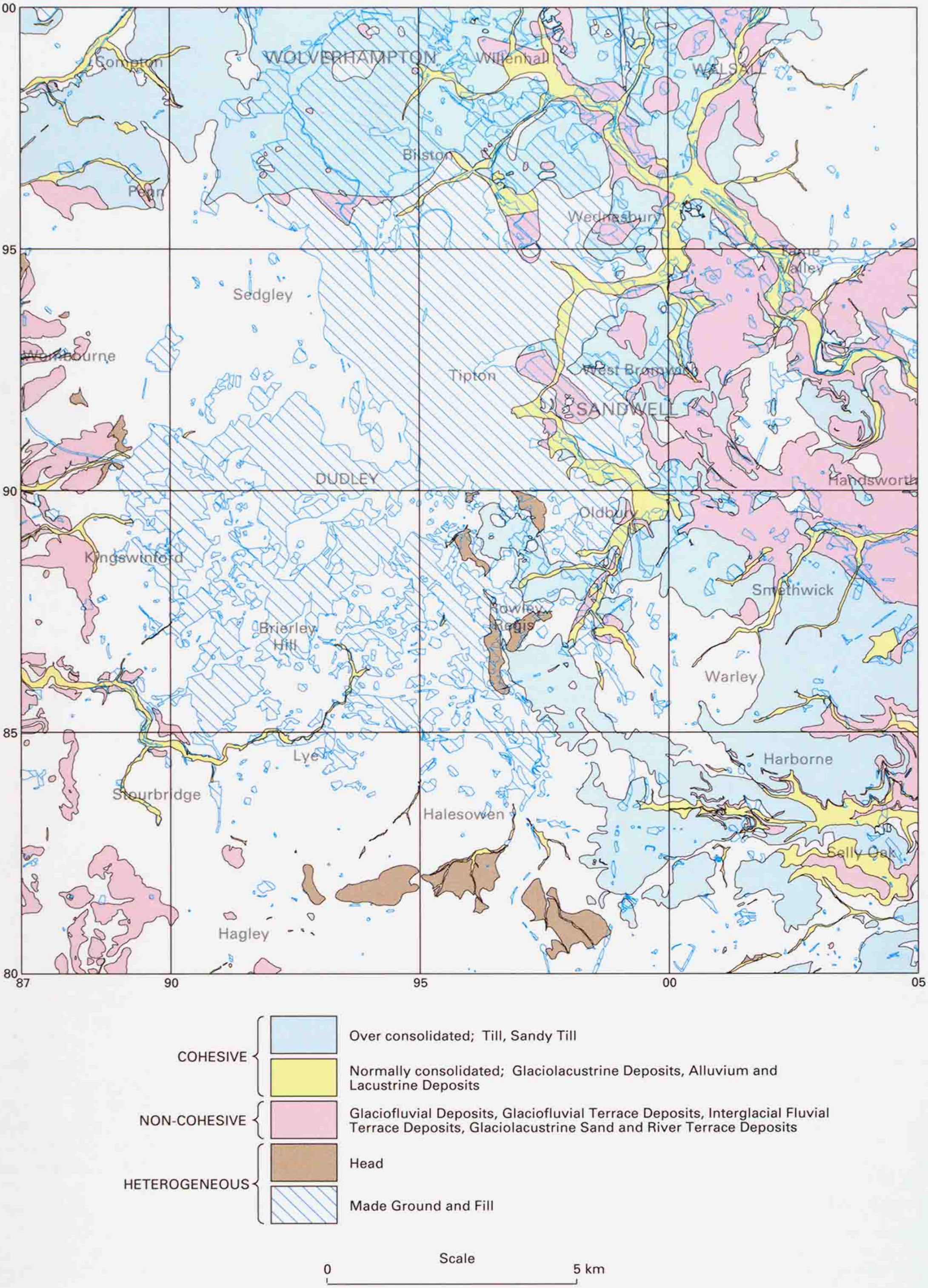


Figure 16 Generalised distribution of engineering geological categories of superficial (drift) deposits.

The description of geotechnical properties which follows deals with materials in three groups:
Made Ground and fill
Superficial (drift) deposits
Bedrock

The bedrock, superficial (drift) and Made Ground/Fill materials of the Black Country can be conveniently classified for the purposes of land-use planning on the basis of their geotechnical properties (Maps 9A, 9B; Table 18).

Made Ground and Fill

Made Ground and Fill are general terms for man-made deposits, generally found within planned areas of landfill or backfill, but including a thin, locally patchy veneer beneath most urban areas of the Black Country. The distribution of Made Ground is shown on Maps 4A, 4B, and generalised in Figure 12; the deposit is shown only where it is more than 2 m thick. **All geotechnical investigations should allow for the presence of made ground overlying superficial (drift) deposits or bedrock.**

The geotechnical properties of Made Ground are difficult to predict. Its behaviour is dependent on its composition, the manner in which it was placed, and the method and degree of compaction. The problems associated with Made Ground and fill include the generation of methane, carbon dioxide and hydrogen sulphide gases, toxic leachates from waste disposal sites, buried voids and underground combustion. In the case of Made Ground composed of colliery waste, conditions are more predictable, but swelling due to pyrite decomposition below foundations may pose a problem at some sites.

When fill material is utilised as part of an engineering scheme, the material used should be placed in a controlled manner and compacted to a specific density. Fill used as part of a waste disposal in backfilled quarries and pits may vary from relatively inert, inorganic waste such as mine waste or building rubble to organic domestic refuse. The geotechnical properties of such a site will depend on the nature of the fill material, and the geological structure, lithology and geotechnical properties of the superficial deposits or bedrock of the excavated pit or quarry. In the case of organic material and any chemical wastes the nature of the material may change with time as decay proceeds. The decay of organic material in domestic refuse may cause a loss of volume of up to 50%, and may result in the generation of methane and hydrogen sulphide, and toxic leachate. Migration of potentialy explosive gases and toxic liquids may then take place through the fill deposit or into adjacent strata by way of interconnected pores or open fissures. Excavation is usually possible with normal digging equipment but stability may be poor and support will be necessary. Precautions should also be taken, in pits and trenches, against the possibility of toxic materials being present and the accumulation of carbon dioxide and methane.

Made Ground and fill in the Black Country consists of a wide variety of materials both natural, such as clay, sand, silt, gravel, mudstone, sandstone and colliery waste (which comprises a mixture of these materials together with carbonaceous shale and coal), and artificial, such as brick rubble, foundry slag, ash and domestic waste. In the study area, geotechnical data (Table 22) for Made Ground and fill are biased towards colliery spoil which repesents the most widespread deposit.

Standard penetration test (SPT) ranges from less than 4 to 33 (very loose to dense) with a median value of 11. Low SPT values may be found down to depths of 25 m. Undrained cohesion, median value 60 kPa (firm) ranges from very soft to stiff and shows an almost random distribution with depth.

Moisture content has a median value of 21% and shows a very wide range in value, with values as high as 50% occurring at 12 m depth. The bearing capacity is commonly low and is likely to vary over short distances, possibly leading to uneven settlement.

Plasticity data show the material to comprise mainly inorganic clays of low, intermediate or high plasticity but a very wide range is present with some samples in almost every category of plasticity and grain size.

Chemical tests show conditions to be neutral or slightly acidic and sulphate content to conform mainly to class 1 conditions for sulphate attack on buried concrete (Anon 1981a) but some class 2, class 3 and a few class 4 or 5 conditions are indicated. Where past industrial activity has resulted in contaminated ground, tests for chemical and biological contamination should be included in the site investigation. Potential hazards to people , including those undertaking building or site investigation work, and possible corrosive leachate attack on services and buried concrete below the water table (Eglington, 1979), should be assessed.

In terms of its engineering characteristics, Made Ground and fill is classified as a heterogeneous deposit (Table 18).

Superficial (drift) deposits

The superficial deposits of the Black Country may be divided into four categories based on their lithology and geotechnical characteristics (Table 18). Soils (in the engineering sense) are initially classified on grain-size. The distribution of engineering geological categories of superficial (drift) deposits is shown in Figure 16 and map 9A.

In general, cohesive soils are fine-grained materials such as clays and silts; non-cohesive soils are coarse-grained materials such as uncemented sands and gravels. The finer soils, clays and silts, where the component particles adhere to each other by natural inter-particle forces are termed 'cohesive soils'. The coarser soils, sands and gravels, where the component particles do not naturally adhere one to another without a cementing agent are termed 'non-cohesive soils'. Further classification of soil is made on the basis of plasticity tests (liquid and plastic limit) for cohesive soils, and detailed particle-size analyses for non-cohesive soils.

The buried bedrock channels infilled with drift deposits, locally up to 35 m thick, located in the west and northwest of the Black Country are of great significance to geotechnical investigations and foundation conditions. The form and types of fill of these deposits are briefly discussed on p. 35. It is important that detailed site investigations are carried out on or adjacent to these buried channels (Maps 3A, 3B), since the drift deposits infilling the depressions are typically heterogeneous and are subject to rapid lateral variation.

Head is a heterogeneous deposit (like Made Ground and fill) and together with peat (organic deposit), it is described separately.

Heterogeneous Deposits

Head

Head is derived from superficial or bedrock materials by the weathering, erosion and downslope movement of deposits on a local scale, during periglacial conditions, by

Table 18 Engineering geological categories

	ENGINEERING GEOLOGICAL UNIT	TYPE OF DEPOSIT OR LITHOSTRATIGRAPHICAL UNIT
SUPERFICIAL (DRIFT)	Cohesive	A Over consolidated Till (Boulder Clay) Sandy Till B Normally consolidated Glaciolacustrine Deposits (silt and clay) Alluvium (other than alluvial gravel) Lacustrine Deposits
	Non Cohesive	Glaciofluvial Deposits Glaciofluvial Terrace Deposits Interglacial Fluvial Terrace Deposits Glaciolacustrine Sand River Terrace Deposits
	Heterogeneous	Head Made Ground
	Organic	Peat
BEDROCK (SOLID)	Strong Rock	*Aymestry Limestone* Upper Quarried Limestone } Much Wenlock Limestone Nodular Limestone } Much Wenlock Limestone Lower Quarried Limestone } Much Wenlock Limestone *Barr Limestone* Dolerite
	Sandstone with some conglomerate	Bromsgrove Sandstone Wildmoor Sandstone Kidderminster Formation Bridgnorth Sandstone *Downton Castle Sandstone* *Rubery Formation*
	Mudstone with some siltstone and fine sandstone	Mercia Mudstone Clent Breccia (northern part of area) Elton Formation Coalbrookdale Formation *Temeside Shales Foramtion*
	Interbedded mudstone and sandstone	Clent Breccia (southern part of area) Enville Formation Keele Formation Halesowen Formation Etruria Formation Coal Measures *Ledbury Formation* *Whitcliffe Formation*

Lithostratigraphical units shown in italics have small outcrop areas for which there are no geotechnical records. The Engineering Geological Category of these units is inferred from their principal lithological characteristics

Table 19 Coefficient of volume compressibility, Mv

CLASS	DESCRIPTION OF COMPRESSIBILITY	Mv (m2/MN)	EXAMPLES
5	Very high	>1.5	Very organic clays and peats
4	High	0.3–1.5	Normally consolidated alluvial clays, e.g. estuarine clays
3	Medium	0.1–0.3	Glaciofluvial clays, Lacustrine clays
2	Low	0.05–0.1	Till (Boulder clays)
1	Very low	>0.05	Heavily overconsolidated 'boulder clays'. Stiff weathered rocks

Table 20 Coefficient of consolidation, Cv

CLASS	Cv (m2/year)	PLASTICITY INDEX	SOIL TYPE
1	<0.1		CLAYS: Montmorillonite
2	0.1–	>25	High Plasticity
3	1–10	25–15	Medium Plasticity
4	10–100	15 or less	Low Plasticity
5	>100		SILTS

Table 21 Sulphates in soil and groundwater.

CLASS	TOTAL SO3 (%)	SO3 In 2:1 SOIL:WATER	SO3 IN GROUNDWATER
1	<0.2		<30
2	0.2–0.5		30–120
3	0.5–1.0	1.9–3.1	120–500
5	>2	>5.6	>500

processes such as solifluction, soil creep and hill wash. Head is commonly thin, up to 2 m thick, but greater thicknesses may accumulate in hollows and at the foot of slopes. Composition varies with that of the parent material as do geotechnical properties which tend to be similar to those of the remoulded parent. On slopes, Head may contain relic shear surfaces which may be reactivated even on shallow slopes if the stability of the slope is reduced by, for example, undercutting during excavation, or by introducing water into the slope (Hutchinson et al, 1973). Where Head is thin it is usually removed before foundations are placed. Where the deposit is thick, its low strength and high compressibility can lead to excessive settlement. Excavations in Head will require support, and water inflow may cause collapse.

Head may vary from a cohesive clay with a soft to stiff consistency such as the red clay found adjacent to the Hagley Road which is derived from the Keele Formation, or a non-cohesive material composed of gravel or rock fragments with a loose to dense relative density.

Chemical tests indicate that conditions are near to neutral pH and sulphate content conforms to class 1 conditions for sulphate attack on buried concrete (Anon 1981a).

Table 18 Engineering geological categories.

Organic Deposits

Peat

Organic deposits such as peat, and organic rich clay and silt, occur locally as channel infills within alluvium and lacustrine deposits, but are not common, at surface, in the study area. The geotechnical properties of peat are taken from investigations outside of the Black Country, but the results are considered comparable.

Engineering problems caused by peat and highly organic silts are due to the low strength, high compressibility and high groundwater content. Peat commonly occurs in relatively small, isolated bodies which may be susceptible to differential settlement compared to the adjacent less compressible materials. Concrete foundations may suffer damage due to sulphate or acid attack by acidic groundwater. Organic deposits may generate methane, but the risk is less than in backfilled landfill sites.

