Stoke-on-Trent: A geological background for planning and development

Technical Report WA/91/01

Onshore Geology Series

British Geological Survey

TECHNICAL REPORT WA/91/01

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A A Wilson, J G Rees, R G Crofts,
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BRITISH GEOLOGICAL SURVEY

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Cover illustration

Aerial photograph from Fenton Manor [SJ 883 452] looking northwestwards across Etruria Vale (underlain by the Etruria Formation) and across higher ground (underlain by the Newcastle and Keele formations) to the Cheshire plain (underlain by rocks of Triassic age). The A500 road, the Trent and Mersey Canal and Stoke-on-Trent railway station can be seen in the foreground. Made ground and sand and gravel form the immediate valley floor on the route of the glacial drainage channel. (*Photograph by Jeffersons Air Photography*)

Geographical index

UK, central England, Staffordshire

Subject index

Land-use planning, thematic maps, resources, stability, safety, Carboniferous, Triassic, Quaternary

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BRITISH GEOLOGICAL SURVEY

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PREFACE

This report describes aspects of the geology which relate to planning in Stoke-on-Trent.

The present study, which was commissioned and partly funded by the Department of the Environment, was concerned with collection and interpretation of geological data relevant to resources, ground stability and pollution. The study resulted in the production of this report, with accompanying thematic maps, as well as separate geological maps and technical reports.

The mapping was carried out by J G Rees, R G Crofts, A A Wilson, A S Howard and J G Buchanan in 1988–89. The geotechnical data were analysed by P J Waine. Major contributions to the production of thematic maps were made by I R Sharp, B J Stirling, M Frost, S Burns and P Finch. Assistance in data collection was also given by A M Brook, R J Tosswill, K Taylor and A Hood. Mr E L Parry (National Rivers Authority) advised on hydrogeology and wrote the section on water resources and aquifer pollution. Ms M Johnston (Department of the Environment) wrote the section on planning background. The nominated officers were Dr S Cosgrove and Ms M Johnston for the Department of the Environment and Dr A A Wilson for the British Geological Survey.

The cooperation of local authorities and other holders of data is gratefully acknowledged. A list of the principal data sources is given in Appendix I. In addition the following are thanked for advice and data used in preparing the text and diagrams in this report: Messrs Chatten, Taylor and Gilbert of Staffordshire County Council, Messrs Jackson, Webb and Tittensor of Stoke-on-Trent City Council, Mr Axon of Newcastle Borough Council, Mr Steward of the City Museum, Stoke-on-Trent, Dr Brown and Mr Norman of Wardell Armstrong, Mr Pate of the National Federation of Clay Industries, Drs Boardman and Buck, Messrs Watkins and Hand and Ms Nunn of British Coal Deep Mines, Messrs Lingham and Skidmore of British Coal Opencast, Mr Gaskell of Parklands Colliery Co., Mr Cragg of Scott, Wilson and Kirkpatrick, Dr Ball of Allott and Lomax and Drs Besly and Thompson of Keele University.

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EXECUTIVE SUMMARY

This study, carried out between 1988 and 1990, was commissioned by the Department of the Environment (DOE) and funded jointly by the Department and the British Geological Survey (BGS). Its main aim was to make a synthesis of geological data relevant to planning of land-use and development in the Stoke-on-Trent area. This report is specifically written for planners and there has been an attempt to avoid complex geological terms. Besides text illustrations the report includes ten thematic maps at a common scale of 1:25 000. An additional volume concentrates on engineering geology for site investigation companies. Seven further short reports feature geological details of separate 1:10 000 sheets, couched in more technical language.

The study area

The study area comprises the City of Stoke-on-Trent, the Borough of Newcastle-under-Lyme and surrounding largely agricultural land, some of it administered by the Staffordshire Moorlands District Council. The total area, all of which lies in the County of Staffordshire, covers 175 km^2. It lies in the foothills of the Pennines and straddles the watershed between the rivers Trent and Mersey (Figure 2).

Whilst Newcastle-under-Lyme is of medieval foundation, Stoke-on-Trent owes its origin primarily to the pottery industry which grew dramatically from the early 17th century onwards. The pots were fired by the local coals, readily available on the doorstep. Initially the pots were made from local clays, but these were soon supplemented and then replaced by materials from farther afield. Brick and tile manufacture, using mostly local clays and coal, has flourished for 300 years. There has been a very long history of coal mining, with the locus of activity now moving south towards hitherto untouched, deeply buried reserves. In recent years engineering, tyre and electrical wire manufacture and warehousing have been added to the local activities. As the population has increased, housing has spread out gradually to form extensive suburbs.

Geology

The northern half of the area is directly underlain by Coal Measures of Carboniferous age lying in a deep downfold containing 60 mined horizons (Figure 3). Most of these were worked for coal and some for ironstone, distributed through over 1100 m of rock strata. In the south the Coal Measures are overlain by dominantly red Barren Measures, lacking coals of workable thickness. It is beneath these beds that the future of mining lies, after two busy centuries of working the more accessible measures.

Exposure of Carboniferous beds beneath the Coal Measures is restricted to the Werrington area in the north-west, where they are brought up in a sharp upfold. These are called the Millstone Grit and include hard sandstones, which form conspicuous ridges (Figure 6).

Above the Carboniferous strata are beds of Triassic age, comprising thick sandstones containing beds of conglomerate (hardened gravel). These are a source of gravel for aggregate. These rocks are more permeable than those they overlie and are a valuable source of borehole water for public supply.

Resting like a discontinuous blanket over the bedrock formations are the deposits of the last, Devensian, ice age. These include clays with stones (till) and also sands laid down by water flowing from the melting ice. Buried valleys, partially infilled by the sands and gravels laid down beneath the melting ice sheet, underlie the headwaters of the River Trent.

Man-made deposits, termed Made Ground, occur as numerous patches spread over the landscape. These provide clues to man's many activities. There is colliery spoil from centuries of mining, slag from defunct ironworks once based on local coal and iron ore, clay and tile debris from the old tileries, dumps full of rejects from the potter's trade, and domestic and miscellaneous industrial waste. Some of the tips stand proud above the landscape, whilst others are deeply hidden in old clay pits, posing a possible hazard for the unwary developer.

Mineral and water resources

The prime mineral resource for over two hundred years has been coal. Easily accessible resources in the area of exposed Coal Measures have largely been mined out, with the exception of some areas of unworked coal which are still accessible by footrail (adit) operations, usually working one or two seams. Currently mining has progressed southwards into deeply buried Coal Measures, overlain by thick red beds, lacking workable coals. Though the mine entrances are within the area, the current workings almost all lie beyond its southern boundary.

Though three boreholes were sunk in an early search for oil, none was found. There have been several discoveries of oil in the coal mines and during the last war much oil was produced directly from coal. There is still some possibility of a natural gas discovery, but at present all the natural gas extracted from the rocks comes from methane drainage schemes in the mines of British Coal.

Ironstones in the Coal Measures provided ore for the iron and steel industry for 150 years, but now only the dumps of slag, itself a valuable resource of hardcore, remain.

Mudstones in the Coal Measures and overlying red beds support a long-established brick and roofing tile industry. Whilst demand for baked roofing tiles has fallen, the brick industry is flourishing. Most of the brick-clay workings are in the red mudstones of the Etruria Formation (Figure 9). One quarry remains in the Coal Measures, but formerly there were several. Areas are discussed in which there are still extensive resources of the favoured mudstones, within the Etruria Formation.

The main gravel resources lie in the Sherwood Sandstone Group. Though there have already been extensive workings, reserves still exist near the eastern fringe of the area. Spreads of glacial sand and gravel, laid down by the melting ice, are identified. The only promising gravels for aggregate are unfortunately buried under valley alluvium in the urban area.

Though building stone has been extracted from the Carboniferous sequence in the past, there seems to be no foreseeable future activity.

Though the abandoned mines are in large measure waterlogged, the quality of the water does not make it suitable for public supply. The Sherwood Sandstone is a good aquifer and is used in the east, mainly for large public borehole supplies.

Land stability and safety

Subsidence has historically been a major problem in the area due to the extensive mining at many different levels in the rock sequence. There is now little active mining, except in the extreme south and at six footrail locations in the west of the area. The immediate dangers come from recently abandoned workings, and in the longer term from the deterioration and collapse of roof supports in the old pillar and stall workings. Many of these latter workings come close to the surface in the urban area, and are often uncharted. They pose a distinct threat to the stability of large buildings, hence nowadays site development in the urban area is very frequently preceded by site investigation, often involving boreholes. The new, much improved geological maps resulting from the present survey will help to pinpoint the outcrops of the most dangerous seams, such as the Great Row, which have commonly been worked close to the surface.

The weak alluvial deposits of the valley floors are singled out as highly compressible soils which can locally include lenses of peat. Running sand has been reported in both valley alluvium and glacial sands in the present area.

The thematic map showing slope steepness emphasises slopes likely to be steep enough to cause trouble for certain construction purposes. Steep slopes in the Etruria Formation are prone to landslip. There are instances of large ancient rotational landslips and also very recent rotational failures on the steep slopes of the mudstone quarries.

There are extensive spreads of colliery spoil in the present area (Figure 17). Historically the tips have frequently caught fire and still pose a risk during excavation, handling and placing, due to spontaneous combustion. Aggressive sulphate-rich groundwater has been recorded in boreholes which include a proportion of colliery spoil. This could attack buried concrete structures.

Flooding risks are localised in a band alongside the River Trent.

Seismic risk is fairly low, but the Chebsey Earthquake of 1916 did cause minor damage in the built-up area.

The possibility of pollution in the Sherwood Sandstone aquifer calls for strict controls for waste disposal within 1 km of the wells following guidelines set by the River Authority. The main danger comes from illegal tipping of toxic chemicals.

Pollution by leachates derived from waste disposal sites, particularly those containing industrial waste, is locally a problem. In theory, old quarries in sandstone-free parts of the Etruria Formation could provide good containment, but there has been leakage in some cases. There are risks from escaping methane gas from domestic waste disposal sites, particularly where there are fissured sandstones in the old quarries used for tipping.

Thematic Maps

Maps at the common scale of 1:25 000 are published with this report to illustrate the following themes:

1. Distribution of records (boreholes, shafts and trial pits). This shows the sites of boreholes, except those for opencast coal.

2. Thickness of superficial deposits. This shows the total thickness of these deposits, excluding made ground. The buried valleys made by waters from the melting ice are well displayed.

3. Distribution and engineering geology of superficial deposits, geomorphology. This shows the deposits of the ice age and of the modern rivers and relates them to their geotechnical characteristics. Ridges of hard rock forming the upland features are also shown.

4. Distribution of made ground. This shows the man-made tips. Old clay-pits deeply infilled with debris have been singled out, since they pose a threat to land stability, particularly at their perimeters, where differential compaction effects are greatest.

5. Solid geology. This shows the main bedrock units, the outcrops of the principal coal seams and the dislocations (faults) which affect the rock strata.

6. Surface mineral resources. This map shows areas where brick clay and coal, sand and gravel could be quarried at surface.

7. Mining. The total known undermined area is shown, together with the area in which there is a risk of workings at depths less than 30 m from the surface.

8. Slope steepness. Slopes are classified with respect to the type of construction they are likely to be able to sustain.

9. Engineering geology of bedrock. The stronger and weaker units for engineering purposes are identified. The underlying statistical work derived from computer analysis of data from site investigation reports forms the subject of a separate report.

10. Resources. This map shows resource areas, some of which need to be protected against overbuilding.

11. Ground stability constraints. This map identifies areas likely to contain shallow old workings, and identifies landslips, old infilled quarries and soft ground.

12. Constraints caused by leachates and gases. This deals with possible leachate and gas problems, defines protection zones round water boreholes and shows areas prone to floods.

Creation of the database

During the course of this study the archived records of the British Geological Survey, collected over 150 years, have been used extensively. The records include past surveys and the extensive borehole database, supplemented by a geological field resurvey on the 1:10 000 scale carried out in 1988–89.

For the present study the databases of British Coal (Opencast and Deep Mines) the County and local councils and numerous site investigation and mining consultant companies have been visited to add to our archives of borehole and shaft records and mine plans. Aerial photographs have been obtained and old maps examined. All this kind help has been of the first importance in amassing a working database.

Copies of this report with its suite of thematic maps, the report on Engineering geology and the 1:10 000-scale geological maps can be obtained from The British Geological Survey, Keyworth, Nottingham, NG12 5GG

1 INTRODUCTION

This report summarises data obtained during a three year study, commissioned by the Department of the Environment as part of the Geological and Minerals Planning Research Programme. The study was undertaken by the British Geological Survey and jointly funded by the Department of the Environment and BGS.

Motivation for the study was the legacy of problems facing planners and developers caused by over two hundred years of mining, the ensuing dereliction and subsidence and the need to protect now scarce mineral resources from sterilisation. Geological data on mineral resources, past and present mining and quarrying, foundation conditions and groundwater, provide a useful framework for assessing potential land use. The study is consequently expected to be of value to a wide range of users from specialists in the earth sciences or related disciplines, to those who may be experts in other fields. The intention of the report, therefore, is to present geological information for land use planning and development control purposes in the Stoke-on-Trent area, in a form that is accessible to all interested parties and particularly to those who have little geological or geotechnical background. Hence technical terms are kept to a minimum.

The study area covers most of the Potteries conurbation and some surrounding country and includes seven component 1:10 000 map sheets (Figures 1, 2). Parts of the urban area in the northeast and southwest lie outside the limits of the study, however (Figure 1). Administratively all the area lies in the county of Staffordshire, the bulk being in the area controlled by Stoke-on-Trent City Council and Newcastle-under-Lyme Borough Council. The remaining area is administered by Staffordshire Moorlands District Council and Stafford Borough Council.

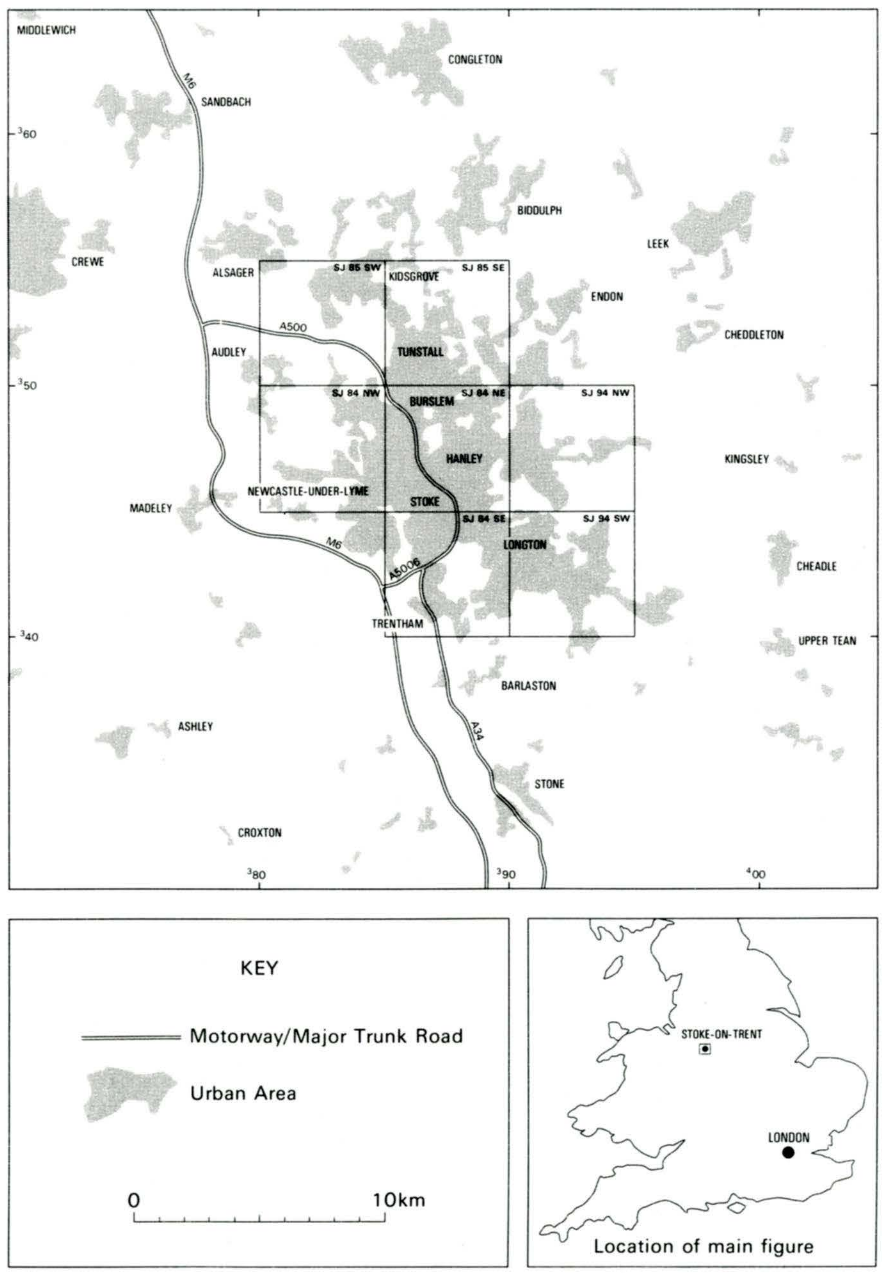


Figure 1 Location of study area in its regional setting.

1.1 Objectives

The aims of the project were to produce:

— New geological maps at the 1:10 000 scale, taking into account a large and greatly augmented database of boreholes, mining information and new field observations.

— A set of thematic maps at the 1:25 000 scale for use by planners, engineering geologists and developers. These stem from the geological survey, from mining and quarrying data, and geotechnical analysis of the bedrock and superficial deposits.

— Explanatory reports, to cover the fields of geology in its relation to planning (this report), engineering geology, and local geology, thus providing a foundation for land-use planning for development and redevelopment, a foundation for the investigation and protection of mineral resources, and a preliminary to site investigations by mining engineers and engineering geologists.

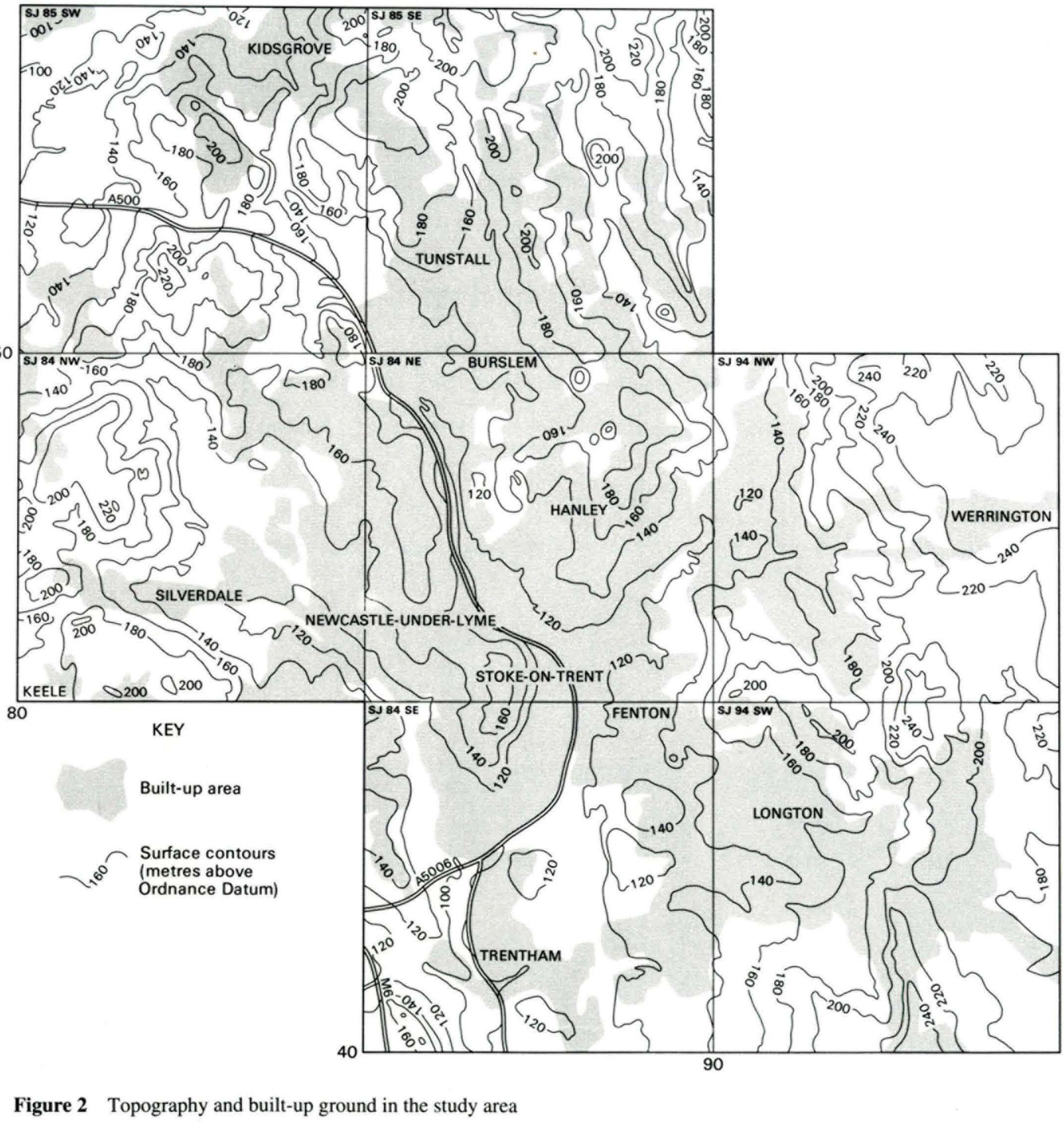


Figure 2 Topography and built-up ground in the study area

1.2 The study

The project was monitored by a Steering Committee which included representatives of the Minerals Division of DOE, Staffordshire County Council, Stoke-on-Trent City Council, Newcastle-under-Lyme Borough Council, Stafford Borough Council, Staffordshire Moorlands District Council, British Coal Deep Mines, British Coal Opencast, National Federation of Clay Industries and the National Rivers Authority.

The main activities were as follows:-

FIELD SURVEY This was carried out on the 1:10 000 scale by five geologists and involved the detailed mapping of solid and drift geology, together with much made ground.

SEARCH FOR DATA To augment the database of boreholes and shafts already held by BGS an extensive search was undertaken, notably at British Coal (Deep mines and Opencast), the local authorities' planning and engineering offices, and firms of mining engineers and site investigation consultants. Records of some 8000 boreholes were collected, in addition to those for opencast coal. The great bulk of these were for site investigation for buildings, roads and sewers.

Cores from 35 boreholes on the projected A50 Blythe Bridge–Queensway link road were transferred to BGS for storage and were all subsequently logged. Eight further cores from brick clay prospects were examined at the offices of Steetley Building Products and at BGS. Visits were paid to opencast sites at High Lane, Red Street and Brown Lees to measure sections.

Up-to-date mine plans for all seams were procured from British Coal. Aerial photographs were also obtained and old topographic maps examined to determine boundaries of old quarries.

1.3 The results

The component 1:10 000 maps were constructed by combining the data described above. They show the distribution of the geological formations that make up solid bedrock, superficial deposits, and made ground. A three-dimensional interpretation for each map is assisted by the addition of selected borehole data and a generalised vertical section.

The seven geological maps at the scale of 1:10 000 are: SJ 84 NW, SJ 84 NE, SJ 84 SE, SJ 85 SW, SJ 85 SE, SJ 94 NW, SJ 94 SW.

These are in standard BGS format and available as dyeline copies in black and white.

Each map has an accompanying open file technical report which gives a general description of the geology; these are part of the BGS Onshore Geology Series of Technical Reports, and are:

WA/90/04 SJ84NW Geology of the Silverdale district.

WA/90/05 SJ84NE Geology of the Hanley district.

WA/90/06 SJ84SE Geology of the Trentham district.

WA/90/07 SJ85SW Geology of the Kidsgrove district.

WA/90/08 SJ85SE Geology of the Tunstall district.

WA/90/09 SJ94NW Geology of the Werrington district.

WA/90/10 SJ94SW Geology of the Longton district.

Engineering hazards which might be posed by the geology are discussed in the separate report WN/90/11 entitled Engineering Geology of the Stoke-on-Trent area. This was written especially with engineering geologists, highway and tunnel engineers and developers in mind.

Twelve thematic maps at a common scale of 1:25 000 were produced by the collation and interpretation of geological, geotechnical and related data from the 1:10 000 survey and a wide variety of sources. The maps each highlight a specific aspect relevant to the planning of land use and development and are packaged with this report. The twelve maps are:

Map 1 Distribution of records (boreholes, shafts and trial pits)
Map 2 Thickness of superficial deposits
Map 3 Distribution and engineering geology of superficial deposits, geomorphology
Map 4 Distribution of made ground
Map 5 Solid geology
Map 6 Surface mineral resources
Map 7 Mining
Map 8 Slope steepness
Map 9 Engineering geology of bedrock
Map 10 Resources
Map 11 Ground stability constraints
Map 12 Constraints caused by leachates and gases

This report has been written for city planners, surveyors and engineers.

Data used in preparing this report and associated maps are lodged at the British Geological Survey, Keyworth. Any enquiries concerning these, or about the purchase of any of the above maps and reports, should be directed to the British Geological Survey, Keyworth, Nottingham NG12 5GG.

1.4 The use of this report

Chapter 2 seeks to link the shape of the landscape to its underlying geology and to explore the connection between the mineral resources and man made landscape formed by the debris of mineral-related activity.

In the section on mineral and water resources (Chapter 3) past and present underground activity and quarrying is analysed and some indications given of the scope of future activity. Above all it is hoped that with the aid of the thematic maps certain valuable resources, notably brick clay in the Etruria Formation, can be protected by the planners from overbuilding.

Chapter 4, the section on land stability and safety, addresses the geologically related factors which can cause problems to present and future developments in this area, and to the safety of the underground water supplies.

Conclusions and recommendations make up Chapter 5.

It must be stressed that the maps only provide a general description of the nature and extent of factors relevant to the planning of land use and development. The data are not comprehensive and are of variable quality and distribution. However, the report and maps provide a valuable source of general information relevant to planning issues and can also be used as a regional and background reference for those designing site investigations. Furthermore, the report should act as a guide to more detailed sources of data including the BGS archives of non-confidential boreholes and other data, the 1:10 000 geological standards, open-file reports and original field slips, which are the fundamental sources of information for this report.

This report and its constituent maps provide 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 carrying out ground surveys and site-investigations if necessary, that ground conditions are suitable for any particular land use or development.

2 GENERAL CHARACTERISTICS OF THE STUDY AREA

2.1 Setting

The Potteries conurbation, the subject of the present study, stands among low Pennine foothills close to the edge of the Cheshire Plain. Most of the area is drained by the River Trent, whilst in the north-west the streams drain into the Mersey.

The rocks beneath the area are almost invariably tilted, so that in a short distance one can cross many different layers of rock. This is clearly shown in the photograph of the High Lane Opencast Site (Plate 1) where numerous coal seams and associated mudstones and sandstones are inclined at about 32°. They are dipping into a great downfold in the rock formations, called the Potteries Syncline, in which most of the coal-bearing rocks (Coal Measures) of the area are preserved (Figure 5). This downfold tends to be more deeply buried towards the south. Generally beds on the western limb of the fold are inclined more steeply than those on the eastern limb.

The harder layers in the bedrock tend to form ridges in the landscape. The pattern of these ridges (Figure 6) reflects the shape of the tilted syncline, with the pattern of escarpments arranged in a shape like the prow of a boat. The ridges tend to be discontinuous due to fractures or faults in the rock formations and also due to a patchy blanket of stony clay (till), which was deposited during the last ice age and which covers the bedrock in many places.

Above the Coal Measures are the Barren Measures, a thick sequence lacking workable coals and including many reddish brown beds. The softest rocks are in the Etruria Formation, which are commonly eroded to form valleys, as at Etruria. Steep slopes in the mudstones of the Etruria Formation lead up to one of the most important ridge-forming sandstones, close to the base of the overlying Newcastle Formation (Figure 6).

The undulating terrain produced by the Coal Measures terminates in the north-west, around Talke and Wedgwood's Monument, in westward-facing slopes flanking the Cheshire Plain. This topographic contrast is due to a major earth fracture, the Red Rock Fault, which brings in, to the west, soft Etruria Formation overlain by Triassic rocks.

Plate 1 High Lane Opencast Site

Beds from the Cannel Row up to above the Bassey Mine Coal dip steeply into the Potteries Syncline. They are dislocated by a triple fault. View looking east [821 481].

This area west of the fault is mostly heavily mantled by deposits from the last ice age and is a generally low lying, gently undulating terrain on the fringes of the Cheshire Plain.

In the east of the area are several patches of higher ground containing dry valleys. This terrain is on one of the highest rock formations in the area, the Sherwood Sandstone of Triassic age (Figure 4).

The floors of the main valleys, notably the Trent and its tributaries, are underlain by flat silty alluvium laid down by the rivers when in flood. In many places the alluvium overlies earlier sands and gravels deposited by meltwaters from the last ice age (Figure 14). These same streams during the ice age made gaps through the hills, glacial drainage channels which now lack large streams, south of Kidsgrove and at Apedale (Figure 6).

2.2 History and land use

The town of Newcastle-under-Lyme is of ancient foundation, having had a castle in the 12th century. It grew slowly over the years into a market town on the London-Liverpool turnpike road. The adjacent six towns which make up the present borough of Stoke-on-Trent were formerly villages which owe their spectacular early growth during the Industrial Revolution primarily to geological factors.

In 1693 a Dutchman, John Elers, settled near Stoke-on-Trent and began to make red teapots from the clays of the Etruria Formation. His example sparked off a community of master potters, notably the inventive Josiah Wedgwood. Ceramic bodies, glazes and colours were rapidly elaborated to make much sought-after products. By the late 18th century the ware of the Potteries, fired by the local long flame coals, travelled the world, gliding on their way on a fine new canal system.

The Grand Trunk or Trent and Mersey Canal was begun in 1766, followed by the Caldon Canal to access the limestone of the Peak District. A further branch went to Macclesfield. The work of Brindley, the engineer of the Grand Trunk, included the driving of the 2630 m long Harecastle canal tunnel transecting the upland rim of the Cheshire Plain. In the 19th century the canals were supplemented by the railways, with a further tunnel at Harecastle.

The original pottery industry and therefore the original rapid early growth of the Potteries towns owes its origin to the deep downfold in the rocks, the Potteries Syncline, in

Plate 2 Central Forest Park, Cobridge

Landscaped colliery tip derived from Hanley Deep Pit. Viewed from the south at [886 487].

which numerous excellent and easily accessible coal seams are preserved (Figure 5). The local coals, notably the Great Row, provided an excellent fuel for the numerous pottery kilns in their beehive shaped 'hovels', designed to improve the draught. The local clays were gradually less used for the clay body, and raw materials brought in from farther afield included kaolin, feldspar, quartz, flint, ball clay and bone ash. Quarry tiles, roofing tiles and bricks have long been made from the local clays.

Nowadays the pottery industry makes sanitary ware, ceramic insulators and tiles, as well as pottery and china. There are many engineering factories, besides tyre manufacturing, light industry and merchandising. The construction of the nearby M6 motorway and its A500 link has greatly improved access by road.

Due to its long history of mineral extraction and as an industrial and urban centre the area has included much derelict land. Since our last geological survey in 1961 there have been dramatic changes brought about by derelict land grants from the Department of the Environment, used to good effect by the local authorities. Priority is given to schemes aimed at economic regeneration, improving the environment to encourage economic regrowth and in particular to recycle land for industrial re-use. Notable changes include the conversion of old colliery tips to playing fields, as at Northwood and Wolstanton; infilling a railway cutting at Chell with colliery waste and conversion to parkland; revegetating tips at Sneyd Hill Park and Central Forest Park and conversion to community use (Plate 2). Industrial estates have been and will be built on the sites of numerous old ironworks and colliery tips and abandoned clay pits. Examples of such overbuilt tips are at Shelton, Fenton, Parkhouse and Birchenwood, whilst restored clay pits have been used west of Tunstall, at Cobridge and in the future at Rowhurst, west of Chesterton. An old quarry at Lightwood, near Longton has been landscaped and utilised for housing. A further old quarry at Chell has been cleverly converted into an athletics stadium, with viewing slopes on the landscaped quarry walls. Opencast coal operations have also become a vehicle for upgrading sites strewn with old mine dumps, shafts and adits. One such former site at Red Street will have 800 new houses built on the newly backfilled and specially consolidated area.

Areas rich in plants, birdlife and interesting rock formations have been designated for conservation (Figure 11). Interestingly, a number of these are on made ground, tipped there by man, which has over the years become a haven for wildlife (see Appendix III). The once heavily mined area of Apedale includes an area which has been designated as a future country park and incidentally includes an interesting geological exposure, worthy of preservation.

Mineral extraction is an important, although transient land-use in the study area with clay, deep-mined and opencast coal actively worked at present. Inevitably, extraction of minerals creates some disturbance, especially if fairly near housing, and a balance has to be struck between the need for minerals to service a modern, industrial society and the protection of the environment.

2.3 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 northern Staffordshire, 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 comprise 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. 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.

The area covered by the present study is administered by county, borough, city and district authorities which prepare structure, local and subject plans as appropriate. As of May 1992, the plans pertaining to the study area comprise the following:

City of Stoke-on-Trent	Stoke-on-Trent City Plan 1990–2001 Written Statement and Technical Appendix. Published in January 1991. The Plan went to Public Inquiry following deposit stage on 31st March 1991.
Borough of Newcastle-Under-Lyme	Newcastle-under-Lyme Lyme Development (Local) Plan is expected to be deposited during the autumn of 1992.
Staffordshire Moorlands District	Biddulph Local Plan.
Borough of Stafford	Stafford Borough Local Plan 2001 (draft).