Engineering solutions to these problems include removal of the peat and replacement by inert fill, raft foundations, piled foundations and the use of chemical attack-resistant mixes for buried concrete.

Cohesive Deposits

This category (Table 18) is subdivided into **overconsolidated** and normally **consolidated** types (see Glossary for

Type of Deposit	SPT 'N'	Moisture Content %	Liquid Limit %	Plastic Limit %	Plastic Index %	Density Bulk Density Mg/m^3	 Dry Density Mg/m^3	pH	SO_3 Class	Undrained Triaxal Compression Test Undrained Cohesion kPa	 Øu °
Head	20 46 31 78 23 96	52 20 17 23 14 30	12 40 32 51	14 22 21 24	12 18 11 29	26 2.10 1.98 2.24 1.83 2.29	18 1.72 1.55 1.91	25 6.40 6.20 6.80 5.80 7.20	24 1 1 1 1 1	26 62 43 118 33 163	26 0 0 8 0 11
Alluvium excluding gravel	45 33 22 67 4 118	92 22 16 32 13 42 10 63	50 36 28 44 23 52	50 19 15 23 14 27	50 18 12 22 11 27	56 2.01 1.86 2.16 1.70 2.24	53 1.57 1.31 1.84 1.12 1.95	23 7.10 6.80 7.70 6.60 7.80	24 1 1 1 1 1	51 24 13 67 7 141	49 0 0 5 0 18
Glaciofluvial Sand and Gravel	508 22 14 33 9 48 5 81	96 15 13 18 11 21 8 26	40 26 23 32 19 36	40 17 15 18 13 23	40 10 7 14 4 18	52 2.15 2.09 2.34 2.04 2.35	41 1.84 1.76 2.00 1.71 2.14	79 7.00 6.20 7.40 5.50 7.70 4.90 9.10	74 1 1 1 1 1 1 2	39 72 40 122 24 210 0 600	39 4 0 12 0 25 0 39
Alluvial and Glaciofluvial Terrace Deposits	36 30 20 48 14 85							3 6.50 6.50 7.10	3 1 1 1		
Alluvial Gravel	24 26 17 49 11 68							2 6.70 6.50 7.00	2 1 2		
Glacio-lacustrine Deposits	54 16 12 26 10 42 4 93	359 20 17 23 14 28 11 87	228 30 27 36 24 48 20 85	225 19 16 21 14 25 12 55	228 12 8 16 6 23 3 33	280 2.06 2.00 2.11 1.84 2.21 1.33 2.27	285 1.71 1.63 1.81 1.38 1.89 0.72 2.02	19 7.10 6.80 7.20 6.50 7.50	20 1 1 1 1 1	196 86 62 119 40 153 3 290	196 3 0 9 0 18 0 30
Till	263 24 12 44 6 90 4 295	686 14 11 17 10 21 9 31	320 28 24 35 20 45 17 52	321 15 13 18 11 21 10 24	321 14 10 18 7 24 4 31	517 2.19 2.11 2.26 2.02 2.32 1.88 2.37	298 1.94 1.84 2.05 1.73 2.12 1.49 2.16	187 6.60 5.40 7.30 4.30 7.70 4.00 8.10	184 1 1 1 1 1 1 2	357 80 40 125 22 184 10 260	357 4 0 12 0 17 0 28
Made Ground and Fill	706 11 6 20 4 33 2 54	282 21 16 27 13 37 10 60	55 43 39 51 29 69 24 82	5 24 20 26 17 29 14 40	53 21 17 27 13 38 8 55	114 1.99 1.80 2.13 1.61 2.19 1.49 2.27	71 1.62 1.49 1.77 1.31 1.92 0.85 2.05	289 7.00 6.50 7.40 6.20 8.20 5 70 9.30	295 1 1 2 1 2 1 4	107 60 41 102 19 147 10 205	107 3 0 9 0 13 0 19

	N	Number of values
	50%	Median value
Percentile values	25 75	Quartile values
	10 90	
	2.5 97.5	

Key for explanation of fields

Table 22 Summary of geotechnical data for superficial materials (see key for explanation of fields).

Particle size analysis				Consolidation		Rock Quality Designation	Fracture Spacing Index	Unconfined Compressive Strength	Compaction		California Bearing Ratio
Clay %	Silt %	Sand %	Gravel %	Mv class	Cv Class	RQD %	FSI mmc	MPa	Max Dry Density Mg/m^3	Optimum M.C. %	C.B.R %
18 0 0 7 0 10	18 10 7 14 2 23	23 71 17 80 11 85	23 16 3 62 2 85	5 2 1 3	5 3 1 3						
88 0 0 0 0 3 0 8	88 4 2 11 0 17 0 23	200 33 19 55 10 79 3 87	208 58 29 76 8 88 1 97	8 1 1 3	6 3 3 4				3 2.05 1.92 2.05	3 11 9 13	4 9 5 14
29 0 0 0 0 0	29 0 0 1 0 3	35 11 8 17 2 20	35 87 80 92 76 94								
13 0 0 0 0	13 2 0 3 0 10	18 11 7 26 5 38	18 87 70 90 42 93								
		11 44 19 60	11 24 1 44	65 2 1 3 1 3 1 3	62 4 3 4 3 4 3 5						2 8 1 15
18 0 0 6 0 16	17 27 15 45 0 63	24 41 21 61 5 64	29 33 16 67 1 92	34 2 1 3 1 3 1 3	28 3 3 4 2 4 1 5				7 1.86 1.63 1.99	7 14 11 22	6 13 2 18
		41 30 25 41 18 46 5 62	60 65 44 84 33 94 15 98								

Lithostratigraphical Unit						Density				Undrained Triaxal Compression Test	
	SPT 'N'	Moisture Content %	Liquid Limit %	Plastic Limit %	Plastic Index %	Bulk Density Mg/m³	Dry Density Mg/m³	pH	SO_3 Class	Undrained Cohesion KPa	Øu o
Mercia Mudstone	1 11	1 19						2 6.10	2 1		
Bromsgrove Sandstone	32 148 21 236 12 248	8 15 13 19	6 27 25 28	6 14 13 16	6 14 11 14	5 2.19 2 13 2 32	5 1.89 1.86 1.92	6 6.50 6.40 6.60	6 1 1 1	5 57 51 63	5 6 0 7
Wildmoor Sandstone	84 109 54 162 33 236 13 300							20 7.35 6.85 7.50 6.60 8 00	19 1 1 1 1 1		
Kidderminster Formation	7 112 67 200							1 8.00	1 8		
Bridgnorth Sandstone	13 107 70 118	1 10				1 2 05		2 7 60	2 1	1 30	1 0
Clent Formation	87 66 43 165 19 300 12 900	43 13 11 16 9 19	17 39 34 44 30 50	17 18 16 19 21 15	17 21 18 27 15 29	17 2 19 2.08 2.27 2.04 2.32	11 1 89 1.77 2.00	17 7.10 6.50 7.60 6.30 7.80	17 1 1 1 1 1	23 86 55 110 33 140	23 13 6 18 1 27
Enville Formation	2 50 50 50										
Keele Formation	116 162 60 279 50 378 14 999	294 12 10 14 8 17 6 22	190 40 35 45 28 52 25 60	190 19 17 21 15 23 13 26	190 21 25 17 13 31 9 37	168 2.24 2.18 2 29 2.08 2 35 2.00 2 40	150 2.02 1.94 2.10 1.83 2.15 1.73 2.23	29 7 2 7 00 7.60 7 00 8.60 6.90 10.00	32 1 1 1 1 1 1 1	130 109 69 139 43 195 17 260	130 11 4 18 0 25 0 33
Halesowen Formation	79 120 50 200 21 300 13 600	38 16 12 18 8 21 7 29	19 39 31 46 23 53	19 20 17 22 14 23	19 20 12 25 7 33	24 2 10 2 03 2.23 1 99 2.32	22 1.84 1 75 1.99 1.70 2.11	11 7.00 6.50 ..7.30	11 1 1 1 1 1	29 103 62 147 14 175	29 16 3 25 0 30
Etruria Formation	568 50 46 77 30 132 17 254	925 14 11 17 9 21 7 28	302 40 33 45 29 52 18 60	296 20 18 22 17 24 15 28	294 19 15 24 10 29 7 37	363 2.16 2.10 2.24 2.00 2.29 1.85 2.36	275 1.92 1.81 2.00 1.67 2.08 1.50 2.15	91 7 6.80 7.30 6.50 7.90 5.90 8.50	91 1 1 1 1 2 1 3	294 103 56 144 30 180 11 254	291 6 0 14 0 23 0 28
Coal Measures	199 62 39 96 22 195 9 360		143 15 11 20 8 25 6 33		59 41 37 48 33 57 31 63		60 20 18 23 16 27 14 32		59 22 18 27 12 30 10 38		86 2.07 1 99 2.19 1.90 2 30 1.70 2.34
Elton Formation	18 46 18 88		37 3 2 3		3 43 21 56		3 28 35 32		3 15 14 24		28 2.63 2.62 2.64
Upper Quarried Limestone			3 0 0 1								3 2 68 2.68 2.68
Nodular Limestone			13 1 1 1		3 49 40 52		3 28 24 33		3 19 16 21		11 2.65 2 65 2.66
Lower Quarried Limestone			1 0								2 2.70
Coalbrookdale Formation	58 183 85 252 50 288		25 15 12 17 8 19		20 31 30 37 28 54		20 19 17 21 14 22		20 15 12 18 11 32		23 2 15 2 08 2 29 2.03 2 30
Dolerite	8 68 46 95										

Table 23 Summary of geotechnical data for bedrock materials (see key for explanation of fields).

Particle size analysis				Consolidation		Rock Quality Designation	Fracture Spacing Index	Unconfined Compressive Strength	Compaction		California Bearing Ratio
Clay %	Silt %	Sand %	Gravel %	Mv class	Cv Class	RQD %	FSI mm	MPa	Max Dry Density Mg/m^3	Optimum M C. %	C.B.R %
2 0	2 15	2 84	2 1								
2 0 0 0	2 18 5 31	2 80 67 93	2 2 2 2			15 56 44 76	15 161 107 205				
22 0 0 6 0 8	22 16 12 20 10 25	22 80 72 84 66 88	22 2 1 2 1 3								
2 1.5 0 3	2 15 8 23	2 80 70 91	2 2 1 4								
2 3.5 3 4	2 61.5 44 79	2 18.5 17 20 11 85	2 16.51 32			81 33 12 65 0 82 0 97	81 9 5 14 3 25 2 40				
		5 13 12 26	5 34 22 61	13 2 1 2	5 3 2 3				13 1.92 1.89 1.97	13 13 12 14	16 16 6 26
									3 1.83 1.79 1.92	3 14 13 16	
				3 3 1 5	3 3 3 3	12 48 35 68					
				7 2 2 3	7 3 3 3	157 41 14 65 0 81 0 95	46 999 500 999 250 999 167 999				
						251 59 31 82 8 92 0 99	400 200 50 500 20 999 0 999				
						17 86 65 93	20 250 184 999	3 81 56 89			
						45 87 63 94	91 999 333 999	11 37 29 41			
						9 83 72 95	91 999 999 999	2 58 40 76			
						5 60 42 95	5 999 999 999				

N	Number of values
50%	Median value
25 75	Quartile values
10 90	Percentile values
2.5 97.5	Percentile values

Key for explanation of fields

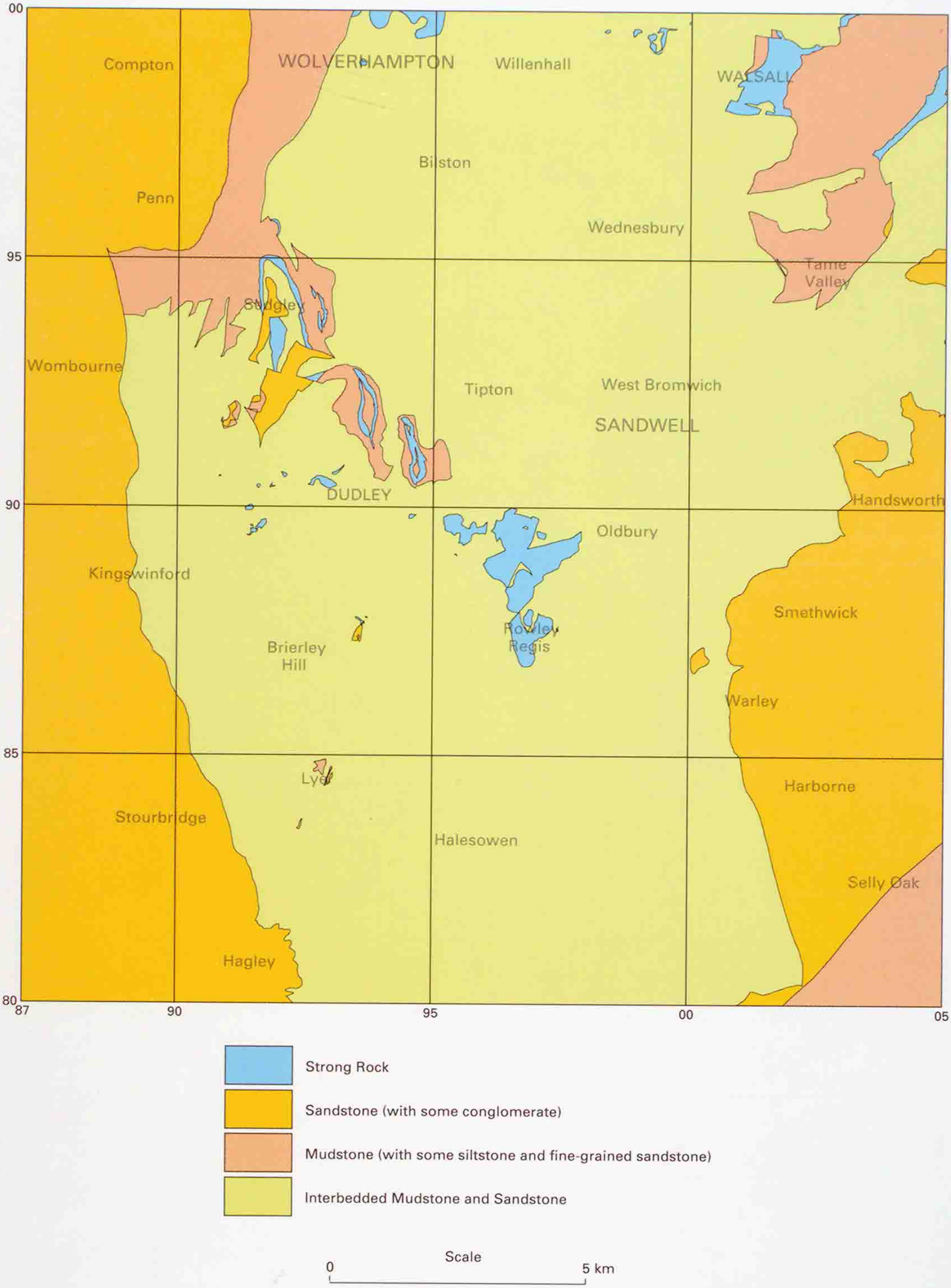


Figure 17 Generalised distribution of broad engineering geological categories of the bedrock in the Black Country.