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 views of various statutory consultees, and may also seek the view 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 subject to stated conditions aimed at controlling the way in which the proposed development 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 the specific issues relevant to the study area, are listed below:

DOE Circulars:
36/78 Trees and forestry.
16/87 Development involving agricultural land.
21/87 Development of contaminated land.
27/87 Nature Conservation.
15/88 Environmental assessment.
17/89 Landfill sites : development control.

Planning Policy Guidance Notes:
1. General policy and principles (March 1992).
2. Green Belts (1988).
3. Land for housing (March 1992).
4. Industrial and commercial development and small firms (1988).
12. Development plans and Regional Planning Guidance (1992).
14. Development on unstable land (1990).

Mineral Planning Guidance Notes:
1. General considerations and the development plan system (1988).
2. Applications, permissions and conditions (1988).
3. Opencast coal mining (1988).
4. The review of mineral working sites (1988).
5. Minerals planning and the general development order (1988).
6. Guidelines for aggregate 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.)

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 materials. Implementation of development and the resulting land uses may have adverse effects on 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 on the characteristics of an area required by:
- — the local planning authority for formulation of planning policies 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 consultants, 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.

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

The West Midlands Regional Forum of Local Authorities issued a public consultation document (1991) as the first step towards the preparation of planning guidance for the region. This identified strategic planning issues for the region as a whole, including those which are covered by policies in the Staffordshire County Structure Plan. Some of these are relevant to the study area and themes covered by this report:

a) providing housing requirements and improving the housing stock;
b) securing sufficient land for industry and commerce;
c) reclamation and reuse of derelict and vacant land, and improvement of the urban environment;
d) protection for the green belt around the North Staffordshire Conurbation and other environmentally sensitive areas;
e) widening and diversification of the rural economy to offset a decline in the agricultural sector;
f) protection of the best and most versatile agricultural land;
g) providing additional facilities for tourism whilst safeguarding the environment; and
h) making provision for supply of minerals and for disposal of waste.

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 conservation 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 planning issues for which geological information is required

The following sections review briefly some of the key planning issues in terms of the need for geological information.

HOUSING, CONSTRUCTION AND INFRASTRUCTURE

The Regional Forum identified that a significant proportion of the existing housing stock in the North Staffordshire Conurbation is in need of attention and is continuing to deteriorate. Provision of new housing is mainly directed towards existing towns since sites outside the conurbation are in environmentally important green belt land and, in some cases, land of high agricultural quality.

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 needs to proceed on a rational basis whether at the level appropriate to Local 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 improvement of the urban fabric requires maintenance and updating of the infrastructure. The initial selection of road lines, for example, take 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 Stoke-on-Trent contained some 245 hectares of derelict land, over 50 per cent of which related to past mineral extraction (Table 1). The reclamation of such land can contribute to meeting the need for development without taking new greenfield sites.

A major part of the present study area is within an Assisted Area. This qualifies relevant local authorities for 100 per cent grant, and other bodies for 80 per cent grant in respect of schemes approved by the Department of the Environment. Stoke-on-Trent was one of the first authorities to place strong emphasis on land reclamation and much as been achieved over the last 20 years. Over 286 hectares of land were reclaimed in Stoke-on-Trent between April 1982 and March 1988 (Table 2).

Table 1 Amount of derelict land justifying reclamation at 1 April 1988, by type, in Stoke-on-Trent and Newcastle-under-Lyme (hectares).

	Stoke-on-Trent	Newcastle-under-Lyme
Colliery spoil heaps	30	57
Other spoil heaps	92	—
Excavations and pits	10	6
Derelict railway land	18	18
Mining subsidence	18	—
General industrial dereliction	68	9
Other dereliction	9	8
TOTAL	245	98

Source: DOE, 1991b

Table 2 Amounts of derelict land reclaimed between April 1982 and March 1988 in Stoke-on-Trent and Newcastle-under-Lyme (hectares).

	Stoke-on-Trent	Newcastle-under-Lyme
Colliery spoil heaps	61	78
Other spoil heaps	—	—
Excavations and pits	26	17
Derelict railway land	28	2
General industrial dereliction	144	2
Mining subsidence	6	—
Other forms of dereliction	21	50
TOTAL	286	149

Source: DOE, 1991b.

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 identification 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.

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 the design of reclamation schemes takes account of all relevant factors.

The reclamation of derelict land has the 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 opportunities for recreation and improvements to the quality of life.

TOURISM AND EDUCATION

North Staffordshire has a rich industrial archaeology and vernacular architecture heritage. The area is noteworthy for its museums, of which a number are dedicated to the history and ware of the Potteries. The Etruria Industrial Museum, for example, is Britain's sole surviving example of a steam-powered Potters Mill. The Coal Industry is also represented, in the form of Britain's first underground mining museum, the Chatterley Whitfield Mining Museum.

The canals which were once used to transport the coal and china ware are still in use today, but now carry tourists on short trips. Similarly, the railways which superseded the waterways as the main transport routes are features in tourist attractions. The Foxfield Steam Railway includes a museum which houses preserved industrial locomotives and artifacts from the age of steam.

In addition, the area has three Sites of Special Scientific Interest designated to maintain their availability for research and, in some cases, educational purposes. 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 pipes and tiles. Minerals can only be extracted from geological sources of the right compositions, so that 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.

In urbanised parts of the study area a major proportion of the remaining mineral resources has already been exploited or sterilised. Those which remain 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. However, extensive mineral resources remain in surrounding countryside 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. 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.

The Staffordshire County Structure Plan recognises the need to secure sources of supply and takes account of Minerals Planning Guidance issued by the Department of the Environment. The County Council also takes note of the deliberations of the West Midlands Regional Aggregates Working Party, a joint local authority–industry–central government committee which considers supply and demand issues for minerals such as sand and gravel and crushed rock. Such consideration requires information on the extent of mineral resources.

WATER RESOURCES

Water resources occur both at the ground surface and within the ground. Surface water is confined to a few minor lakes such as Westport lake and to the rivers and canals of the area, such as Lyme Brook, the River Trent and the Trent and Mersey Canal. However, there are sources of groundwater, principally within the Sherwood Sandstone, which are extracted from wells. Such development has taken place at Meir, Sheepwash and Wallmires with the water being fed into Stoke-on-Trent.

Groundwater accumulates in pores, cracks and cavities in rocks over a long period of time. If depleted by extensive 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 (Plate 3). 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

Plate 3 Ceramic tip, Middleport

Tip, containing much kiln furniture ware. Viewed from the north-west [860 499].

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.

RURAL LAND USE

Parts of the study area consist of farmland. This includes some of the best and most versatile agricultural land which it is national policy to safeguard from other land uses. Much of the remaining agricultural land is within green belt and receives the protection which that designation affords. However, a decline in farming over the last decade or so has led to the concept of diversification of rural land uses such as putting more land to forestry or setting land aside for conservation.

Such alternative land uses are strongly influenced by the nature of the soil and the availability of water, both of which are related to the geological ground conditions. These factors are taken into account in the classification of agricultural land used by the Soil Survey and Land Research Centre and taken as a basis for implementation of policy by the Ministry of Agriculture, Fisheries and Food.

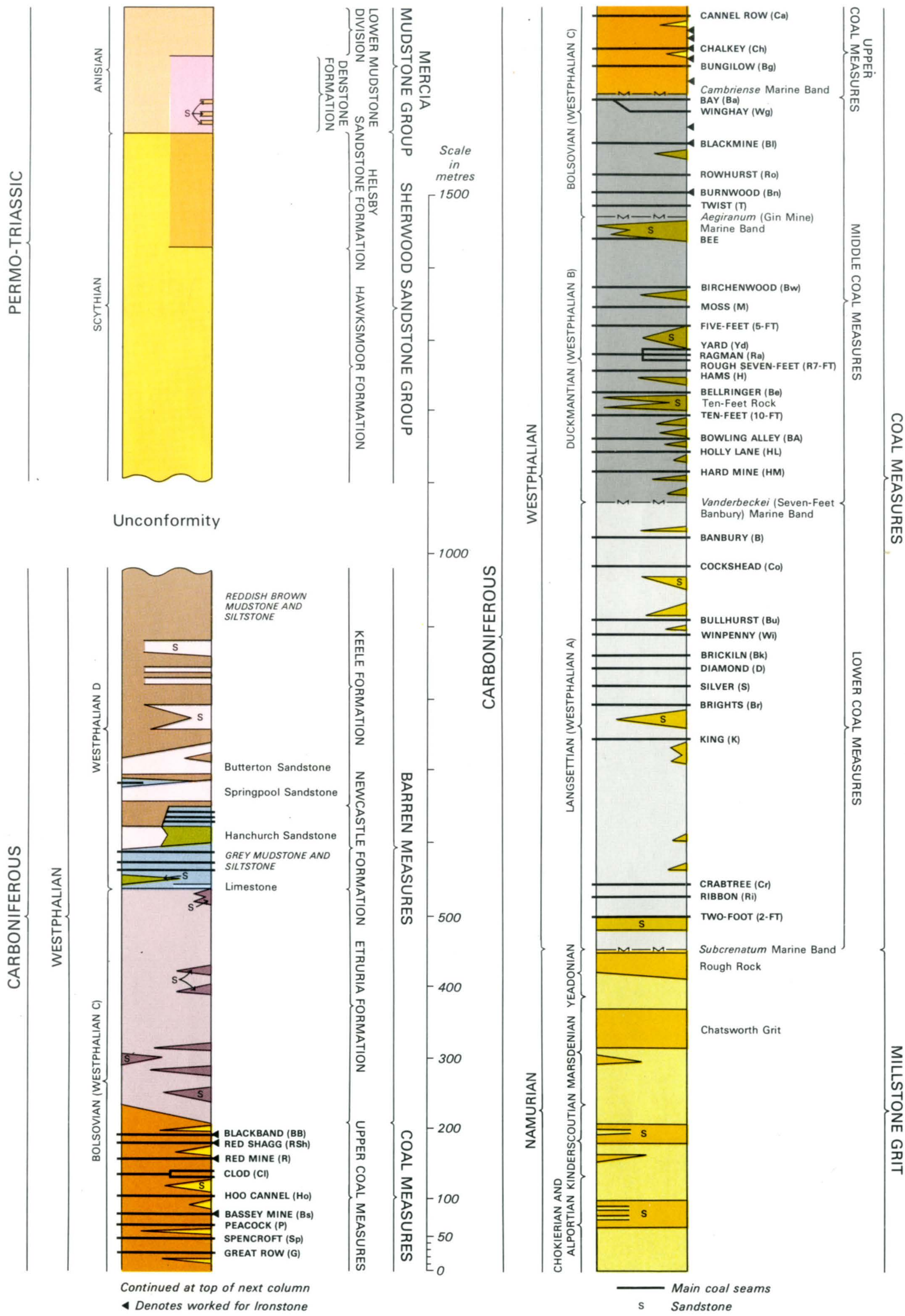
The results of the present study give a general indication, for example, of areas underlain by deposits such as sand and gravel, which may be well drained, or by clays which may have poor drainage characteristics. Such properties influence the types of plants which the land can best support and the susceptibility of soils to erosion.

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 improvement of the urban landscape, safeguarding of water resources, conservation of the natural environment and diversification of rural land use, 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.

Figure 3 Generalised vertical sections of bedrock formations


PERMO-TRIASSIC
ANISIAN
SCYTHIAN
MERCIA MUDSTONE GROUP
LOWER MUDSTONE DIVISION
DENSTONE FORMATION
SHERWOOD SANDSTONE GROUP
HELSBY SANDSTONE FORMATION
HAWKSMOOR FORMATION
Scale in metres
1500
1000
500
400
300
200
100
50
0
Unconformity
CARBONIFEROUS
WESTPHALIAN
WESTPHALIAN D
BOLSOVIAN (WESTPHALIAN C)
REDDISH BROWN MUDSTONE AND SILTSTONE
Butterton Sandstone
Springpool Sandstone
Hanchurch Sandstone
GREY MUDSTONE AND SILTSTONE
Limestone
KEELE FORMATION
NEWCASTLE FORMATION
ETRURIA FORMATION
BARREN MEASURES
UPPER COAL MEASURES
COAL MEASURES
BLACKBAND (BB)
RED SHAGG (RSh)
RED MINE (R)
CLOD (Cl)
HOO CANNEL (Ho)
BASSEY MINE (Bs)
PEACOCK (P)
SPENCROFT (Sp)
GREAT ROW (G)
Continued at top of next column
◄ Denotes worked for Ironstone
CARBONIFEROUS
WESTPHALIAN
NAMURIAN
BOLSOVIAN (WESTPHALIAN C)
DUCKMANTIAN (WESTPHALIAN B)
LANGSETTIAN (WESTPHALIAN A)
YEADONIAN
MARSDENIAN
KINDERSCOUTIAN
CHOKIERIAN AND ALPORTIAN
CANNEL ROW (Ca)
CHALKEY (Ch)
BUNGILOW (Bg)
Cambriense Marine Band
BAY (Ba)
WINGHAY (Wg)
BLACKMINE (Bl)
ROWHURST (Ro)
BURNWOOD (Bn)
TWIST (T)
Aegiranum (Gin Mine) Marine Band
BEE
BIRCHENWOOD (Bw)
MOSS (M)
FIVE-FEET (5-FT)
YARD (Yd)
RAGMAN (Ra)
ROUGH SEVEN-FEET (R7-FT)
HAMS (H)
BELLRINGER (Be)
Ten-Feet Rock
TEN-FEET (10-FT)
BOWLING ALLEY (BA)
HOLLY LANE (HL)
HARD MINE (HM)
Vanderbeckei (Seven-Feet Banbury) Marine Band
BANBURY (B)
COCKSHEAD (Co)
BULLHURST (Bu)
WINPENNY (Wi)
BRICKILN (Bk)
DIAMOND (D)
SILVER (S)
BRIGHTS (Br)
KING (K)
CRABTREE (Cr)
RIBBON (Ri)
TWO-FOOT (2-FT)
Subcrenatum Marine Band
Rough Rock
Chatsworth Grit
UPPER COAL MEASURES
MIDDLE COAL MEASURES
LOWER COAL MEASURES
COAL MEASURES
MILLSTONE GRIT
Main coal seams
S Sandstone

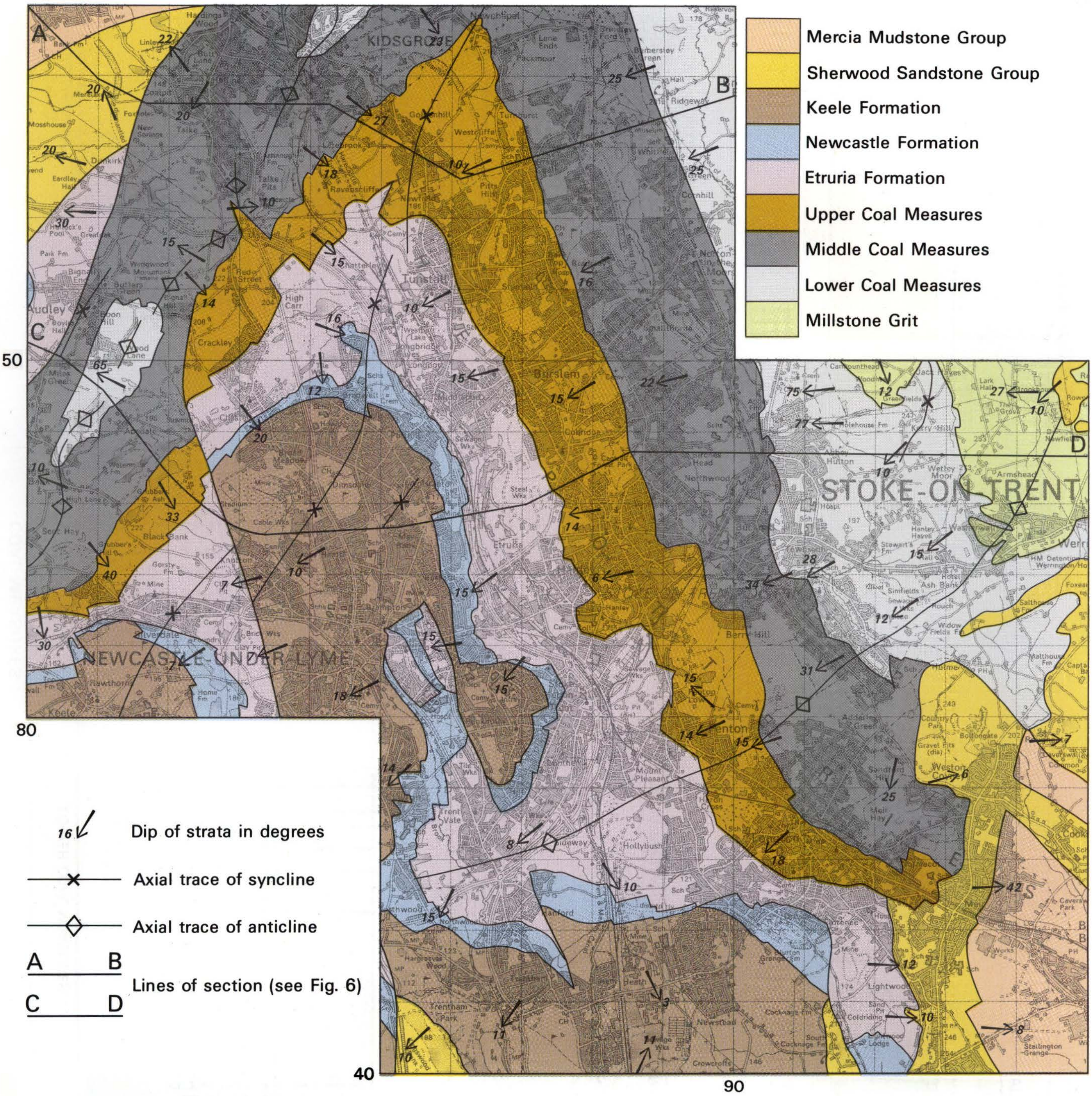


Figure 4 Simplified map of bedrock geology.

2.4 Geology

The bulk of the bedrock formations in the study area are water-laid deposits, sediments, of Carboniferous age, formed between 270 and 340 million years ago. These are overlain by patches of younger Permo-Triassic sediments, some 240 to 220 million years old.

The earliest formation known in the area is the debris of an ancient volcano, penetrated in Apedale No. 2 Borehole in the west of the area. Overlying this, and also of Carboniferous age, are mudstones and sandstones of the Millstone Grit (Figure 3). The coarser sandstone units were originally laid down in a river delta, and now form hard rocky ridges which swing round the nose of an upfold (anticline) in the east, near Werrington.

The overlying beds, also of Carboniferous age, consist of grey Coal Measures containing workable coals, overlain by dominantly red beds generally lacking coal seams of useful thickness. They make up one of the thickest sequences of these beds in the country.

The Coal Measures consist chiefly of grey mudstones and siltstones with some sandstones. There are numerous

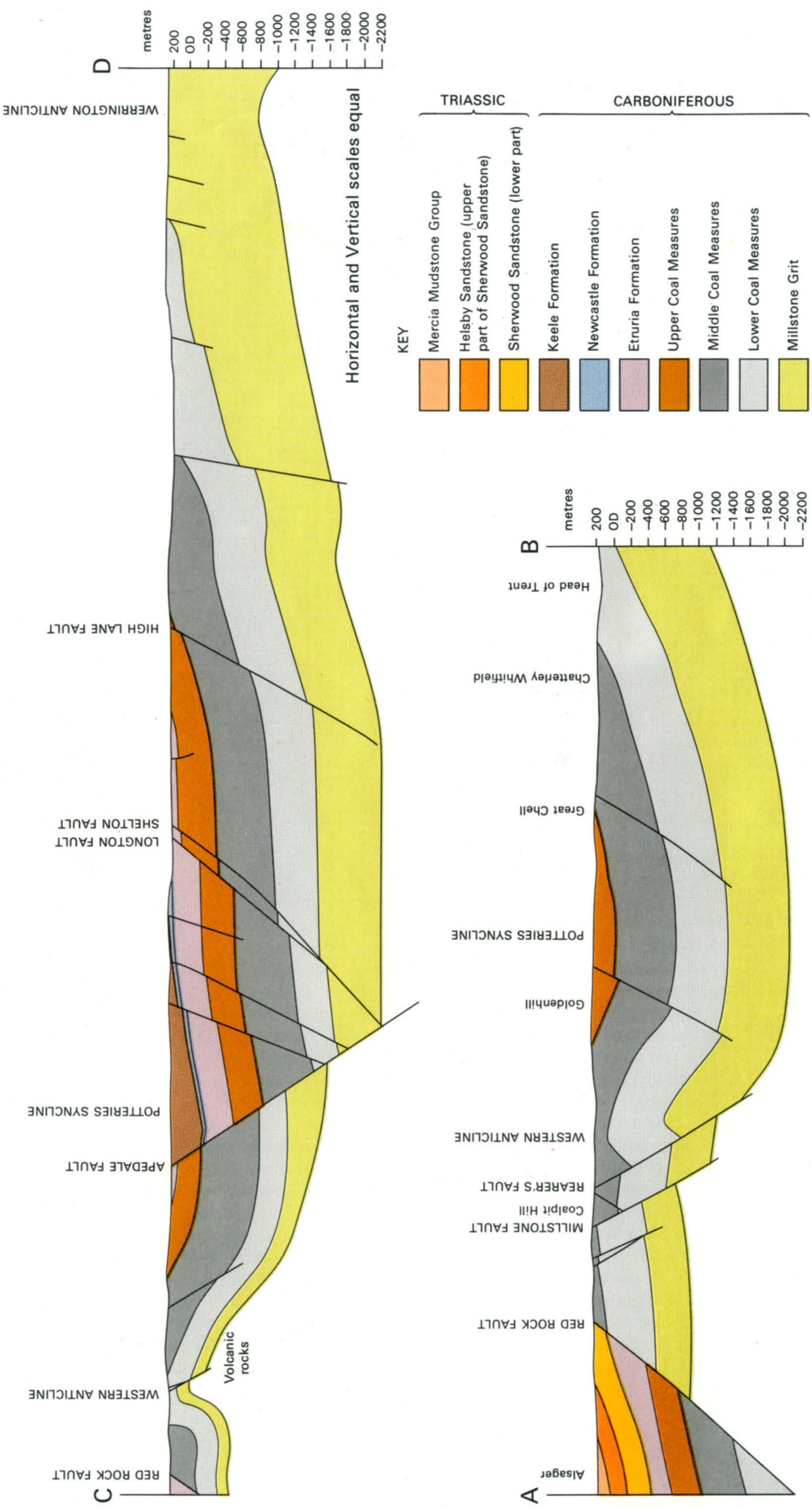


Figure 5 Cross-sections to show geological structure. For lines of section see Figure 4.

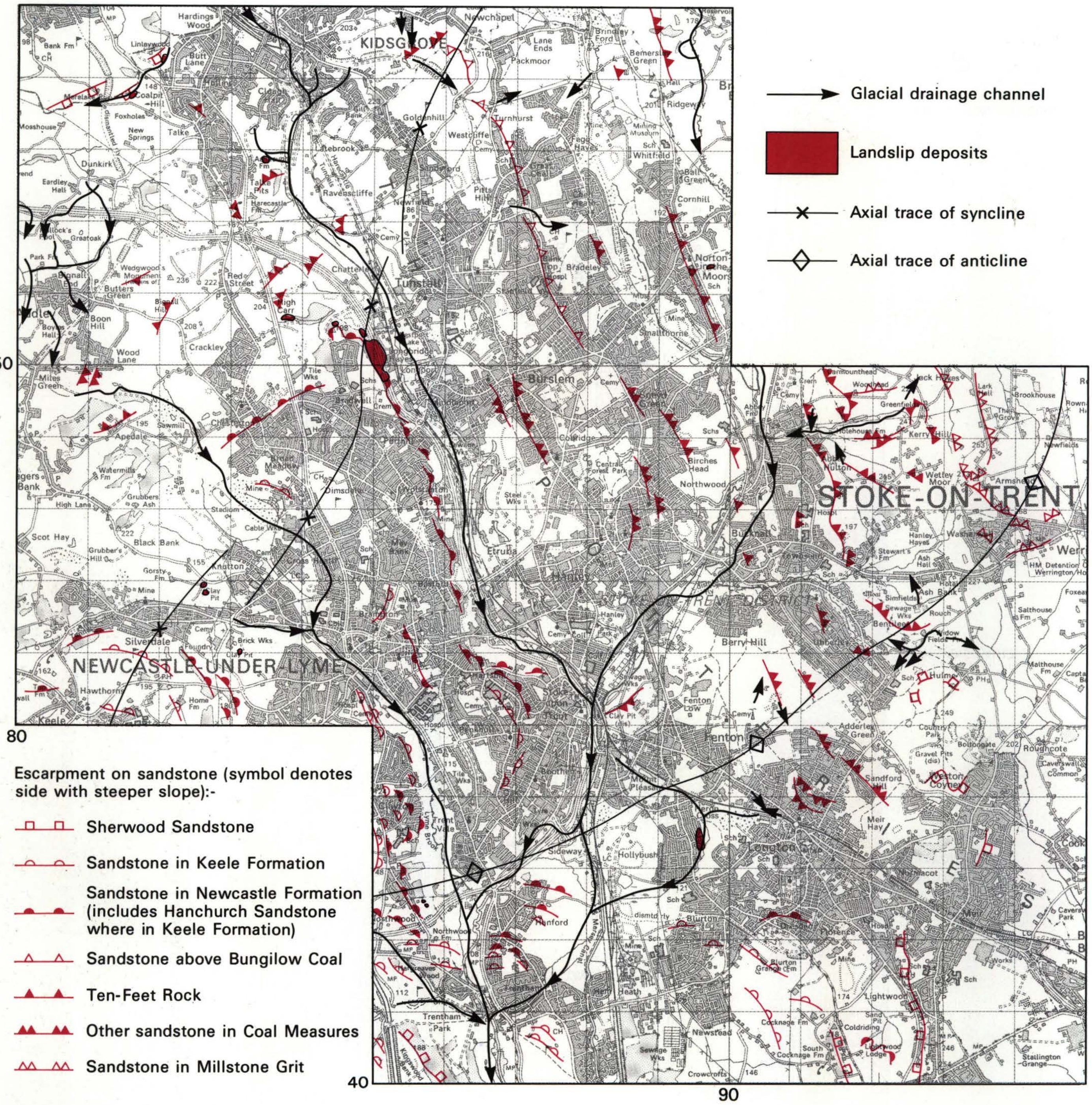


Figure 6 Main landforms in the study area.

old soil horizons called seatearths. Commonly these are overlain by coal, the compressed debris of old forests. These rocks were deposited in swampy conditions in which ironstones also formed, particularly in the higher beds. The coal seams vary in thickness from 1 cm to 3.5 m and all the workable ones have names, some of which reflect their prevailing thickness (e.g. Ten-Feet Coal).

The Coal Measures sequence has been divided up by geologists using intervals when the sea flowed in across the swampy Carboniferous lowland and extended continuously as far east as the Donbass, close to the Ural Mountains. Mudstones rich in the shelly animal life of these ancient seabeds define the junctions between the Lower, Middle and Upper divisions (Figure 3). In one part of the sequence within the Middle Coal Measures there are several other marine bands and in consequence few coals. The roof mudstones above a large number of coal seams contain fossilised freshwater mussel shells which lived in lakes within the swampy lowland.

Above the Burnwood Coal, thin layers of ironstone become a major feature of the sequence. There are two types, clayband and blackband. Workable clayband, a light

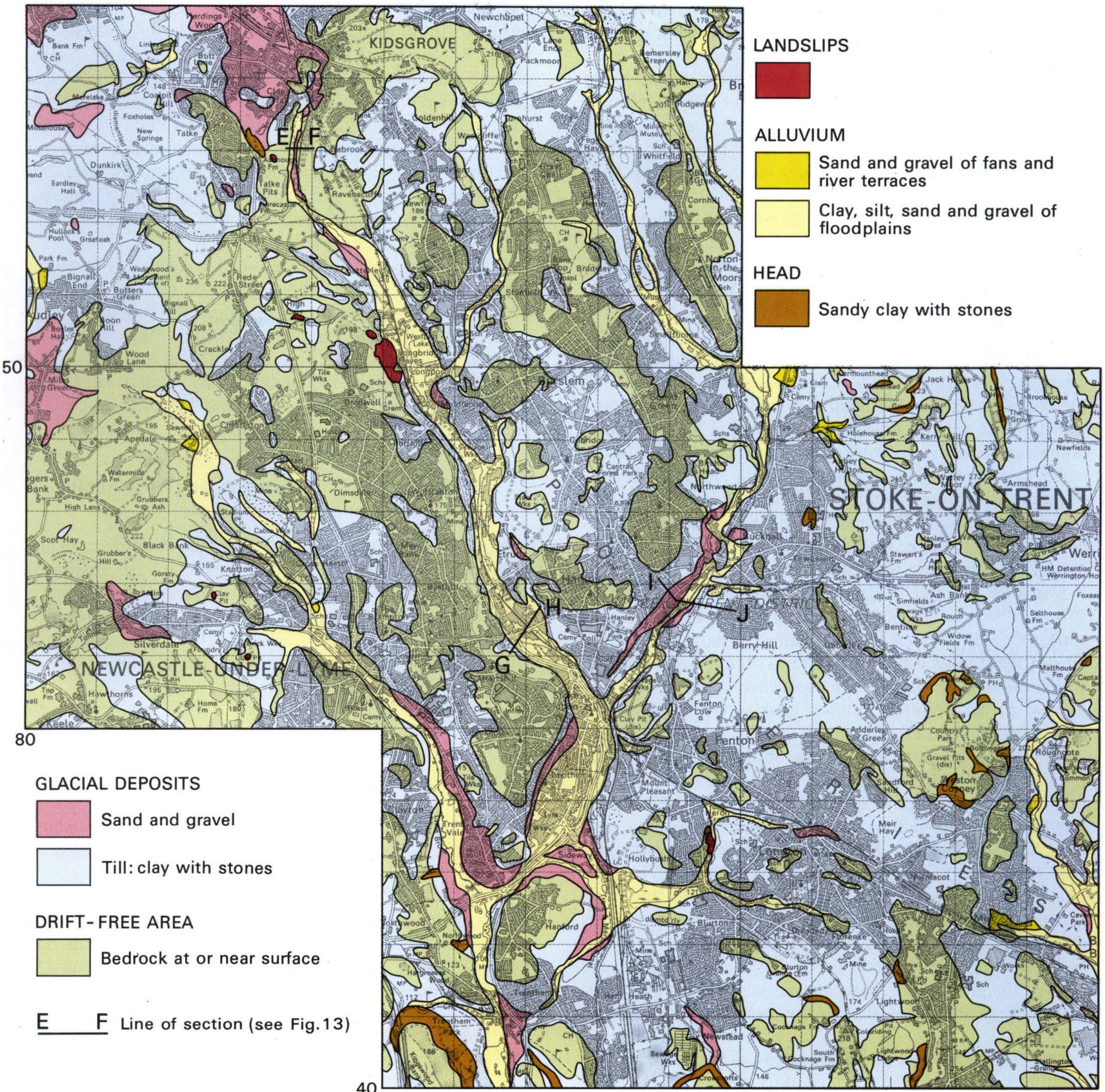


Figure 7 Distribution of superficial deposits and landslips. Made ground omitted.

coloured type of siderite (iron carbonate), occurs in the lower part of the Upper Coal Measures, between the Winghay and Cannel Row coals (Figure 3). Here the mudstones contain several thin coal seams commonly worked in conjunction with the overlying layers and nodules of clayband ironstone.

Higher up the sequence, from the Bassey Mine up to the Blackband Coal, the coals tend to be overlain by darker, carbonaceous ironstones of the blackband type. These are thought to have formed under boggy conditions, rather like modern bog iron ores (Boardman,1989). Lower in the sequence the Burnwood Ironstone is of semi-blackband type, intermediate between clayband and blackband.

Some 20 m above the Blackband Coal there is a dramatic change from grey beds with scattered red beds upwards into soft variously coloured mudstones with many red beds, the Etruria Formation (Figure 3). These beds were laid down on a well drained alluvial plain where thick soils formed from time to time (Besly, 1988). These old soils are usually variegated in shades of green, purple, yellowish brown and grey, whilst intervening mudstones are commonly reddish brown. Former river channels filled with greenish grey sandstone occur sporadically, with more persistent sandstones present generally towards the base of the sequence and also in the middle beds locally, south of Fenton. The Etruria Formation is mostly soft and tends to form valleys, with steep slopes leading up to the escarpment formed by the overlying Newcastle Formation.

The Newcastle Formation marks a return to the more waterlogged depositional conditions of the Coal Measures alluvial plains, and grey beds predominate over red. Close to the base of the formation are one or two impersistent limestones laid down in freshwater lakes. Overlying beds consist of greenish grey mudstones and siltstones with two groups, each of four or five coal seams, almost everywhere too thin to work. Grey sandstone beds, chiefly near the base and in the middle of the sequence, form strong ridges overlooking slopes in the underlying soft Etruria Formation mudstones.

The overlying Keele Formation consists of dominantly reddish brown mudstones and siltstones with purplish grey sandstones (Figure 3). These deposits, like those of the Etruria Formation, are thought to have been laid down on a well drained alluvial plain. The base of the Keele Formation is defined by the lowest occurrence of purple sandstone. Locally the sandstone in the middle of the Newcastle Formation changes laterally from grey to purple, as for instance near Chesterton and Keele village. In such places the Keele Formation includes beds which are elsewhere part of the Newcastle Formation.

Towards the end of Carboniferous times a period of strong earth movements threw the rock formations into a series of folds, dislocated by fractures or faults (Figure 5). One of these folds was the Potteries Syncline (downfold) in which the thick Coal Measures sequence is preserved (Figures 4, 5). In Permian times a land surface was eroded across the folded rock formations.

In Triassic times the climate was more arid, but seasonal rivers drained northwards from an upland area, near the site of present-day Brittany. The sandstones of the Sherwood Sandstone Group include probable wind blown beds near their base, followed by 300 m of reddish brown sandstones with layers of pebbles (Hawksmoor Formation). The pebbles and cobbles are chiefly tough quartzite and vein quartz, set in a sand matrix, laid down by braided rivers (Steel and Thompson, 1983). Nowadays these are resistant beds forming uplands trenched by dry valleys. The highest beds of the Sherwood Sandstone are only seen in the north-west. These comprise the Helsby Sandstone, 140 m in thickness.

Overlying the Sherwood Sandstone are mudstones and siltstones of the Mercia Mudstone Group, the youngest bedrock formations in the area, laid down in arid conditions. In the east they include siltstones, mudstones and sandstones of the Denstone Formation.

Throughout Triassic times earth movements tended to stretch the area whilst the split was forming at the site of the present Atlantic Ocean. This led to further faulting and some folding, culminating in the Kimmerian earth movements near the close of Jurassic times, 145 million years ago.

Then followed a long interval for which no record is preserved, before the start of the ice ages. The latest, or Devensian, glaciation has left the clearest traces. About 30 000 years ago the area was deeply covered by ice. Clay and stones were transported within and underneath the moving ice, even bringing in far travelled blocks from the Lake District. This deposit is till, or boulder clay, which forms a shroud over the bedrock formations, especially in the north-west where the ice was thickest (Figure 7). As the climate ameliorated about 15 000 years ago, meltwater flowed down crevasses in or beneath the ice and laid down patches of sand at Kidsgrove and Halmer End. The escaping waters dug trenches across the upland divide between the Mersey and Trent catchment, leaving the present-day wind gaps at Apedale and Bath Pool, Kidsgrove (Figure 6). These channels became partially filled with the sands and gravels from the melting ice.

After the end of the Devensian ice age the vegetation cover slowly returned. The blanket of boulder clay has been reduced by stream erosion and the topographic features formed by the bedrock formations have gradually become re-emphasised (Figure 6). The rivers laid down alluvial silts on their floodplains. Many modern landscape details in this area have been added by human activity, notably those related to the extractive minerals industry.

2.5 Geological factors relevant to land use planning, development and conservation

The pattern of present-day land use in the Potteries area has been determined to an unusual degree by the historical development of certain extractive industries which have their root in geology. Some of these ventures are long since defunct, but their legacy lives on. The main categories which ought to be considered in land use planning individually are as follows:

Mining industry

The Potteries coalfield has 60 recorded separate mined horizons, 52 being for coal and eight exclusively for ironstone.

The impact of mining, an industry of very long standing, on land use is best considered under two main headings:

Creation of voids

Many of the earliest workings were in former green field areas now within urban Hanley, Burslem, Tunstall and Longton, where numerous coal seams inclined at about 15° come to outcrop. There were surface diggings, small quarries, bell-shaped excavations (termed bell pits), shallow inclined tunnels (adits or footrails) and shallow shafts. Most of the underground workings were of the pillar and stall pattern, where pillars of coal were left as the roof support. The others were bell pits which comprised restricted unsupported excavations at the base of a shallow shaft (Plate 7). Most of these workings predate the times when mine plans were commonly made or kept. Buildings, particularly large, heavy structures, are at risk from voids, from badly compacted old fill and most particularly from the possible collapse of coal pillars and roof measures in shallow abandoned pillar and stall workings. In the light of such risks in recent years numerous site investigation boreholes have been sunk in the areas affected. With the aid of these boreholes the geological map has been considerably refined to define outcrops of the potentially most dangerous seams such as the heavily mined Great Row Coal. It is still essential, however, to sink boreholes, with the guidance of mining or foundation engineers, to test for seam levels and voids in advance of construction work. Measures to deal with old mine workings are discussed at length in a report by Healy and Head (1984).

Deep mining has caused considerable subsidence in the past, but this type of working has now largely moved outside the study area into mostly rural terrain. Subsidence due to current mining activities is therefore likely to be concentrated in a few localities in the south.

In the western part of the area several small footrails (adits) are currently working at depths of less than 150 m. These are in rural terrain with stringent controls to prevent undermining of villages. Workings are by pillar and stall, with stipulations on the dimensions of the pillars of support. Probably the commonest type of collapse in old footrails is failure of the tunnel supports close to surface, following abandonment.

Opencast mining has been carried out for almost 50 years, notably in the dominantly rural western area, where the seams dip steeply, commonly at about 35° from the horizontal. These have been worked at most levels in the Coal Measures sequence, though usually excepting beds between the top of the Moss Coal up to the Twist Coal, where coals are generally thin. Much of the recent activity has been in areas of poor agricultural land strewn with abandoned shafts, footrail mouths and old tips (e.g. High Lane and Red Street Opencast sites). On restoration such areas will be landscaped and used for amenity areas, housing and light industry. The High Lane Opencast site is unusual in that it is a deeper development on the site of previous smaller opencast workings, long since infilled.

The Stoke-on-Trent conurbation contains some 8000 shafts known to British Coal. Many of these are very old, with no record of their precise depth. It is essential when planning any development in the coalfield area to check the detailed position of known shafts from the British Coal database at Gadbrook Park, Northwich. Unrecorded shafts may also be present. Though many have been capped or filled, shafts pose a great danger to developers. The treatment of disused mine openings is dealt with in a report by Freeman Fox Ltd (1988).

Creation of colliery spoil tips

A constant feature of mining activity from the earliest days has been the creation of surface tips of spoil or minestone, consisting mostly of mudstone with lesser amounts of siltstone, sandstone, ironstone and coal (Figure 17). The coal content of the minestone is large enough in some cases to warrant testing of tips by boreholes with a view to extracting the coal. The Whitehill spoil mound at Birchenwood Colliery was washed to recover low grade coal in 1983–85, prior to a reclamation scheme for the area.

The content of coal within the minestone has apparently been in some cases high enough to lead to spontaneous combustion. For example, the large Parkhouse tip was on fire in 1961. Inspection of several old colliery tips shows belts of red material within them, and it is evident that they have been burnt in this way. In places there are excavations in the burnt, ashy portions of these tips, where ash has been removed for ballast. The tendency for tips of minestone to catch fire may present problems during development because the disturbance may allow air to reach combustible material previously isolated within the tip.

Most of the tipped areas have been left as open land, and in recent years there has been a move to landscape several of the most prominent tips. The Central Forest Park, planted in grasses and trees, includes the huge conical tip of the Deep Pit (Plate 2). After the tip at Birchenwood had been washed for coal the area was landscaped as an amenity area and industrial estate. Since the tip-fire in 1961, the Parkhouse tip has been bulldozed into a nearby quarry and partly spread widely onto the flank of a nearby valley to form the foundation of part of a new industrial estate. At Silverdale part of the tip complex has been landscaped and forms farmland pasture. Other tips, such as those in the valley below Apedale, are colonised by dwarf birch and are beautiful places, not in need of landscaping.

Iron industry

The 19th century saw the rapid growth of a major iron industry based on the blast furnace. The tip heaps of furnace slag, in places mixed with ash, are a valuable source of hard core and have been extensively worked at Apedale where a large slag tip [826 488] has been reduced to a small fraction of its original size during the last 30 years. The largest tips of slag are at Shelton Steelworks, the longest running iron and steel venture in the area (1839–1978).

Brick and tile industry

Next to mining, the quarrying of mudstone for the brick and tile industry, a two hundred year old activity, has left the greatest mark on the area. The impact on land use has three main aspects:

Resources

Considerable reserves of mudstone still exist in the Etruria Formation (Figure 17). As they are the prime source of clay for the brick industry it is important that they are not unwittingly overbuilt. This matter is dealt with in more detail in Chapter 3.

Infilled quarries

A large number of old quarries have been dug over a 200 year period in both the Etruria Formation and the underlying Coal Measures. Using archive maps at Staffordshire County Council Record Office and at the British Geological Survey, an attempt has been made to reconstruct the approximate outlines of the old quarries. Also, where the quarry outlines can still be discerned they have been mapped in on the ground, in the course of the 1988–89 geological survey.

The most common type of fill is waste from the clay industry itself, namely till stripped off the surface of the site, unwanted mudstone, siltstone and sandstone, and faulty tiles, bricks and ash (Plate 3). Other quarries have been used for disposal of domestic and industrial waste. Some of the infilled quarries contain as much as 20 and even 30 m of this man-made deposit. The difference in compressibility between fill and the original country rock round its edges can cause problems where structures bridge the former quarry edge.

Facilities for waste disposal

Quarry sites in the Etruria Formation in particular appear to present an attractive place for disposal of domestic and industrial waste. The bedrock is generally an impermeable mudstone with few persistent permeable sandstone beds which could provide an escape route for gases and/or leachate. Examples of quarries formerly used for domestic waste are at Blurton [889 423], Crackley [834 499] and Apedale Road, Chesterton [828 493]. The third site is giving some leachate problems, an indication that sites in Etruria Formation are not necessarily impervious to fluid flow.

The former quarry of the Metallic Tilery Company [841 498] near Chesterton was a 30 m deep excavation in mudstones of the Etruria Formation, lacking significant sandstones. During the period 1972–84 this large oval hollow was used as a disposal site by Redland Purle and Cleanaway. The site was licensed to take 4 million gallons per annum of liquid waste as well as a variety of solid waste. The substances disposed of included a variety of inorganic and organic chemicals, paints, dyes, oils, biological waste etc. The site has been capped, but there is migration of leachate toward the site boundary. The leachate is contained in a pond from whence it is drained off from time to time (see p.45).

3 RESOURCES FOR DEVELOPMENT

3.1 General

The area has been rich in mineral resources, notably coal, ironstone and clays for brick and tiles. Inevitably the long history of mining and quarrying has greatly depleted these resources, which in some instances merit protection from overbuilding. Dumps of slag and minestone are a possible resource of hardcore and coal, respectively (Figure 17). The Sherwood Sandstone aquifer is mostly outside the area, but provides a useful public supply and there are limited untapped resources in the northwest. The following sections cover the past, present and likely future situation in respect of the main resources.

3.2 Coal

GENERAL

The Potteries coalfield contains an unusually thick coal-bearing sequence, with 52 separate seams on the mining plans (Figure 3). Because the downfold is so deep and the seams are so numerous the reserves have lasted a long time. The seams are inclined almost everywhere, usually at dips of 10°–40°. They are thus easily accessible from the surface but harder to work than in other coalfields where seams are almost flat.

Workings from the Middle Ages onwards were initially close to the surface by use of inclined tunnels (footrails), bell-shaped cavities termed bell pits, shallow, shafts and surface diggings. Shafts were sunk to ever increasing depths throughout the 19th century as ventilation improved. At the close of the 19th century coal was extracted from a shaft 823 m deep at Stafford Colliery. In old pillar and stall workings, pillars of coal have been left for roof support, generally on a rectangular pattern. These were largely superseded by the longwall system of mining in the early years of the 20th century. Since the Second World War virtually all mining has been mechanised, except in many of the small footrail mines.

As early as 1835 fifty collieries were operating in the area and there has been extensive activity during the last 150 years. Throughout the first 70 years of this century production ran at roughly 6 to 7 millions tons of coal per year.

The gradual exhaustion of reserves depleted the number of collieries at Vesting Day, 1947, to 17 (Figure 8). A number of these were nearing the end of their active life and now only two large colleries remain, namely Trentham and Silverdale. Resources of coal with a reasonably low sulphur and chlorine content exist in the present workings, and the product is the subject of close quality control.

Shallow 'footrail mines' accessed by inclined tunnels and operated by small teams of less than 30 men have been active for several decades. Almost all such mines have been in private ownership. Many of these have been in seams such as the Rowhurst and Winghay which have been less favoured by the old deep miners in the western ground. Newly enacted legislation allows for the employment of up to 150 men and women on such projects, but prospects for new small mines appear limited.

A limited amount of coal has been worked in crop workings and quarries for brick clay in the Burslem, Hanley and Longton areas for 200 years or more. Seams such as the Peacock and Bassey Mine have been extracted along with the mudstones and used to fire the kilns. Almost all these quarries are now backfilled.

There has been almost continuous opencast activity during the last 40 years, chiefly in the more rural west of the area. The workings have mostly been in steeply dipping seams and have in recent years become both larger and deeper, effecting economies in the extraction and processing of the coal (Plates 1, 4). Besides British Coal, there have been a few other operators exploring for and working small opencast sites in recent years.

Opencast coal is generally lower in chlorine content than deep mined coal, with which it is commonly mixed before transport to power stations, where a maximum 0.35% chlorine content is specified to protect the boiler tubes (Shryane and Price, 1991).

DEEP MINES

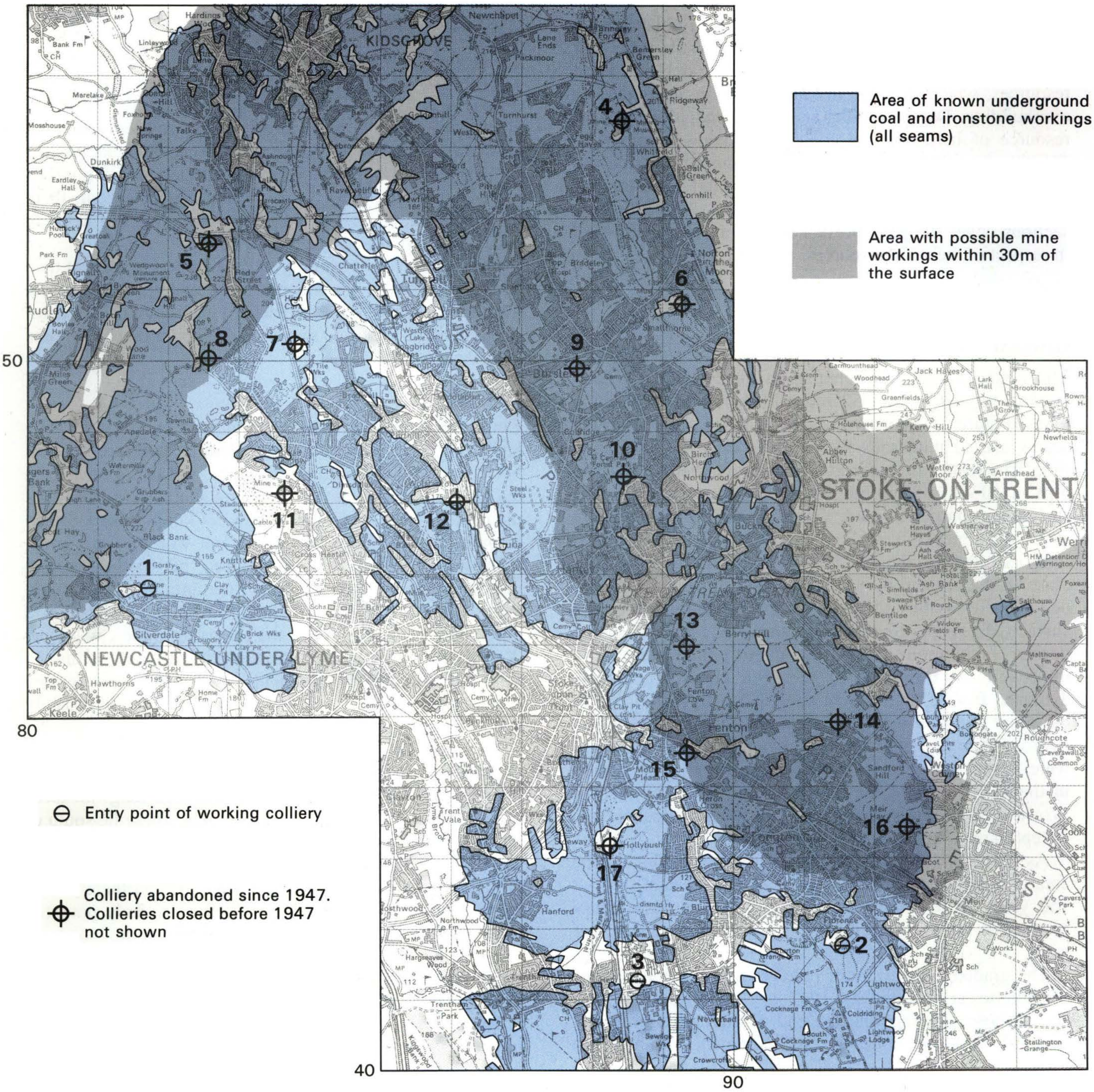
Currently there are two mines active in the area. The largest of these is the combined Hem Heath/Florence Colliery, now called Trentham Colliery, with an annual production of 2.5 million tons. Existing shafts have been supplemented by new inclined tunnels 2.7 km in length, driven from surface. The bulk of the current workings are in six seams just south of the project area, but in the medium term there is a likelihood of further mining in the study area south of the latitude of Hanford (Figure 17). There is a potential to work several of the seams from the Great Row downwards as far as the mine temperatures will permit. In the south-east this could potentially include seams as low in the sequence as the Bowling Alley Coal, or possibly deeper.

The new Silverdale Colliery is located in the old pit yard at Silverdale. Access to the new winnings is by three inclined tunnels 3.5 km long to mechanised longwall faces in the Cannel Row and Great Row coals. These lie south of the M6 motorway, well outside the present project area. Further resources lie beneath Keele in an area south of the Hollywood Fault (see Thematic Map 10), but there are no plans at present to work these. There is a likely potential for extending Silverdale Colliery workings in the long term into the Madeley area (south-west of the present area) where there has only been limited past working from the defunct Leycett Colliery.

Due to virtual exhaustion of reserves it is unlikely that a new deep mine (excepting footrails) will be opened in the area. Though Wolstanton had some reserves, the colliery was shut due to the complex geological structure, high mining costs and the necessity to maintain a pillar of support for the Stoke-on-Trent hospitals complex. Further working actually beneath the project area is likely to be chiefly in the Trentham Colliery take (Thematic Map No. 10). In addition there are reserves under Keele University and village.

SHALLOW UNDERGROUND WORKINGS

Eight footrails are in production in the area today, all of them situated in the west of the area, beneath farming land



1	Silverdale Adit	7	Parkhouse	13	Berryhill
2	Florence ⎤ Trentham	8	Glasshouse	14	Mossfield
3	Hem Heath ⎦	9	Sneyd	15	Glebe
4	Chatterley Whitfield	10	Deep Pit	16	Park Hall
5	Bignall Hill	11	Holditch	17	Stafford
6	Norton	12	Wolstanton		

Figure 8 Mining of coal and ironstone

Plate 4 High Lane Opencast Site

This view features the Spencroft Coal which is also visible on Plate 1. A prominent triple fault is evident. View looking east [821 481].

and woodland. These are pairs of inclined tunnels usually driven down the tilted coal seams. Workings are by the pillar and stall system and commonly within 150 m of the surface.

Footrails have been in a variety of seams, but in recent years most of the activity has been in the Winghay, Rowhurst, Spencroft and Great Row seams. The first two seams had long unworked sections of outcrop, but few unworked areas now remain. Some of the current activity is in fairly narrow zones between parallel or branching faults, but with worthwhile reserves of untouched coal. The workings of Parklands Colliery at Apedale in the Bullhurst and Cockshead coals are in this category.

The number of small mines has been considerably reduced since the peak production around 1956 (Jones 1969) and prospects for further mines are somewhat limited by the following factors: firstly there is a requirement to mine only under open country; secondly there has been much activity in the past, particularly in rural areas towards the west. The panels which remain are mostly narrow and close to faults; thirdly, much accessible coal has been removed by opencast operations.

Future small mine workings are likely to be in narrow segments close to faults. There is a possibility that there is sufficient unworked Bullhurst coal south of Werrington to support a small mine in open country.

Opencast coal

Currently one active site operated by Crouch Mining for British Coal Opencast is located wholly within the area. The High Lane Opencast site [820 480] is a fine example of a large modern opencast operation (Plates 1, 4) working coal at 22 horizons ranging from the Twist up to the Blackband Coal. The seams dip at 32° towards the south-east and are stripped off in a series of inclined planes which merge as work progresses to make a 120 m-deep excavation. The coal is taken to the treatment plant at Chatterley Valley Disposal Point. An interesting feature of the High Lane site is that it has been worked before, in 1950 and 1957. The present working is a larger and deeper development of earlier infilled opencast sites, and will take four more years to complete.

The southern fringe [866 584] of the extensive recently opened Brown Lees Opencast Site is located in the area.

Seams from the Twist up to the Blackmine coal are inclined at 11–19° towards the west and are relatively free of faults. A third site at Bates Wood, outside the western perimeter of the area, has very recently been restored for cultivation.

Inevitably in an area with so many tilted coal seams coming to crop there must be further possibilities for opencast. However, very extensive areas have been overbuilt, particularly in the east, or are too near houses, roads, railways and canal tunnels. In the west numerous footrails have reduced the quantity of accessible remaining coal, now reduced to pillars within the workings. Potential rural sites exist both in the west and in the east. Their viability is controlled by the ratio of coal to other measures, the presence of thick sandstones which might require blasting, the prevalence of old workings and the complexity of the fault pattern. In the western terrain nearest the Cheshire Plain the thickness of drift must locally be a deterrent, as is the likely ingress of water from sandy superficial deposits. Currently the Berryhill Site [905 455] is under consideration as a possible future opencast site. It contains seams from the Twist up to the Bassey Mine Coal and is largely free from faulting. Seams dip between 14–26° towards the west, providing a site which should be relatively easy to work.

Coal Measures between the Moss and Twist coals generally lack any persistent coal seams and are usually not a likely target for opencasting. Thus a strip covering these measures, which historically have not been worked for brick clay either, is excluded from the area of Coal Measures resources (Thematic Map 6 and Figure 9). Locally, However seams within this corridor are thick enough to be considered for opencast working.

Both the High Lane Opencast Site and the possible Berryhill Site have previous shallow, backfilled opencast workings. For the purposes of protecting any rural areas for possible future opencasting it should be borne in mind that the shallow old opencast strips are capable of being later subsumed into larger sites.

A number of smaller licensed opencast operations existed in the past, mainly in the west of the area, and there is some potential to continue this type of working. The top limit on tonnage from such sites has recently been increased by legislation from 25 000 to 250 000 tonnes. Such operations are best suited to areas where a large and hence potentially deep opencast is not possible due to the pattern of houses and roads.

3.3 Mudstone

General

The mudstones of the Coal Measures and Etruria Formation have long been a source of clay for the manufacture of bricks and tiles, fired by the local coals. As early as 1750 Tunstall was noted for these products and in 1850 Dobson described a prosperous industry (Celoria, 1971).

The tile industry has flourished at a number of sites, making roofing tiles, floor quarries and tubular drain tiles. The roofing tile industry reached its zenith in the 1930's when there were about a dozen active tileries. Nowadays demand is much reduced due to competition from cement tiles and only the Knutton tilery is active in the study area. The Etruria Formation provided much of the raw material. Perhaps the most famous tiles made primarily from this material were Herbert Minton's Encaustic Tiles, used to such decorative effect in the Palace of Westminster.

The brick industry was well established when Dobson wrote his Treatise in 1850 and is still very active, in some cases on the sites of former tilery workings. The area was already well known in 1850 for especially strong blue brick, fired from the Etruria Formation with extra fuel. Red bricks were also made.

Current production is chiefly in the hands of Steetley Building Products, with their main manufacturing facility at Parkhouse Industrial Estate, processing local Etruria Formation from four quarries in advanced tunnel kilns. Most of the brick production in the area is from the Etruria Formation, because it is easy to work, relatively homogenous and less variable in rock type than the Coal Measures.

The Coal Measures have been worked for bricks for at least two centuries. Beds between the Spencroft and Hoo Cannel coals have been extensively worked in a belt between Longton and Tunstall. Other workings were largely between the Twist and Bungilow coals; nowadays only one working quarry, Birchenwood, remains. Bricks are of excellent quality, but the variable rock type, including some useless ironstone layers, makes the beds more costly to utilise than the Etruria Formation.

Coal measures

At the time of the earlier geological survey in 1961 four quarries were open in the belt between Longton and Tunstall, working the beds between the Spencroft and Hoo Cannel coals. All are defunct and now mostly infilled. The beds included excellent brick making mudstones above the Peacock Coal, whilst the fireclay beneath was used for refractory saggars (containers for pottery ware being fired). Any remaining resources at this level in the sequence are overbuilt.

Also at the time of the 1961 survey, two large quarries were working beds from the Twist Coal almost up to the Bungilow Coal at Bank Top [875 513] and Birchenwood [852 541]. This latter quarry is still working. Local clay is here mixed with other similar clays brought in from Kingsley near Cheadle. The remaining resources at this level are chiefly in the possible future Berryhill Opencast Site [905 455] (Figure 17).

The best mudstone resources are in the west of the area, where they have scarcely been worked at all. One of the most favoured horizons, the mudstones above the Peacock Coal (formerly worked in the Tunstall area) are currently excavated at the High Lane opencast in the process of coal extraction, but are not commercially exploited. In some parts of the country, opencast extraction includes provision for stock to be set aside for brick clay. Government Guidance is that when considering proposals to work opencast coal, where coal seams are found in conjunction with brick clay resources, it is important that the opportunity to work these other minerals commercially is fully explored (DOE, 1988).

Mudstone in Etruria Formation

This is currently the favoured source of raw material for brick clay since it is soft and easy to work; it is also more homogenous than the Coal Measures. Sandstones within this sequence are not suited for brick making, and in several cases limit the depth of working quarries. The most abundant sandstones tend to be in the lower part of the formation, but are locally common in the middle beds south of Fenton. Small calcareous pellets or 'shot' frequently occur in the top 20 to 30 m of the Etruria Formation. During the firing of a brick these pellets are converted into lime, which hydrates on weathering, thus causing some bricks to flake.

The Etruria Formation has been divided into three parts in this report and on the maps (Figure 9 and Thematic Map 6) based on variations in rock character, as follows:-

Lower division This includes both greenish grey laminated mudstone and much reddish brown or variegated structureless mudstone (i.e. it lacks lamination). There are

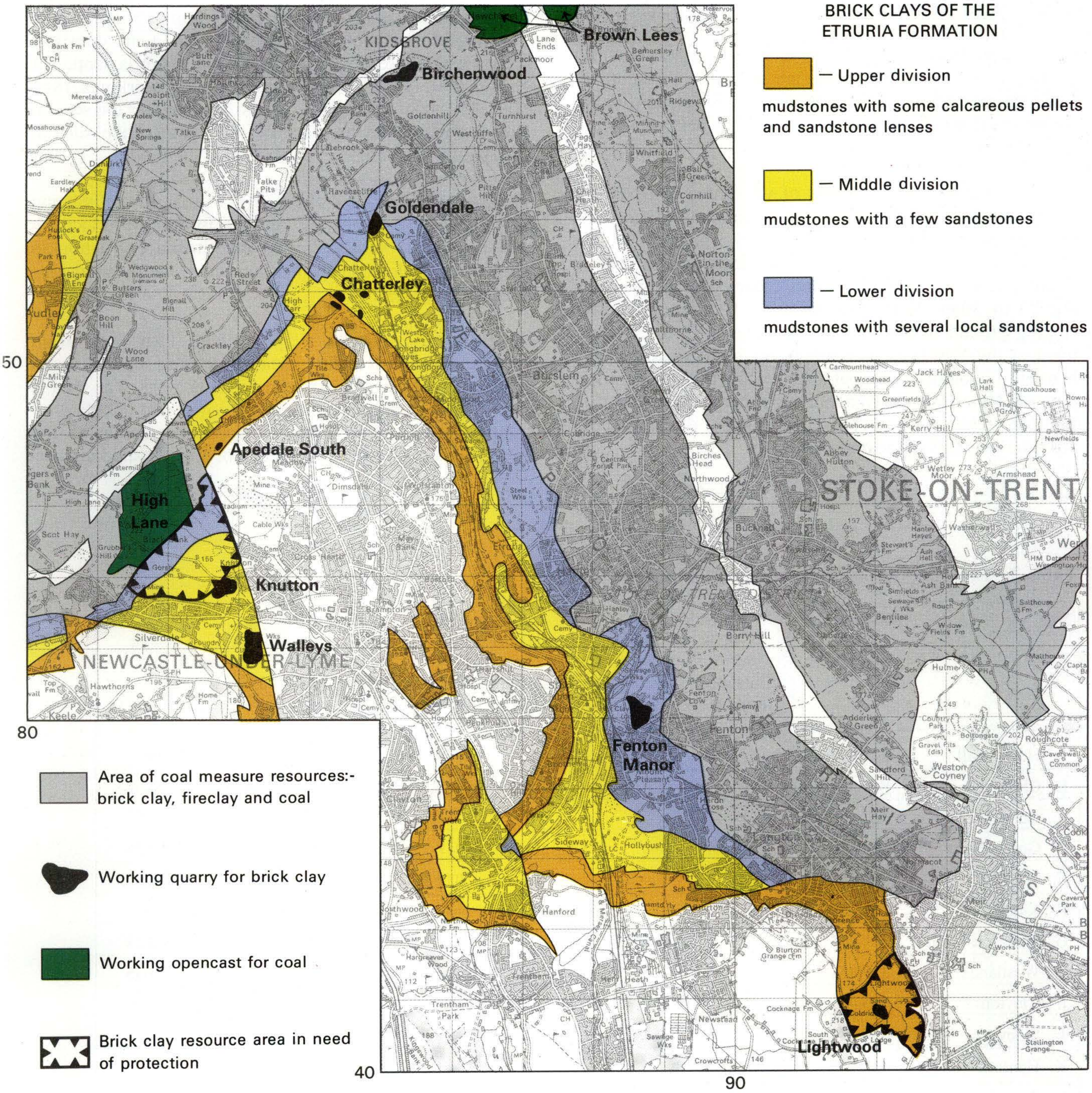


Figure 9 Surface resources in the Coal Measures and overlying Etruria Formation.

several old soil horizons overlain by carbonaceous beds or thin coal seams. The most persistent sandstones lie within this division, which totals 55–58 m in thickness and has thus far been only rarely worked for brick clays, with the notable exception of Fenton Manor Quarry [884 451]. This large quarry, now at the end of its active life, is in an area where sandstone bands in the lower division are thinnest and there are thick workable runs of mudstone.

Middle division This is the thickest subdivision of the Etruria Formation (105–167 m, thickening northwards) and consists of structureless mudstones of variegated colour, such as yellowish brown, greenish grey and purple, with runs of reddish brown mudstone. Sandstones are chiefly impersistent lenses except south of Fenton, where a number are locally persistent. There are numerous disused and working quarries in this division (see Surface Mineral Resources thematic map 6) notably in the Chesterton–Tunstall and Silverdale areas.

Upper division This consists of variegated and reddish brown mudstones in roughly equal amounts. Sandstone beds are generally rare and lens shaped. Thickness of the division varies from 78 to 115 m (maximum in the north). Small calcareous nodules or shot commonly occur in the top 20 to 30 m. Many quarries have been excavated in sloping ground in this division, leading up to the escarpment of the Newcastle Formation. Such quarries have the benefit of good drainage, but after a while the cost of stripping the Newcastle Formation overburden can become prohibitive. The most recent new quarry development, Apedale South, is in the upper division.

Remaining resources in Etruria Formation

The remaining brick clay resources of the area are limited by extensive old quarries, by overbuilding, and locally by drift over 4 m in thickness. The remaining resource blocks are considered in order from north to south (see Figure 17 and Table 3).

A. Holly Wall [849 519] This small site is already being worked by P Powell and is capable of some deepening, but little lateral extension.

B. Chatterley [845 507] All three divisions of the Etruria Formation are present in this area of complex shape (Table 3). Currently P Powell and J Kimberley and Sons are working on a small scale (Appendix II) and there is scope for considerable enlargement of one of the workings [844 509]. The main constraints on development are the several stream valleys, the presence of two conservation sites at Bradwell Wood, and the route of the A500 road.

C. Apedale South [827 488] This site is currently being developed as a quarry by Steetley Building Products. It includes the topmost 30 m of the Etruria Formation in which small calcareous pellets can occur, but the mudstone is of adequate quality.

D. Gorsty Farm [822 475] About 1 km^2 of terrain includes an area recently cleared of mine dumps as an adjunct to the High Lane opencast operations. The area is almost equally divided between the lower and middle divisions. Sandstones have been mapped hereabouts in the lower division at the western edge of Area A and may per-

Table 3 Brick clay resources in the Etruria Formation

Site	National Grid Reference	Area in lower division (km^2)		Area in middle division (km^2)		Area in upper division (km^2)		Total area
		Untapped resource	Being worked	Untapped resource	Being worked	Untapped resource	Being worked	
A. Holly Wall	849 519	—	—	—	0.2	—	—	0.02
B. Chatterley	845 507	0.205	—	0.2425	0.035	0.315	0.005	0.8025
C. Apedale South	827 488	—	—	—	—	0.045	0.01	0.055
D. Gorsty Farm	822 475	0.53	—	0.535	0.06	—	—	1.125
E. Walleys	832 460	—	—	0.0975	0.085	0.055	—	0.2375
F. Keele	803 459	0.075	—	0.08	—	0.08	—	0.235
G. Stoke-on-Trent	885 455	0.125	—	—	—	—	—	0.125
H. Westlands	830 451	—	—	—	—	0.035	—	0.035
I. Clayton	856 430	—	—	—	—	0.255	—	0.255
J. Sideway	856 430	—	—	—	—	0.65	—	0.65
K. Hanford	856 430	—	—	—	—	0.545	0.025	0.57
L. Lightfoot	920 410	—	—	—	—	0.545	0.025	0.57

sist eastwards, thus possibly limiting the amount of mudstone available in this division. The existing Knutton quarry of Steetley Building Products is in the middle division.

E. Walleys [832 460] The existing Walleys quarry of Steetley Building Products in the middle division of the Etruria Formation is being actively deepened and extended towards the north. Mudstones in the western fringe of the area, beyond the working pit and south of the Hollywood Fault, are in the upper division of the Etruria Formation and likely to contain small calcareous nodules.

F. Keele [803 459] The area includes parts of all three divisions of the Etruria Formation and could possibly include a potential quarry site south of the railway.