Cohesive Deposits

This category (Table 18) is subdivided into **overconsolidated** and normally **consolidated** types (see Glossary for definition).

In general the **overconsolidated** materials, such as Till (Boulder Clay) and Sandy Till offer good bearing capacity but may contain patches of softer material and lenses of sand and gravel. Shrinking and swelling of the clays is unlikely to be a problem, and sulphate attack on buried concrete below the water table is unlikely. Excavations may usually be accomplished by digging equipment, but may be difficult if boulders are present. The stability of excavations is usually good unless water-bearing gravel, sand or silt cause running conditions, flooding and side collapse. Trafficability should be reasonably good except where patches of soft clay are present.

Till and Sandy Till

Samples analysed in the study area indicate that the Till is predominantly an overconsolidated silty sandy or gravelly CLAY with some silty clayey or gravelly SAND, with a variable pebble content. Sandy Till has a higher proportion of sand in the clayey matrix and is often interbedded with thin lenses of clayey SAND and GRAVEL.

The median value of standard penetration tests for Till is 24 (very stiff) and ranges from 6 (firm) to 90 (very hard). SPT results show an increase in value with depth from 1 metre to 12 m depth. Undrained cohesion has a median value of 80 kPa (stiff) and ranges from soft to very stiff. It shows a tendency to increase with depth but high values occur near to the surface.

Moisture content, median value 14%, shows a spread in values from 6% to 53% down to a depth of 9 m, but below this the range is 8% to 18%.

Plasticity data show the Till (Boulder Clay) to be an inorganic clay of low plasticity. The data plot above the A line of Casagrande plasticity chart (Casagrande 1948) and on, or a little below, the T line (Boulton and Paul 1976). The implication is that those samples which fall on, or close to, the T line, are of relatively undisturbed lodgement Till but those which fall closer to the A line are flow till or have been disturbed by periglacial processes and weathering. Plots of moisture content against plastic limit show a majority of samples to have a moisture content below the plastic limit and confirm the interpretation of the material as predominantly overconsolidated lodgement till. Consolidation data show the Till (Boulder Clay) to have very low to medium compressibility with fairly fast consolidation.

Chemical tests indicate slightly acidic or acidic conditions to prevail. Class 1 conditions for sulphate attack on buried concrete are usually found, but class 2 conditions are sometimes present.

The **normally consolidated** Alluvium, Lacustrine Deposits and Glaciolacustrine Deposits offer poor bearing capacity and may suffer severe, possibly uneven, settlement. Settlement may be rapid, over peat or laminated silt, sand and clay, or slow on soft clay. These deposits are easily dug but the excavation stability may be poor and require more support than normal practice. Trafficability is poor; a desiccated crust may be present which gives reasonable trafficability until disrupted when trafficability will deteriorate rapidly. Sulphate attack on concrete buried below the water table is unlikely, but aggressive ground-water conditions may be found in or near to peat deposits. Silt lithologies close to the surface may be susceptible to frost action.

Alluvium and Lacustrine Deposits

The Alluvium and lacustrine deposits of the study area predominantly consist of CLAY which is often silty, sandy or gravelly and less commonly organic. Silty and clayey SAND are also present in significant amounts with smaller amounts of SILT and some GRAVEL.

Penetration test data show a wide range of values and when plotted against depth no clear relationship is evident due to the wide range in material type. However, when split into subsets based on lithology a general trend of increase in value with depth is apparent. Clay lithologies vary from firm to hard over the depth range of 1 to 8m and gravel lithologies from medium dense to very dense over the depth range 2 to 8 m. The relationship for sand is scattered but ranges from loose near surface increasing rapidly to very dense. No relationship is apparent for silt.

Undrained cohesion for silt and clay lithologies has a median value of 24 kPa (soft) and ranges from very soft to stiff. Moisture content for clays and silts, median value 22%, shows a fairly wide spread in value down to 6 m depth but no correlation is seen with depth except where the deposit has been buried by thick fill and moisture content has dropped to between 10% and 18%.

Plasticity data show the alluvium to comprise mainly inorganic clay of low and intermediate plasticity. A few organic clays and silts of high and very high plasticity are present and some sandy clay of low plasticity. Moisture content is usually greater than, or close to, the plastic limit which is indicative of a normally consolidated clay.

Chemical tests show conditions close to neutral with a median pH value of 7.1 and class 1 conditions for sulphate attack on buried concrete.

Glaciolacustrine Deposits

Glaciolacustrine Deposits consist mainly of normally consolidated silty CLAY or clayey SILT; either may also be sandy, gravelly or organic (peaty).

Gravelly, silty or clayey SAND is also present together with small amounts of clayey or silty PEAT.

The median value for standard penetration test N value for undifferentiated sand, silt and clay Glaciolacustrine Deposits is 16 (stiff clay, medium dense sand) and ranges from 10 (stiff clay, loose/medium dense sand) to 42 (hard clay, dense sand). The N value is greater with increasing depth. The median value of undrained cohesion for silt and clay lithologies is 86 kPa (stiff) and ranges from 40 kPa to 153 kPa. Undrained cohesion results show a slight trend of increase in value with depth but there is considerable scatter.

Moisture content has a median value of 20% and values range from about 10% to 30%; there is a distinct fall in moisture content towards a value of about 10% at 40 m depth. The exceptions to this trend are samples of highly organic material from between 8 m and 18 m which have moisture contents in the ranges 30% to 170%.

Plasticity data show that the Glaciolacustrine Deposits comprise a number of different materials, chiefly consisting of inorganic clays of low plasticity with some samples in the intermediate plasticity category.

Consolidation data indicate that, in general, the Glaciolacustrine Deposits have low to medium compressibility with medium to fast consolidation. However, the variation in lithology found within the Glaciolacustrine Deposits will give a wide range in consolidation behaviour.

Chemical tests show close to neutral pH conditions to prevail and sulphate content to conform to class 1 conditions for sulphate attack on buried concrete.

Non-cohesive deposits

The non-cohesive deposits comprise Alluvial gravel, Glaciofluvial Deposits (sand and gravel), Glaciofluvial Terrace Deposits, Interglacial Fluvial Terrace Deposits, Glaciolacustrine Sand and River Terrace Deposits. They offer good bearing capacity with very low and rapid settlement. Standard penetration test results may be an unreliable guide to bearing capacity due to the coarse nature of the deposit.

Excavations may be accomplished by digging equipment but sides may require support to maintain stability. Water inflow into excavations below the water table may be excessive and require dewatering measures to be taken. Ground will be free draining and trafficability should be good. Material is generally suitable as fill and as a source of aggregate but some selection will be necessary in the Glaciofluvial and Glaciolacustrine deposits. Sulphate attack on concrete buried below the water table is unlikely.

Alluvial Gravel

Alluvial gravel is not distinguished on the maps, but pockets and lenses may be present within the Alluvium. The deposit consists of GRAVEL or sandy GRAVEL locally, with thin intercalations of SAND and sandy CLAY. Standard penetration test data show it to be mainly medium dense, and particle size analyses confirm it is a GRAVEL or sandy GRAVEL.

River Terrace Deposits, Glaciofluvial Terrace Deposits, and Interglacial Fluvial Terrace Deposits

These deposits mainly comprise sandy GRAVEL or GRAVEL. Standard penetration test data show the material to be be mainly medium dense or dense, and particle size analyses confirm it to be a sandy GRAVEL or GRAVEL.

Glaciofluvial Deposits and Glaciolacustrine Sand

These deposits consist of impure sands and gravels, including sandy GRAVEL and gravelly SAND with a small component of silt or clay. Standard penetration test data show that they range from loose to dense, but are generally medium dense.

Bedrock materials

The engineering geological classification of the bedrock strata, based on their lithology and geotechnical characteristics, is outlined in Table 18, and their distribution is shown in Figure 17 and Map 9B. The general characteristics regarding design considerations are described below, followed by more detailed information on each of the bedrock formations.

Strong rock

This category is characterised by very good bearing capacity except where ground is undermined by limestone workings in the Upper or Lower Quarried Limestone members of the Much Wenlock Limestone (see p.23) Excavation is difficult and may require blasting in Dolerite and the Upper and Lower Quarried Limestones. The Nodular Limestone may be rippable especially where weathered. Slope stability is controlled by discontinuities within the rocks. Low angle cooling joints in dolerite and thin mudstone beds in the Upper and Lower Quarried Limestones may be a problem where they are coincident with hill slope or intersect an excavated face with a dip into the excavation. Sulphate or chemical attack on buried concrete is unlikely.

Much Wenlock Limestone

The Upper and Lower Quarried Limestones Members (UQL and LQL, respectively) consist of LIMESTONE with thin SILTSTONE partings. The LQL has a rock quality designation (RQD) median value of 83%, and high fracture spacing indices classify it as 'good' quality; a median unconfined compressive strength of 58 MPa (two values 40 and 76) indicate that it is a moderately strong rock, although this value is possibly lower than expected for this formation. The Upper Quarried Limestone has a similar lithology and the rock quality designation median value is 86% (good). The median value for unconfined compressive strength is 81 MPa (3 values) which classifies it as a strong rock.

The Nodular Limestone consists of interbedded LIMESTONE and SILTSTONE. The rock quality designation values are high with a median value of 86% (good). Unconfined compressive strength with a median value of 37 MPa indicate it to be a moderately strong rock.

Dolerite

No data were available for dolerite in the Black Country, but in general it is a strong rock with a high bearing capacity; low and high angle cooling joints may be present which could induce failure on high angle slopes, particularly where the dolerite is in contact with mudstones of the Etruria Formation.

Sandstone

Sandstone formations generally offer good bearing capacity with very low and rapid settlement of weathered material. Some silty or fine sandy lithologies may be frost susceptible near to the surface and affect shallow (<0.5m deep) foundations such as concrete paths. Excavatability depends, in part, on the weathering state, varying from diggable in the weaker sandstones (Bridgnorth and Wildmoor formations) and weathered material, to rippable in the stronger sandstones (Bromsgrove Sandstone). The lower part (c.20 m) of the Kidderminster Formation is a locally cemented pebble conglomerate which may prove unsuitable for excavation by digging or ripping and require pneumatic tools or blasting. Excavations should be stable in unweathered material but support will be needed in weathered material which may be reduced to sand. Trafficability should be very good but with the possibility of some silty, sandy clay being present in some formations which may impair trafficability when wet. No sulphate or chemical attack on concrete buried below the water table is likely.

Bridgnorth Sandstone

This unit is a SANDSTONE or silty SANDSTONE which weathers to a SAND or silty SAND. Standard penetration test values show an increase with depth and range from 40 (dense) to >50 (very dense sand to weak rock).

Kidderminster Formation

The Kidderminster Formation consists of a weakly cemented SANDSTONE or SAND with a median penetration test value of 112. At outcrop the lower part (c. 20 m) of the formation generally consists of poorly cemented CONGLOMERATE, which locally forms a strong rock where it is cemented by calcium carbonate. Conglomerate and pebbly sandstone beds decrease in abundance upward through the unit.

Wildmoor Sandstone Formation

The Wildmoor Sandstone consists of silty or gravelly SANDSTONE or SAND. The median penetration test value is 109. Few tests results fall in the range N = 10 to N = 50 indicating loose to dense sand; most test results fall in the N >50 range indicating very dense sand or weak rock. Particle size data (22 samples) confirm that the Wildmoor Sandstone is predominantly a silty sand with median particle size values of clay 0%, silt 15.5%, sand 80% and gravel 1.5%.

Bromsgrove Sandstone

The Bromsgrove Sandstone predominantly consists of SANDSTONE and gravelly SANDSTONE, occasionally silty or clayey, and weathers to clayey, silty or gravelly SAND. Silty or sandy MUDSTONE beds may also be present, which weather to silty, sandy or gravelly CLAY. Standard penetration test values for sand lithologies range from 6 (loose) to 50 (dense) and extend as extrapolated values to 250 (weak rock). Rock quality designation data for sandstone lithologies give a median value of 56% (fair) and range from poor to good. The higher values and hence better quality rock are associated with well-cemented, conglomeratic sandstone rather than sandstone.