G. Stoke-on-Trent [885 455] This site lies immediately north of the Fenton Manor quarry which is nearing the end of its active life. The resource lies in the lower division of the Etruria Formation. Since there is a tendency for sandstones to increase in number northwards from Fenton Manor, the viability of this site would depend on where precisely the northward increase in sandstones takes place.

H. Westlands [830 451] This narrow belt extends southwards and broadens across the M6 motorway to Shutlanehead [823 425] but is largely outside the area. It is in the upper beds of the upper division of the Etruria Formation and likely to contain some calcareous nodules.

I. Clayton [856 430] This area is entirely in the upper division of the Etruria Formation and hence is likely to include small calcareous pellets in the topmost 20 m of beds. The site is well drained and split in the south by the A500 road.

J. Sideway [875 430] This site is in the upper division of the Etruria Formation. A small portion on the southern fringe may contain small calcareous pellets, but otherwise the site should provide a useful resource area.

K. Hanford [856 430] This long strip is entirely in the upper division of the Etruria Formation, but only the southern part, straddling the A500 road, includes any of the topmost 20 m with calcareous nodules.

Plate 5 Parkhall Country Park

Conglomerates and sandstones of the Hawksmoor Formation (Sherwood Sandstone Group). View in old quarry looking north [930 447].

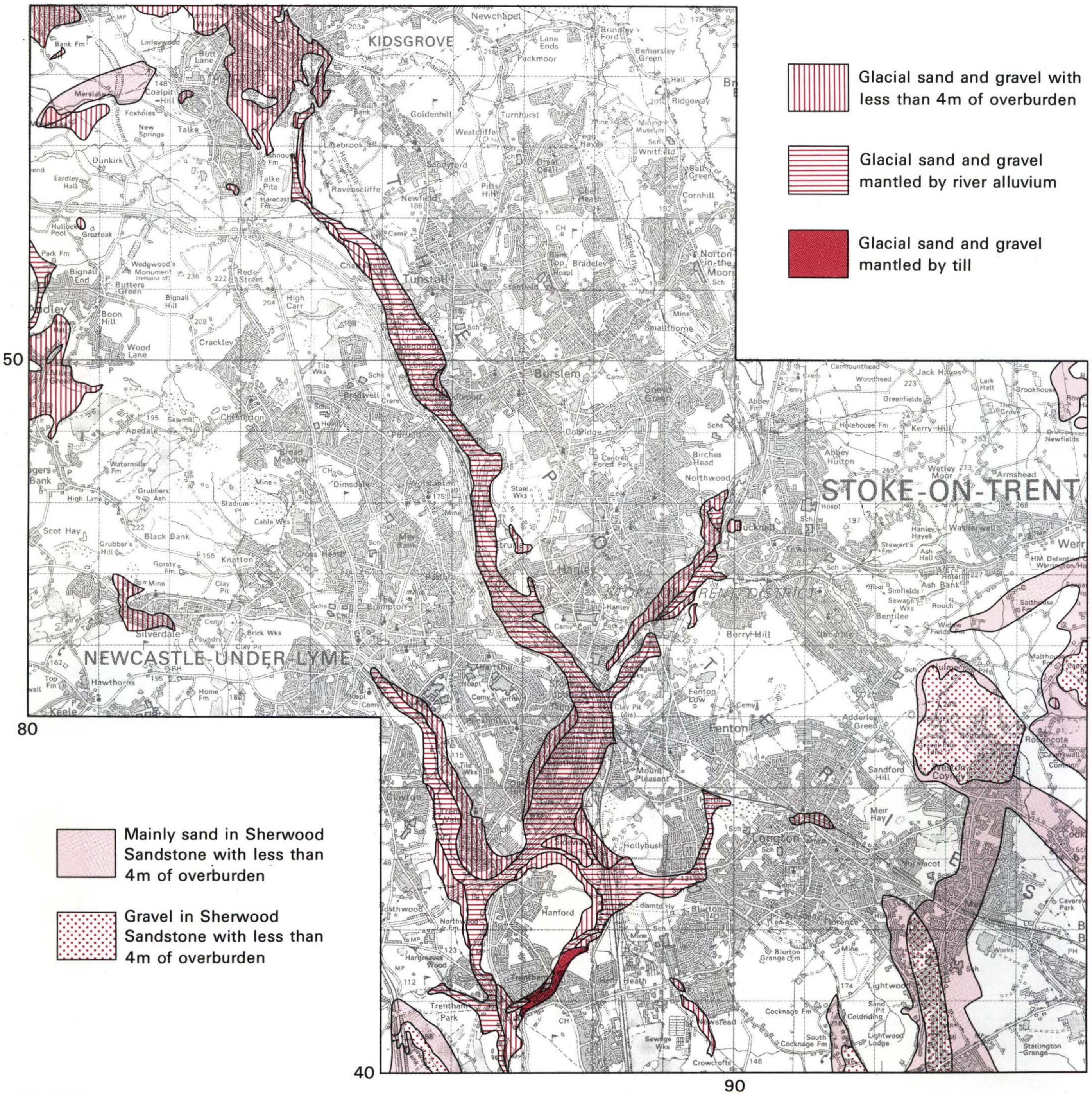


Figure 10 Sand and gravel resources.

L. Lightwood [920 410] This substantial rural area is in the upper division of the Etruria Formation. It includes the active pit, currently owned by Daniel Platt and Sons, from which the Minton tiles were made. This quarry does not include the top 20 m of the Etruria Formation which may include small calcareous pellets hereabouts. There is scope of considerable further development in this area, particularly in beds at the same geological level as in the Lightwood quarry, or somewhat lower in the sequence (in the north of the tract).

3.4 Sand and gravel

General

At the present time, sand and gravel are not produced in the Stoke-on-Trent area. There is, however, potential for sand and gravel to be obtained from two basic sources, one in the superficial deposits (Glacial Sand and Gravel) and one from the bedrock (Sherwood Sandstone Group), as shown in Figure 10 and Thematic Map 6. In the past, only small pits are known to have worked Glacial Sand and Gravel deposits, as for example at Rye Hill [802 501]. However, considerable quantities of sand and gravel were formerly won from outcrops of the Sherwood Sandstone Group at Weston Coyney [930 445] (Plate 5), Meir [924 420] and Trentham Park [855 403].

The potential for future workings in the superficial deposits is seriously limited by urban overbuilding. In addition, any new workings in remaining areas are likely to be hampered by the proximity of urban development, restricted outcrop area, variable overburden thicknesses and high water tables. There is potential for further workings in the Sherwood Sandstone Group and assessment of sand and gravel resources in these areas has been the subject of mineral assessment reports commissioned by the Department of the Environment in the early 1980's (Piper, 1982; Malkin, 1985).

Glacial Sand and Gravel

These potential sand and gravel resources comprise deposits laid down by meltwater from the ice. There are two types, one forming broad spreads on the surface and the other confined within glacially deepened valleys (Figure 10). The latter category may be either exposed, or concealed by a thin cover of silt and clay.

Extensive spreads of Glacial Sand and Gravel can be found at Silverdale [813 466], Miles Green [803 498], Mosshouse [807 534], Alsager [802 549] and Kidsgrove [833 543]. No details of any extractive activity at these localities are known, apart from a small sandpit at Rye Hill in the Miles Green deposit. The resource here is known to be at least 15 m thick at one part, but is likely to show great variability, not only in thickness, but also in grade. Most of these deposits lie in areas that are now heavily urbanised and few details are available. Table 4 shows the potential resources that may lie in these five areas.

Extensive deposits of Glacial Sand and Gravel also exist within the valleys deepened by meltwaters from the ice sheet. The most extensive of these is to be found in the valley that runs from the southern outskirts of Kidsgrove [841 540], through Bathpool Park [837 525], Longport [857 500] and Cliff Vale [868 464] to Stoke [879 453] (Figure 11). A second valley runs down the present-day line of the River Trent from Milton [904 500], through Stoke and Hanford [867 427] to Trentham Gardens [866 406]. Two further valleys join this line, the Lyme Brook from Newcastle-under-Lyme [849 457], at Hanford, and Longton Brook from Heron Cross [897 439] to Trentham Gardens.

Most of these deposits are concealed beneath a blanket of alluvial silt and clay (Figure 10). Generally, this overburden averages about 1.5 m in thickness but silty deposits in excess of 9 m are known in the Trent valley at Hanley and 3.5 m are recognised in Longton Brook. Terraces of Glacial Sand and Gravel can be found in Lyme Brook, the Trent valley and Longton Brook where the overburden is no more than a thin soil.

Boreholes are able to provide a broad picture of these deposits. The sand and gravel resources within these areas are locally very thick, with up to 16.3 m in Bathpool Park

Table 4 Sand and gravel resources within major areas of exposed Glacial Sand and Gravel

Locality	Total area	Worked out area	Built over	Remaining area	Maximum recorded thickness	Mineral type
	km^2	km^2	km^2	km^2	m	
Silverdale	0.25	0.0?	0.20	0.05	4.8	mainly sand
Miles Green	0.70	<0.01	0.10	0.60	15.2	mainly sand
Mosshouse	0.25	0.0	<0.01	0.24	2.4	mainly sand
Alsager	0.22	0.0	0.17	0.05	1.5	mainly sand
Kidsgrove	1.83	0.0	1.33	0.50	9.1	sand and gravel

Table 5 Glacial Sand and Gravel deposits confined within fluvioglacially deepened valleys

Locality	Total area	Worked out area	Built over	Remaining area	Maximum recorded thickness	Mineral type
	km^2	km^2	km^2	km^2	m	
Bathpool to Longport	1.25	0.0	0.40	0.85	16.3	mainly sand
Longport to Stoke	2.25	0.0	2.25	0.0	10.2	mainly gravel
Milton to Stoke	1.00	0.0	0.50	0.50	15.2	sand and gravel
Stoke to Trentham Gardens	3.15	0.0	1.65	1.50	11.3	mainly gravel
Lyme Brook	1.40	0.0	0.40	1.00	7.2	sand and gravel
Longton Brook	1.15	0.0	0.60	0.55	4.8	sand and gravel

and 11.3 m at Hanford, but in general they show great variability in thickness. Gravel grade material is often present, with over 65% recorded in the Cliffe Vale area and generally over 75% in the Stoke area. Details for the Lyme and Longton brooks are not known, but gravel is probably present. The gravel content south of Hanford is in the region of 40%. Boreholes in the Bathpool Park area indicate that sand grade material is the norm in that area.

Again, most of these deposits lie in areas that are now heavily urbanised, and Table 5 shows the potential resources that may lie in these areas. High water tables are likely to be encountered in these valley deposits and any workings may have to employ dredging rather than dewatering techniques.

Sherwood Sandstone Group

The Sherwood Sandstone Group outcrops to the north, south and east of Longton, in Trentham Park and west of Kidsgrove (Figure 4). Most workings have exploited the conglomerate-rich beds; only the Meir Quarry [927 420] is known to have worked in the more sand-dominated parts of the sequence. The area of Sherwood Sandstone Group to the west of Kidsgrove, which covers approximately 3.7 km^2, appears to be dominantly in this sandy facies.

Additionally, much of the outcrop area here is covered by thick drift. These factors are likely to preclude this area from being exploited for sand and gravel (Figure 17 and Thematic Map). Areas where the highly prized conglomerate-rich beds can be found are around Cocknage Wood [916 404], to the south-west of Hulme [931 453], at Caverswall Common [948 445] and on Kingswood Bank [859 401]. Figure 10 shows areas of outcrop where overburden is estimated to be less than 4m thick. Much of the area of potential sand and gravel in the Weston Coyney, Meir and Meir Heath areas has already been sterilized for the foreseeable future by urban development. Details of the resources present in this southern part of the area are shown below in Table 6.

3.5 Oil and gas

General

Oil and gas occur locally in sedimentary rock formations. They derive from decay of animal and plant matter and can migrate within the rocks to where there is a suitable trap, such as an anticline. The liquid fraction, oil, is commonly overlain by natural gas, consisting of methane with small amounts of higher hydrocarbons like butane and propane. Other methane liberated mostly from decaying plant matter is adsorbed into coal; this gas, mixed with some carbon dioxide is liberated during mining. Gas can also be generated by organic decay within a landfill site which liberates a mixture of methane and carbon dioxide.

Exploration for oil and gas is controlled by exploration licenses granted by the Department of Energy. Currently the study area is divided up into four active hydrocarbon license areas plus one open area. The exploration licenses are held by Elf Petroleum (PL252), Fina Petroleum (EXL067), Shell Petroleum (PL190) and Edinburgh Oil and Gas (EXL144). Some seismic reflection data have been recently acquired around Werrington and also in the west near Apedale to determine the structure of the Carboniferous rocks, but no drilling has as yet followed. There appears to be no need to protect any sites for hydrocarbon exploration, given the present techniques for drilling wells at an angle where necessary.

Oil and gas (deep source)

During the First World War it became apparent that Britain would need domestic sources of petroleum. A national oil search was mounted and with government backing three exploratory boreholes were sunk in the present area in 1920–21, targeting the anticlines (upfolds) on the flanks of the Potteries Syncline (Giffard, 1923).

The first two boreholes were sunk close together on the Western Anticline. Apedale No. 2 Borehole [8073 4862], the deeper of the two, reached a depth of 1294 m. The final 850 m of this borehole were in the debris of a volcano, probably of Carboniferous age, and a most unpromising host for oil. A third borehole [9434 4856] sunk on the

Table 6 Sand and gravel resources within the outcrop of the Sherwood Sandstone Group in the southern part of the Stoke-on-Trent area

Locality	Total area	Worked out	Built over	Area of conglomerate remaining	Maximum thickness, conglomerate	Mineral type
	km^2	km^2	km^2	km^2	m	
Cocknage Wood	0.31	0.0	0.0	0.16	12.5	sand and gravel
Hulme–Weston Coyney	2.80	0.34	0.82	1.30	36.5+	mainly gravel
Caverswall Common	1.60	0.10	<0.01	0.20	10.0	mainly sand, some gravel
Cookshill	1.26	0.0	0.06	<0.01	—	mainly sand
Meir–Meir Heath	3.40	0.15	3.25	unknown	12.0	mainly sand, some gravel
Kingswood Bank	0.67	0.07	0.0	0.21	35.0	sand and gravel

Werrington Anticline had to be abandoned when the hole became obstructed at 814 m. The borehole never reached the Carboniferous Limestone, its ultimate target. Some oil does undoubtedly occur in the area since it was found in Hanley Deep Pit, where the miners were locally wading in oil, and subsequently in 1955 in Black Lake Crut, Florence Colliery, a drivage to the Ten-Feet Coal. Oil has also been encountered in workings for Rowhurst Coal at Florence Colliery and Winghay Coal at Hem Heath Colliery. None of these constitutes a viable resource, but they do point to the potential existence of a commercial deposit.

It is just possible that a deeper version of the Werrington Borehole might yield methane, or even oil, if a suitably fractured or porous bed were to occur. The Werrington Anticline has good closure towards the south and may provide a trap, provided the flanking faults are tight. In the west the presence of the thick volcanic rocks makes a similar discovery rather unlikely.

Oil has been experimentally extracted from oil shale in the roof of the Red Shagg Ironstone, yielding 12–15 gallons per ton, whilst similar shale above the Red Mine Ironstone yielded 28 gallons per ton (Homer, 1875). Figures for roof cannels in the Cannel Row are 60 gallons per ton and Great Row 30 gallons per ton (C Williams, personal communication). During the Second World War and in ensuing years oil was extracted from coal at the National Benzol plant in Goldendale, Tunstall. Should oil ever become scarce and expensive again, there may be further call on coal and oil shale as a source of oil. Were this ever needed it could be extracted from the coal mines, since all the above beds are at mineable depth in existing collieries.

GAS (COAL SOURCE)

Methane gas is present in large quantities in the Coal Measures, most of it adsorbed in the coal. It is both a risk in the mines and a resource. Currently methane drainage systems are in place at Florence, Hem Heath and Silverdale. Special boreholes lead to a piped system, the North Staffordshire Grid, connected to a dedicated gasholder at Etruria. The effect is to help to de-gas the mines and to provide a valuable natural energy resource. Any surplus gas which seeps out in the mines is flushed away by a modern ventilation system. Methane is an undesirable 'greenhouse' gas, the escape of which is minimised by the drainage systems.

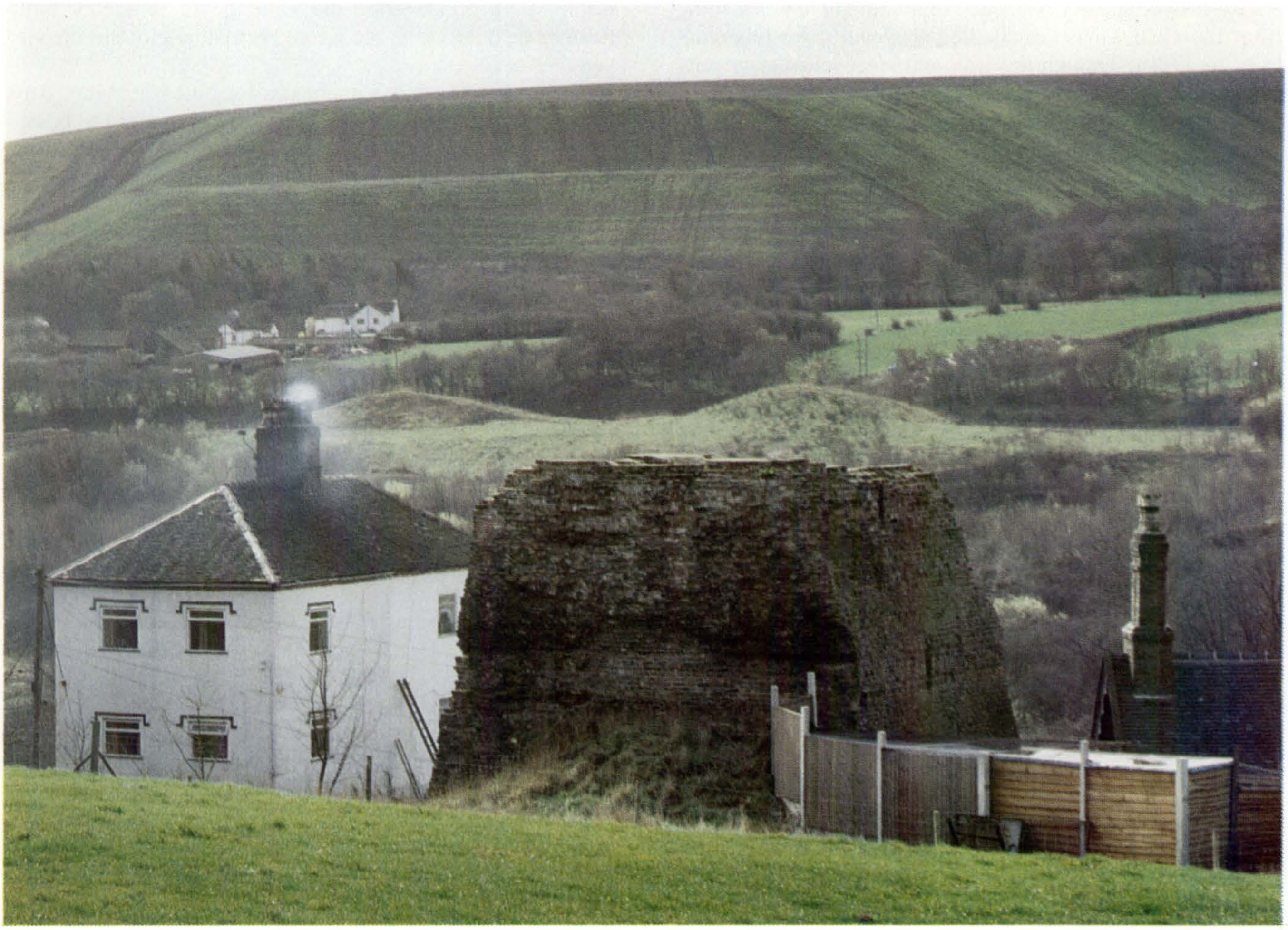


Plate 6 Old Blast Furnace, Springwood

The earliest surviving blast furnace, dated 1789, at Springwood, Apedale [8211 4991]. The green slopes in the background beyond the valley of Lyme Brook are temporary banks of debris from the High Lane Opencast Site.

The most gassy pits were in the west of the area, but it is unlikely that any effective methane drainage scheme for an energy source could be engineered in the flooded old workings.

It is likely that substantial quantities of methane are slowly liberated from colliery spoil since the in-situ methane content of coal varies from a trace to 25 m^3 per ton. Coal has a low permeability to methane, so any contained methane can be released over a long period. It is too dispersed in the tips, however, to provide a likely energy resource, even as a pre-planned exercise with methane extraction pipes and plant installed before tipping.

GAS (LANDFILL SOURCE)

Gases generated in landfill sites for general and domestic refuse usually contain 50–65% methane mixed with 35–50% carbon dioxide. Each ton of waste is estimated to generate about 250 m^3 of gas. There is a potential for draining off this methane as an energy resource provided that the necessary pipework and plant is installed as a pre-planned exercise during the landfill process. Since methane is a 'greenhouse' gas, one would ideally aim to collect such gas for use as an energy resource, liberating less harmful gases by its eventual combustion.

3.6 Ironstone

An extensive industry was once founded on local ironstone from the Coal Measures, fuelled by local coke (charcoal prior to 1700). Though the iron and steel industry is now defunct, it is included for completeness and because it relates to old workings and dumps.

The earliest workings for ironstone were in 1280 in the Manor of Tunstall. There was further activity in the 14th and 15th centuries around Chesterton, Knutton and Talke. Plot (c.1686) noted that ironstone was worked by footrails at Red Street, Apedale and Tunstall. The earliest surviving blast furnace, dated 1789, stands near Apedale [8211 4991] (Plate 6). The iron industry grew rapidly after 1839 with the introduction of blast furnaces at Earl Granville's Shelton works and peaked in 1870. Records made in 1880 show that furnaces were active at eight locations in the present area, namely Apedale, Silverdale, Norton, Chatterley, Kidsgrove, Goldendale, Shelton and Longton Hall.

With the local introduction in 1888 of the open hearth process for steel making, the phosphorous-rich ironstones could be converted for the first time into steel. However, cheaper and richer ores from abroad replaced the local ironstones. Then, in the early 20th century intense international competition brought about the demise of all the smaller steelworks except Shelton. Closure of Shelton and hence the whole local industry came in 1978.

Ironstone in layers and nodules was mined at 14 horizons, 11 of them in the Upper Coal Measures (most of them shown on Figure 3). The thickest bands were reputed to reach 4 m, but around 0.6 m is a more usual thickness. Some ironstones were mined along with their underlying coals, whilst other bands were worked separately. The ironstones are of two types, clayband and the more carbon-rich blackband (p.17).

It is very unlikely that there will be a regeneration of ironstone mining, due to the availability of cheaper and more suitable foreign ores. In addition, most of the blackband ironstones which are so persistent beneath Silverdale deteriorate into the area of Trentham Colliery, though they are still good beneath Keele.

3.7 Building stone

Several sandstones have been quarried for building stone, but all workings have been long since closed. The coarse-grained Chatsworth Grit in the Millstone Grit was formerly quarried at Armshead near Werrington [935 483]. The Rough Rock was formerly worked in Washerwall Quarry, Werrington, now totally landscaped, with housing [935 477]. The Ten-Feet Rock within the Coal Measures was worked at Coalpit Hill, Talke [8252 5355] and at Alsagers Bank [808 485]. Christ Church, Tunstall was built in 1831-2 from stone quarried in Chell, probably in the sandstone above the Bungilow Coal [871 522].

The Hanchurch Sandstone, in the grey coloured Newcastle Formation, was formerly worked near Keele in Job's Wood Quarry [823 460] and in its purple development in the Keele Formation, at Quarry Bank Quarry [807 461]. Both quarries are designated as Regionally Important Geological Sites (Figure 11). A higher sandstone in the Keele Formation was also formerly worked [8203 4565] near Keele. Both Keele Hall and Church are reputedly built from stone quarried in the Keele Formation close to the village.

Currently there is no quarrying for building stone. Any future use of building stone is likely to be limited to possible specialised use in restoring buildings in conservation areas. It does not seem necessary to advise any protected areas of outcrop for resource purposes.

3.8 Ironworks slag

A number of old tips adjoin the sites of former ironworks. They consist of very tough grey slag varying to a mixture of furnace ash and slag (Figure 17, Thematic Maps 4, 10). These materials have been used for hard core and in the manufacture of cement blocks. They have been extensively quarried in recent years at Apedale [826 488] and the greater part of a large dump has been removed. Further tips exist, but the largest, at Shelton, has been partly landscaped or overbuilt. Several other tips have been partly overbuilt, but there are some remaining resources near Brindley Ford [880 549], Goldendale [851 510] and a partially worked out area near Hollybush [898 433].

3.9 Minestone

Minestone consists of a variable mixture of pieces of mudstone, siltstone, sandstone, ironstone and coal, tipped as a consequence of past and present mining operations. In places it has been converted into ash due to spontaneous combustion. Minestone is a resource (Figure 17, Thematic Map 10) because of its coal content and its use as bulk filling.

Coal has been recovered by washing tips at Birchenwood [850 545] and Norton [892 505] and is currently being extracted from the Hem Heath tip of Trentham Colliery. Borehole tests have been carried out elsewhere to determine coal content in tip heaps.

Minestone can sometime be used as bulk filling. It is most safe for such a purpose if it has already been washed for coal to reduce its inflammable content, or alternatively has been converted to ash by earlier spontaneous combustion. In the present area, the remains of the Parkhouse Colliery tip were spread to make part of the Parkhouse Industrial Estate, but they do include much ash, following a fire in the tip in 1961. Elsewhere small parts of old tips have been worked for their ash content.

3.10 Water

Along the eastern margin of the study area, water resources within the Sherwood Sandstones have been extensively utilised, primarily for public water supply. Development has taken place at Meir, Sheepwash and Wallmires (Figure 16 and Thematic Map 12) with the water feeding into

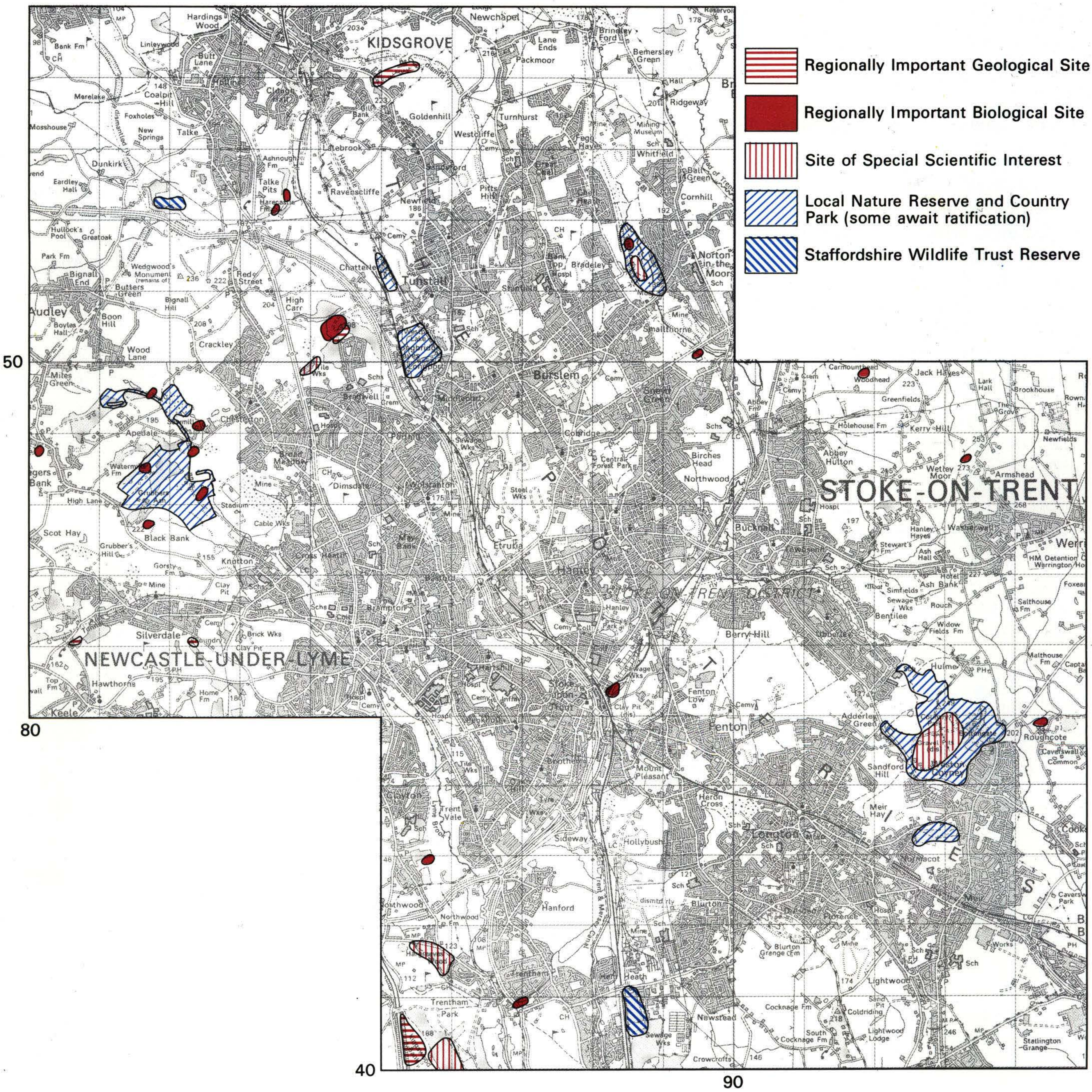


Figure 11 Location of conservation sites.

Stoke-on-Trent. Due to this extensive development, no further license applications are considered from the sandstones, in order to protect the existing license holders and baseflow support to the River Blythe.

In the north-west of the area, a substantial length of Sherwood Sandstone outcrop, part of which is drift-free, is likely to be a valuable water resource. In the main study area, namely in the terrain underlain by Carboniferous rocks, there are no objections in principle to groundwater development, providing that it does not adversely affect any existing licensed or unlicensed sources. Borehole yields are generally poor and boreholes can be dry if no sandstone horizons are encountered during drilling. This is in contrast to the Sherwood Sandstones where yields are invariably good.

Within the main study area groundwater quality can be poor with high chlorides and sulphides being recorded — this again is in contrast to the Sherwood Sandstones where quality is generally good.

3.11 Quarries as potential waste disposal sites

There has been much past disposal of waste in quarry sites; however, most of them are now infilled. Besides the active quarries for brick clay in the Etruria Formation and Coal Measures, which will eventually become available for infilling, the following old quarries contain some space for infill: Trent Vale [862 442] old quarry in Etruria Formation and Sandyford [862 526] in Coal Measures (Figure 17 and Thematic Map 10).

3.12 Conservation sites

Many areas rich in plants, birdlife and interesting rock formations have already been designated for conservation (Figure 11). Many sites are on made ground, which has over the years become a haven for wildlife. These sites, including RIBS (Regionally Import Biological sites), LNRS (Listed Nature Reserves) and Country Parks and SSSI's (Sites of Special Scientific Interest) are listed in Appendix 3, with a note of any geological factors which could affect the habitat.

Sites of geological interest (SSSI's and RIGS — Regionally Important Geological Sites) are all old quarries with good sections in rocks of Carboniferous and Triassic age (Appendix 3). A suggested new site worthy of preservation has been noted at a worked out opencast coal working during the present survey. This is an exposure of the Vanderbeckei Marine Band [8119 4940], one of only four or five such exposures in Britain. This fossil band is the demarcator between the Lower and Middle Coal Measures and extends eastwards across central Europe to the Donbass Basin near the Ural Mountains. The appropriate authorities now have the preservation of the site in hand. Future SSSI's and RIGS will generally derive from quarry sections, but future road and other cuttings may be worthy of preservation.

4 CONSTRAINTS TO DEVELOPMENT

4.1 General

Although the constraints to development can be grouped into those resulting from human activities and those which are naturally occurring, they have been divided in this report and on the maps into those relating to ground stability (Thematic Map 11 and Figure 15) and those relating to the effects of fluids (Thematic Map 12 and Figure 16).

Ground stability is potentially the main geological constraint for planning and development. The earth has in the study area been honeycombed by man to an unusual degree in a network of shallow old passages, with some risk of collapse due to loading by heavy new structures, and there is continuing activity in the deep mines as voids are created and gradually are allowed to collapse. Other constraints are caused by the unconsolidated valley alluvium and unstable old landslips, prone to move again if loaded by building or embankments. Lesser risks attach to running sand and swelling clays. Finally, the very stability of the 'solid' ground, the earthquake risk, has to be taken into account.

The fluid-related constraints are grouped together on Thematic Map 12 and Figure 16. Constraints caused by water are considered in relation to flooding, and to problems caused by leachates. The latter conduct noxious substances into the watercourses and permeable rocks and hence potentially into underground water supplies. The potentially explosive gas methane is liable to be produced both from natural sources underground and from accumulations of man-made waste, while the naturally occurring radioactive gas radon may become dangerous in certain situations.

Although most ground problems can be overcome by appropriate engineering or construction works, the early recognition of problems is of great importance, because late solutions may be prohibitively expensive. Assessment of ground stability includes not only the properties and stability of bedrock and superficial materials, but also the changes brought about by man, such as mining, quarrying and landfill. Government advice on development on unstable ground is available in Planning Policy Guidance Note 14.

4.2 Subsidence

THE NATURE OF THE PROBLEM

The present area has been much affected by mining subsidence caused by workings for coal and ironstone at sixty different levels in the rock sequence. The current and future risk comes from old shafts, collapse of pillars of support within old workings and from any subsidence effects of new workings, which are located in the south of the area (Figure 17 and Thematic Map 7).

Abandoned workings near the surface

Many of the earliest workings were in former green-field sites now within urban Hanley, Burslem, Tunstall and Longton, where numerous coal seams inclined at about 15° come to crop. The Cannel Row, Great Row and Peacock coals were particularly favoured for firing the pottery kilns. There were surface diggings, small quarries, shallow inclined tunnels (adits or footrails) shallow shafts and rare bell pits (Plate 7). Most of the underground workings were of the pillar and stall pattern, where pillars of coal were left as the roof support (see Healy and Head, 1984, for an excellent account of such workings and remedial measures). The others were bell pits which comprised restricted unsupported excavations at the base of a shallow shaft (Plate 7). Most of these workings predate the times when mine plans were commonly made or kept. Areas in which there is a risk of shallow workings close to the surface are shown on Figure 15 and Thematic Map 7.

Plate 7 Old Bell Pit

An infilled bell pit encountered in foundation excavations in the Hanley area. The side of the pit is undercut into the coal seam. Total height of section about 6 m.
Photograph by Allott and Lomax

The risk from shallow old workings is twofold. Firstly there are buried voids close to surface; secondly pillars of support are prone to collapse. A practical illustration of the presence of old voids in pillar and stall workings was seen in about 1964 when the interchange was being excavated at the A34/A500 northern junction [832 518]. The road cutting coincided with the outcrops of the Cannel Row and Great Row coals and the drivers of scrapers uncovered deep voids, which necessitated remedial works. The threat from possible collapse of pillars in old workings has long been recognised in the project area, which is notably and

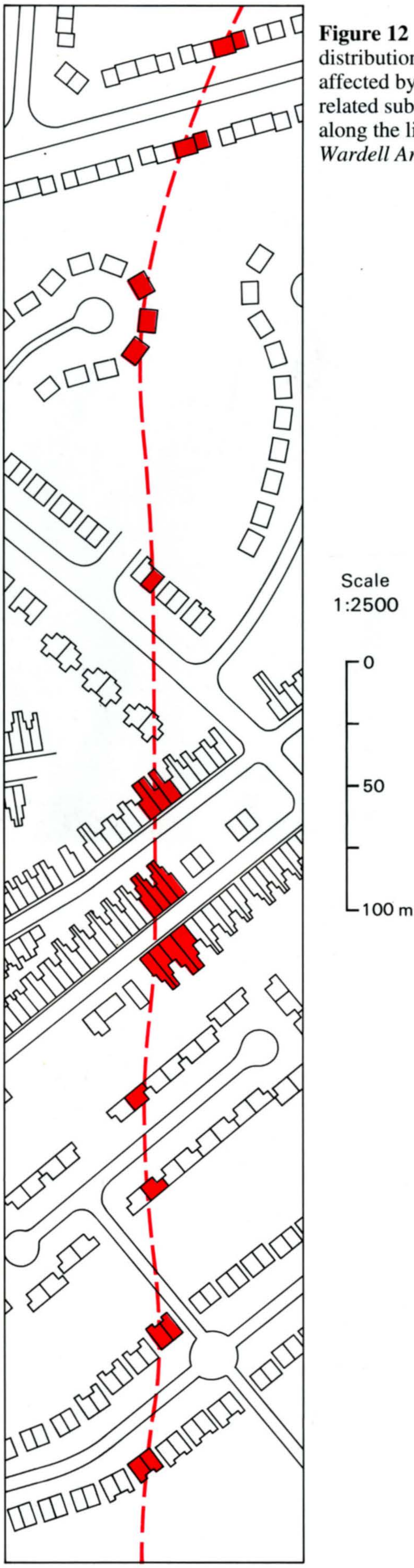


Figure 12 Typical distribution of houses affected by mining-related subsidence along the line of a fault. *Wardell Armstrong*

rightly deficient in the high-rise housing that characterises so many large English towns (Figure 13). Houses built some 15 years ago in the Berry Hill area [8978 4643] were placed on rafts due to the threat from uncharted shallow workings in the Great Row Coal, which had earlier been laid bare in a nearby opencast site. Despite these precautions one of the houses is now notably tilted and others are cracked, probably due to deterioration of pillars of support in the shallow old workings.

The Potteries area includes over 200 abandoned footrails, some of them of great antiquity (Plot, 1696). The bulk of the workings date from the present century and their positions are well known. Most of the old workings are in the west of the area in rural situations. The most common site of collapse is close to the footrail mouth where support arches in the entry tunnel have fallen in leaving a crown hole or subsidence pit. In some cases, for instance in the case of long abandoned footrails in the Apedale area, additional "crown" holes have developed over the old workings. One farmer described how he and his tractor had narrowly escaped being engulfed in such a hole, overlying abandoned workings, which had opened up beneath his machine, prior to 1961. The site of this incident will be made safe during the High Lane opencast operation by taking out this area.

Abandoned shafts

The Potteries area includes some 8000 shafts of varying degrees of antiquity known to British Coal. Many of these are fairly shallow, very old shafts, the depth of which is not accurately known. The deeper shafts are frequently well documented and their depth and mined seams accurately known.

There is a twofold danger from abandoned shafts. Firstly there is the risk of a person falling down an unprotected shaft and secondly there is a risk of a surface subsidence in the vicinity of a shaft. In cases where the shaft lining has deteriorated such a subsidence can cause a crater. There is also possibility of a collapse within the shaft, which can reduce the load bearing capacity of ground around the shaft.

Abandoned deep workings

The area has suffered extensive subsidence effects in the past, but as the current workings have moved southwards, the incidence of subsidence effects from deep mining has diminished, following early settlement of the workings.

In the past the most spectacular subsidence effects have been near colliery barriers and near major faults, where several seams of coal have been extracted in one piece of ground and few or none in the adjacent patch. This has led to the formation of flooded areas in valleys, as for instance at the barrier between the defunct Norton and Chatterley Whitfield collieries [887 509] and along the Apedale Fault [829 476]. Westport Lake [856 502] is also due to mining subsidence and includes part of Port Vale Football Club's former practice ground. An area of allotments at Hanford has become marsh following coal extraction in the mid-1970's (McDade, 1983).

Several salutary examples can be given of the effects of subsidence transmitted up fault planes. Firstly, there was the cracking and abandonment, prior to 1961, of the then new outdoor swimming bath at Smallthorne [811 501] due to mining-related movement on the High Lane Fault. Secondly a line of damaged houses in the study area (Figure 12) shows dramatically the effects of subsidence transmitted up a fault crossing several residential streets. This particular fault is known in the deep workings and its subsidence effects have refined the position of its surface outcrop on our map. A third example is the metre high rise in road level across the Apedale Fault in Church Lane, Knutton [832 466].

Current and future mining operations

All current and likely future mining is concentrated in the south of the area, with most of the activity beyond its southern boundary. Much effort goes into minimising subsidence, but from time to time significant subsidence is lable to occur. For instance in the Newstead estate [894 412] there are cracked houses on Waterside Drive, possibly associated with mining in three seams at depths varying from about 500 to 1000 m. The effect of the subsidence appears to have been transmitted up the plane of the Hollybush Fault.

Some solutions to the problem

This topic is considered in relation to different types of workings.

Abandoned workings near the surface.

Since 1872 there has been a statutory duty to lodge plans of coal and ironstone workings with the mining record office, but there are many areas undermined prior to that date without plans. When examining old plans it is not uncommon to find the words 'old gob' on the up-dip side of the charted workings, indicating that there are shallower, but uncharted workings in that same seam, extending an unknown distance towards the surface.

There is thus a marked risk of shallow abandoned workings, notably in central Hanley and in Longton (Figure 8, Thematic Map 7). As a first step the updated 1:10 000 geological maps are an important guide to the likely outcrops of the several regularly mined seams. The present resurvey has taken into account several thousand new foundation boreholes in these areas and is now more accurate than hitherto. Secondly the advice of locally knowledgeable firms of mining and geotechnical engineers is important, and a programme of site investigation boreholes is usually needed, particularly for high-rise buildings. The chief purpose of such a programme is to locate seams of coal and ironstone under the site, to provide an indication of the presence of abandoned workings, and to locate geological faults.

There are a number of shallow, uncharted pillar and stall workings beneath the town which have been identified by site investigations (Fig 13). In some cases these have had to be stabilised by costly cementation programmes using multiple boreholes to inject the cement, as for instance at the Crown Courts and Museum sites in Hanley (Plate 8 shows the use of grout at another site in Hanley). The new geological map has used the many site investigation boreholes to refine the accuracy of the outcrops, but must not be used as

Plate 8 Grouted Old Working

The excavation in the Hanley area shows a layer of grey cement filling a former horizontal void immediately below the 15 cm-long yellow pen. The vertical feeder borehole, also plugged with cement, is visible 40 cm from the right of the photograph. *Photograph by Allott and Lomax*

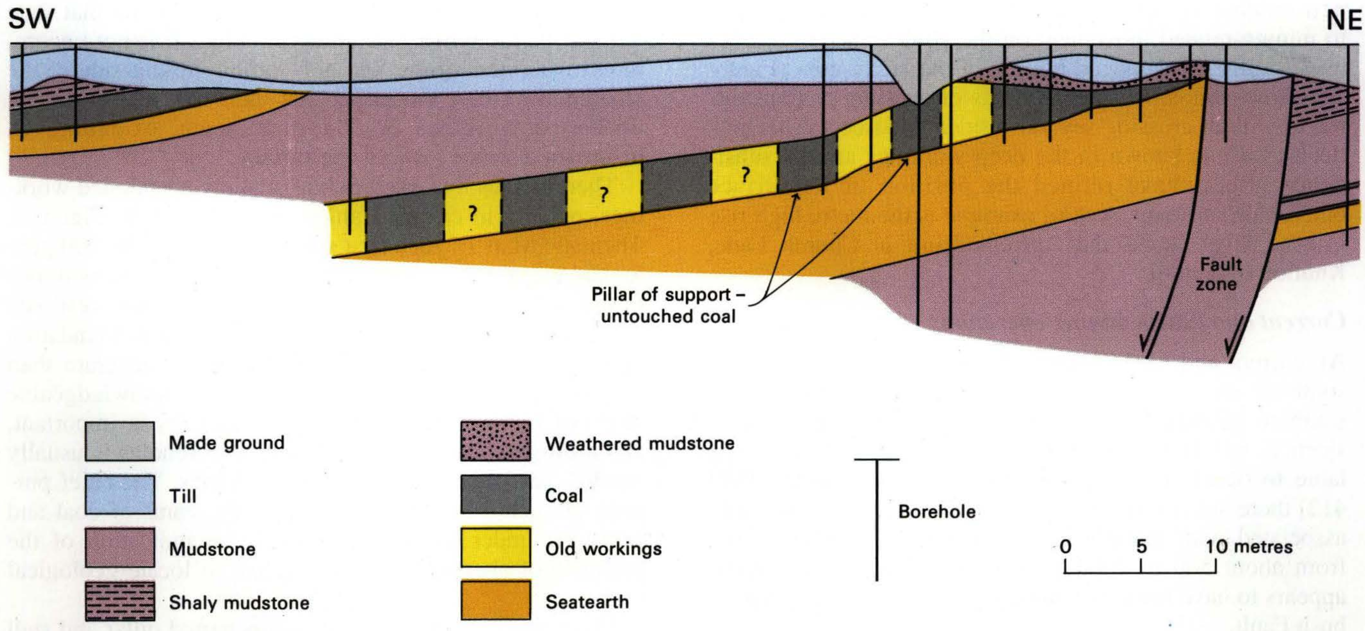


Figure 13 Section in Hanley showing a fault, likely pattern of old pillar and stall workings and coal provings in recent site investigation borehole. *Wardell Armstrong*

a substitute for detailed site investigation, particularly where there is a probability of shallow old voids.

Abandoned shafts

The most comprehensive shaft database available is held by the Area Surveyor, British Coal Corporation, North West Group, Gadbrook Park, Rudheath, Northwich, Cheshire CW9 7RA to whom enquiries should be made. Though many of the old shafts have been filled, the fill is in some cases poised on decayed girders or wooden beams and it is essential to seek expert advice in locating and treating the shafts prior to development. Inevitably not all old shafts will have yet been discovered, so caution is advised within the mined area. There are now geophysical techniques to aid the location of abandoned shafts (Bell, 1988). The responsibility for locating shafts at or close to development sites rests on the site owner or developer.

Treatment of shafts in an urban area usually involves a partial or total closure at the head of the shaft. Partial closure provides for manhole access in the rare cases where this is necessary. Closure is effected by use of the following methods (Freeman Fox, 1988):

A reinforced concrete slab at rockhead (base of drift) or in bedrock, or in the overburden.

A concrete plug at or below rockhead. This is usually in the shape of an inverted cone constructed of dense Portland cement, or sulphate resisting cement where necessary.

Filling of the shaft. This is generally less satisfactory than a good plug because there is ongoing compaction of the fill for some 2 years after filling (Freeman Fox, 1988). There is also a possibility of fill merely lodging on obstructions in the shaft or moving sideways into mine passages. Hardcore is much more satisfactory than clay due to its compaction characteristics. Cement fills are an alternative in shallow shafts, but there can be a risk of migration of the fill into workings during placement of the fill.

Footrail operation

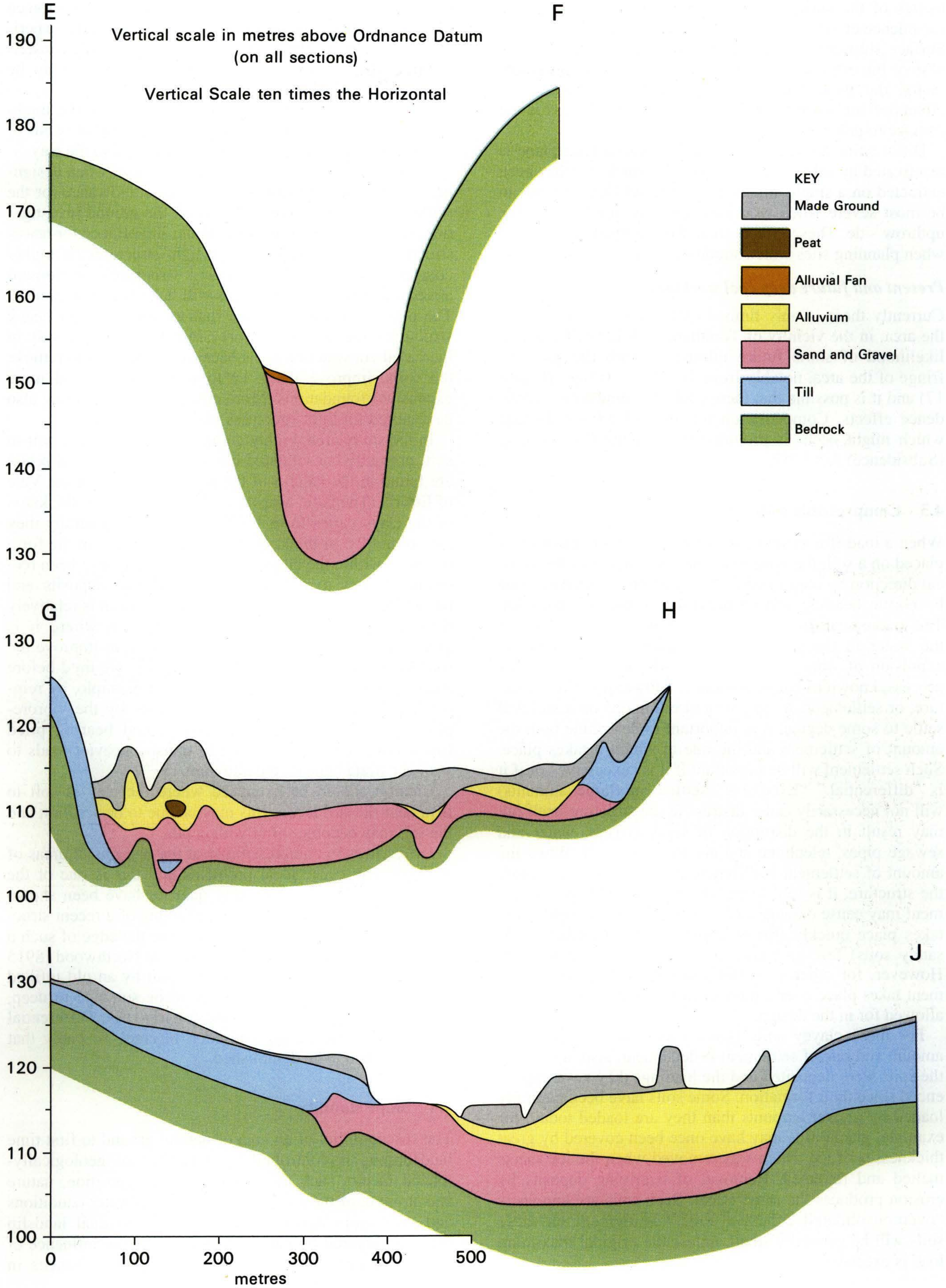
Current footrail activity, by pillar and stall working, is very closely regulated by British Coal. Firstly the mining by private firms takes place beneath open country and there are strict plans to prevent undermining of villages. Secondly the spacing and dimensions of pillars of support are strictly defined, so that there are enough coal pillars to support the roof. Older, pre-war footrails may pose a greater threat due to collapse of pillars of inadequate size.

On abandonment an expensive, but effective way to prevent later collapse near a footrail mouth is to infill the tunnel for such a distance that the cover is ten times the height of the opening (National Coal Board, 1982). This would have prevented several known local cases of collapse of old footrails close to their mouths.

Abandoned deep workings

Subsidence effects from longwall mining are usually complete about a year after extraction, but it may be more than 10 years before the surface is completely stable (McLean and Gribble, 1985). Major surface effects caused by eventual collapse of pillars in old pillar and stall workings are usually restricted to collapse in workings within 30 or 40

Figure 14 Sections across major glacial drainage channels. The sands and gravels of the buried valley are overlain by compressible alluvium (silt with peat lens) in turn blanketed by patchy made ground. For location of section lines see Figure 7.


E
F
Vertical scale in metres above Ordnance Datum
(on all sections)
Vertical Scale ten times the Horizontal
190
180
170
160
150
140
130
KEY
Made Ground
Peat
Alluvial Fan
Alluvium
Sand and Gravel
Till
Bedrock
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100
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500
metres

metres of the surface. Later deeper workings can trigger subsidence effects in overlying abandoned workings (p.43). Surface subsidence is principally a function of the thickness of the extracted seam and the depth of working. Generally, the greater the depth of working, the wider the effects of subsidence are at the surface and the less is the damage to property.

Differential subsidence may occur when a fault plane is reactivated by subsidence, particularly where coal has been extracted on a single side of the fault. Subsidence tends to be most severe when workings approach the fault on the upthrow side. These effects should be carefully considered when planning sites which straddle faults.

Present and future deep coal workings

Currently there is only limited extraction of coal beneath the area, in the vicinity of Trentham Park Lake. There is a likelihood of some future mining beneath the southern fringe of the area, notably from Trentham Colliery (Figure 17) and it is possible that there could be some future subsidence effects. Compensation for any subsidence damage which might occur is provided through the Coal Mining (Subsidence) Act 1957.

4.3 Compressible soils

When a load (for example a building, or other structure) is placed on a soil, the volume of the soil reduces in the vertical direction by compression. This compression takes place by elastic bending and reorientation of the soil particles. The loading causes the development of excess pressures in the water in the soil which are gradually dissipated by expulsion of water through soil voids. The result of this process, known as consolidation, is a lowering of the structure, or settlement. As any structure founded on a soil will settle to some degree, it is important to determine both the amount of settlement and the rate at which it takes place. Such settlement will be important if it is "excessive" or if it is "differential." "Excessive" settlement (large amounts) will not necessarily cause distress to the structure itself but may result in the disruption of services (gas, water and sewage pipes, telephone and electricity cables). When the amount of settlement is different at various places beneath the structure, it is said to be "differential" and such settlement may cause damage to the structure. Where settlement takes place quickly (for example, during construction on sandy soils) few problems are likely to be encountered. However, for other soils (for example, soft clays) settlement takes place over a number of years and this has to be allowed for in the design.

For these clayey soils (known as cohesive soils), the amount and rate of settlement is dependent, also, upon how the soils were deposited and the loadings they have experienced since their formation. Some soils have been naturally loaded by greater amounts than they are loaded today; for example, glacial tills may have once been covered by great thicknesses of ice which was removed when the ice sheets melted and retreated. Removal of overlying deposits by erosion produces the same effect. Such soils are known as "overconsolidated cohesive soils." Settlement on these soils will be generally small, unless the original maximum load is exceeded.

Other cohesive soils (such as clay alluvium) experience today loads which are as great as any that they have experienced in the past. These soils are called "normally consolidated cohesive soils" and settlements on these may be unacceptably high.

Differential settlement may take place where the thickness of the compressible layer varies or if lenses or bands of less or more compressible soil are present within the clay.

Settlement is of importance to the engineer when designing new structures; the design will make allowance for the settlement that it is anticipated, from the ground investigation, will take place. It is of particular importance for heavy structures on most soils and for light structures on highly compressible soils. For existing structures, settlement already will be taking place (or will have been completed). The planner should be aware that locating large or heavy structures on highly compressible soils may result in increased construction costs because of the need to remove the soils, improve them, or to use different (and more expensive) foundations. More costly foundations may also be required for light structures placed on these soils.

In the study area, highly compressible soils (very soft to soft, normally consolidated clays, organic clays and peats) are found in the valleys of the River Trent and in the Vale of Etruria (Thematic Map 11 and Figure 15). The thickness of the clays varies from 1.7 m to 6.5 m but generally they are around 2.5 m thick. Peat, where present, is in the form of lenses within the clays (Figure 14). There have been recommendations to remove the soft alluvial deposits and replace them with hardcore where the alluvium is relatively thin; however, this may be uneconomical where it is greater than 2.5 m thick. Ground treatment to improve the foundation characteristics of the ground is required before shallow foundations can be utilized (for example, by reinforcing the alluvium with stone columns by the vibroreplacement technique). Alternatively, end bearing piled foundations may be employed to transfer heavier loads to stronger strata beneath the alluvium.

Caution should be exercised where the clay is soft to firm near the surface, as this may be due to desiccation and the soil may become softer with depth.

Differences in compressibility at the margins of areas of thick fill can cause local problems and this is one of the reasons why infilled deep clay quarries have been shown on Thematic maps 4 and 11. An example of a recent structural failure likely to be due to bridging the edge of such a filled area is at the site of a bus garage at Northwood [8915 4760]. Part of the garage was underlain by an old infilled pit for brick clay and coal, likely to be some 15 m deep, whilst the other part overlay the country rock. Differential settlement of the garage caused it to crack so badly that recently it had to be demolished.

4.4 Slope stability

The susceptibility of an area of natural ground to first time landslipping is controlled by a number of geologically-related factors such as structure, the composition, nature and strength of the soils and rocks, groundwater conditions and geomorphological processes. An individual landslip may be triggered by natural factors, or by the influence of man, for example: by increased rainfall, by changes in

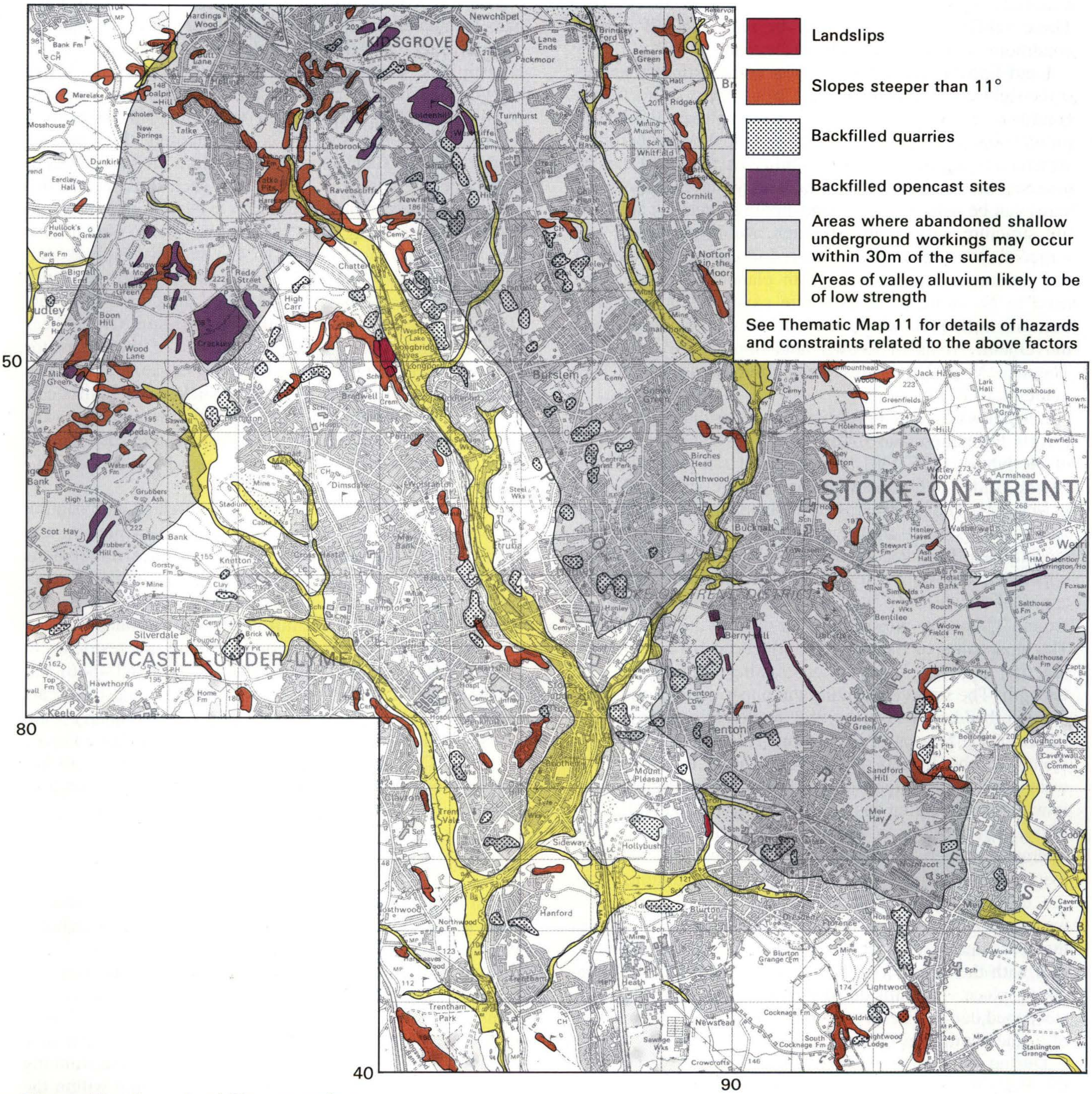

Figure 15 Ground stability constraints

groundwater conditions, by weathering of the soil or rock, by removal of vegetation cover (particularly trees), by overloading of the slope, or by undercutting the toe of the slope. Undisturbed natural slopes have generally attained a considerable degree of stability in our present climate; construction of any sort disturbs this equilibrium and may present problems in certain circumstances.

Areas underlain by Head may be susceptible to mass movement (landslipping). Immediately following the last ice age there was alternate freezing and thawing of the ground, with permafrost (permanently frozen ground) beneath. The thawed ground moved downslope forming the deposit known as Head. This process is known as "solifluction." The Head is generally weak and sheared and consists of reworked upslope deposits, be they bedrock or superficial materials. In places the Head can be seen forming shallow lobes, but in other areas it has no topographic expression. For this reason significant deposits of Head may be more extensive than is shown on Thematic Map 3 and, indeed, a thin (<1m) surface veneer of this and related soft materials is widely present throughout the study area. These solifluction deposits may be reactivated if ground conditions are altered naturally or by man.

Landslipping can affect both new and existing structures if the right conditions for ground failure exist or if existing conditions are altered. Therefore, it is important to identify ground that may be susceptible to landslipping before a structure is built so that the stability of the slope can be assessed and the cost of any necessary stabilisation measures can be determined. If landslipping threatens an existing structure, ground investigation, stability analysis and remedial measures may be required to ensure the safety of the structure. Consequently, both planners and engineers need to be aware of areas where existing landslips have been identified or which may be susceptible to ground movement. Areas of known landslipping are shown on Thematic Maps 3, 11 whilst steep ground is shown on Thematic Maps 8, 11.

Landslips have been observed on slopes underlain by the Etruria Formation near Bradwell Wood [862 473] and east of Hollybush [896 436] 80m south of the projected A50 Blythe Bridge to Queensway Road (Figure 15 and Thematic Map 11). The backscarps of the landslips are situated on valley slopes with angles greater than 15°. The largest landslip near Bradwell Wood has a slope angle of 25° in its upper degradation zone, and an accumulation zone at an angle of between 6° and 16°. The lowermost slope, at around 3°, merges into the alluvial plain in the valley floor. The steepening of the slope is influenced by a geological junction between strata of contrasting composition and strength. The strata underlying the upper parts of the slope are interbedded mudstones and moderately strong sandstones of the Newcastle Formation. These overlie the mudstones of the Etruria Formation which are commonly weathered to an overconsolidated homogeneous clay, within which landslipping has occurred. It seems likely that stability is reduced as a consequence of the difference in hydraulic properties at the junction of these two rock formations with differing permeability. Water draining from the more permeable sandstones above will soften and weaken the underlying mudstone, and water pressures in the mudstone may be increased. These factors, in combination with the steep slope angles, may lead to landslipping taking place. The hillside in this area was probably oversteepened due to glacial processes, when it formed one side of a glacial drainage channel (p.18).

During the construction of the Talke to Etruria link of the Potteries 'D' Road (A500) in 1971, problems were encountered when an embankment was constructed across the lower parts of the large landslip mentioned above. The embankment failed as a result of re-activation of the landslip along pre-existing shear planes within the Etruria Formation mudstone, at shallow depth beneath the original ground surface. Additionally, a relatively new light industrial unit located on the slipped mass [852 502] has suffered extensive cracking and associated vertical displacements.

The proximity of the projected A50 road to landslips mapped at Hollybush is known to the site engineers, acting for Staffordshire County Council, and will be taken account of in the planning of the road.

There is a possibility that solifluction flows may have been formed on the steeper slopes of the Etruria Formation, without backscar features, and that, in consequence, no landslip has been mapped. In some cases, also, the lower margins of landslips in the Etruria Formation are likely to be ill-defined due to flow at the toe of the slips, ploughing for agriculture, landscaping or overbuilding. It is recommended that on such slopes investigations are carried out to determine the presence or absence of such slips. Where slip planes are likely to be less than c.5 m deep, trial pits should be dug to expose any relict shear planes and to obtain samples for geotechnical testing so that stability analyses can be carried out to determine the foundation design necessary to ensure the safety of the proposed structure. Trial pits should be logged in detail during excavation. Often shear surfaces are exposed when the bucket of the excavator pulls away the material along the plane of shear, and can be identified by their polished, often slickensided (striated), surfaces. Logging the sides of a pit alone will not necessarily reveal these surfaces. If shear surfaces are suspected at depths below c.5m then boreholes may be required additionally.

All areas of Head deposits should be treated with caution as they may contain relict shear planes. Even sites on low angle slopes are potentially at risk. Surface undulations may indicate recent ground movements which may be reactivated by engineering works. Excavations in Head will require support, and water inflow may cause collapse.

Landslips in the Etruria Formation are not restricted to natural features. Clay quarries at Knutton [8263 4686] and Silverdale [831 460] both show recent arcuate backscars which have formed on the steep slopes of the quarry wall. These overlook a tract in which the mudstones have moved downhill. One of the landslips at Knutton [8268 4676] has involved overlying made ground as well as the Etruria Formation.

4.5 Running conditions

When granular soils (sands and fine gravels) are saturated with water they may flow into excavations or boreholes which are unsupported (Figure 7 gives the location of such deposits). Under high water pressures, the material can enter the excavation rapidly as a fluidised flow. Such situations are described as "running" conditions. Trial pits, trenches and tunnel faces will become unstable and may collapse, and borehole drilling may be hampered. Running conditions have been reported when excavating within the alluvial sands adjacent to water courses and within glacial sands and gravels, which also are well developed in the valley areas.

The presence of potential running conditions should be identified during the ground investigation as it will be necessary to prevent such conditions from affecting construction excavations. Failure to do so will make excavation more difficult or impossible and may endanger plant and personnel. Sheet pile cut-offs, shoring and well-point dewatering (pumping of groundwater from boreholes adjacent to the excavation) have been employed to maintain stable excavations.

4.6 Swelling ground

Swelling takes place when water is absorbed into the lattice structure of expansive clay minerals causing an increase in volume. This process may result in high swelling pressures developing if the soil is confined (say by a foundation) or in the ground heaving. This may result in cracking of foundations and the superstructure, or the disruption of road surfaces. On drying, the soils shrink and decrease in volume, which may result in excessive settlement. Removal or planting of vegetation on expansive soils may cause swelling or shrinkage as the soil moisture content is altered. The problem can affect new developments when soil moisture conditions are altered during construction, or post-construction, if water (say from a leaking water main) is allowed to increase the soil moisture content, or if other conditions are changed.

Remedying the problem after construction is likely to be expensive, so it is important to identify soils with a significant swelling potential during ground investigation work.

None of the site investigation reports studied whilst compiling this report tested for, or referred to, swelling potential. Therefore, there is no available evidence for the Stoke-on-Trent area, on whether swelling is a potential problem there. However, plasticity is a property that commonly is measured during ground investigations on clayey soils. Following work on the mudstones of the Bettisfield Formation near Wrexham (which are similar to the Coal Measures mudstones found in the Stoke-on-Trent area), Entwisle (1989) suggested that where plasticity values are high (liquid limit >60%, plasticity index >35%) tests should be carried out to determine swelling potential. These tests might include the determination of one dimensional swelling pressure, three dimensional swelling strain, as well as shrinkage limit and linear shrinkage. The results should then be related to the soil moisture content and any changes of it likely to be induced as a result of construction activities.

The lack of evidence of foundation problems related to swelling, in the area, should not be taken as indicating either that such problems do not exist or that they do exist, but that they have not been recognised. Such problems may exist and ground investigators need to be aware of the possibility so that the correct testing procedures can be followed where necessary.