Mudstone

Unweathered mudstones generally offer good bearing capacity, although weathered mudstone will be softened to a greater or lesser extent and will offer lower bearing capacity accordingly. The mudstones are unlikely to cause problems due to swelling or shrinking clays except for some higher plasticity layers which may have a higher potential for shrinking and swelling when weathered and remoulded. The mudstones will soften on exposure to water and excavations should be protected with a blinding of lean concrete. Excavations should be achievable by digging with the possibility that harder mudstone and occasional sandstone, limestone or conglomerate beds may require ripping. Excavations may be stable in the short term but may require support for long term stability. Sulphate attack on buried concrete is unlikely except in the Mercia Mudstone which may contain gypsum, although this is often leached out of the near-surface zone. Consequently, foundations in the weathered zone are unlikely to suffer attack. Trafficability of the mudstone formations may be poor in wet weather.

Mercia Mudstone

Too few data were available from the project area for comment on the geotechnical properties of the Mercia Mudstone Group. However, the Mercia Mudstone of the Coventry area is similar to that of the Black Country and the the following comments are taken from geotechnical studies in the Coventry area (Hobbs 1990).

The Mercia Mudstone is a heavily overconsolidated, fissured CLAY which may be weathered to a depth of 10 m or more. Penetration test values show a general increase with depth from about N = 30 (very stiff) at 2 m to N = >30 (hard) at 3 m; below 3 m N increases as the material becomes progressively harder and may be classified as a weak rock. The median value of undrained cohesion is 108 kPa (stiff) with a consistency range from very soft to hard. Undrained cohesion increases generally with depth over the depth range 2–18 m. Plasticity data show the Mercia Mudstone to be a clay of low to intermediate plasticity with a few samples in the high plasticity category. Consolidation data indicate the Mercia Mudstone to be of low to moderate compressibility and to consolidate fairly rapidly. Chemical tests indicate conditions to be slightly alkaline, median pH is 8.7, and to conform usually to class 1 for sulphate attack on buried concrete. However, gypsum beds are present in the Mercia Mudstone and some high sulphate values up to and including class 5 are present.

Clent Formation (northern part of the area)

In the northern part of the Black Country the typical breccia lithology of the Clent Hills is absent and the formation is represented by SILTSTONE, silty CLAY and SANDSTONE, and less commonly clayey, silty or gravelly SAND and sandy or gravelly CLAY. Standard penetration test values for clay lithologies show an increase in value from about 10 (stiff) to 50 (hard) in the depth range 2 to 6 m. Penetration test data for N >50 (weak rock) mainly relate to sand or silt lithologies and show a wide scatter with no correlation with depth. Undrained cohesion for mainly clay lithologies has a median value of 86 kPa (stiff) and ranges from soft to very stiff over the depth range 0 to 6 m. The median value for rock quality designation for Clent Formation as a whole is 33% (poor) and ranges from very poor to good. Plasticity data show the Clent Formation clays to be inorganic clays of low to intermediate plasticity . Moisture content is usually below the plastic limit. Chemical tests show conditions to be close to neutral, pH 6. Sulphate tests show conditions to be class 1 for sulphate attack on buried concrete.

Elton Formation

The Elton Formation is a heavily overconsolidated SILTSTONE with some LIMESTONE bands, weathering to a silty CLAY or clayey SILT. RQD has a median value of 59% (fair) and ranges from very poor to excellent. Unconfined compressive strengths have a median value of 35 MPa and classify the Elton Formation as a moderately strong rock. Standard penetration test N values for material within 10 m of the surface and, therefore, presumed to be more or less weathered, range from 15 at about 1 metre depth to >50 at about 11 m. Plasticity values (3 samples) indicate an inorganic silty clay of intermediate to high plasticity.

Coalbrookdale Formation

This formation consists of heavily overconsolidated MUDSTONE or SILTSTONE, weathering to silty CLAY or clayey SILT; nodular LIMESTONE is also present. The unconfined compressive strength of the formation ranges from about 100 kPa at 4 m depth to approximately 1.5 MPa at 10 m depth. This would classify the unweathered material as a weak rock. Laboratory triaxial tests on material from the softened 0 to 4 metre zone give undrained cohesion values in the range 40 to 200 kPa (median 84 kPa). Five rock quality designation values from 33 and 93 m depth fall in the range 39% to 99% with the higher values at the greater depth. Plasticity data show the formation to be a clay of low to intermediate plasticity; only two samples fall into the high classification. The plasticity data are mainly from samples in the 0–4 m depth zone and show a range of 10% to 18% for plasticity index, but some samples near the surface, at less than 1 metre depth, have much higher plasticity indices of about 38%.

Interbedded Mudstone and Sandstone

Interbedded mudstone and sandstone usually offer good bearing capacity when the mudstones are unweathered and the site is not undermined by past coal, ironstone, fireclay or limestone mining. Mining-induced hazards include ground collapse, underground fires in abandoned workings and coal seams, and methane migration into underground

Plate 8 Dolerite workings at Hailstone Quarry, Rowley Regis. Note the prominent vertical joints. Roadstone/aggregate resource.

space giving a risk of explosion. Excavation of weathered material is often possible with digging equipment but sandstone units and unweathered material may require ripping, the use of pneumatic tools or blasting. Mudstones will soften on exposure to water and excavations should be protected with a blinding of lean concrete. The sandstone beds may carry water and form spring lines on hillsides softening the mudstones to the detriment of the stability of the slope. Sulphate attack on buried concrete is unlikely although some Coal Measures rocks contain pyrite which has caused problems due to pyrite breakdown and calcium sulphate formation in some areas of the UK.

Clent Formation (southern part of area)

Geotechnical data for the breccia-dominated facies of this formation, typical of the southern part of the outcrop, are sparse. The breccia has a weak clayey, locally carbonate matrix, and weathers to a clayey GRAVEL. The geotechnical characteristics for the breccia are probably very similar to those of the gravelly clay of the northern part of the area (see above).

Enville Formation

The Enville Formation is a heavily overconsolidated silty CLAY. At outcrop the formation predominantly consists of MUDSTONE interbedded with thin SANDSTONE; both lithologies are expected to have geotechnical properties similar to the underlying Keele Formation. Locally, however, well-cemented limestone-chert CONGLOMERATES are present which are expected to fall in the 'strong rock' category.

Keele Formation

The Keele Formation predominantly consists of heavily overconsolidated MUDSTONE or SILTSTONE weathering to silty sandy or gravelly CLAY, with thin beds of SANDSTONE which weathers to gravelly SAND. Penetration test data show little correlation with depth in the N = 0 to 50 range. The undrained cohesion of Keele Formation clay lithologies, median value 109 kPa (stiff) shows little correlation with depth.

Moisture content has a median value of 12% and ranges from 6% to 27%, but this decreases to 5% to 18% below 10 m depth. Plasticity data show Keele Formation clays to be inorganic clays of mainly low to intermediate plasticity but with a significant number of samples in the high plasticity class.

Halesowen Formation

The Halesowen Formation mainly consists of SANDSTONE or clayey SANDSTONE which weather to silty or clayey SAND, interbedded with MUDSTONE and SILTSTONE which weather to silty or sandy CLAY. Penetration test results show a trend of increasing value with depth; the majority of values are greater than N= 50 and are classed as very dense sand or weak rock. The median value for undrained cohesion for clay lithologies is 103 kPa (stiff) and ranges from very soft to very stiff. Median moisture content, for mainly clay lithologies, is 16%. There is a distinct drop in moisture content at a depth of 4 m from a range of about 7%–30% to 5%–12% which is interpreted as the effects of weathering in the near-surface zone. Plasticity data for clay lithologies show the Halesowen Formation clays to be inorganic clays of low to intermediate plasticity.

Etruria Formation

The Etruria Formation mainly consists of CLAYSTONE and SILTSTONE with occasional sandy or gravelly SANDSTONE beds. In some areas it can be regarded as a 'soil', mainly heavily overconsolidated CLAY, occasionally sandy or gravelly; silty or sandy GRAVEL is locally present. Penetration test data for mainly clay lithologies show a general increase with depth down to 10 m. The median N value for rock lithologies is 65 and ranges from about 50 to 186. The median N value for soil lithologies is 50 and ranges from about 21 to 87. Median undrained cohesion for clay lithologies is 103 kPa, stiff, and ranges from soft to very stiff. Undrained cohesion shows a clear increase with increasing depth from about 20 kPa at 2 m to about 180 kPa at 12 m. Median moisture content is 14% and shows a distinct change at 10 m depth where the range

Plate 8 Dolerite workings at Hailstone Quarry, Rowley Regis. Note the prominent vertical joints. Roadstone/aggregate resource.

Table 24 Categories of slope (after Demek 1972, Young 1972, Crofts 1973, and Small and Clark 1982)

SLOPE DESCRIPTION	GRADIENT	ANGLE (degrees)	AGRICULTURAL PROBLEMS	CONSTRUCTIONAL PROBLEMS
Level to gentle or gently inclined.	<1 in 10	<5.7	Practical limitations minimal	
Moderate or strongly inclined.	1 in 10 to 1 in 3	5.7–18.4	Difficulties for large scale mechanical agriculture. Soil erosion a problem	Major industrial construction and engineering structures present difficulties. Limit for railways.
Steep to precipitous and vertical	>1 in 3	>18.4	Mechanical cultivation highly problematical requiring special measures (viz. contouring and terracing).	Extreme difficulty in most construction including roads and housing.

of moisture content drops from about 10% to 40% down to about 5% to 22%. Plasticity data show Etruria Formation clays to be mainly inorganic clays of low or intermediate plasticity.

Coal Measures

The lithologically heterogeneous Coal Measures predominantly consist of heavily overconsolidated SILTSTONE, weathering to silty or silty sandy CLAY, and SANDSTONE. Penetration test values show a wide range from about 10 at 2 m depth to 350 (extrapolated value) at about 16 m. The high N values relate almost entirely to siltstone lithology. Undrained cohesion shows a steady but scattered increase with depth from the surface to 15 m depth. Unconfined compressive strength values are few with a median value of 6.5 MPa for siltstone at about 15 m depth. Values of 36 MPa for siltstone and 50 MPa for sandstone are also recorded. Rock quality designation values for the depth range 0 to 50 m for siltstone and sandstone have a median value of 62% (fair) and range from very poor to good. RQD for sandstone is generally higher than siltstone with a lowest value of about 22% (very poor); RQD for siltstones drops to 0% (very poor) in the depth range 8 to 28 m. Moisture content has a median value of 15% and decreases in value from a range of 6% to 30% near to surface to a range of 6% to 21% below 10 m. Plasticity data show the clay lithologies to be inorganic clays of mainly intermediate plasticity. Coal Measures clays have low compressibility and a medium rate of consolidation. Class 1 conditions for sulphate attack on buried concrete are usually found; a few class 2 values and a single class 3 value have been recorded.

Geological structures

Faults and folds in the bedrock and superficial structures in the Drift deposits or weathered regolith may have an important effect on foundation conditions.

Bedrock faults shown on Maps 2A, 2B and in Figure 9 commonly juxtapose strata of different lithology with different geotechnical properties (Plate 6). In such cases, loading may induce differential settlement resulting in structural damage. In undermined areas, collapse of disused workings on one side of a fault may result in subsidence-induced damage along a zone parallel to the fault. Consequently, site investigations should attempt to precisely locate any faults whose presence is suspected from surface or underground information. It is advisable not to place rigid constructions across faults, but if this is unavoidable then appropriate engineering solutions allowing for differential settlement should be adopted. No differential movement along faults other than that induced by mining subsidence has been noted in the area.

Joints are common in the more massive bedrock units, particularly the sandstones, limestones and dolerite. They may have an effect on the stability of rock faces where water pressure or tree roots can induce slab failure; stress release during quarrying or excavation may also induce open joints, particularly where the joints lie parallel or subparallel to the exposed face. Bedding plane joints are essentially the surfaces between the naturally stratified layers; where the beds dip steeply at a rock face or on a slope, such as the steep folds of the Silurian inliers, large areas of the bedded rock face may become unstable. Mining-induced subsidence may widen joints in the overlying strata. Roof collapse in the Silurian limestone mines is chiefly due to to the effects of softening and removal of clay infill of joints or solution along joints in the roof strata which become weakened, resulting in collapse of the roof of the mines. At depths of 100 m or more, the weight of the overlying strata is sufficient to cause the crushing of softer, jointed strata, such as the Elton Formation, which forms the roof above the Upper Quarried Limestone.

In weathered mudstone bedrock and clay-rich superficial deposits, small-scale faults and joints (fissures and shears) caused by periglacial cryoturbation may be present. Relic shears in these deposits may affect foundation conditions; excavated slopes may be subject to failure along the shear surfaces (Hutchinson et al., 1973). Cryoturbated materials are in a remoulded condition and have less strength than the parent deposit.

Stability of natural and excavated slopes

The stability of slopes is dependant on three main factors:
(a) the slope angle

(b) the nature, structure and strength of the underlying material (bedrock, superficial deposits or fill), and
(c) the influence of groundwater.

Undisturbed natural slopes have generally attained a considerable degree of stability in our present climate; excavation, construction or exceptional climatic conditions may disturb this equilibrium, and may present problems in certain circumstances.