4.7 Seismic risk

England is not a highly active seismic area, but for certain sensitive buildings or plants an appreciation of the possible risks is necessary.

Risk from earthquakes

Earthquakes are a major hazard in some parts of the world, but Britain is an area of low seismicity. Most of the shocks felt in the English Midlands over the last century had their epicentres in the east. The nearest considerable earthquake which took place in the West Midlands was centred on Chebsey [860 287] near Stafford (Neilson and others, 1984). The tremor, locally of intensity 7 on the MSK scale, occurred on January 14th, 1916. At Chebsey the shock lasted several seconds and caused chimneys to fall. In Stoke-on-Trent a few chimney pots were dislodged and the vibration was initially taken by many to be due to a colliery explosion. The shock was felt underground in several collieries and safety men were alerted. The shock waves were felt as far away as Lancaster, Bristol and Cambridge.

From time to time the shocks of distant earthquakes have been felt over wide areas of Britain, including Stoke-on-Trent. Like the Chebsey shock, these have their origin some 10 to 15 km below the ground.

A series of tremors were felt in 1975–77, chiefly in the Hanford area, but also at Silverdale and Knutton. With the assistance of the local authorities and of British Coal a study was set up, involving Keele University and the British Geological Survey Global Seismology Unit. An array of seismometers was set up locally (Westbrook and others, 1980). The conclusion was that the shocks were related to the planned, routine collapse behind longwall faces some 900 m underground. The collapses had triggered off changes in the residual stress field remaining in somewhat older, abandoned coal workings closer to the surface, thus causing the tremors.

Courses of action

Seismic shocks can have an enhanced effect on structures built on unconsolidated alluvial silts and clays. Thus those planning new buildings with equipment which needs to be protected, particularly those to be built on the valley alluvium within the conurbation, should be covered by advice on the likely hazards.

A detailed analysis of local seismic risk to major construction projects can be obtained from the Global Seismology Unit, British Geological Survey, Murchison House, West Mains Road, Edinburgh, EH9 3LA.

4.8 Leachates

Fluid leachates are derived by rainfall and groundwater acting on seepages from factory sites or heaps of debris, or from similar action on landfill. This second source, landfill, was mapped during this study and forms the subject of this account.

Two main types of landfill cause leachate problems, namely industrial waste and domestic landfill (Figure 16 and Thematic Maps 4 and 12). The aqueous leachates so derived can seep into surface drainage, causing stream and river pollution. Leachates can also seep into an aquifer. Heavy organic liquids are particularly troublesome since they tend to sink to deep levels in an aquifer, thus causing long-term pollution which can take decades of pumping to dissipate.

The nature of the problem

The nature of the problem is considered in relation to the various types of fill.

The principal occurrences of made ground are delineated on Thematic Map 4 and include several major landfill and waste disposal sites.

Where made ground has been redeveloped or restored, there is little indication of the nature and composition of the deposits. Also, there is no guarantee that the nature of the fill is consistent within a site, either laterally or verti-

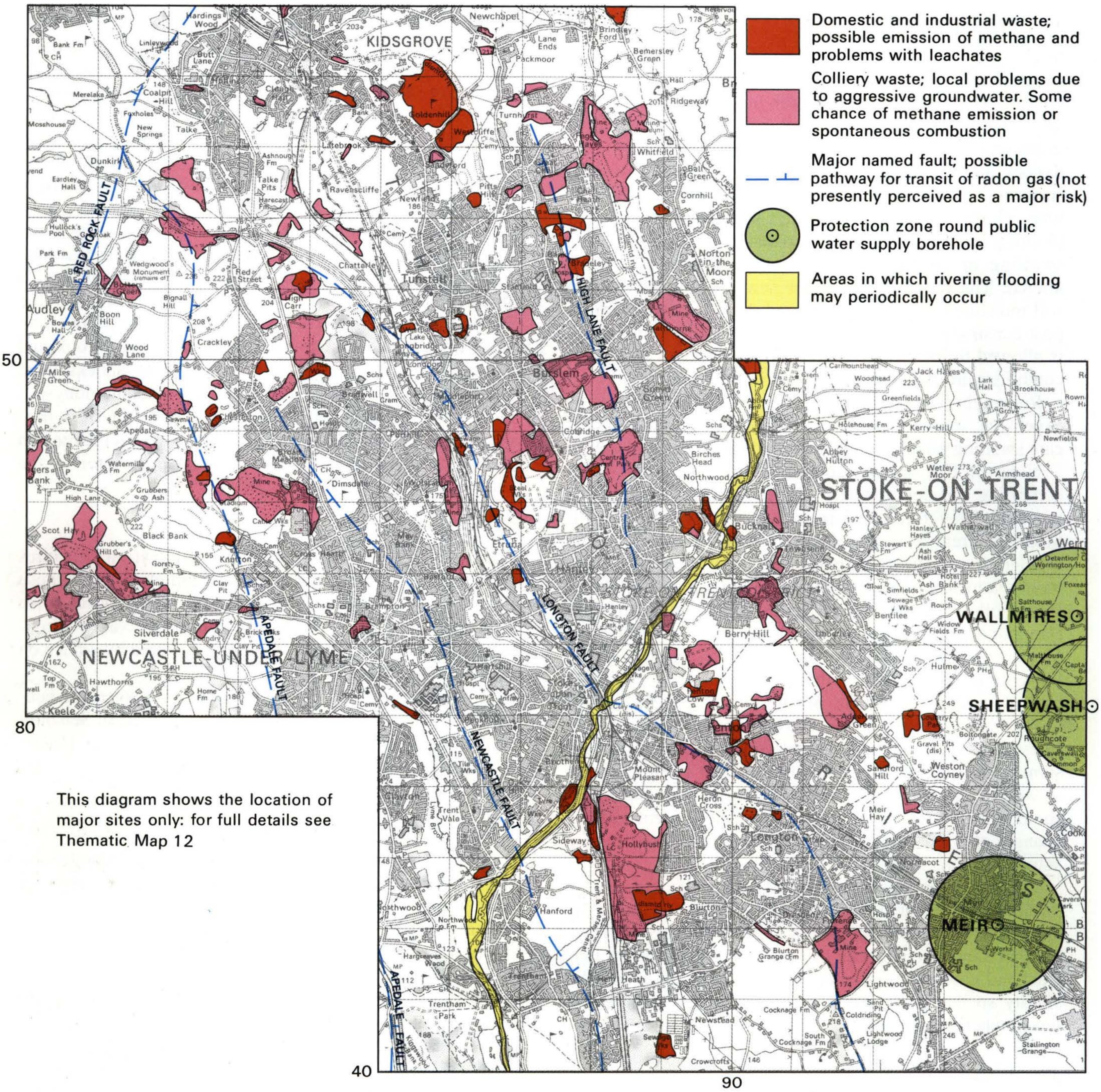

Figure 16 Constraints caused by leachates and gases.

cally. The composition of the fill will need to be ascertained prior to development.

Industrial landfill

Industrial landfill may be potentially chemically active and capable of generating toxic leachates. Leachate from industrial landfill in old quarries in impervious clayey rocks is likely to be contained within the site, provided that the site is not overfilled. The Etruria Formation contains much mudstone and old quarries in this formation have been used for several landfills for industrial waste.

An example of a site in Etruria Formation which has proved troublesome is the former Metallic Tilery quarry [841 498] near Chesterton. This is a 30 m deep excavation in mudstones lacking significant sandstones. The country rocks within the pit itself should be fairly impervious to liquids and gases. This large oval quarry was used during the period 1972–84 as a disposal site, initially unlicensed, but for most of the time it was licensed to take 4 million gallons per annum of liquid waste, as well as a variety of solid waste. The substances disposed of included a variety of inorganic and organic chemicals, paints, dyes, oils, biological waste etc. The site has been filled in such a manner that only the southern back face of the quarry rises above the fill. Despite a clay capping there is a migration of leachate towards one edge of the site, and a pond has had to be built to contain this leachate, which is drained off from time to time. It would appear that some rainwater is entering the tip through the cap and perhaps also off the southern back face.

Another site, currently not giving problems, overlies Coal Measures. Some disposal of industrial waste has occurred in the base of the former glacial drainage channel at Apedale [815 497]. Much of this site is lined by old mine dumps resting on the valley sides, but in the bed of the tipping area there is likely to be some contact with the largely clayey bedrock formations. These rocks contain old footrail mouths in the Cockshead and Hams coals. Whilst this site seems less than ideal, there has not been any reported leachate problem. There is a possibility that unworked resources in the Bullhurst Coal, potentially workable by footrail beneath the Apedale valley, have been put at risk by this disposal site.

Domestic waste

Domestic waste, too, can cause leachate problems. Old quarries in mudstones of the Etruria Formation on the edge of the Apedale valley [826 493] and infilled with domestic waste include several sandstones. There has apparently been some leachate migration into the surface drainage, either through these sandstones or through sandy superficial deposits which abut the western perimeter of the sites.

Former mine workings

Leachate problems can occasionally also be associated with former mine workings. For instance, at Berry Hill the drives of recently built houses are affected by chalybeate (ferruginous) seepage, apparently derived from old workings (Plate 9).

SOME SOLUTIONS TO THE PROBLEM

Whilst the Etruria Formation, in particular, should form a good container in old quarries where sandstones are absent, problems have arisen in practice. In the case of the Metallic Tilery site it would appear that filling right up to the level

Plate 9 Ferruginous Leachate Seepage

Though this is not a common problem from old mine workings, this example has been selected because it shows clearly the effect of an escaping leachate, in this case of chalybeate (ferruginous) character.

of the northern rim of the quarry has permitted migration of leachate, despite the clay capping. A more successful site in similar rocks, situated outside the present area, but worth emulating, is situated at the former Joberns quarry near Aldridge [SK 051 023]. Here the toxic infill is contained in such a way that the old quarry cliff still stands as a raised rim round the entire perimeter of the fill. Monitoring the periphery suggests no leakage.

Tipping on the prime aquifer, the Sherwood Sandstone, poses a potential threat to water quality. Thus the nature of any tipping is closely controlled, following the provisions of the Control of Pollution Act, 1974. Illegal tipping is the main risk here.

Future sites for waste disposal of substances likely to cause severe leachate problems are very limited in number. For instance the working brick-clay quarries at Walleys and Knutton, which may eventually be available for landfill, both have a sandstone floor, and more sandstone in the quarry wall, which would provide migration routes for leachate.

Aquifer Protection Policy

It is a responsibility of the National Rivers Authority (NRA) to ensure that existing and potential groundwater resources are adequately protected. The prevention of quality deterioration is therefore an essential aspect of water resource management.

The risk of pollution of aquifers is increasing both from the disposal of waste materials and from the widespread use of potentially polluting chemicals in the environment by industry and agriculture.

The NRA accepts that disposal of waste to landfill sites is essential and that the choice of available sites is often limited. At the same time it must ensure that the disposal of polluting wastes is avoided in sensitive areas unless appropriate precautions are taken to protect aquifers and rivers from pollution.

An aquifer protection policy was first introduced in 1976 by Severn Trent Water Authority. This has now been revised by the NRA and has the following objectives:

1. To enable the NRA to meet its statutory responsibilities for the protection of groundwater from pollution.

2. To make known the NRA's likely attitude to development proposals to external bodies, most notably the planning and waste disposal authorities.

Under (1) the present legislative controls include:

Control of Pollution Act 1974 (Part 1).

Water Act 1989.

EC Directive on the Protection of Groundwater Against Pollution caused by Certain Dangerous Substances.

Town and Country Planning Act 1971.

The policy recognises four categories of land which require different degrees of protection, depending on the proximity to a public supply abstraction borehole and also the hydrogeological parameters of the various strata types, as follows:

Zone 1 is that area within a 1km radius of existing or designated future groundwater source for public supply but generally excluding those areas where the aquifer is overlain by significant thicknesses of low permeability strata (Figure 16 and Thematic Map 12). These zones will receive maximum protection because any pollution is likely to affect the abstracted water rapidly and significantly.

In Zone 1 the NRA will usually object in principle to all development proposals which would result in, or would be likely to result in, pollution of groundwater. These proposals would normally include:

1. The establishment of waste disposal sites accepting potentially polluting wastes.
2. The building of substantial residential development which could not be connected to a public sewer.
3. Any industrial development which would involve the use, protection, storage or handling of toxic or potentially polluting material unless adequate protective measures are agreed.
4. Development of extensive agricultural activities.
5. The construction of oil and gas pipelines and main foul sewers.

Zone 2 comprises the major aquifers (Figure 17 and Thematic Map 10). These aquifers are already intensively utilised to yield a large proportion of the total public water supply. In the study area this zone encompasses all the exposed area of Sherwood Sandstones excluding Zone 1. They will therefore receive a high degree of protection to ensure that neither their current use nor their future development is needlessly restricted.

Activities to which an objection would normally be made include:

1. Waste disposal sites intended to receive substances hazardous to water supplies, including toxic and oily wastes, many industrial sludges and liquids, biologically degradable domestic and trade wastes, and sewage sludges. However, certain sites would be acceptable providing adequate precautions to minimise leachate generation and migration were agreed.
2. Major industrial or agricultural developments which involve the use, production, storage or handling of toxic or potentially polluting materials, unless adequate protective measures were agreed.
3. The disposal of sewage effluents by aquifer recharge.

Zone 3 comprises the minor aquifers but excludes both Zones 1 and 2 and areas where minor aquifers are overlain by thick drift or impermeable strata. These aquifers at present yield locally important quantities of water and are expected to do so in the future. They have not, however, the potential to be developed to yield major additional water supplies.

In Zone 3 the NRA will normally object to development proposals which would result or would be likely to result in pollution or derogation of licensed or unlicensed sources. Zone 3 includes strata where permeable sandstones are interbedded with impermeable strata (Carboniferous strata, shown in Figures 3, 4). In Zone 3, therefore, consideration of development proposals will be carried out on an individual basis, having due regard to the particular conditions pertaining at the site.

Zone 4 comprises the remaining areas, excluding Zones 1, 2 and 3. Groundwater within this zone is of no regional importance although the numerous small and frequently discontinuous aquifers are utilised for local supplies.

In Zone 4 the NRA will seek to protect all licensed and known unlicensed sources and will only object on aquifer protection grounds to the development proposal which would result in the pollution of an existing groundwater source.

Further details of the Aquifer Policy can be obtained from:

National Rivers Authority (Severn Trent Region)
Sapphire East
550 Streetsbrook Road
Solihull
West Midlands B91 1QT.

4.9 Aggressive groundwater

When the concentration of soluble sulphates present in groundwater and soil exceeds a threshold value, any buried concrete structures will be chemically attacked and weakened unless special cement types are employed. Similarly, where acidic groundwater is found, buried structures and services can be corroded.

The highest soluble sulphate concentrations in the Stoke-on-Trent area have been obtained from strata overlain by made ground which probably contains colliery spoil, known to contain sulphates. Lesser concentrations have been recorded in the Etruria Formation and the Mercia Mudstone. In the latter case, the presence of gypsum/anhydrite (calcium sulphate) veins may be responsible. Acidic groundwater is associated with organic soils (particularly peat).

Ground investigations for new developments in areas underlain by made ground (particularly colliery spoil), alluvial clays, organic clays and peats, and rocks of the Etruria Formation and the Mercia Mudstone (Thematic Maps 3, 4 and 5) should include tests for the sulphate content of the soils and groundwater, and for the degree of acidity, to determine whether sulphate and/or acid corrosion resistant foundation materials are required. Depending upon the sulphate concentration level found, cement type can be selected to resist attack on the basis of recommendations of a report on sulphate resistant cements by the Building Research Establishment (Anon 1986). Five classes are identified in this report, depending upon the level of sulphate concentration, and guidance on the type of cement to select is provided for each class. Metal in foundations may need to be protected from acid corrosion, for example by sheathing, though permanent ground anchors normally will be designed to resist corrosion regardless of whether aggressive groundwater has been proved to be present.

Where chemical damage to the foundations of existing structures is suspected advice should be sought from consulting materials/structural engineers with respect to the need for remedial measures.

4.10 Flooding

The only area designated by the River Authority as at risk from flooding lies along the entire length of the valley of the River Trent (Figure 16, Thematic Map 12). The width of the belt at risk from seasonal flooding averages some 100m, with a local width of up to 260 m. Whilst most of this area has not been built on, the potentially floodable area does include a number of houses in Bucknall [898 477].

4.11 Radon

Radon is a naturally occurring radioactive gas formed by decay of Uranium within rocks.

The extent of the problem

Radon can be a hazard in certain areas where there is flow of the gas into basement or sub-floor areas close to a source rock. This can then seep into houses and give rise to cancer risk. The type of rock with the greatest risk of liberating radon, namely well fractured granite, is not known in the present area.

Large faults with unusually wide shatter belts, like the Apedale Fault, could possibly provide pathways for radon leakage from deep sources. (Figure 16 and Thematic Map 12).

There is perhaps a very slight risk of higher than average radon levels near the outcrops of bands of mudstone with marine fossils in the Coal Measures and Millstone Grit. These mudstones commonly cause a deflection of the gamma log taken in boreholes, due to the higher than average uranium content. Any small radon release is likely to be mitigated, however, by the steep dip of local strata, which carries any slightly radioactive bed underground in a short distance.

Some solutions

Testing for radon gas is best carried out by geochemists who collect samples of gas from the soil using special equipment, prior to testing by radon emanometer in the laboratory. The area has a complex fault pattern which could conduct small quantities of this gas to the surface (Figure 16 and Thematic Map 12 show the largest faults and Thematic Map 5 gives the entire known fault pattern). Should it ever be suspected of being a risk locally it is suggested that soil gas testing be in the first instance carried out across the Apedale Fault, which has a wide fracture belt and large throw. The Geochemical Division of the British Geological Survey at Keyworth, Nottingham NG12 5GG is well equipped to carry out such tests.

4.12 Methane

The nature of the problem

Methane is present in some of the solid rock formations, notably within coal seams, and is also being liberated from tips of minestone, which include coal debris. It is also generated from some landfill sites by organic decay. Methane forms a potentially explosive mixture when present in concentrations of 5–15% in air and is a particular risk in enclosed spaces where a spark can set off a dangerous explosion. The problem is considered in relation to the source of methane, as follows:

Landfill sites

In recent years there has been heightened awareness of the risk of methane generation from landfill sites (Figure 16 and Thematic Map 12). This stems from several incidents in England, notably the explosion at Loscoe, Derbyshire (Aitkenhead and Williams, 1986; Williams and Aitkenhead, 1989). The nature of the risk is summarised in the following key points:

a) The nature of domestic refuse has changed over the years. Much less of it is burned on the kitchen fire and the proportion of biodegradable rubbish has risen.

b) It has been a matter of policy at many British landfill sites in recent years to firmly roll and compact the refuse, to increase the capacity of the landfill and close pathways for vermin.

c) Layers of impervious clay have commonly been spread over the domestic fill at frequent intervals to prevent debris being blown away by the wind.

d) The anaerobic bacteria, the methanogens, operate optimally in a very wet and anaerobic environment. Procedures commonly followed under B and C above have helped to create this anaerobic, wet environment. Successive clay layers have created perched water tables within the tips, hence promoting fuller saturation by water and thus fuller methane generation.

e) The gas generated in highly compacted well rolled fill containing clay layers cannot easily migrate upwards. Instead it tends to migrate laterally out of the landfill, through the surrounding rocks. The best pathways are provided by well-fractured strata, such as sandstones. Examples are known where the gas has migrated 500 m from the site.

f) Gases generated in landfills usually contain 50–65% methane mixed with 35–50% carbon dioxide. Each ton of waste is estimated to generate about 250 m^3 of gas. Methane forms a potentially explosive mixture when present at concentrations of 5–15% in air.

Examples of sites of the type where a methane risk would be likely are as follows:

a) A valley site near Kidsgrove was being infilled with domestic waste during our previous survey in 1961. The surrounding green fields were underlain by Coal Measures, largely mudstones with several coal seams, inclined at 30° to the south-east. In recent years the former green field site has been developed with housing estates surrounding the old landscaped dump which is now an amenity area. However, the country rock is apparently relatively free of thick sandstones which might particularly facilitate migration of gas, and the site is monitored.

b) A 20m deep old quarry in Etruria Formation which was being actively infilled in 1961, is situated near Chesterton [833 499]. This quarry includes both mudstone and sandstone, and the sandstones continue their outcrops to the north-east and south-west of the site. Had housing been built on these outcrops, there would have been substantial risk from gas migration through the well-jointed sandstones. The flanking areas have been largely kept free of development thus far, and it is suggested that this situation be maintained. Whilst we understand that this site has been monitored for methane, we would advise a check that the tests were in fact made on the sandstone outcrop, shown on our map, as well as on the mudstone.

There are a number of other sites, many of them old, which are close to housing (Figure 16 and Thematic Map 12).

Colliery spoil (minestone)

A further aspect of methane generation is the possible risk of emission from colliery spoil (Figure 16 and Thematic Map 19). The in-situ methane content of coal varies from a trace to 25 m^3 per ton. Coal has a low permeability to methane, so that any contained methane can be released over a long period. Thus "the property of coaly material to emit gas over considerable period of time after extraction, has possible implications in connection with the use of colliery waste in land reclamation schemes" (Creedy, 1989).

EMISSION FROM BEDROCK

Methane is continuously liberated from coal mines, but much of it is recovered in the present area by a purpose built methane drainage system and used as an energy source (p.31). The remainder is vented by the mine ventilation systems to secure the safe working of the collieries.

Locally methane can escape to surface, particularly up near-vertical joints and faults in the bedrock. Since the cessation of mining at Wolstanton and Holditch collieries mine water levels are tending to rise. There is a risk that gas present in old mining voids may be forced nearer the surface as the underlying waters rise. Gas could then escape up fissures in the rock formations and possibly be a problem, but we are unaware of any such cases in the area thus far.

The likelihood that methane will be encountered during tunnelling operations in the present area, notably in Coal Measures or in drift deposits overlying them, should be borne in mind. Besides the methane that can be liberated from the country rocks, including coal, methane is soluble in groundwater and can be released from it in air.

SOME SOLUTIONS TO THE PROBLEM

These are classified according to the same scheme as the previous section:

Landfill sites

Currently monitoring of landfill sites is carried out using surface monitoring, gas probes and boreholes dedicated to this task (HM Inspectorate of Pollution, 1989 and Institute of Waste Management, 1989). Control is effected by gas barriers such as synthetic membranes (Krause and Everest, 1989) clay or bentonite linings and grout curtains. Venting is by permeable vent trenches, gas drains, gas wells and gas pumping systems (H.M. Inspectorate of Pollution, 1989).

Tipping in separate cells is particularly advised to minimise lateral migration into bedrock (Needham, 1989).

The United Kingdom disposes of 90% of its waste in landfill compared with 30% in Denmark and 35% in France (Fabry, 1989), so that total UK landfill gas emissions are considerable.

Fortunately, methane generation at landfill sites has been considerably reduced in the study area by the longstanding presence of the municipal incinerator at Sideway, though many landfill sites exist.

Landfill gas emissions are now seen to be undesirable since uncontrolled leakage of methane adds to the 'greenhouse effect'. When landfill gas is burnt two important 'greenhouse gases' are destroyed, methane and chlorofluorocarbons (CFC's). The resultant carbon dioxide also contributes to the greenhouse effect, but in a markedly smaller degree. Currently the Department of Energy is seeking to increase the number of schemes for methane utilisation from landfill in the United Kingdom (Fabry 1989, and numerous other papers given in the same conference) so that as much landfill gas as possible is collected as an energy resource. Pipework for gas extraction is placed during the tipping process and there are cappings and membranes or cut-off trenches to diminish leakage. Currently the energy from the gas is used to fire kilns, generate electricity and run boilers (Brown 1989).

Colliery spoil

In cases where buildings have been constructed on thick colliery spoil with a high coal content, monitoring for methane in confined spaces, particularly beneath floors, is indicated.

Emissions from bedrock

Such emissions have occurred locally, but there is risk of confusion with biogenic methane. The gases are chemically distinctive, however, and expert advice will usually define whether the source is bedrock or landfill. Solutions include monitoring and active venting from below the floors of buildings. Possible future problems associated with rising water levels in abandoned mines, which may force gas closer to the surface, should be borne in mind.

4.13 Spontaneous combustion

Colliery waste tips (Figure 16 and Thematic Map 12) containing unburnt discard may be susceptible to spontaneous combustion if:

a) they contain sufficiently high combustible carbon content to provide a fuel (generally over 25% coal)
b) they have a sufficiently high iron pyrites content, the oxidation of which generates the heat for spontaneous combustion,
c) there is sufficient availability of oxygen to sustain the combustion.

If other sources of heat are available the presence of iron pyrites may not be necessary.

The presence of red ash in the minestone may provide evidence of tips having caught fire in the past. For example, in 1961 the Parkhouse tip, then part of a working colliery, was on fire.

The problem is sometimes encountered when old tips are reclaimed (Bell 1977). Spontaneous combustion also may give rise to subsurface cavities within the tip, and burnt ashes may cover red hot zones. Further, there is the danger of explosion if a cloud of coal dust is formed near a hot surface during reworking and noxious gases (for example carbon monoxide, carbon dioxide and sulphur dioxide) are emitted from burning spoil.

When engineering works are carried out within colliery waste tips, specialist advice should be sought from consulting mining engineers or from British Coal, to assess the risk of spontaneous combustion. British Coal (Anon 1973) recommend digging out, trenching, blanketing, injection with non-combustible material and water, and water spraying, as ways of controlling spontaneous combustion. When utilising unburnt colliery spoil as a fill material, compaction of embankments and shallow slopes is necessary to reduce the amount of available oxygen, so preventing the likelihood of combustion. The slope faces should be protected with a thicker than average cover of clay or top soil.

5 CONCLUSIONS AND RECOMMENDATIONS

There has been a long history of active mineral extraction in the Stoke-on-Trent area. It is important now to protect the remaining mineral resources.

It is also important to recognise constraints on planning set by the varied types of bedrock, superficial deposits, made ground and old mineral workings.

5.1 Mineral extraction

FUTURE COAL EXTRACTION This is likely to be in the workings of Trentham and Silverdale collieries, with most of the active mining taking place south of the present area (Figure 17). Coal remains untouched beneath the Keele University campus, but it is likely that much of it will be left to protect Keele Hall, a listed building. Other untouched areas lie close to the City hospitals, where there is likely to be need for a pillar of support.

A few small mines are likely to carry on working the western ground, mostly in narrow panels of coal. Likely resources of Bullhurst Coal beneath the Apedale valley will probably now be unsafe to work due to the presence of the disposal site for industrial waste in the valley bottom. There is probably potential for a further small mine in the Bullhurst Coal, south of Werrington, in the east.

There is still a potential for opencast coal extraction on the western and eastern rural fringes of the coalfield. Currently two large sites are active, at High Lane and Brown Lees. The recently backfilled opencast at Red Street involved the reclamation of land strewn with mine dumps and abandoned mine entries. A similar transformation is taking place at High Lane.

CLAYS FOR BRICK AND TILE MANUFACTURE Currently the main source of clay is the Etruria Formation. Quarries are mostly located in the middle and upper parts of the formation, with the exception of Fenton Manor in the lower division. The principal future resources in the project area are north of Silverdale in the middle division and at Lightwood in the upper division (Figure 17). It is recommended that these areas in particular be protected against overbuilding.

There may be scope for planned extraction of brick clays in tandem with opencast coal excavation. Certain horizons which were greatly sought after for brick clay in the past are being opencasted and jettisoned. The factory processing grey Coal Measures clays is still in production at Birchenwood, using a mixture of local and brought-in mudstones.

SAND AND GRAVEL Substantial resources of gravel remain in the Sherwood Sandstone south of Werrington and it is advised that they be protected from overbuilding. Further resources of alluvial gravel exist in the Stoke-on-Trent area, but much is buried beneath variable thicknesses of silty river alluvium. A considerable part of these buried resources is now overbuilt and it is probably not worth protecting the remainder as a resource. Should they ever be worked, a dredger would probably be necessary.

WATER Resources of water from the chief aquifer, the Sherwood Sandstone, have been extensively utilised for public extraction in the east. Resources remain in the northwest, but extraction for public supply takes place farther south in this same aquifer, outside the limits of the area.

Other economic minerals are building stone, ironstone, oil and gas, but none appears to be in any need of protection.

5.2 Geological factors affecting foundations

COMPRESSIBLE SOILS The tracts of alluvium in the Trent valley and the vale of Etruria are identified as compressible clays and silts with sporadic peat lenses. Ground treatment by reinforcement of the alluvium by vibroflotation techniques may be needed. Alternatively end bearing piled foundations may be used to transfer loads to more competent strata, commonly sand and gravel, beneath the alluvium.

Differential compaction of made ground in infilled abandoned clay pits poses a risk to constructions if they bridge the contact between the more compressible fill and the quarry walls. Efforts have been made to outline these old quarries on the Made Ground thematic map, using archival sources.

LANDSLIPS These are chiefly in the Etruria Formation and have caused some damage to constructions near Bradwell Wood [862 473]. Other, smaller landslips in Etruria Formation have been mapped at Hollybush [896 436], 80m south of the projected A50 Blythe Bridge to Queensway road. Failures have also occurred on the steep slopes of some clay pits in Etruria Formation. It is advised that no building takes place on mapped landslips and that steep slopes in Etruria Formation be treated with caution. These slopes may contain solifluction lobes which have not been recognised by us and it is advised that trial pits be dug on such slopes in order to expose and detect any shear planes, prior to any development. Deposits of Head are also likely to contain shear planes.

SWELLING GROUND AND RUNNING CONDITIONS These two further factors are dealt with in the section on Constraints to Development (p.42–43).

A further BGS report (WN/90/11) dealing with the engineering geology of this study area, based on a perusal and computer analysis of many site investigation reports, is available from the British Geological Survey, Keyworth, Nottingham, NG12 5GG.

5.3 Geological factors affecting safety

These are largely dealt with in the section on Constraints to Development. The main themes are re-emphasised here:

MINING SUBSIDENCE Effects due to recent mining are now diminishing, since most of the recent winnings are south of the present area. The main risks are posed by deterioration and collapse of pillars of support in long abandoned, but relatively shallow workings. It is recommended that for major projects, precautions be taken in the area outlined on Figure 8 and Thematic Map 7 as having workings likely within 30 m of the land surface. Enquiries about charted workings should be addressed to the Area Survey-

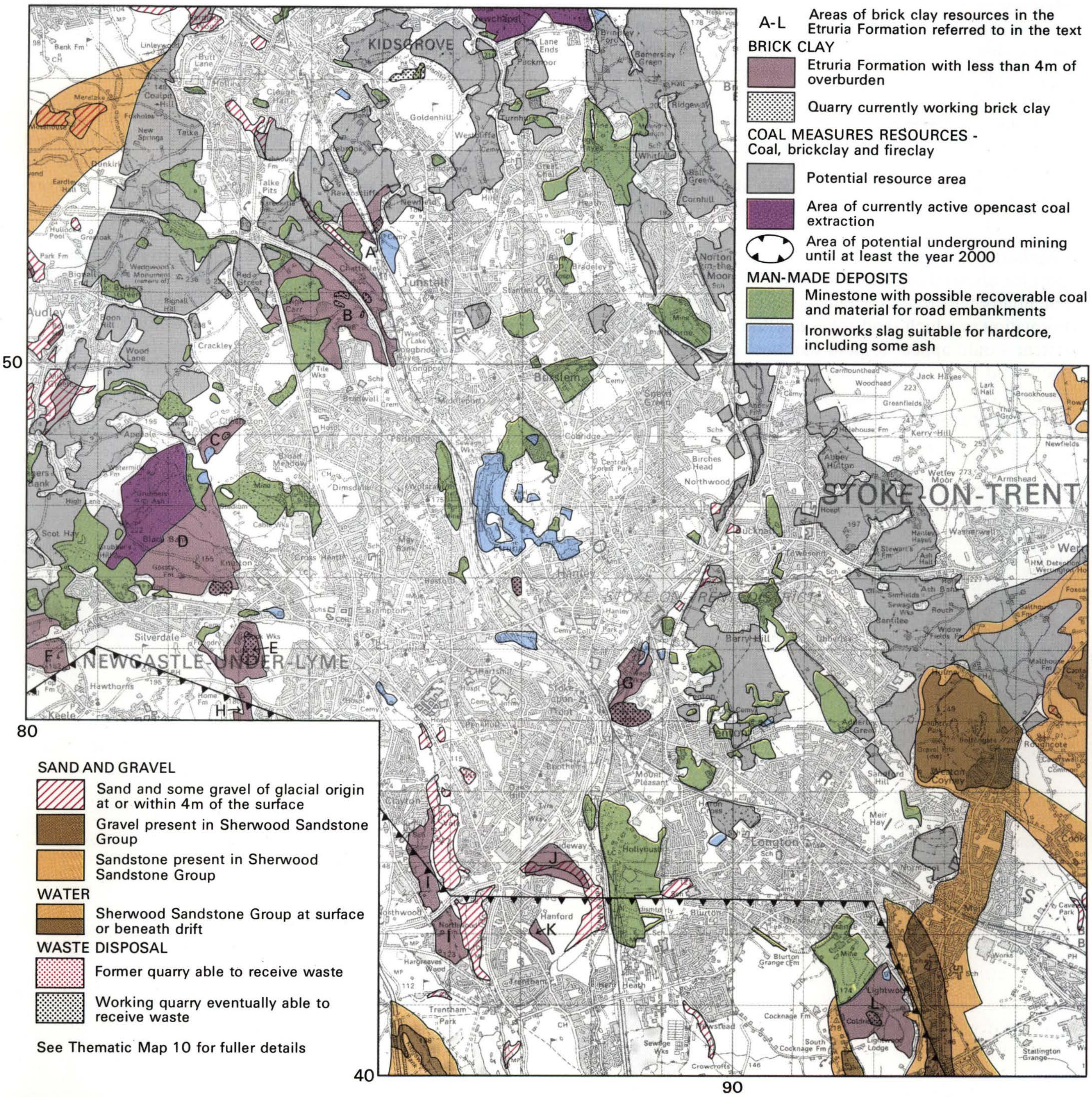

Figure 17 Resources

or, British Coal Corporation, North West Group, Gadbrook Park, Rudheath, Northwich, Cheshire CW9 7RA. A site investigation to locate buried coal seams and shallow old workings is usually advisable in this area of likely shallow workings. In some cases shallow old voids have necessitated an underground cementation programme. Further risks are posed by the presence of old shafts and footrail entries, the bulk of which are known to British Coal.

Made ground Besides the problem of compressible soils outlined above, various risks attach to the nature of the fill. These are chiefly:

Spontaneous combustion This problem relates to colliery tip material (Figure 17) where there is some risk of spontaneous combustion during excavation, handling and placing of minestone if there is a sufficiently high coal content (usually over 25%).

Methane emanation Whilst this can occur from colliery tip material, the greater risk probably comes from waterlogged domestic waste. Recent events in other areas have shown the necessity to monitor former and active landfill sites. Sandstones in particular have acted as pathways for the gas and it is recommended that, when undertaking gas monitoring, samples are taken from the sandstone outcrops as well as the mudstones. Should sampling solely be taken in mudstones flanking the landfill, a falsely reassuring picture of apparent lack of gas migration could be built up.

Leachates There do not appear to be any totally safe sites for disposal of dangerous waste in the present area. As potentially watertight containers, disused pits in the Etruria Formation in which sandstones are thin and laterally impersistent would appear to hold the most promise. In practice such a pit has given leachate problems. If such sites must be used it is suggested that the toxic infill is contained in such a way that the old quarry cliff still stands as a raised rim round the entire perimeter of the fill. An example of a pit apparently successfully filled in this way is outside the present area at Aldridge, near Walsall. This is the former Joberns quarry in Etruria Formation [SK 051 023].

Aggressive groundwater High concentrations of sulphates in groundwater, which may attack cement, have been noted near areas of colliery waste, from which the contaminants are probably derived. Sulphate resisting Portland Cement is indicated in such circumstances.

SEISMIC RISK Whilst this area appears to be of low seismicity, the local tremor in 1916 at Chebsey, only 11 km to the south of the area, shows that earthquakes are possible. For high-rise or sensitive structures a detailed analysis of local seismic risk can be obtained from the BGS Global Seismology Unit, Murchison House, West Mains Road, Edinburgh, EH9 3LA.

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APPENDIX I
NOTES ON THE THEMATIC MAPS

This section is included as a guide to the way the maps have been assembled and as an acknowledgement of the sources of information on which they are based. Comments on their content are also included.

MAP 1 Distribution of records (boreholes, shafts and trial pits)

This map is a computer generated printout. It shows the sites of borehole records currently held in the paper-based records system at the National Geosciences Data Centre at the British Geological Survey, Keyworth. All boreholes are shown, both non-confidential and confidential, excepting boreholes sunk to prove opencast coal.

Boreholes and trial pits under 10 m deep are shown in one category; these are almost all for site investigation purposes. The remainder, over 10 m in depth, include the deeper site investigation boreholes, and all other boreholes. Shafts and British Coal boreholes which start underground are shown by special symbols.

Whilst we have been able to greatly augment our borehole database by means of an extended search, a large number of such records have only been given to us on the understanding that their information is kept confidential. Whilst the records of these boreholes have been extensively used in drafting the geological and thematic maps, it is clear that specific information from such boreholes cannot be made available to third parties. Records of non-confidential boreholes and their sites can be inspected by prior arrangement at The National Geosciences Data Centre, Keyworth, Nottingham, NG12 5GG (telephone 0602 363100).

Acknowledgements are here made for the great help given in the search for additional records. Data came from five main types of source:

a. The existing database of BGS which has been built up over 150 years.
b. British Coal. Extra records and maps have been provided by the Area Geologist for Deep Mines at Trentham and for Opencast at Staffordshire House, Berry Hill Road, Stoke-on-Trent, ST4 2NH.
c. Local and County Authorities. Extensive datasets have come from the City Engineer at Stoke-on-Trent and Newcastle-under-Lyme and the Chief Highway Engineer and Chief Architect at Stafford.
d. Site investigation companies, including mining engineers. Extensive datasets have kindly been given by Wardell Armstrong, Strata Surveys, Subsoil Surveys and Scott Wilson Kirkpatrick. Other valuable datasets came from Wimpey Laboratories, Travers Morgan, Manchester Geotechnical, Georesearch, Geotechnics, Mouchel and Partners, Sir William Halcrow and Rigby and Partners, amongst others.
e. Brick and tile companies. Steetley Building Products have kindly provided us with many borehole records, besides access to cored samples.

The British Geological Survey would like to thank all other firms and organisations which assisted in the search for additional data.

MAP 2 Thickness of superficial deposits

This map shows the drift-free areas which lack significant superficial deposits. The remaining area, covered by superficial deposits, is contoured for drift thickness at 2 m intervals. The contours show the total thickness of till, glacial sand and gravel, all forms of river alluvium and head. The thickness of made ground is excluded from the data used to draw the contours.

Data for contouring come chiefly from boreholes, supplemented by visible sections in quarries and on valley sides. The drift is thickest in the glacial drainage channels and on the Cheshire Plain in the north-west.

Unfortunately, it has not proved possible to include the data points, due to the high proportion of confidential borehole records involved. All relevant records have been used in the compilation, but their sites are not shown on this map. Inevitably the quality of the contouring depends heavily on the density of useful borehole data, and is therefore variable from place to place.

MAP 3 Distribution and engineering geology of superficial deposits, geomorphology

This map shows the deposits at surface left by the Devensian ice age and the valley alluvium deposited by streams and rivers since the ice melted. The map was compiled from the 1988–89 geological surface survey, supplemented by borehole records.

The patchy nature of the till sheet left by the ice is well shown, with drift-free areas tending to occur on the higher ground. Whilst the ice was melting, water escaped southwards via drainage channels, partly buried beneath the present-day valleys. The centre lines of these channels are shown (compare with the Drift Thickness Map) and deposits of sand and gravel at the sides and mouths of the channels are also depicted on the map. In the south and east a hill-creep deposit, called 'head', consisting of local stones in a sandy clay matrix, has been locally mapped.

In the drift-free areas the harder sandstones form escarpments which are shown on the map. Among the sandstones forming the most persistent escarpments are the Chatsworth Grit, Ten-Feet Rock, sandstone above the Bungilow Coal, the basal sandstone of the Newcastle Formation and the Sherwood Sandstone.

The engineering geology aspects are here discussed in conjunction with Map 9.

MAP 4 Distribution of made ground

This map has been compiled from field surveys, borehole and archival data. Where possible the type of made ground has been defined, but there are many areas in which the type of fill is not known, or is so mixed that it cannot be simply classified.

Probably the easiest areas of Made Ground to locate are the numerous colliery dumps, which are usually upstanding constructional features with clearly defined margins. In contrast, some types of fill occur in old clay quarries. The fill has frequently been spread beyond, and therefore conceals, the former margins of the abandoned quarry. It has been decided to outline the margins of such quarries on the Made Ground map, but it must be stressed that these outlines are approximate. The outlines are derived from successive geological surveys by BGS in 1898, 1943–45, 1961–63 and 1988–89 and their respective topographical base maps at 1:10 560 and 1:10 000 scale. In addition, base maps from the following topographic surveys have been consulted at the Archive Section of Staffordshire County Council: 1890, 1900-02, 1920.

The kind assistance of the Chief Waste Disposal Officer of Staffordshire County Council is acknowledged. A 1:10 000 map of waste disposal sites in Stoke-on-Trent has been particularly useful and records have been made available from the area around Newcastle-under-Lyme.

It should be stressed that the composition of any given category of fill cannot be guaranteed. In particular the absence of chemical waste in any given tip cannot be vouched for.

MAP 5 Solid geology

This is a somewhat simplified version of the 1:10 000 geological map, reduced to 1:25 000 scale. This map is based on a complete resurvey in 1988–89 by J G Rees, R G Crofts, A A Wilson, A S Howard and J G Buchanan. In an urban setting exposures change rapidly and many important observations from previous surveys have been incorporated in the new map. These earlier geological surveys were by C E DeRance, W Gibson and C B Wedd in 1895–1900, F W Cope and J R Earp in 1941–45 and by W B Evans and A A Wilson in 1960–62. Aerial photographs at the 1:10 000 scale, flown in 1982 for Staffordshire County Council, have been used extensively during the present mapping.

MAP 6 Surface mineral resources

This map shows resources which can be quarried at surface. These comprise brick clays, refractory clays, coal, sand and gravel. Besides the key to the map, the section in the report on Resources gives extra information.

The blank strip running through the area of Coal Measures resources lies between the Moss and Twist coals and is commonly deficient in workable seams. However, locally seams within this corridor are thick enough to be considered for opencast working.

The kind assistance of Steetley Building Products Ltd and of British Coal are here acknowledged.

MAP 7 Mining

This map shows the area undermined at April, 1990 compiled from 1:10 560 reductions of mine plans, supplied by the Area Surveyor, British Coal, supplemented by 1:10 000 plans of the latest workings. Compilation of the total mined area shown on these plans has been by BGS, but we cannot accept any responsibility for any errors or omissions in the compilation. For any specific development scheme it is always important to consult the Area Surveyor, British Coal Corporation, North West Group, Gadbrook Park, Rudheath, Northwich, Cheshire CW9 7RA.

Prior to 1872 there was no legal compulsion to make mine plans, or to lodge them with the Mining Record Office. Hence there are many uncharted workings, usually of a shallow nature. Whilst most of these will already overlie ground marked as undermined at lower levels, there will inevitably be a few small areas where there are old workings, in areas not shown as undermined on the map. This particularly relates to a strip in the north- east where no workings have been plotted.

Additionally on this map a line has been drawn to show the area in which there is a high risk of encountering mine workings within 30 m of the ground surface. This leaves a substantial area in the south and north-west where there is a very low possibility of workings within 30 m of the surface. This is due to the thickness of cover of Barren Measures.

Acknowledgement in preparing this map is made to the survey and small mines departments of North West Group, British Coal, and also the Parklands Colliery Company.

MAP 8 Slope steepness

The slope steepness map was derived from the contour information shown on the 1:25 000 scale Ordnance Survey topographic maps, which display contours at 8 m vertical intervals. From the spacing of the contours, it is possible to calculate the general steepness of the slope between any two contour lines by trigonometry. Some error is incorporated in this technique in that detailed variations in the slope steepness between contours cannot be detected. Also, the direction in which the ground slopes can, in some areas, be difficult to appreciate on the map by a depiction of slope steepness alone. Therefore, slope direction arrows have been included on the slope steepness map to clarify this ambiguity. For cartographic clarity, the slope steepness has been displayed in steepness classes. Grouping into classes reduces the level of detail which can be displayed, but allows a meaningful and 'uncluttered' regional presentation of slope zones to be made at the 1:25 000 map scale. In addition, the values of slope steepness that have been chosen as class boundaries are generally considered as marking bounding values for various development, construction and other land-use purposes. For example, a slope of 1 in 5 (11°) is often considered as a planning boundary for urban (constructional) and large-scale industrial site development. Therefore, this has been included as one of the slope class boundaries on the map. The slope classification adopted for this study is shown on the map legend, where the class boundaries are presented both in degrees and as a gradient ratio. The general significance of the slope steepness classes for various land uses is presented in the table on Thematic Map 8.

The slope steepness map indicates the wide range of slope angles (classes) which occur within the study area and, particularly, the presence (although limited) of some very steep slopes, i.e. above 15°. Steep slopes and flat ground may both present some problems for planning and development. In most cases, the steeper slopes will tend to provide better-drained conditions but may have vehicular access problems. Flatter ground may have drainage problems, particularly if low-lying or underlain by clay lithologies of low permeability (for example, superficial clays and mudrocks). The slope steepness map also locally shows several slope classes in the steeper groups (in excess of 7°) running close together, indicating where ground slopes are changing in a short distance and are therefore possibly the most difficult and/or costly to develop. The present areas of ground which fall into slope classes of 3°–7° and <3°, provide no major constraints to urban expansion.

Natural slope instability has been recognised on slopes greater than 11° underlain by the Etruria Formation. Modification as a result of engineering works may adversely alter the conditions controlling slope equilibrium and trigger further mass movements. Similarly, proposed works on presently stable slopes underlain by mudrocks may lead to oversteepening and induce failure.

MAP 9 Engineering geology of bedrock

The distribution of engineering geology units across the study area is shown on two Thematic Maps, namely Map 3 for superficial deposits and Map 9 for solid (bedrock) geology. An engineering geology unit comprises geological units with similar geotechnical properties. This grouping into engineering geology units was carried out by examining geotechnical data and engineering comments extracted from 166 site investigation reports on sites located in the study area. The geotechnical information is not necessarily representative or comprehensive. For some formations (for example, the Mercia Mudstone) data are limited to those from a small number of boreholes. The geographical spread of data across the outcrop and subcrop areas of most formations is also limited, with the exception of grey Coal Measures strata.

Although the engineering geology of bedrock map is based on the mapped stratigraphic boundaries, these are not all necessarily relevant to the engineering geological units. For example, the differentiation of strata into Lower, Middle and Upper Coal Measures on the geology map is not maintained, and all argillaceous strata fall into the engineering geology unit 'Mudrocks'. The sandstones have been placed into the engineering geology unit 'Strong Sandstones' which also contains the strong sandstones of the Etruria and Newcastle Formations. In this manner, areas of bedrock deposits of similar engineering behaviour are shown on Map 9, and for drift deposits (soils) the engineering geology units are presented on Map 3.

In total, ten engineering geology units have been distinguished, four comprising superficial deposits (Map 3), six comprising bedrock formations (Map 9). Some gradation between the states of rock and soil (in engineering terms) occurs in the case of the highly to completely weathered mudrocks of the Lower to Upper Coal Measures, which weather to a soft stiff silty clay. Because the mudstones of the Etruria Formation have been strongly weathered to a greater depth than those of the Coal Measures, they behave as soils and have therefore been placed in a different engineering geology unit.

MAP 10 Resources

Brick clay resources in the Etruria Formation are identified on this map, with the currently working quarries.

The anticipated area in which future deep coal mining operations may take place in the next decade is shown, using data provided by British Coal. Areas of Coal Measures resources, including brick clay, coal and fireclay, are shown. Active areas of opencast coal extraction are indicated. Areas of colliery waste are a possible resource for reclaimed coal and also material for road embankments.

Areas of potential gravel resources are identified as well as areas of Sherwood Sandstone and glacial sand with some gravel. Fluvioglacial gravel underlying valley alluvium within the conurbation has not been included since it is mostly overbuilt.

MAP 11 Ground stability constraints

This map combines information from several other thematic maps and focuses on areas with the possibility of old mine workings at shallow depth, on an assessment of the areas with steepest slopes, and of landslipped areas. Other possible difficulties due to soft ground and deeply infilled sites with potential settlement problems are identified.

MAP 12 Constraints caused by leachates and gases

Landfill sites of domestic and industrial waste which could generate methane gas are noted. These were plotted with the assistance of records held by Staffordshire County Council Waste Disposal Department. Areas which could generate leachates are shown and the protection zones around water abstraction boreholes identified. Landfill occasionally liable to spontaneous combustion is shown. River valleys prone to periodic flooding are also delineated.

APPENDIX II
LIST OF ACTIVE MINES, OPENCAST SITES AND QUARRIES

(I) MINES — BRITISH COAL, NORTH WEST GROUP

Florence Mine [915 418]
Hem Heath Mine [887 415]
These mines, worked as one unit named Trentham Colliery, are currently active in the Great Row, Rowhurst, Yard, Hams and Bowling Alley seams, all to the south of the present area. Only the Winghay Coal is currently being worked in the study area, beneath Trentham Park.

Silverdale Mine [818 468]
Currently working Great Row and Cannel Row coals south of the present area.

(II) LICENSED MINES (FOOTRAILS)

Acres Nook Mine [840 529] Europa Minerals Group plc
Working Rowhurst Coal

Apedale Mine [823 484] Floyd Coal Ltd — Great Row Colliery
Working Great Row to Bassey Mine coals

Bank Top Farm Mine [800 467] Floyd Coal Ltd — Great Row Colliery
Working Rowhurst Coal

Haying Wood No. 2 Mine [802 469] J A Knight (Coppice) Ltd.
Working Rowhurst Coal

Little Sherriff Mine [809 472] Apedale Hall Colliery Co. Ltd.
Working Winghay Coal

Parklands Mine [808 491] Parklands Colliery Co. Ltd.
Working Bullhurst and Cockshead coals

(III) OPENCAST SITES — BRITISH COAL OPENCAST, CENTRAL WEST REGION

Brown Lees [870 549]
Ten Feet to Black Mine Coal

High Lane [820 480]
Twist to Rowhurst Coal, Great Row to Blackband Coal

(IV) BRICK CLAY QUARRIES, IN COAL MEASURES

Birchenwood [855 540] Steetley Building Products Ltd
Working beds from Burnwood to Bungilow Coal

(V) BRICK AND TILE CLAY QUARRIES IN ETRURIA FORMATION

Apedale South [826 489] Steetley Building Products Ltd

Chatterley [847 508] J Kimberley and Sons Ltd

Chatterley [844 509] P Powell

Fenton Manor [883 451] Steetley Building Products Ltd

Goldendale [851 519] P Powell

Knutton [826 468] Steetley Building Products Ltd

Lightwood [921 408] Daniel Platt and Sons Ltd

Walleys [832 460] Steetley Building Products Ltd.

APPENDIX III
LIST OF CONSERVATION SITES

a. Geological Sites

SSSI — Site of Special Scientific Interest — awaiting notification

Metallic Tileries [840 498]
Junction of Etruria and Newcastle formations, limestone with algae, mudstone with mussels.

Hulme Quarry [925 445]
Disused quarry in conglomeratic sandstones in the Hawksmoor Formation (Sherwood Sandstone Group).

RIGS — Regionally Important Geological Site

Kidsgrove Brickworks Quarry [855 542]
In abandoned part of quarry. Sandstone below the Twist Coal.

Bradwell Wood Quarry [843 504]
Disused quarry in Etruria Formation capped by Newcastle Formation.

Quarry Bank Quarry [807 461]
Purplish grey Hanchurch Sandstone in Keele Formation 1 km to east becomes grey and passes laterally into Newcastle Formation.

Job's Wood Quarry [823 460]
Grey Hanchurch Sandstone in Newcastle Formation.

Trentham Park/Kingswood Bank [854 403]
Disused quarries in conglomeratic sandstones in Hawksmoor Formation (Sherwood Sandstone Group).

Geological site worthy of preservation

Apedale Wood [812 494]
Vanderbeckei Marine Band, junction of Lower and Middle Coal Measures.

b. Biological Sites, with comment on the geological setting

SSSI — Site of Special Scientific Interest

King's and Hargreaves Woods [860 402]
Ancient and semi-natural woods. King's Wood on gravelly soils from Hawksmoor Formation (Sherwood Sandstone Group). Hargreaves Wood on sandy and clayey soils, derived from Keele Formation, with some boulder clay.

SSSI — Site of Special Scientific Interest — awaiting notification

Ford Green Reed Bed [887 510]
Reed bed in subsidence-related hollow in valley bottom alluvium.

LNR — Listed Nature Reserves (proposed) and Country Park

Goldendale Ponds [851 513]
Pool with surrounding scrub. Pools surrounded by made ground on alluvium.

Ford Green [887 510]
Valley alluvium, till and Middle Coal Measures. Includes special interest areas of Ford Green Reed Bed [887 510] and Chatterley Whitfield [884 516].

Westport Lake [855 502]
Area of ornithological interest. Pool initially formed by mining subsidence now surrounded by made ground resting on valley alluvium.

Park Hall Country Park [930 450]
Mostly on Hawksmoor Formation (Sherwood Sandstone Group) and some made ground. Includes special interest areas of Park Hall [923 444] and Hulme Quarry [925 445].

Staffordshire Wildlife Trust Reserves

Parrot's Drumble [820 522]
Rich deciduous stream valley woodland. Till at least 15 m thick with thin alluvium in valley bottom.

Hem Heath Wood [885 409]
Mixed woodland planted 120 years ago. Till up to 9m thick on mudstones of Keele Formation.

RIBS — Regionally Important Biological Sites

Situated on 1:10 000 SJ 84

Apedale [818 496]
Pools with marginal plants and sallow carr. Birch/willow scrub in drier parts. Pools margined by dumps of spoil from the disused Burley Pit, Apedale collieries.

Burley Farm [824 491]
Emergent vegetation around north end of pool. Area of made ground around pond includes clay, hardcore, roof tiles and some blast furnace slag.

Gresley Canal [823 488]
Area of fen with some pools and wooded areas. Area of made ground.

Hayes Delph Wood [801 487]
Area of mine spoil with healthy colonisation. Spoil of disused Podmorehall Colliery mounds.

Watermills Wood [816 485]
Small area of oak dominated woodland in steep sided valley. Middle Coal Measures, mostly mudstones.

Chesterton Old Ironworks [824 482]
Spoil and brick mounds with dense scrub, open grassy areas and marshy depressions. Made ground, colliery waste, ironworks slag to north.

Trentside [883 454]
Pool with some emergent vegetation, formed by Trent when in flood, of ornithological interest. Valley alluvium.

Dark Wood [856 430]
Area of broadleaf woodland on east-facing slope. Mudstone of Etruria Formation.

Ash Green [869 409]
Strip of open woodland along the Longton Brook; ground flora with uncommon and rare species. Valley alluvium close to the brook, flanked by slopes in glacial sand and gravel and till.

Situated on 1:10 000 map SJ 85
Harecastle Clump [836 524]
Mature and relatively recent birch/oak wood on hillside with some planted turkey oak. Mainly mudstones in Middle Coal Measures.

Target Wood [835 521]
Mature mixed deciduous woodland with oak dominant in most parts alongside rough meadow. Mainly mudstones in Middle Coal Measures.

Chatterley Whitfield [884 516]
Grassland. Till on Middle Coal Measures.

Holden Bridge Pools [894 502]
Pools and marshes forming a rich site for birds. On valley alluvium surrounded by made ground.

Situated on 1:10 000 map SJ 94
Jack Hayes Marsh [918 499]
Acidic flush with diverse flora near stream. Till over uppermost Millstone Grit.

Wetley Moor [433 487]
Area of mixed moorland. Thin till overlies uppermost Millstone Grit, lowermost Coal Measures.

River Blythe [942 449]
Marshy ground.
River alluvium.


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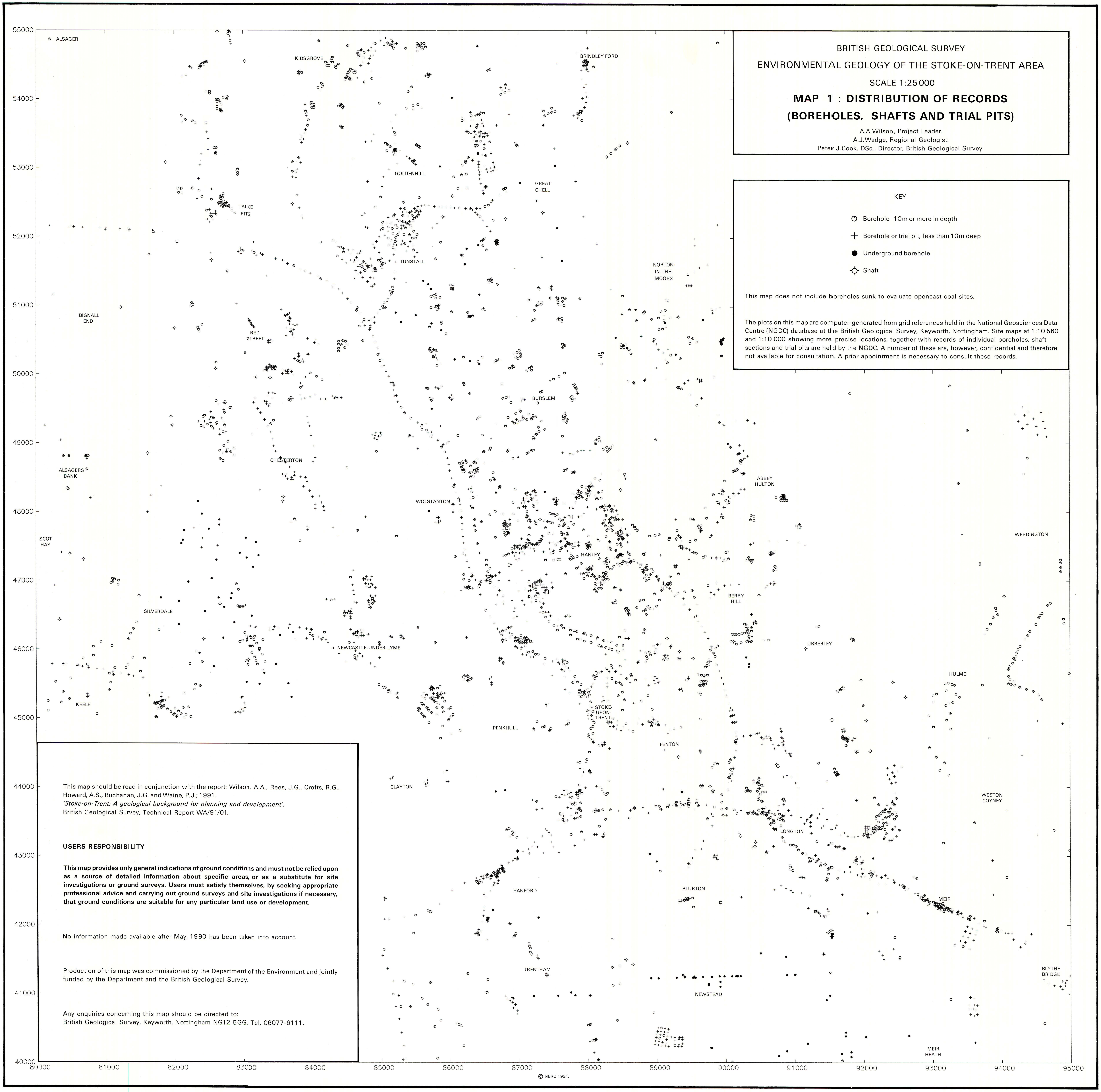
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 1 : DISTRIBUTION OF RECORDS (BOREHOLES, SHAFTS AND TRIAL PITS)

A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey



KEY

- Borehole 10m or more in depth
- Borehole or trial pit, less than 10m deep
- Underground borehole
- Shaft

This map does not include boreholes sunk to evaluate opencast coal sites.

The plots on this map are computer-generated from grid references held in the National Geosciences Data Centre (NGDC) database at the British Geological Survey, Keyworth, Nottingham. Site maps at 1:10 560 and 1:10 000 showing more precise locations, together with records of individual boreholes, shaft sections and trial pits are held by the NGDC. A number of these are, however, confidential and therefore not available for consultation. A prior appointment is necessary to consult these records.

This map should be read in conjunction with the report: Wilson, A.A., Rees, J.G., Crofts, R.G., Howard, A.S., Buchanan, J.G. and Waine, P.J.; 1991. *'Stoke-on-Trent: A geological background for planning and development'.* British Geological Survey, Technical Report WA/91/01.

USERS RESPONSIBILITY

This map 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 carrying out ground surveys and site investigations if necessary, that ground conditions are suitable for any particular land use or development.

No information made available after May, 1990 has been taken into account.

Production of this map was commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey.

Any enquiries concerning this map should be directed to:
British Geological Survey, Keyworth, Nottingham NG12 5GG. Tel. 06077-6111.

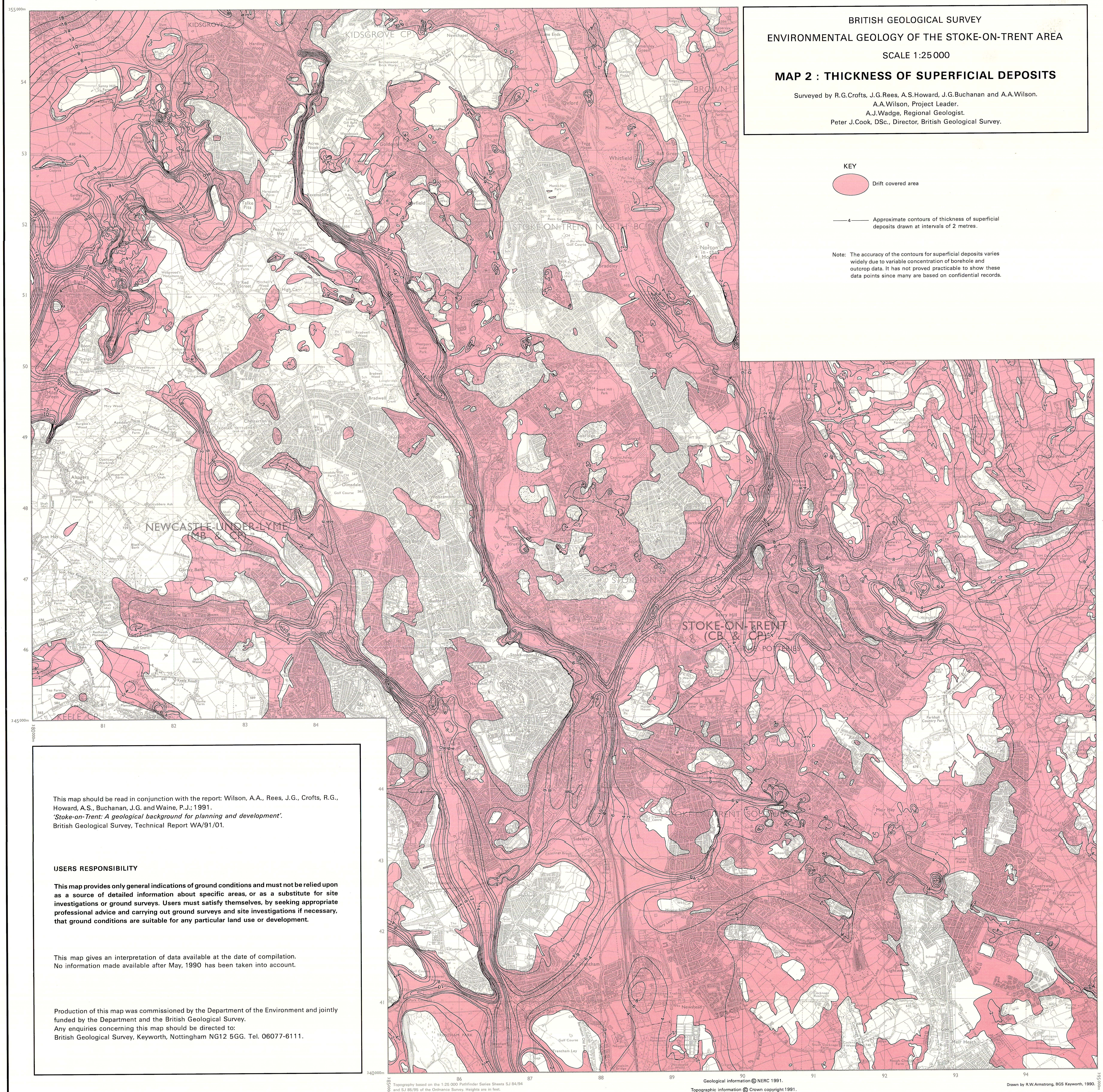
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 2 : THICKNESS OF SUPERFICIAL DEPOSITS

Surveyed by R.G.Crofts, J.G.Rees, A.S.Howard, J.G.Buchanan and A.A.Wilson.
A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.



KEY

Drift covered area

——4—— Approximate contours of thickness of superficial deposits drawn at intervals of 2 metres.

Note: The accuracy of the contours for superficial deposits varies widely due to variable concentration of borehole and outcrop data. It has not proved practicable to show these data points since many are based on confidential records.

This map should be read in conjunction with the report: Wilson, A.A., Rees, J.G., Crofts, R.G., Howard, A.S., Buchanan, J.G. and Waine, P.J.; 1991.
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This map gives an interpretation of data available at the date of compilation.
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Topography based on the 1:25 000 Pathfinder Series Sheets SJ 84/94 and SJ 85/95 of the Ordnance Survey. Heights are in feet.

Drawn by R.W.Armstrong, BGS Keyworth, 1990.