Slope steepness in the Black Country area is divided into various categories shown in Map 7 and Table 24. Steep slopes present little hazard to development provided water is not introduced to the slope and they are not undercut by excavation or natural features such as rivers. However, former landslips and incipient unstable ground have been recorded at a number of localities (Map 7). Areas most prone to landslip in the Black Country are those where mudstone-dominated strata such as the Etruria Formation are overlain by water-bearing rock, such as the sandstone of the Halesowen Formation near The Hayes [931 841], and interbedded sandstone/mudstone units such as the Coal Measures near Stourbridge [910 847]. Heterogeneous deposits such as Made Ground, fill and Head are also susceptible to landslip where they are present on steep slopes, such as Bury Hill [937 894] (Hutchinson et al., 1973). Ingress of water in the permeable sandstones may increase the porewater pressure in the mudstones leading to failure along relic shears and faults. Landslip may occur when the toe of a slope is disturbed by excavation, loading on the slope or the introduction of water. Small landslips have been noted in canal cuttings in unconsolidated Glaciofluvial sand and gravel near Spon Lane [SP009 897].

Failures in competent rock types such as sandstone, limestone and dolerite are controlled by structural discontinuities such as joints, faults and bedding planes. Steep faces can fail by rock fall, planar sliding and wedge failure. Preventive measures include the construction of concrete buttresses and rock bolting and the appropriate alignment and angle of cut faces. Netting and the provision of catch fences, ditches or banks may be used to control the effects of minor rock-fall.

Earthquakes

The Birmingham-Black Country region is characteristically a low seismicity area and is not known to have suffered from any damaging earthquakes in the past. The largest known historical earthquake was the magnitude 4.0 ML Birmingham event of 14 July 1940. Earthquakes this size occur approximately once per year on Britain and its surrounding waters. In the last twenty years, only a few small events have occurred in the area; the largest of which was the magnitude 1.4 ML earthquake of 12 March 1986 which also had its epicenter in the Birmingham area. The region has also been shaken by two large, recent British earthquakes. Both the magnitude 5.4 ML Lleyn Peninsula event of 19 July 1984 and also the magnitude 5.1 ML Bishop's Castle event of 2 April 1990 gave rise to intensities of IV MSK in the Black Country.

Movement on major faults, at depth, is thought to be the cause of the earthquakes. Although the Black Country area is crossed by many major faults, including the Western and Eastern boundary faults, historical records indicate that the area is characterised by low seismicity.

Detailed analysis of local seismic risk to major constructions such as pipelines and dams can be obtained from the BGS Global Seismology Research Group, Edinburgh.

Potentially explosive and toxic gases (radon, methane, carbon dioxide, hydrogen sulphide)

Radon is a naturally occuring radioactive gas which originates from the decay of uranium present in geological materials, soil and groundwater, with minor amounts produced by building materials. The National Radiological Protection Board (NRPB) have established that exposure to high levels of radon radiation will increase the risk of lung cancer in the population. The main areas at risk are those where the bedrock is granitic, or where uraniferous mineralisation is present, such as parts of Cornwall and Scotland. However, marine bands in the Coal Measures and cavernous limestones such as the Carboniferous Limestone have been shown, in other areas, to produce relatively high levels of radon, particularly in zones adjacent to major faults. No systematic monitoring records for radon levels are available for the Black Country. It is recommended, therefore, that reconnaissance surveys are carried out in areas of cavernous limestone such as the Much Wenlock Limestone of the Dudley area and parts of the Coal Measure outcrop, particularly where the marine bands rest unconformably on the Silurian limestone, and adjacent to the major faults. Thick deposits of Made Ground consisting of colliery waste provide another target for monitoring.

Methane is a colourless, odourless, inflammable gas (CH_4) which forms an explosive mixture with air at concentrations of between 5 and 15% by volume. It is generated in landfill sites from the breakdown of buried organic material (anaerobic biodegradation) such as plant and wood debris, organic domestic material and coal waste; during the first few years following burial, 1 tonne of domestic waste produces about 30 cubic metres of methane annually. It is also generated during the mining of coal, and may be liberated from the surface outcrops of coal seams, along geological faults, abandoned mine shafts and bell pits (Staff et al., 1991). Methane is also a significant contributor to 'greenhouse gases' in the atmosphere. Where methane is generated biogenically it is accompanied by the production of **carbon dioxide** (CO_2). Both gases can cause asphyxiation by the exclusion of air. If groundwater levels in abandoned mines rise, then there is a risk that entrapped methane and carbon dioxide may be 'pushed' to the surface due to increased gas pressurisation. Migration of the gas may take place through the fill material, or via pore spaces and fissures (faults; joints) in the adjacent bedrock. Sites with known high levels of methane generation should be carefully managed and monitored so that the gas is drained or vented off by controlled collection or flaring. The risk of lateral migration of landfill gases (and associated leachates) can be reduced by the installation of impervious membranes between the landfill material and the rock face, and/or between the fill material and any overlying construction. Underground spaces in buildings on methane- or carbon dioxide-bearing rocks and soils should be positively ventilated to avoid the build up of gas. In addition the fill material should be vented to release any trapped gases.

Hydrogen sulphide (H_2S) is a colourless, poisonous gas, with an unpleasant smell. It may be generated in landfill sites where rotting organic material is present.

If the landfill site is well managed the methane generated can be utilised to provide a local source of fuel. Thus, a brick-clay manufacturer, for instance, could generate methane from a carefully controlled landfill site created by excavating the brick-clay; methane thus generated could then be used to fire the brick-kilns.

Guidelines for the control and treatment of landfill gases are set out in Department of the Environment publications such as circulars 21/87 and 17/89, ICRL Guidance Note 17/78 and HMIP Waste Management Paper 27.

GROUNDWATER: POTENTIAL FOR CONTAMINATION AND RISING GROUNDWATER LEVELS

Contributed by the National Rivers Authority.

Groundwater considertaions present constraints to land use in the Black Country area in two ways. Firstly, restrictions must be placed on developments which might cause pollution to the major Sherwood Sandstone aquifer or other minor aquifers (Map 8), and, secondly, rising groundwater levels may cause problems beneath parts of the urban conurbation, particularly the coalfield area and the Sherwood Sandstone outcrop in the east.

Aquifer/Groundwater Protection

The National Rivers Authority is charged with protecting the groundwater resources of the area. Prevention of pollution is an important aspect of water resource management.

The NRA Severn-Trent Region currently operates an Aquifer Protection Policy which divides the area into four zones relating to the importance of the groundwater resources and proximity to public water supply and major potable supply abstractions. The zones are defined below and are outlined in Map 8.

Zone 1 is defined as the area within 1km radius of public water supplies and other major potable supply abstractions such as Crown Exempt supplies to hospitals (Map 8). These zones are generally located on the Triassic Sherwood Sandstone outcrop in this study area; the exception is the supply to the hospital at Churchfield which is sourced in Carboniferous strata.

Zone 2 is the outcrop of the Sherwood Sandstone aquifer and represents the rest of the outcrop outside of Zone 1.

Zone 3 is defined as minor aquifer outcrop where groundwater provides locally important abstractions for many uses, but in this area primarily for industry. It includes the Carboniferous strata and the Clent Formation.

Zone 4 is defined as non-aquifer where groundwater is not generally considered to be present in significant quantities. This zone includes the Silurian shales and limestones, the Mercia Mudstone and the igneous dolerite such as the Rowley Regis intrusion.

The NRA is currently producing a new national 'Policy and Practice for the Protection of Groundwater'. This document defines slightly different zones based on the vulnerability of the groundwater and sources. Policy statements are made on a range of potentially polluting activities. The draft document is currently out for public consultation prior to review and final publication later in 1992. The Resource Protection Zones A (Major Aquifer), B (Minor Aquifer) and C (Non Aquifer) broadly equate to the current Zones 2, 3, and 4, respectively, as listed above. The Siurian limestones, however, are likely to be defined, in the new document, as Minor Aquifers. The main difference will be the Source Protection Zones defined, initially, around major potable supply abstractions. These areas will include three protection zones including an inner protection Zone 1, defined to protect from bacterial contamination, an outer protection Zone 2, and the source catchment Zone 3, defining the area where all the recharge will eventually reach the borehole(s). These zones will vary in shape and size according to local hydrogeological circumstances, and will be defined on a progressive basis over the next few years. The effect, in this area, will be that parts of the Sherwood Sandstone outcrop will be included in the Source Protection Zones rather than as a Major Aquifer. The current and new policies are implemented both by the NRA, with its own legislation, and via close liaison with other bodies such as Planning Authorities using their relevant legislation.

Rising Groundwater Levels in the Birmingham aquifer unit

The eastern part of the study area encompasses part of the Sherwood Sandstone aquifer centered on Birmingham. Over the past century this aquifer has been extensively developed for groundwater supply with most of the heavy industrial users in the area depending on their own wells and boreholes rather than relying on public water supplies. Groundwater development for public water supply usage has been limited due to the ready availability of surface water, via aqueduct, from the Elan Reservoirs in central Wales.

The Birmingham aquifer unit was characterised by falling groundwater levels from 1900–1960 (Land, 1966). Groundwater abstraction reached a peak in the early 1950's after which there has been a gradual drop in both licensed and actual abstractions. This has been primarily due to a pronounced decrease in industrial activity in the Birmingham area; total abstractions now stand at 15 megalitres per day, which is only a third of what they were in 1960.

This reduction in abstraction has caused a rise in groundwater levels, with some observation boreholes recording a rise of over 10 m in 16 years within the Birmingham aquifer unit. This rise is most marked just to the east of the study area and coincides with the area of greatest decrease in industrial abstraction. There are no observation boreholes in the study area but it is estimated that the rise, over the same period, has probably been less, of the order of 6 m, and no problems have been reported as a result of this. A research programme , instigated by CIRIA, entitled 'Rising Groundwater Levels in Birmingham and the Engineering Implications' will be published in March 1992, and will have some relevance to the study area. Due to rising groundwater levels the NRA is currently actively encouraging increased groundwater abstraction in the Birmingham aquifer area. Yields are generally good, but groundwater quality is extremely variable and the applicant, who requires a licence to abstract, is warned that the water may not be of potable standard.

HUMAN ACTIVITIES AFFECTING GROUND CONDITIONS

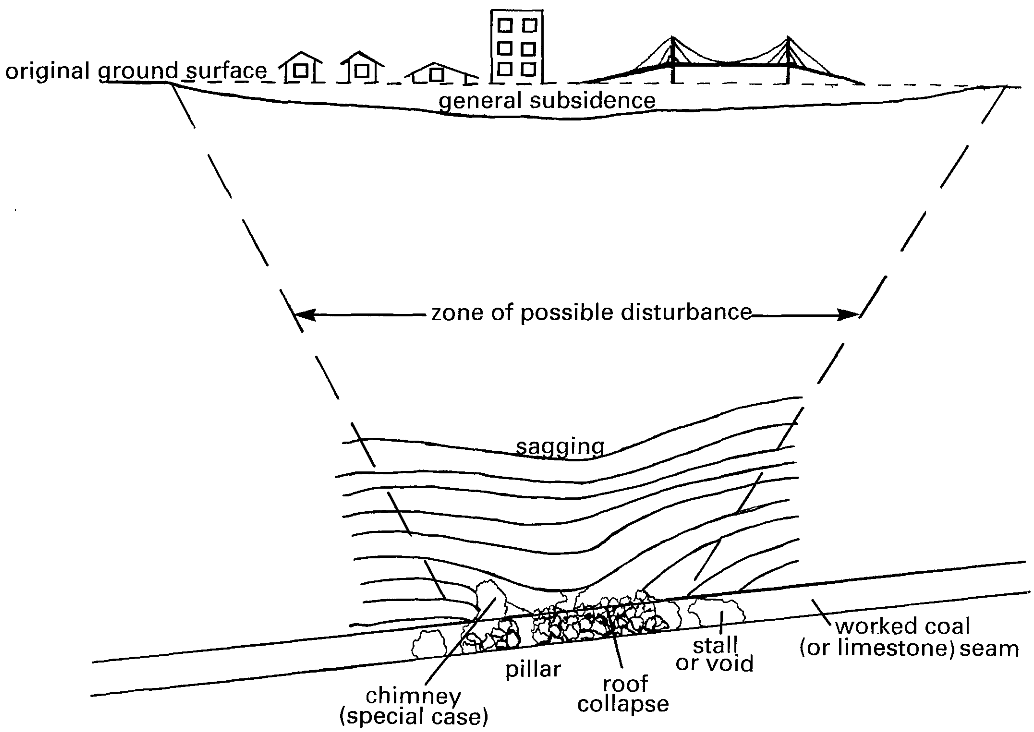
Shallow and deep mining, and quarrying activities in the Black Country area have left a legacy of voids and pits, some filled and others open. Most of the early mining operations were unrecorded and uncontrolled, and many are recorded inaccurately. Furthermore, unrecorded backfilling of voids, together with constructed made ground, took place until 1970 when the licencing was introduced for landfill sites. The following sections review the constraints imposed on development by mining and former land use.

Coal and Colliery-Based Mining

The long history of colliery-based mining (coal, fireclay and ironstone) has left a legacy of shallow workings, shafts, adits and backfilled opencast pits which present problems for land use, such as mining subsidence, shaft collapse and poor foundation conditions.

Mining methods are summarised in Table 25 and Figure 15, and the historical development of coal mining in the Black Country is illustrated in Figure 14.

Figure 18 Generalised development of general subsidence due to collapse of disused workings.



Early mining was restricted to small pits or shallow 'bell pits' which exploited the seams near the outcrop. In order to mine the seams at depth, a 'pillar and stall' method was introduced to support the roof of the mine (Plate 2); in many mines the supporting pillars of coal were subsequently mined and the roof allowed to collapse. A new method of mining termed 'square works' extraction, a precursor to modern longwall methods, was introduced in the 17th century and was adopted by many though not all collieries. In this method the whole of a long face of coal was extracted in front of gate roads which serviced the face; the roof was allowed to collapse behind the working face (Plate 3).

Subsidence induced by longwall mining can to a great extent be predicted, but accurate prediction of subsidence and ground movements resulting from the collapse of older mines which employed pillar and stall or square work methods are unpredictable, due to the collapse of voids and the crushing of supporting pillars. Surface instability and subsidence is largely a function of the thickness and width of the mined seam and the depth of the workings. In general, the greater the depth of workings the more the effects of subsidence will be attenuated through overlying strata, so that the effect at surface will be less, although it will extend over a wider surface area. The effects of subsidence are not restricted to the area above the workings, but, on average, extend at an angle from the edge of the workings and the ground surface of about 35 degrees from the vertical, in a sub-horizontal seam (Figure 18).

The surface stability in undermined areas is partly dependant on the method of mining (Figure 15; Table 25). Old, shallow workings at less than 50 m below rockhead are the most significant in terms of surface stability, but workings at greater depths may occasionally produce surface subsidence. The weight of new buildings, as a result of redevelopment of a site, may affect the ground stability, particularly where the workings are near the surface. Furthermore, the subsidence may be migrating upwards towards the surface from old workings.

Subsidence is assumed to have taken place soon after mining where longwall methods (Figure 15) were used, as in the more modern mines such as Sandwell Park, Hamstead and Baggeridge. With this method subsidence generally takes place within ten years of extraction, but even then collapse of formerly supported areas such as roadways may occur. Subsidence takes place as a 'wave' as the roof is allowed to collapse behind the working face; the void is also filled with mine waste created by the mining. Since the last deep mines in the Black Country closed in the 1960's, it is assumed that subsidence has ceased from the most recent longwall mines. Although the amount of subsidence is largely predictable, the presence of geological faults may cause differential subsidence, particularly where coal has been extracted only from the upthrow side of the fault. Geological faults are usually shown as a line on the map, but in reality, many faults are not single planes, but consist of a series of closely spaced, sub-parallel discontinuities forming a fault zone up to tens of metres wide. Other factors affecting subsidence include the dip of the seam, method of waste stowage, the nature and structure of the overlying strata (including superficial deposits), and surface topography. Settlement in a deep seam my trigger further settlement in higher seams.

Prior to developing a site, the developer should inform British Coal of the proposals, particularly in relation to foundation design, at the local Group Headquarters responsible for deep mines (Appendix 3).

Bell pits (Figure 15) were used until the 17th century, largely in areas where the seams crop out with low dips, and in areas where the overlying superficial deposits are thin. Many pits were not backfilled and they were left to collapse naturally after abandonment. Consequently the fill material may have a low bearing capacity. Areas of former bell pits may be characterised by the presence of low cones of waste material and/or shallow depressions along the line of the outcrop of the seam.

Pillar and stall methods (Figure 15) replaced bell pits in the 16th and 17th centuries; access to the mine was either by adit or vertical shaft. The roof was supported by unworked pillars of coal, but after initial extraction, the pillars were subsequently 'robbed' as the mined area was

Table 25 Summary of types and methods of coal mining and associated problems for land use

TYPE OF MINING (period used)	AREA	METHOD	PROBLEMS FOR LAND USE
Crop workings (Middle Ages and earlier)	Exposed coalfield	Direct working of coal at surface.	1. Very shallow workings. 2. Line of subsidence along the crop.
Bell pits (Middle ages & 16th century)	Exposed coalfield	Shaft c.1.25 diameter up to 12 m deep: radial working to 10 m from shaft.	1. Risk of voids remaining. 2. Shaft sites poorly known. 3. Shaft infilling variable and doubtfully compacted.
Pillar and stall (from 15th to 17th century)	Exposed coalfield	Coal cut along grid of roads with rectangular pillars left for support.	1. Up to 60% coal may be left, so site investigation may not detect working. 2. Overlying beds of high strength (such as sandstones) may have resisted collapse leaving large voids. 3. Collapse may result in cavities and breccia pipes in rock above; or in crown holes, at surface. 4. Shaft sites poorly known. 5. Shafts variably backfilled and doubtfully compacted.
Panel working and longwall (from 18th century)	Progressively deeper workings from colleries on, and later to east and west of, exposed coalfield.	Coal extracted along continuous coalface (up to 200 m wide). Temporary support of roof then collapse of all except lateral roadways.	1. Collapse of face underground produces subsidence and lowering of ground surface. Effects usually immediate and assumed to be largely over within a few years. 2. Differential subsidence along faults at surface can lead to severe damage. 3. Variable backfilling and capping procedures applied to shafts.
Opencast mining (from 1940)	Scattered localities in exposed coalfield.	Excavation of pit, extraction of coals, backfill with spoil; restoration of site.	1. Compaction may be incomplete, locally, on older sites. 2. Differential settlement possible along sides of former workings. 3. Natural drainage altered.

abandoned. Weakening of the pillars induced haphazard roof collapse. Subsidence is, therefore erratic and unpredictable, and may take place as a result of floor heave, crushing of pillars or roof collapse (Healy and Head, 1989). Voids left after mining may be subject to roof collapse. In some cases the void is filled by the roof material which is subject to an increase in its bulk; in others the void may propagate upwards until it meets a competent stratum such as a strong sandstone. In extreme cases the void will continue to generate towards the ground surface to form a crown hole (Figure 19). Crown holes are unusual above coal mines deeper than 70 m (Healy and Head, 1989). It is not possible to predict this type of collapse.

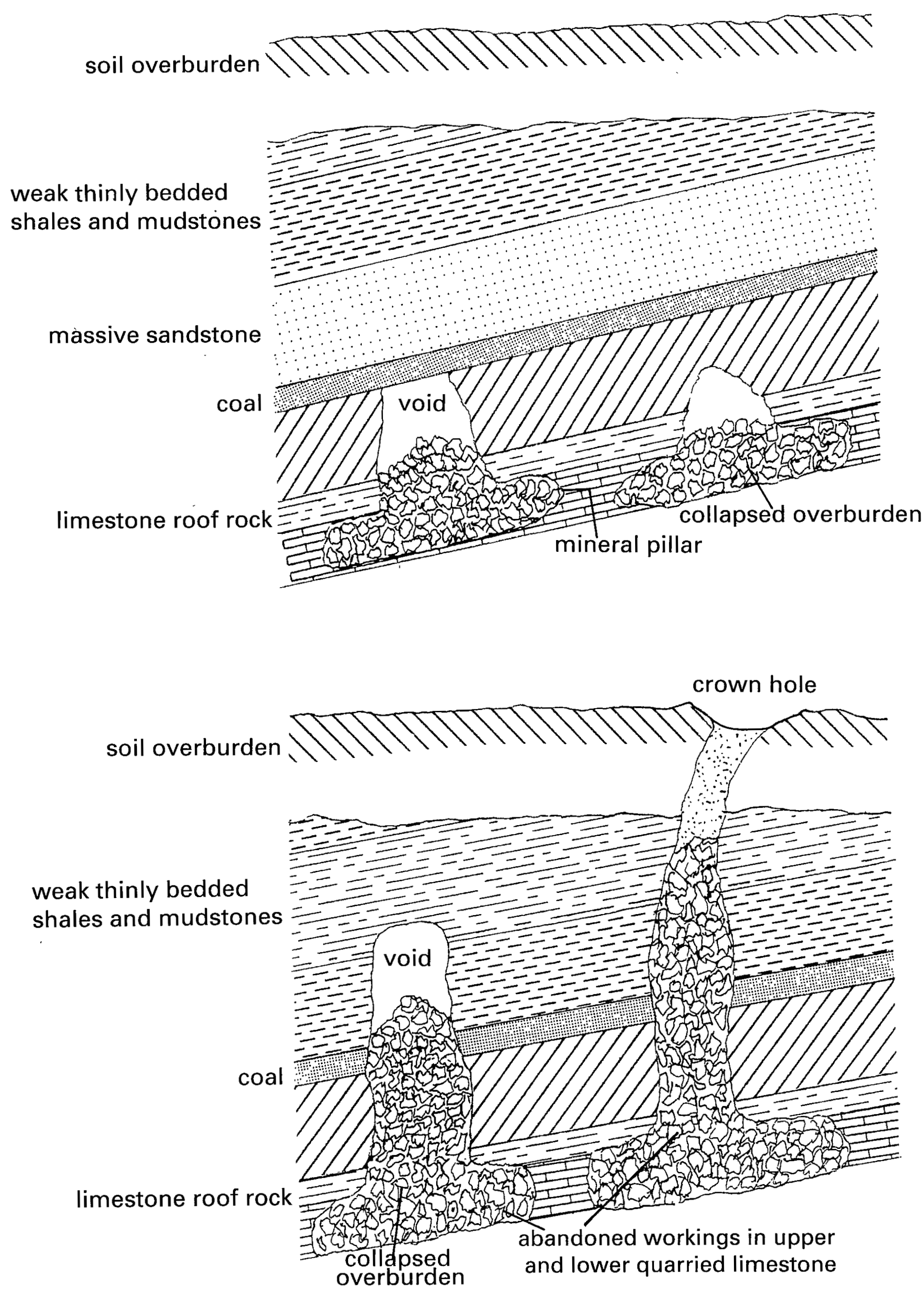
Mine Gases

Dangerous gases such as methane, carbon dioxide and carbon monoxide may accumulate in any voids remaining after collapse of workings. These gases are generated during the mining of coal, and may migrate along geological faults, shafts, and adits, or be present in old bell-pits. The gases may also migrate through permeable strata, within pore spaces or as dissolved gases in water. Rising groundwater table may pressurise the gas in the voids and cause it to migrate to higher levels.

Documentation of mined ground

The most serious problem associated with former workings is poor documentation. The 1872 Coal Mines Regulation Act stipulated that accurate plans be lodged with the Mines Inspectorate, but prior to this date only the larger mines were documented. Similarly the position of many of the associated shafts, bell pits and adits are poorly recorded and may remain open below a near-surface capping. The outline of abandoned colliery-based workings is shown on Maps 6A, 6B. It should be noted, however, that the boundaries are generalised and approximate, and that unrecorded former workings may occur at shallow depths; commonly

Figure 19 Diagramatic development of mining voids and crown holes.



more than one seam has been worked within the demarcated area. The sites of known shafts and adits are also shown on Maps 6A, 6B; other unrecorded shafts and adits may exist. Where the site of a shaft is uncertain, two sites may be shown. Responsibility for locating shafts, adits and undermined areas lies with the site owner or developer. The data have been taken from British Coal and BGS records, which may be incomplete. Records of shafts and abandoned mines are lodged with the British Coal Mines Records Office, Bretby (see Appendix 3), who should be consulted for detailed information prior to the development of any site. Additional records may be held by the Building Control Officer or Structural Engineer of the appropriate Metropolitan Borough Council (Appendix 3). Guidance for engineers and planners involved with the planning and development of sites previously undermined for coal and other minerals is given in the CIRIA/DoE publication, 'Construction over abandoned mine workings' (Healy and Head, 1989), and the DoE publication 'Treatment of Disused Mine Openings' (7/1/223).

Spoil tips

Coal mining produces large amounts of waste material; some is used to backfill the workings but considerable amounts remain as waste tips. Much of the waste produced during early mining operations in the Black Country was spread evenly over the land surface as constructional made ground. However, some of the more recently worked pits, particularly those in the concealed coalfield, have tip mounds. The possibility of exploiting this material is considered in an earlier section on Mine Stone; other areas have been converted to recreational parkland. The existing tips such as those at Oldnall, Cradley Park and Old Hawne collieries present a constraint to development. The tips are steep-sided and composed largely of compacted shale, poor quality coal, mudstone, siltstone and sandstone. Internal

Table 26 Index of Silurian limestone mines (from Ove Arup & Ptnrs, 1983)

Index no.	Mine name	Seams worked *	Approximate depth (m)
1	Arboretum	L	25
2	Bentley	U & L	120 & 165
3	Birchills	U & L	140
4	Blackham	U & L	120 & 165
5	Castle Hill	U & L	10 to 30
6	Coneygre	U	200
7	Cow Pasture	U	155
8	Darlaston Green	U	200
10	Dudley Port, Ensells	U	175
11	Dudley Port, D & B	U	225
12a	East Castle	U & L	15 & 25
12b	Castlemill	U & L	15 to 90
12c	Castlefields	U	30 to 100
13	Dudley Port, Giles	U	190
14	Grovelands	U	195
15	Hay Head	BL	20
16	Hay Head (3 Crowns)	BL	20
17	Hurst Hill	U & L	variable
18	James Adams	L?	50 to 90
19	James Bridge	U	200?
21	Littleton Street	L	55 to 70
22	Mons Hill	U & L	15 to 30
23	Moss Close	L	10 to 50?
24	Peal Street	L?	10?
25	Pennant Hill	U & L	125
26	Springhouse	BL	335
27	Tividale	U	190
28	Trough Pits	U	195
29	Wolverhampton St	U & L	70 & 100
30	Wren's Nest	U & L	10 to 70
31	Yew Tree	U & L	220 & 260

U = Upper Quarried Limestone] Much Wenlock
L = Lower Quarried Limestone] Limestone Fm.
BL= Barr Limestone

drainage can be expected to be poor, and combustion of contained fragmentary coal could take place leading to heat generation and subsidence. Furthermore, the waste tips may generate noxious gases such as methane and carbon dioxide if drainage conditions within the tip material are poor.

Underground limestone mining

Underground mining of Silurian limestone is considered in the section on mineral resources. The constraints placed on planning and development of undermined limestone areas are similar to those outlined in the section on coal and colliery-based mining. The areas of known underground limestone mines are shown on Maps 6A, 6B. As with coal mining the principal risk is subsidence due to collapse of voids. There are special factors associated with the limestone mines which affect surface stability (Ove Arup & Partners, 1983). The limestone was mined by pillar and stall methods, but in areas of steeply dipping strata elongate galleries were produced with sub-horizontal floors and pillars orientated at right angles to the steeply dipping roof of the mine (back cover). In general, thickness of the extracted material was greater and the proportion of void to pillar was much larger than in the coal mines, due to the greater mechanical strength of the limestone pillars and the roof. Furthermore, the limestone mines were rarely backfilled with mine waste so that the void was left intact. Most of the voids filled with water soon after abandonment; some of those in the Dudley area remained dry because they lie above the level of the canal into which they drained. Crushing of the pillars, roof collapse and floor heave contribute to the infilling of the voids through time. The sudden collapse of the roof may cause upward migration of the void as a chimney shaped conduit, until the surface is reached when a crown hole is formed (Figure 19). A well publicised crown hole developed in the middle of Dudley cricket ground, above part of the abandoned Castlefields Mine, in 1985; no injury or damage to constructions was caused.

The generation of crown holes is unpredictable, and a cautious approach to development of such sites is required. Development or redevelopment should be conditional on site investigations establishing the extent of former workings and whether voids are present. General subsidence occurs where the roof collapses but the chimneys do not migrate up to surface level, often due to the presence of strong competent strata above the void which prevents further upward passage (Figure 19). In 1978 substantial subsidence over a cavern, at depth, resulted in damage to industrial buildings in Sandwell. Where a large area of the mine roof collapses in this manner, a conical shaped zone of general subsidence may occur above, and outwards, from the area of collapse in a manner similar to coal-mining induced subsidence (Figure 18). The Ove Arup study has shown that about 100 collapses have been sufficiently large to generate identifiable surface disturbances. Since the last mine was abandoned in 1935, the number of surface disturbances has continued at a steady rate of about one disturbance every 1.5 years. About two thirds of the identified surface disturbances occurred above mines where the depth of the roof is less than 30 m. General subsidence, in contrast to crown hole development, is largely restricted to mines deeper than 70m, and is the only form of disturbance noted in mines deeper than 100 m.

Although many of the mines were poorly documented, recent studies (Ove Arup and Partners, 1983) have located, mapped and recorded the sites of most of the former mines in the Black Country. Records and updated appendices of this study are held by the relevant Metropolitan Borough Council. The outlines of currently known limestone mines are shown on Maps 6A, 6B; the depths of workings and seam, or seams, worked are given in Table 26. In view of the potential for subsidence or crown hole development in undermined areas, they require careful archival, geological and geotechnical investigations. Site investigation boreholes may penetrate pillars leading to an underestimation of the extent of former workings. The Ove Arup study has shown that the principal factors to be taken into account in assessing relative risk of an undermined area are: the geology (sequence of strata), the depth, the layout, and the age of the mine. They have drawn up consideration zones around the known mines and assessed the relative risk of collapse for each mine. Recommendations for methods of monitoring, site investigation and remedial work to be undertaken in the treatment of the mine are also outlined in the report; guidance is also given on the structural design of buildings to withstand ground disturbance. It should be pointed out that the overall relative risk is low since only 12 of the 100 or so disturbances have caused damage to property and there has been no loss of life attributable to the surface disturbances; the area affected by surface disturbance is about

12 acres, a small fraction of the total undermined area. Experimental studies designed to monitor incipient collapse of abandoned mines have been carried out using microseismic techniques (Miller et al., 1987; 1989). These techniques may have an application in detecting roof falls in air-filled and flooded abandoned mines, in order to give warning of surface or near-surface disturbance, such as crown hole development, which may result from progressive collapse. Other methods of monitoring, applicable to mines deeper than 70 m, comprise optical level surveys and horizontal strain measurements of the ground surface above a mine; these methods may detect strain due to subsidence caused by roof collapse, at depth. Changes in the condition of open mines can also be monitored, in some cases, by visual inspection (near-surface, accessible mines) and by remote cameras lowered down boreholes (deep, inaccessible mines).

The most feasible engineering solutions recommended for treatment of the mines are:

(a) infilling the voids by injecting grout comprising gravel, sand, pulverised fuel ash (pfa) or colliery waste, together with cement in various proportions. The injected material should spread out in the voids and thereby prevent block-falls from the roof and spalling from the pillars, so that further collapse is largely eliminated and void migration minimised or prevented. This will improve the stability of the overlying strata.

(b) bulk excavation and controlled backfilling of shallow workings.

(c) additional design measures may be incorporated into the design of the buildings above the area of risk.

Quarries and pits

Surface extraction of minerals is restricted to small and medium sized pits and quarries; although large-scale excavations are created by opencast coal mining, the sites are short-lived and are backfilled and the land reclaimed soon after extraction. Many of the pits and quarries have been backfilled, others partially filled and degraded, some are flooded while others remain open. Former excavations present constraints to development related to:

(a) geotechnical problems of variable fill types and variable ground conditions such as drainage between the natural surface and the fill, and variable compaction of the fill,

(b) properties and nature of the fill material and any risks associated with the migration of gases (such as methane or carbon dioxide) or leachates, from the fill to the atmosphere or into the surrounding bedrock or superficial deposit,

(c) risk of failure of steep slopes created within the excavation.

A knowledge of the extent and type of former excavations can resolve many of the problems for development. Former pits and quarries are shown on Maps 4A, 4B; they have been sited using archival geological and topographical maps, but other excavations no doubt exist. In some cases the boundaries of the excavations are approximate. Thorough site investigations should be carried out in areas of known or suspected backfilled workings. Table 14 summarises the types of former excavation, their distribution and the problems they may pose for development.

Landfill

The use of quarries and pits for landfill waste disposal may present a hazard from the generation of noxious or explosive gases such as methane, carbon monoxide and carbon dioxide (p.64), and toxic leachates. Liquid toxic residues may be present either as a primary component of the fill, or generated by secondary chemical or biological reactions within the fill. These can migrate within the fill or into adjacent permeable strata, either within the pore spaces of the surrounding deposit or along joints, fractures and faults. Landfill sites situated on the Sherwood Sandstone aquifer or Glaciofluvial and alluvial sands and gravels cause particular risks, especially if the site is in hydraulic continuity with the aquifer. In a similar manner gases generated within the fill can migrate laterally or vertically, and may accumulate within buildings or voids such as tunnels or excavations nearby or at some distance away. Migration of methane from a landfill site at Loscoe, Derbyshire resulted in explosion at some distance from the landfill site (Aitkenhead and Williams, 1987).

Sites with known high levels of methane generation should be carefully managed and monitored so that the gas is drained or vented off by controlled collection or flaring. The risk of lateral and vertical migration of landfill gases and associated leachates can be reduced by the installation of impervious membranes between the landfill material and the rock face, and/or between the fill material an any overlying construction. Underground spaces in buildings on methane-bearing ground should be positively ventilated. In the latter case the fill material should be vented to release any trapped gases in order to prevent build up of gas. If the landfill site is well managed the methane generated can be utilised to provide a local source of fuel.

Guidelines for the control and treatment of landfill sites are set out in Department of the Environment publications such as circulars 21/87 and 17/89, ICRL Guidance Note 17/78 and HMIP Waste Management Paper 27.

Constructional landfill and tips

This category comprises fill that is deposited on the original land surface; it may be spread out to form a general rise in the land surface levels (sometimes as componsation for subsidence), dumped as more obtrusive colliery waste tips (p.67), or used as constructional material for embankments. The areas of constructional made ground are shown on Maps 4A, 4B. In general, the older parts of the exposed coalfield, such as the Tipton, Wolverhampton, Darlaston, and Willenhall areas are covered by made ground between 1 and 10 m thick, and locally it is up to 20 m thick. Elsewhere it is more local in its occurrence and often forms distinctive landforms.

Constraints to development occur where the fill is composed of materials of low bearing strength or high compressibility, and in areas where the material has not been sufficiently compacted. Organic waste may generate methane or other noxious gases, and toxic leachate residues may be present. Artificially steep slopes on embankments and at the edges of constructional landfill sites may be subject to slope failure, especially in areas of poorly managed groundwater flow or poorly compacted material. Low-lying sites such as the Tame Valley were prone to flooding prior to tipping and the construction of artificial levees. Settlement of alluvial deposits such as clay, peat and organic rich soils, beneath a cover of fill, may lead to rising water table within the fill material and the generation of methane from organic material due to biodegradation in anaeorobic conditions. Superficial materials such as Head or soil, below the fill deposits, may form a weak layer which could act as a zone of potential failure if overloaded by construction on the stronger fill, or act as a zone of shear failure if the fill has been placed on a slope.

GLOSSARY

ADIT Horizontal or low angle (walkable) entrance into a mine.
AEOLIAN DEPOSITS Sediments deposited after transport by wind.
AGGLOMERATE Volcanic rocks consisting of fragmental volcanic and/or sedimentary material which have been formed by explosive activity within a volcanic system. Clasts are generally greater than 2 centimetres in diameter.
AIRFALL TUFF Consolidated, subaerially deposited volcanic ash.
ALLUVIAL FAN A mass of sediment deposited at a point where there is a decrease in gradient e.g. from a mountain to a plain.
ANGLIAN A part of the Pleistocene epoch dating from approximately 0.38–0.45 Ma and representing a period of glaciation over much of England.
ANTICLINE A rock structure in which beds are folded convexly upwards.
AQUICLUDE A body of relatively impermeable rock that does not readily transmit water.
AQUIFER A body of rock that is sufficiently permeable to yield groundwater to boreholes, wells and springs.
BEDDING The arrangement of sedimentary rocks in beds or layers of varying thickness and character.
BEDROCK Unweathered rock beneath the soil or DRIFT cover.
BIOCLASTIC Term applied to sediments made of broken fragments of organic skeletal material.
BONE BED A sedimentary layer characterised by a high proportion of fossil bones, scales and teeth.
BOULDER CLAY An alternative name for TILL.
BRECCIA A rock consisting mainly of angular pebbles implying minimum transport.
CALICHE A fossil soil characterised by concentrations of calcium carbonate commonly in the form of nodules. The soil formation is commonly associated with an arid to semi-arid climate.
CHERT A rock composed entirely of silica with no visible crystalline structure.
CONGLOMERATE A rock consisting of rounded fragments implying rather more transport than a breccia.
CROSS-BEDDING A series of inclined bedding planes having some relation to the direction of current flow.
CRYSTALLINE Composed of crystals.
CUESTA A hill or ridge with a a gentle slope (DIP-SLOPE) on one side and a steep slope (ESCARPMENT) on the other.
DEVENSIAN A geological succession dating from approximately 0.12–0.10 Ma (part of the Pleistocene epoch) and representing a period of glaciation which partly covered England.
DIP-SLOPE The generally gentle slope which conforms closely to the dip of the underlying strata: marking one side of a cuesta.
DOLERITE A medium-grained intrusive basic igneous rock.
DYKE A sheet-like igneous body which cuts across bedding.
ESCARPMENT The slope marking the steep side of CUESTA: generally formed by the resistance to erosion of a rock unit near the crest.
ESPLEY A local mining and quarrying term applied to greenish coarse-grained, often pebbly sandstones present in the Etruria Formation.
EXPOSURE An area of a rock unit that is unobscured by soil or other materials.
FAULT A fracture in rock along which displacement of one side relative to the other has taken place.
FAUNA Animals of a region or period collectively.
FELDSPAR A rock-forming mineral composed of silicon, aluminium, oxygen and variable amounts of potassium, sodium and calcium.
FIRECLAY A fossil soil commonly found in association with coal seams. It is especially useful as a refractory mineral.
FLOODPLAIN A tract of land bordering a river, mainly in its lower reaches, and consisting of alluvium deposited by the river.
FLUVIAL Of or pertaining to a river.
FOSSIL An organic trace buried by natural processes, and subsequently permanently preserved.
FRACTURE SPACING INDEX A measure of the average length of intact rock core pieces. The unit length is divided by the number of fractures within the unit.
FORMATION Distinctive unit of sedimentary rock with defined and mappable boundaries.
GLACIAL Of or relating to the presence of ice or glaciers; formed as result of glaciation.
GROUP A stratigraphical unit usually comprising one or more FORMATIONS with similar or linking characteristics.
GROUNDWATER Water contained in saturated soil or rock below the water table.
HEAD An earthy deposit containing angular fragments produced as a result of SOLIFLUCTION in PERIGLACIAL regions.
INLIER A limited area of older rocks completely surrounded by younger rocks. It may be produced by erosion, faulting or folding.
INTERGLACIAL Ice ages are often divisible into periods of maximum advance and periods of ice retreat. A period of retreat is referred to as an INTERGLACIAL.
JOINT A fracture in a rock between the sides of which there is no observable relative movement.
LACUSTRINE Pertaining to lakes.
LAMINATED Description of very thin bedding less than 10 millimetres thick.
LEVEE Raised embankment of a river, showing a gentle slope away from the channel. May be natural or man-made.
LITHOLOGY The characteristics of a rock such as colour, grain size and mineralogy.
LIQUID LIMIT The moisture content at the point between the liquid and the plastic state of a clay.
LOPOLITH Concordant igneous intrusion that has a sagging, saucer-like form.
MARINE TRANSGRESSION A relative rise in sea level which results in the invasion of a large area of land by the sea.
MARINE REGRESSION A relative fall in sea level resulting in the withdrawal of the sea from a large area of land.
MARL A calcareous mudstone containing 35–65% cal cium carbonate.
MARLING The incorporation of calcareous mudstone into the soil as a form of mineral enrichment. The `marl' was usually locally quarried from suitable carbonate-rich strata.
MASSIVE Containing no visible internal structure.
MEMBER A distinctive, defined unit of strata within a formation.
METHANE A colourless, odourless, inflammable gas (CH_4); forms an explosive mixture with air.

NORMALLY CONSOLIDATED Normally consolidated deposit, such as clay, that is compacted by exactly the amount to be expected from the pressure exerted by the overburden.
OROGENY A period of mountain building.
OUTCROP The area over which a particular rock unit occurs at the surface, whether exposed or not.
OVERCONSOLIDATED Overconsolidated deposit, such as clay, that in previous geological times was loaded more heavily than now and consequently has a tendency to expand if it has accesss to water.
PERIGLACIAL Said of an environment beyond the periphery of an ice sheet influenced by severe cold, where permafrost and freeze-thaw conditions are widespread.
PERMEABILITY The property or capacity of a rock, sediment or soil for transmitting a fluid.
PLASTICITY INDEX The difference between the water contents of a clay at the liquid and at the plastic limits. It shows the range of water contents for which the clay is plastic.
PLASTIC LIMIT The water content at the lower limit of the plastic state of a clay. It is the minimum water content at which a soil can be rolled into a thread 3mm in diameter without crumbling.
POINT LOAD TEST Index test to give an indication of strength; usually carried out on rock core.
PLUNGE The angle between the axis of a fold (ANTICLINE or SYNCLINE) and the horizontal.
PYRITE The most widespread sulphide mineral, FeS2.
QUARTZITE A sandstone rich in quartz grains - usually over 75%.
RIVER TERRACE Approximately planar surface in a valley above the present river level, representing the dissected remnants of an abandoned floodplain produced during a former stage of deposition.
ROCK QUALITY DESIGNATION (RQD) The percentage of constant diameter core >100mm in length recovered in a single core run. An indication of the fracture state of the rock mass.
SEATEARTH A type of fossil soil commonly found in association with coal.
SILL A sheet-like body of igneous rock which conforms to bedding or other structural planes.
SOLIFLUCTION The slow, viscous downslope flow of waterlogged surface material, especially over frozen ground.
SPIRORBIS A small worm-like (annelid) fossil occasionally found in strata deposited in fresh water e.g. limestones of the Keele and Halesowen Formation.
Genus: *Spirorbis*, Order: Tubicolar Annelides.
SUBSIDENCE The settling of the ground or a building in response to physical changes in the subsurface such as underground mining, clay shrinkage or response to overburden.
SUPERFICIAL DEPOSIT A general term for an unconsolidated deposit of QUATERNARY age overlying bedrock.
STANDARD PENETRATION TEST (SPT) An *in-situ* test for soil where the number of blows (N) with a standard weight falling through a standard distance to drive a standard cone or sample tube a set distance is counted. A measure of the bearing capacity of a soil.
SYNCLINE A rock structure in which beds are folded concavely upwards.
SYNSEDIMENTARY Occurring simultaneously with sedimentation or deposition.
TILL Unsorted mixture of clay, silt, sand, gravel and boulders deposited from melting ice without subsequent reworking by meltwater.
UNCONFORMITY A substantial break in a stratigraphic sequence where strata are missing. There may be an angular relationship between the strata above and below the surface of unconformity.
VEIN A mineral or lithic infilling of a fault or other fracture in a rock: usually sheet-like or tabular.
WASHOUT A coal mining term used to describe a channel cut into strata (usually coal) subsequently filled by sediment such as sand or silt.

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TECHNICAL APPENDICES

Appendix 1 Data Sources

Borehole Data
Sources of borehole data collected during this study are listed below. Those marked with an asterisk * are major sources:
(a) Public authorities
*Birmingham City Council, Industrial Research Laboratories
*Dudley MBC
*Sandwell
*Walsall MBC
*Wolverhampton
(b) Private companies including consultants and nationalised industries
ARC Ltd
Applied Geology Ltd
Ascough & Associates
Baggeridge Brick PLC
Baynham Meikle Partnership
Hobson Associates
British Coal Opencast Executive
British Geotechnical
*British Railways Board
Burne Associates
Bryant Homes Ltd
Cameron Taylor Partners
Bylander Waddell Partners Ltd
Cooper MacDonald & Partners
Clayton, Bostock, Hill & Rigley
S M Cooper and Associates
Douglas Technical Services
Exploration Associates
Fairclough Civil Engineering Ltd
*Geotechnics Ltd
G K N Keller Foundations
Griffin Mellors & Associates
*Ground Exploration Ltd
*Ground Investigation & Piling
Groundworks (Dudley) – now J.P. & B.
Ian Farmer Associates
M & J Drilling Services
*Johnson, Poole & Bloomer
Keith Palmer Associates
L V Ingram & Partners
McCarthy & Stone (Development) Ltd
Norwest Holst Soil Engineering Ltd
*Ove Arup & Partners
Parkman Consulting Engineers
Redland Bricks
*Rendel Geotechnics Ltd
Robinson James Partnership Ltd
*Sir Alexander Gibb & Partners
Soils & Materials Testing
Strata Survey Ltd
Structural Design Partnership
*Subsoil Surveys Ltd
Geo-Research Ltd
Tarmac Roadstone (Western) Ltd
T & L Explorations Ltd
*Wardell Armstrong Ltd
Wimpey Homes Ltd

The borehole data are catalogued in the BGS archives at Keyworth on individual 1:10 000-scale sheets, each catalogue consisting of a site map at 1:10 560 or 1:10 000-scale and a borehole register, together with the individual records. The sheet numbers included in this study and the numbers of boreholes in each catalogue are listed below:

Sheet No.	Boreholes registered before this study	Total number of registered boreholes
SO88NE Kingswinford	69	382
SO88SE Stourbridge	48	209
SO89NE Penn	41	207
SO89SE Wombourne	46	180
SO98NE Rowley Regis	34	41628
SO98NW Brierley Hill	56	41639
SO98SE Halesowen	16	1367
SO98SW Lye	14	0541
SO99NE Willenhall and Darlaston	1968	2538
SO99NW Wolverhampton	859	1185
SO99SE Dudley and Wednesbury	737	3300
SO99SW Dudley and Sedgley	673	1526
SP08NW Smethwick	146	653
SP08SW Harborne	79	273
SP09NW Walsall	410	930
SP09SW Hamstead	344	790
Totals	6629	16,348

Mine Plans

Coal, ironstone and fireclay
Copies of all known colliery abandonment plans, together with many of the abandonment plans of the Silurian limestone mines, are held by the Mining Records Officer, British Coal, Technical Services and Research Executive, Bretby, Staffordshire; the original plans are housed at Staffordshire House, Stoke on Trent. Abandonment plans are held by British Coal in the public domain, but are not available for reference at BGS.

Silurian limestone
In addition to the abandonment plans of Silurian limestone mines held by British Coal, noted above, an up to date register of all the known limestone mines and approximate outlines of the workings are held by the Building Control Officer of the relevant Metropolitan District Council.
For Wolverhampton MBC, mines other than coal and limestone are held at the Central Library, Wolverhampton.

Hydrogeology
Hydrogeological data held by the National Rivers Authority consist of:
(a) A data bank of all licensed wells, boreholes and springs. These data give the permitted rates of abstraction, the specific location and the depth and diameter of the well or borehole. Abstraction data are confidential where they relate to individual industrial users.
(b) A data bank of groundwater chemistry relating to all public water supply sources and a few selected industrial sources.
(c) Limited data on long-term changes in groundwater levels.
Similar data are held by the Hydrogeology Group, British Geological Survey, Wallingford.

Appendix 2. List of Mineral Industry Operators (1992)

1. Brick Clay

Baggeridge Brick, Baggeridge Wood Quarry [SO 899 911], Fir Street, Gospal End, Sedgeley, DY3 4AA

Hinton, Perry and Davenhill Ltd., Ketley Quarry [SO 897 889] Dreadnought Works, Pensnett, Brierley Hill, DY5 4TH

Ibstock Brick, Himley Quarry [SO 897 902] Pensnett Trading Estate, Stallings Lane, Kingswinford, Dudley.

Redland Bricks Ltd., Stourbridge Brickworks [SO 910 898] Tansey Green Road, Kingswinford, Brierley Hill, DY6 7LS

2. Dolerite aggregate and coated stone

ARC-Western, Edwin Richards Quarry [969 883] Portway Road, Rowley Regis, Warley, B65 9DN

Tarmac-Western, Hailstone Quarry, [968 879] Portway Road, Rowley Regis, Warley, B65 9DW

3. Coal

Opencast Executive, British Coal, Staffordshire House, Stoke on Trent, Staffordshire. Former recent workings at Bilston, Dibdale Road and Patent Shaft sites.

4. Sand and Gravel, and sand-rock

Davies, F. & Sons Ltd., Enville Road Quarry [SO 873 899] Enville Road, Wall Heath, West Midlands

Element, T., Stewpony Quarry [SO 865 845] (east of study area)Halesowen Street, Oldbury, Warley

D J Shakespeare, Highdown Quarry [879 816], (Sherwood Sandstone)16 Oak Lane, Brierley Hill, West Midlands

Appendix 3. List of statutory bodies relevant to planning and development

1. Coal

British Coal*
Technical Services and Research Executive,
Bretby, Staffordshire DE15 0QD

British Coal**
Group Surveyor & Minerals Manager
Midlands and Wales Group
Beaumont House
Coleorton
Leicestershire LE6 4FA

*Responsible for plans of abandoned mine workings
**Responsible for deep mines

British Coal Opencast Executive
Staffordshire House
Berry Hill Road
Stoke on Trent Staffordshire ST4 2NH

Responsible for current and future opencast mining

2. Planning and development

Dudley Metropolitan Borough Council
3 St James Road
Dudley
West Midlands DY1 1HZ

Sandwell Metropolitan Borough Council
Wigmore Buildings
Pennyhill Lane
West Bromwich B71 3RZ

Wolverhampton Metropolitan Borough Council
Civic Centre
Saint Peter's Square
Wolverhampton WV1 1RG

Walsall Metropolitan Borough Council
Darwall Street
Walsall WS1 1TW

Birmingham City Council
Baskerville House
Broad Street
Birmingham B1 2MO

Black Country Development Corporation
Black Country House
Rounds Green Road
Oldbury
West Midlands B 69 2DG

3. Groundwater supply and sewage disposal

National Rivers Authority
Severn Trent Region
Abselon House
2297 Coventry Road
Sheldon
Birmingham B26 3PU

All applications for licences to drill and test pump boreholes for water should be sent to the above address and not to BGS.

4. Geology

Various Acts of Parliament ensure that information obtained from the sinking of boreholes and shafts for minerals , including petroleum, and for water, is made available to the British Geological Survey.

The following operations must be notified in writing to the British Geological Survey:

The sinking of a new borehole or shaft to a depth of more than 30 m (15 m for water), or the deepening of an existing borehole or shaft to a depth of greater than 30 m (15 m for water).

Any person carrying out these operations is also required to:

(a) Keep a record of the nature and depth of the strata encountered,

(b) Retain specimens of cores and chippings for examination,

(c) Allow properly authorised officers of the British Geological Survey free access to specimens and records.

In addition BGS will be pleased to receive records of shallow boreholes and trial pits for the area. These records are sited on 1:10 000 scale maps and archived at BGS, Keyworth. The data are used to update the geological database and geological maps of the area. Data of a commercial nature can be held 'commercial in confidence'.

For minerals and site investigation boreholes, written notices should be sent to:

The Manager
National Geosciences Data Centre
British Geological Survey
Keyworth
Nottingham NG12 5GG

For water, written notification should be sent to:

The Manager
Hydrogeology Research Group
British Geological Survey
Maclean Building
Crowmarsh Gifford
Wallingford OX10 8BB

5. Geological conservation

English Nature
Northminster House
Peterborough PE1 1UA

Black Country Geological Society
Honorary Secretary
16 St Nicolas Gardens
Kings Norton
Birmingham B38 8TW

Keeper of Geology
Dudley Museum.and Art Gallery
St James' Road
Dudley DY1 1HU

Appendix 4. List of 1: 10 000-scale geological maps and accompanying technical reports

Each component 1:10 000-scale map in the study area has an equivalent Technical Report describing the geology of the sheet, including generalised logs of selected boreholes and shafts held in the BGS archives. Copies of these reports may be ordered from BGS, Keyworth, Nottingham, NG12 5GG. The reports and authors are listed below:

Sheet no.	Sheet name	Technical report no.	Author
SO88NE	Kingswinford	WA/91/39	Waters C N
SO88SE	Stourbridge	WA/91/70	Powell J H
SO89NE	Penn	WA/91/76	Powell J H
SO89SE	Wombourne	WA/90/76	Glover B W
SO98NE	Rowley Regis	WA/91/55	Waters C N
SO98NW	Brierley Hill	WA/91/62	Wilson D and Waters C N
SO98SE	Halesowen	WA/90/74	Glover B W
SO98SW	Lye	WA/91/59	Powell J H
SO99NE	Willenhall and Darlaston	WA/91/78	Hamblin R J O, Henson M R, Powell J H
SO99NW	Wolverhampton	WA/91/77	Hamblin R J O and Powell J H
SO99SE	Dudley and Wednesbury	WA/91/73	Hamblin R J O and Glover B W
SO99SW	Dudley and Sedgley	WA/91/72	Hamblin R J O and Glover B W
SP08NW	Smethwick	WA/91/71	Powell J H
SP08SW	Harborne	WA/90/75	Glover B W
SP09NW	Walsall	WA/91/63	Hamblin R J O, Henson M R, and Waters C N
SP09SW	Hamstead	WA/91/08	Waters C N

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