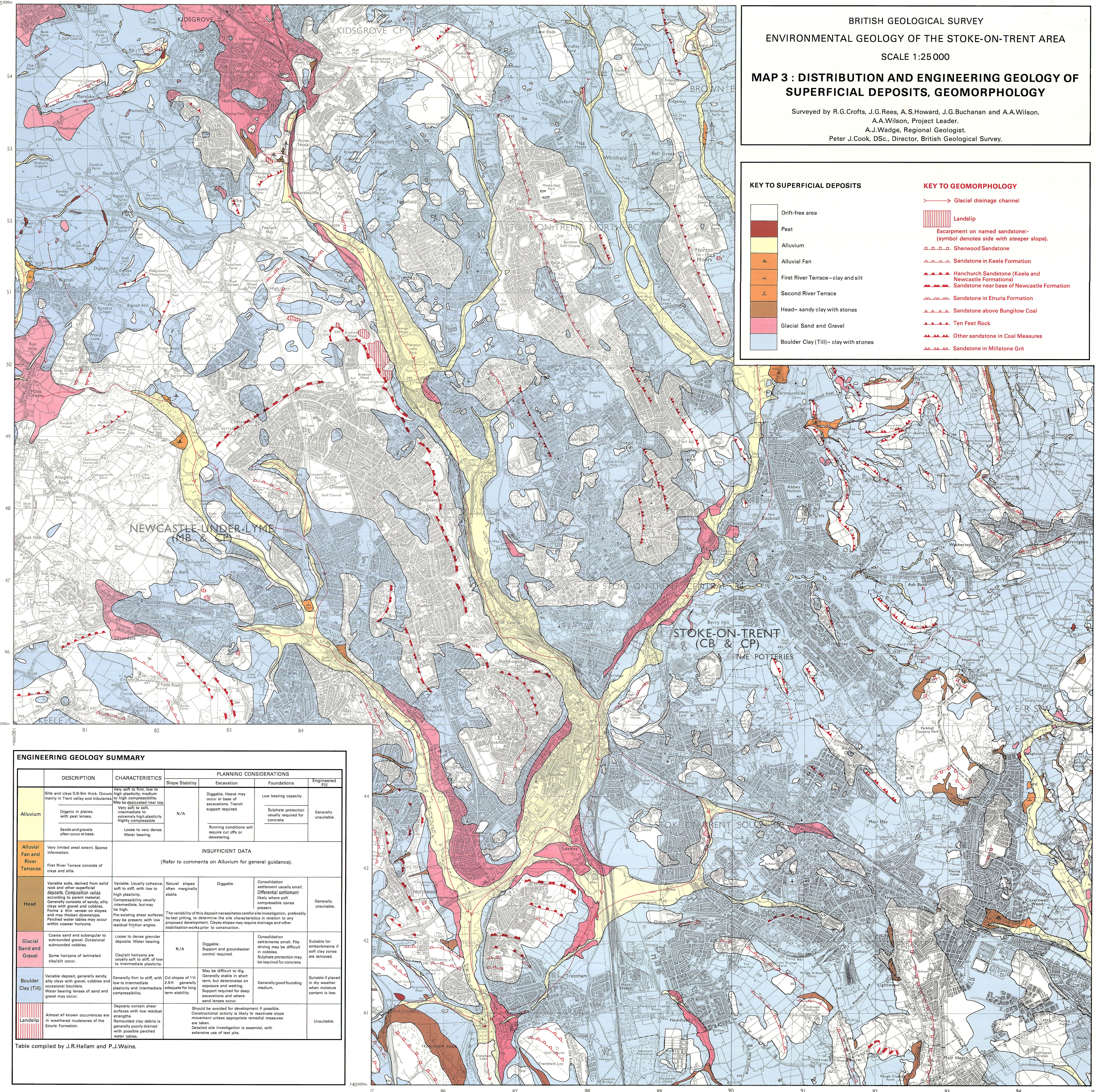
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 3 : DISTRIBUTION AND ENGINEERING GEOLOGY OF SUPERFICIAL DEPOSITS, GEOMORPHOLOGY

Surveyed by R.G.Crofts, J.G.Rees, A.S.Howard, J.G.Buchanan and A.A.Wilson.
A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.



KEY TO SUPERFICIAL DEPOSITS

- Drift-free area
- Peat
- Alluvium
- Alluvial Fan
- First River Terrace – clay and silt
- Second River Terrace
- Head – sandy clay with stones
- Glacial Sand and Gravel
- Boulder Clay (Till) – clay with stones

KEY TO GEOMORPHOLOGY

- Glacial drainage channel
- Landslip
- Escarpment on named sandstone:- (symbol denotes side with steeper slope).
  - Sherwood Sandstone
  - Sandstone in Keele Formation
  - Hanchurch Sandstone (Keele and Newcastle Formations)
  - Sandstone near base of Newcastle Formation
  - Sandstone in Etruria Formation
  - Sandstone above Bungilow Coal
  - Ten Feet Rock
  - Other sandstone in Coal Measures
  - Sandstone in Millstone Grit

ENGINEERING GEOLOGY SUMMARY

	DESCRIPTION	CHARACTERISTICS	PLANNING CONSIDERATIONS			
			Slope Stability	Excavation	Foundations	Engineered Fill
Alluvium	Silts and clays 0.6-9m thick. Occurs mainly in Trent valley and tributaries. Organic in places, with peat lenses. Sands and gravels often occur at base.	Very soft to firm, low to high plasticity, medium to high compressibility. May be desiccated near top. Very soft to soft, intermediate to extremely high plasticity Highly compressible Loose to very dense. Water bearing.	N/A	Diggable. Heave may occur at base of excavations. Trench support required. Running conditions will require cut offs or dewatering.	Low bearing capacity. Sulphate protection usually required for concrete.	Generally unsuitable.
Alluvial Fan and River Terraces	Very limited areal extent. Sparse information. First River Terrace consists of clays and silts.	INSUFFICIENT DATA (Refer to comments on Alluvium for general guidance).				
Head	Variable soils, derived from solid rock and other superficial deposits. Composition varies according to parent material. Generally consists of sandy, silty clays with gravel and cobbles. Forms a thin veneer on slopes and may thicken downslope. Perched water tables may occur within coarser horizons.	Variable. Usually cohesive, soft to stiff, with low to high plasticity. Compressibility usually intermediate, but may be high. Pre-existing shear surfaces may be present, with low residual friction angles.	Natural slopes often marginally stable.	Diggable.	Consolidation settlement usually small. Differential settlement likely where soft compressible zones present.	Generally unsuitable.
			The variability of this deposit necessitates careful site investigation, preferably by test pitting, to determine the site characteristics in relation to any proposed development. Clayey slopes may require drainage and other stabilisation works prior to construction.			
Glacial Sand and Gravel	Coarse sand and subangular to subrounded gravel. Occasional subrounded cobbles. Some horizons of laminated clay/silt occur.	Loose to dense granular deposits. Water bearing. Clay/silt horizons are usually soft to stiff, of low to intermediate plasticity.	N/A	Diggable. Support and groundwater control required.	Consolidation settlements small. Pile driving may be difficult in cobbles. Sulphate protection may be required for concrete.	Suitable for embankments if soft clay zones are removed.
Boulder Clay (Till)	Variable deposit, generally sandy, silty clays with gravel, cobbles and occasional boulders. Water bearing lenses of sand and gravel may occur.	Generally firm to stiff, with low to intermediate plasticity and intermediate compressibility.	Cut slopes of 1V: 2.5H generally adequate for long term stability.	May be difficult to dig. Generally stable in short term, but deteriorates on exposure and wetting. Support required for deep excavations and where sand lenses occur.	Generally good founding medium.	Suitable if placed in dry weather when moisture content is low.
Landslip	Almost all known occurrences are in weathered mudstones of the Etruria Formation.	Deposits contain shear surfaces with low residual strengths. Remoulded clay debris is generally poorly drained with possible perched water tables.	Should be avoided for development if possible. Constructional activity is likely to reactivate slope movement unless appropriate remedial measures are taken. Detailed site investigation is essential, with extensive use of test pits.			Unsuitable.

Table compiled by J.R.Hallam and P.J.Waine.

Topography based on the 1:25 000 Pathfinder Series Sheets SJ 84/94 and SJ 85/95 of the Ordnance Survey. Heights are in feet.

Drawn by R.W.Armstrong, BGS Keyworth, 1990.

This map should be read in conjunction with the report: Wilson, A.A., Rees, J.G., Crofts, R.G., Howard, A.S., Buchanan, J.G. and Waine, P.J.; 1991. *'Stoke-on-Trent: A geological background for planning and development'.* British Geological Survey, Technical Report WA/91/01.
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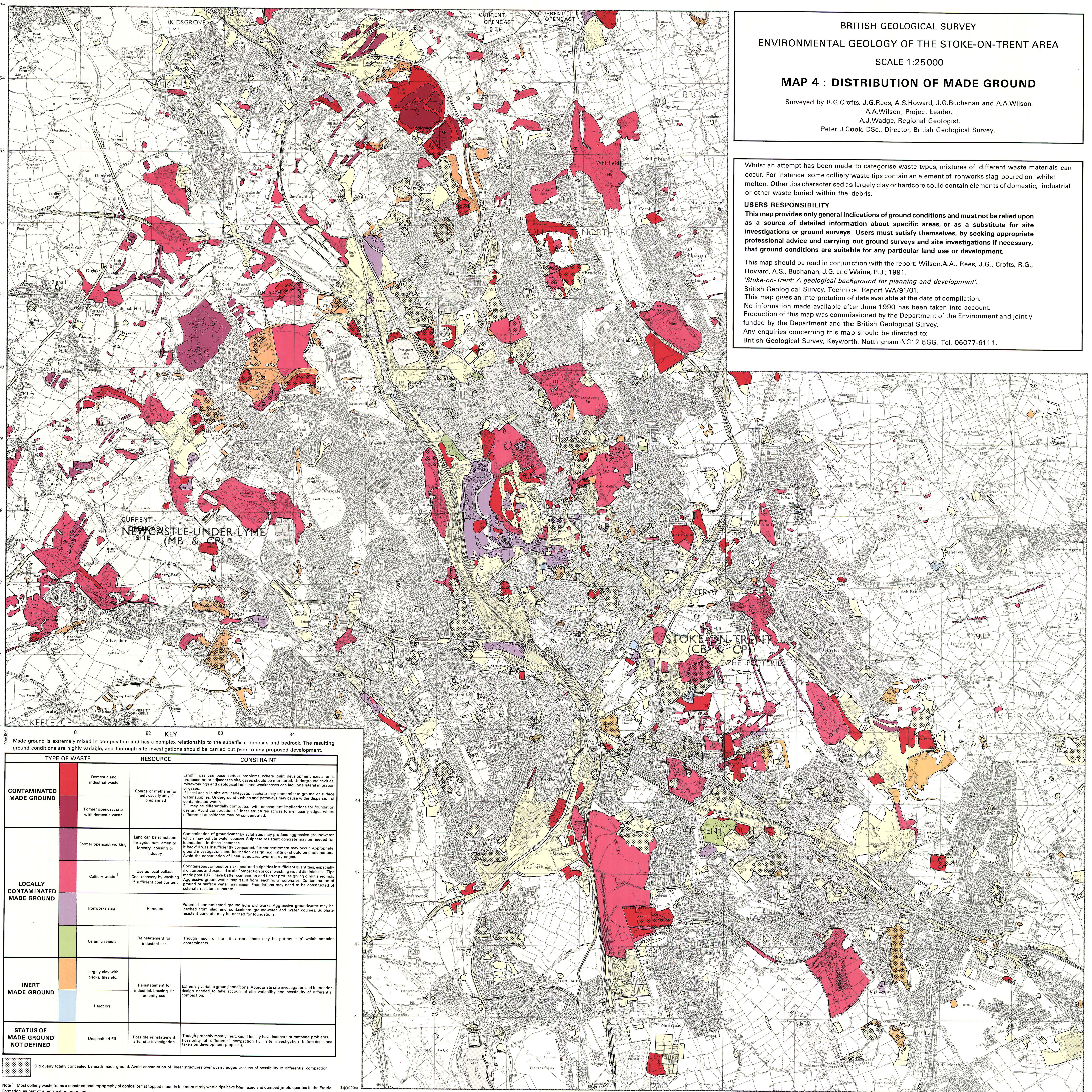

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25000

MAP 4 : DISTRIBUTION OF MADE GROUND

Surveyed by R.G.Crofts, J.G.Rees, A.S.Howard, J.G.Buchanan and A.A.Wilson.
A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.

Whilst an attempt has been made to categorise waste types, mixtures of different waste materials can occur. For instance some colliery waste tips contain an element of ironworks slag poured on whilst molten. Other tips characterised as largely clay or hardcore could contain elements of domestic, industrial or other waste buried within the debris.

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KEY

Made ground is extremely mixed in composition and has a complex relationship to the superficial deposits and bedrock. The resulting ground conditions are highly variable, and thorough site investigations should be carried out prior to any proposed development.

TYPE OF WASTE			RESOURCE	CONSTRAINT
CONTAMINATED MADE GROUND	(red)	Domestic and industrial waste	Source of methane for fuel, usually only if preplanned	Landfill gas can pose serious problems. Where built development exists or is proposed on or adjacent to site, gases should be monitored. Underground cavities, mineworkings and geological faults and weaknesses can facilitate lateral migration of gases. If basal seals in site are inadequate, leachate may contaminate ground or surface water supplies. Underground cavities and pathways may cause wider dispersion of contaminated water. Fill may be differentially compacted, with consequent implications for foundation design. Avoid construction of linear structures across former quarry edges where differential subsidence may be concentrated.
	(dark red)	Former opencast site with domestic waste		
LOCALLY CONTAMINATED MADE GROUND	(purple)	Former opencast working	Land can be reinstated for agriculture, amenity, forestry, housing or industry	Contamination of groundwater by sulphates may produce aggressive groundwater which may pollute water courses. Sulphate resistant concrete may be needed for foundations in these instances. If backfill was insufficiently compacted, further settlement may occur. Appropriate ground investigations and foundation design (e.g. rafting) should be implemented. Avoid the construction of linear structures over quarry edges.
	(pink)	Colliery waste [1]	Use as local ballast. Coal recovery by washing if sufficient coal content.	Spontaneous combustion risk if coal and sulphides in sufficient quantities, especially if disturbed and exposed to air. Compaction or coal washing would diminish risk. Tips made post 1971 have better compaction and flatter profiles giving diminished risk. Aggressive groundwater may result from leaching of sulphates. Contamination of ground or surface water may occur. Foundations may need to be constructed of sulphate resistant concrete.
	(lilac)	Ironworks slag	Hardcore	Potential contaminated ground from old works. Aggressive groundwater may be leached from slag and contaminate groundwater and water courses. Sulphate resistant concrete may be neeced for foundations.
	(green)	Ceramic rejects	Reinstatement for industrial use	Though much of the fill is inert, there may be pottery 'slip' which contains contaminants.
INERT MADE GROUND	(orange)	Largely clay with bricks, tiles etc.	Reinstatement for industrial, housing or amenity use	Extremely variable ground conditions. Appropriate site investigation and foundation design needed to take account of site variability and possibility of differential compaction.
	(light blue)	Hardcore		
STATUS OF MADE GROUND NOT DEFINED	(pale yellow)	Unspecified fill	Possible reinstatement after site investigation	Though probably mostly inert, could locally have leachate or methane problems. Possibility of differential compaction. Full site investigation before decisions taken on development proposals.

(stippled) Old quarry totally concealed beneath made ground. Avoid construction of linear structures over quarry edges because of possibility of differential compaction.

Note [1]. Most colliery waste forms a constructional topography of conical or flat topped mounds but more rarely whole tips have been razed and dumped in old quarries in the Etruria Formation, as part of a reclamation programme.

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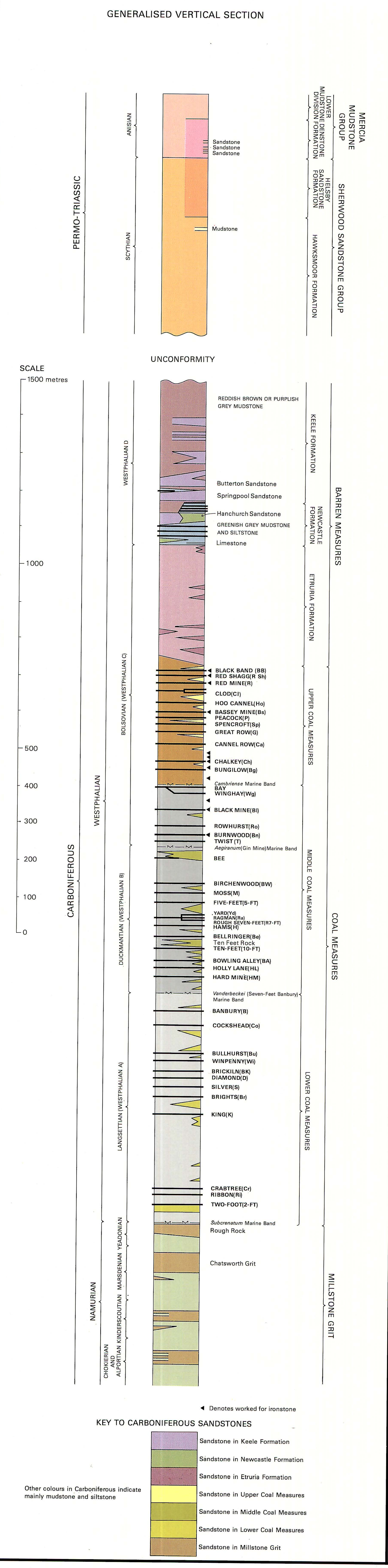
Drawn by R.W.Armstrong, BGS Keyworth, 1990.



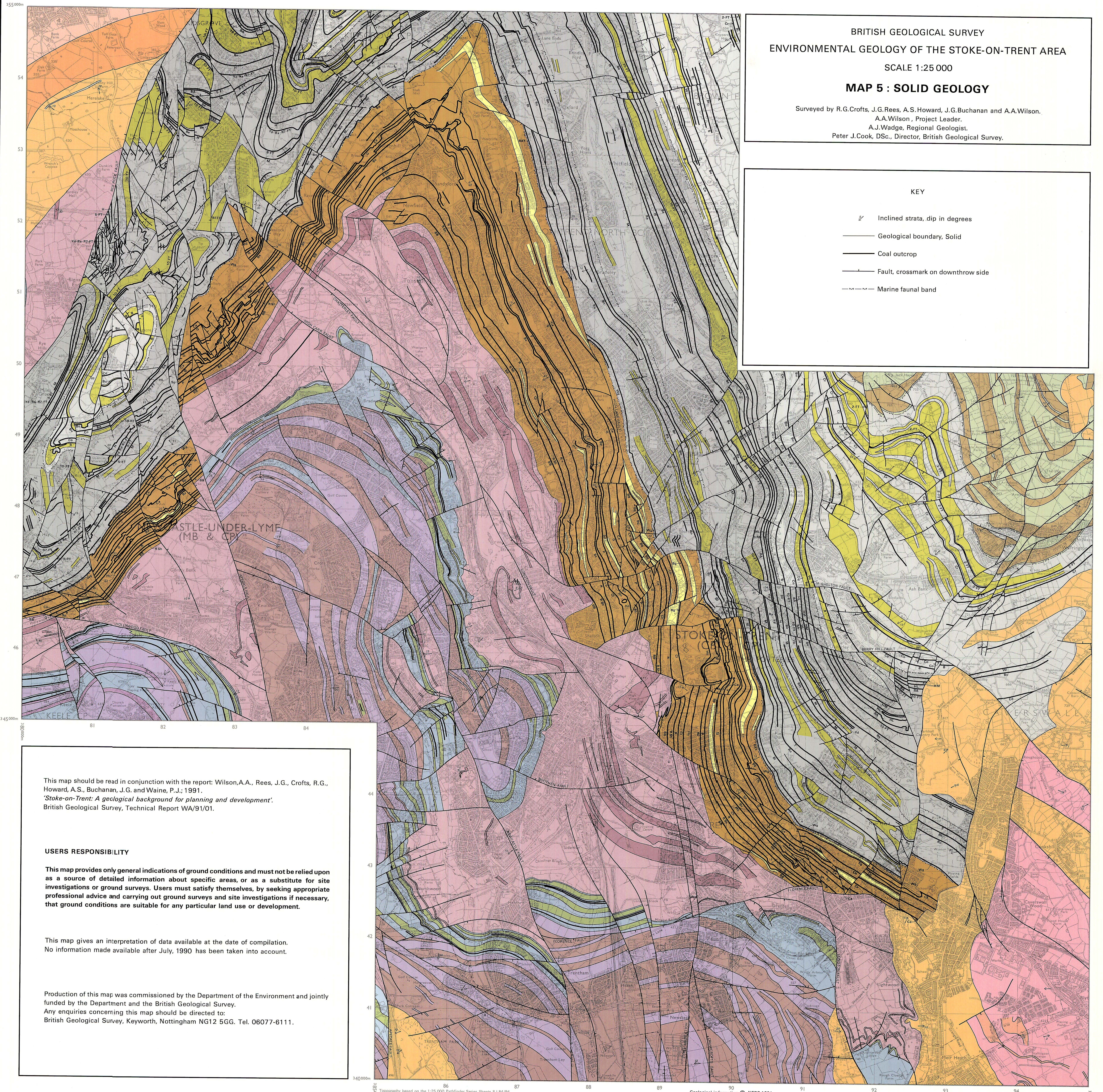
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 5 : SOLID GEOLOGY

Surveyed by R.G.Crofts, J.G.Rees, A.S.Howard, J.G.Buchanan and A.A.Wilson.
A.A.Wilson , Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.



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BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

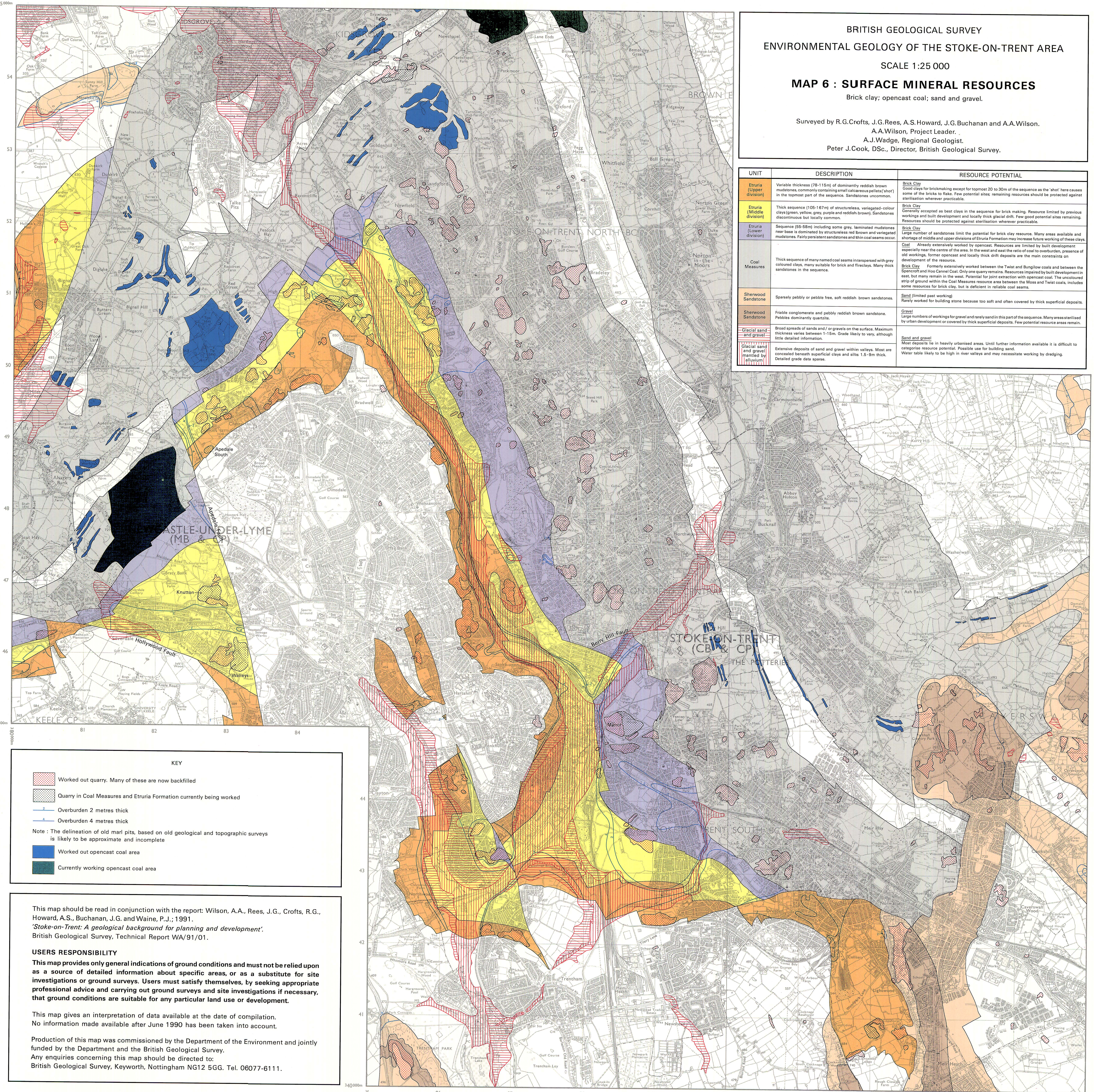
SCALE 1:25 000

MAP 6 : SURFACE MINERAL RESOURCES

Brick clay; opencast coal; sand and gravel.

Surveyed by R.G.Crofts, J.G.Rees, A.S.Howard, J.G.Buchanan and A.A.Wilson.
A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.

UNIT	DESCRIPTION	RESOURCE POTENTIAL
Etruria (Upper division)	Variable thickness (78-115m) of dominantly reddish brown mudstones, commonly containing small calcareous pellets ('shot') in the topmost part of the sequence. Sandstones uncommon.	Brick Clay Good clays for brickmaking except for topmost 20 to 30m of the sequence as the 'shot' here causes some of the bricks to flake. Few potential sites; remaining resources should be protected against sterilisation wherever practicable.
Etruria (Middle division)	Thick sequence (105-167m) of structureless, variegated-colour clays (green, yellow, grey, purple and reddish brown). Sandstones discontinuous but locally common.	Brick Clay Generally accepted as best clays in the sequence for brick making. Resource limited by previous workings and built development and locally thick glacial drift. Few good potential sites remaining. Resources should be protected against sterilisation wherever practicable.
Etruria (Lower division)	Sequence (55-58m) including some grey, laminated mudstones near base is dominated by structureless red brown and variegated mudstones. Fairly persistent sandstones and thin coal seams occur.	Brick Clay Large number of sandstones limit the potential for brick clay resource. Many areas available and shortage of middle and upper divisions of Etruria Formation may increase future working of these clays.
Coal Measures	Thick sequence of many named coal seams interspersed with grey coloured clays, many suitable for brick and fireclays. Many thick sandstones in the sequence.	Coal Already extensively worked by opencast. Resources are limited by built development especially near the centre of the area. In the west and east the ratio of coal to overburden, presence of old workings, former opencast and locally thick drift deposits are the main constraints on development of the resource. Brick Clay Formerly extensively worked between the Twist and Bungilow coals and between the Spencroft and Hoo Cannel Coal. Only one quarry remains. Resources impaired by built development in east, but many remain in the west. Potential for joint extraction with opencast coal. The uncoloured strip of ground within the Coal Measures resource area between the Moss and Twist coals, includes some resources for brick clay, but is deficient in reliable coal seams.
Sherwood Sandstone	Sparsely pebbly or pebble free, soft reddish brown sandstones.	Sand (limited past working) Rarely worked for building stone because too soft and often covered by thick superficial deposits.
Sherwood Sandstone	Friable conglomerate and pebbly reddish brown sandstone. Pebbles dominantly quartzite.	Gravel Large numbers of workings for gravel and rarely sand in this part of the sequence. Many areas sterilised by urban development or covered by thick superficial deposits. Few potential resource areas remain.
Glacial sand and gravel	Broad spreads of sands and / or gravels on the surface. Maximum thickness varies between 1-15m. Grade likely to vary, although little detailed information.	Sand and gravel Most deposits lie in heavily urbanised areas. Until further information available it is difficult to categorise resource potential. Possible use for building sand. Water table likely to be high in river valleys and may necessitate working by dredging.
Glacial sand and gravel mantled by alluvium	Extensive deposits of sand and gravel within valleys. Most are concealed beneath superficial clays and silts 1.5-9m thick. Detailed grade data sparse.	



KEY

- Worked out quarry. Many of these are now backfilled
- Quarry in Coal Measures and Etruria Formation currently being worked
- 2 — Overburden 2 metres thick
- 4 — Overburden 4 metres thick

Note : The delineation of old marl pits, based on old geological and topographic surveys is likely to be approximate and incomplete

- Worked out opencast coal area
- Currently working opencast coal area

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Drawn by S.B.Myers, BGS Keyworth, 1990

BRITISH GEOLOGICAL SURVEY

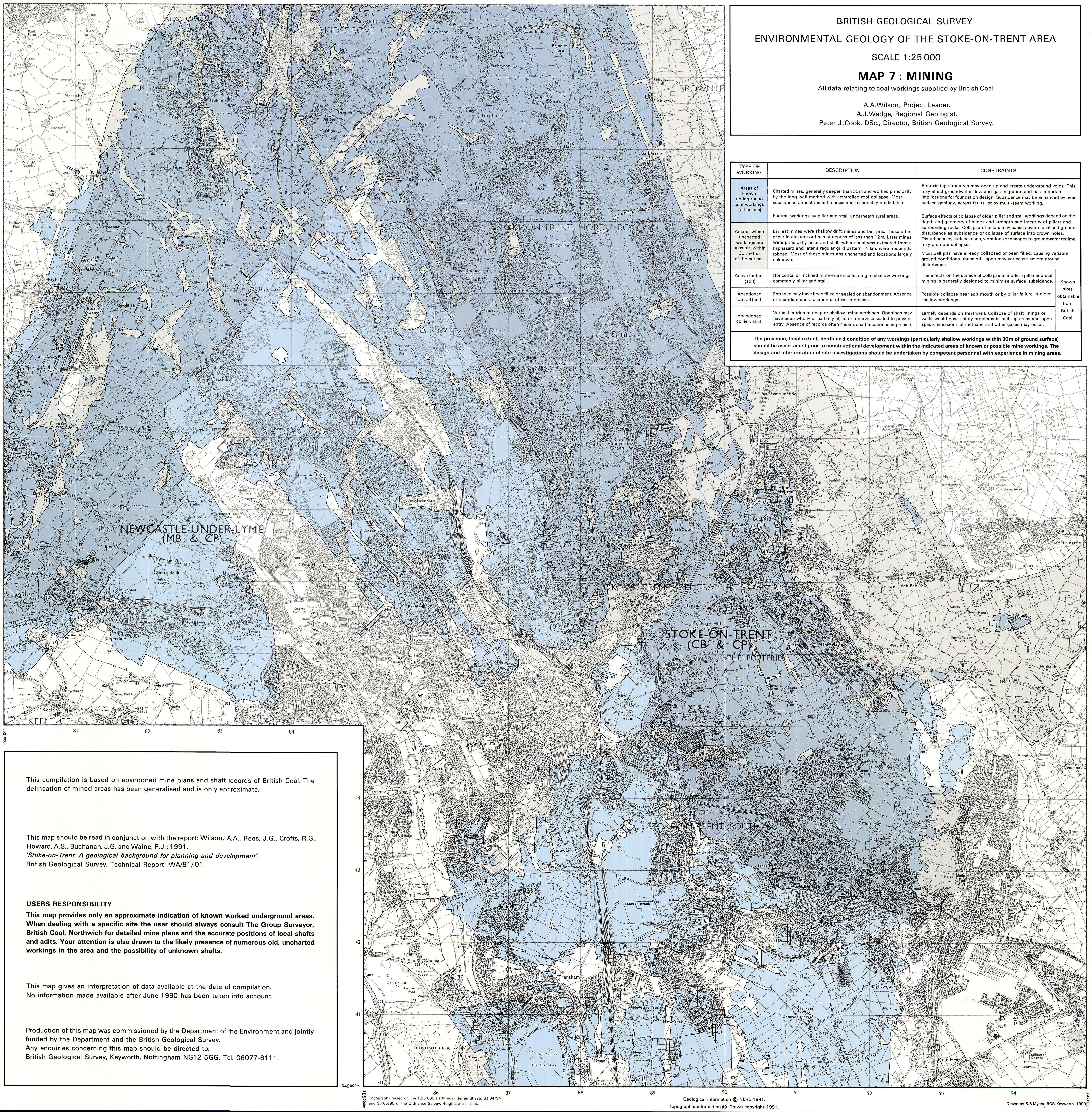
ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 7 : MINING

All data relating to coal workings supplied by British Coal

A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.



TYPE OF WORKING	DESCRIPTION	CONSTRAINTS	
Areas of known underground coal workings (all seams)	Charted mines, generally deeper than 30m and worked principally by the long wall method with controlled roof collapse. Most subsidence almost instantaneous and reasonably predictable. Footrail workings by pillar and stall underneath rural areas.	Pre-existing structures may open up and create underground voids. This may affect groundwater flow and gas migration and has important implications for foundation design. Subsidence may be enhanced by near surface geology, across faults, or by multi-seam working. Surface effects of collapse of older pillar and stall workings depend on the depth and geometry of mines and strength and integrity of pillars and surrounding rocks. Collapse of pillars may cause severe localised ground disturbance as subsidence or collapse of surface into crown holes. Disturbance by surface loads, vibrations or changes to groundwater regime may promote collapse.	
Area in which uncharted workings are possible within 30 metres of the surface	Earliest mines were shallow drift mines and bell pits. These often occur in clusters or lines at depths of less than 12m. Later mines were principally pillar and stall, where coal was extracted from a haphazard and later a regular grid pattern. Pillars were frequently robbed. Most of these mines are uncharted and locations largely unknown.	Most bell pits have already collapsed or been filled, causing variable ground conditions, those still open may yet cause severe ground disturbance.	
Active footrail (adit)	Horizontal or inclined mine entrance leading to shallow workings, commonly pillar and stall.	The effects on the surface of collapse of modern pillar and stall mining is generally designed to minimise surface subsidence.	Known sites obtainable from British Coal
Abandoned footrail (adit)	Entrance may have been filled or sealed on abandonment. Absence of records means location is often imprecise.	Possible collapse near adit mouth or by pillar failure in older shallow workings.	
Abandoned colliery shaft	Vertical entries to deep or shallow mine workings. Openings may have been wholly or partially filled or otherwise sealed to prevent entry. Absence of records often means shaft location is imprecise.	Largely depends on treatment. Collapse of shaft linings or walls would pose safety problems in built up areas and open space. Emissions of methane and other gases may occur.	

The presence, local extent, depth and condition of any workings (particularly shallow workings within 30m of ground surface) should be ascertained prior to constructional development within the indicated areas of known or possible mine workings. The design and interpretation of site investigations should be undertaken by competent personnel with experience in mining areas.

This compilation is based on abandoned mine plans and shaft records of British Coal. The delineation of mined areas has been generalised and is only approximate.

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This map provides only an approximate indication of known worked underground areas. When dealing with a specific site the user should always consult The Group Surveyor, British Coal, Northwich for detailed mine plans and the accurate positions of local shafts and adits. Your attention is also drawn to the likely presence of numerous old, uncharted workings in the area and the possibility of unknown shafts.

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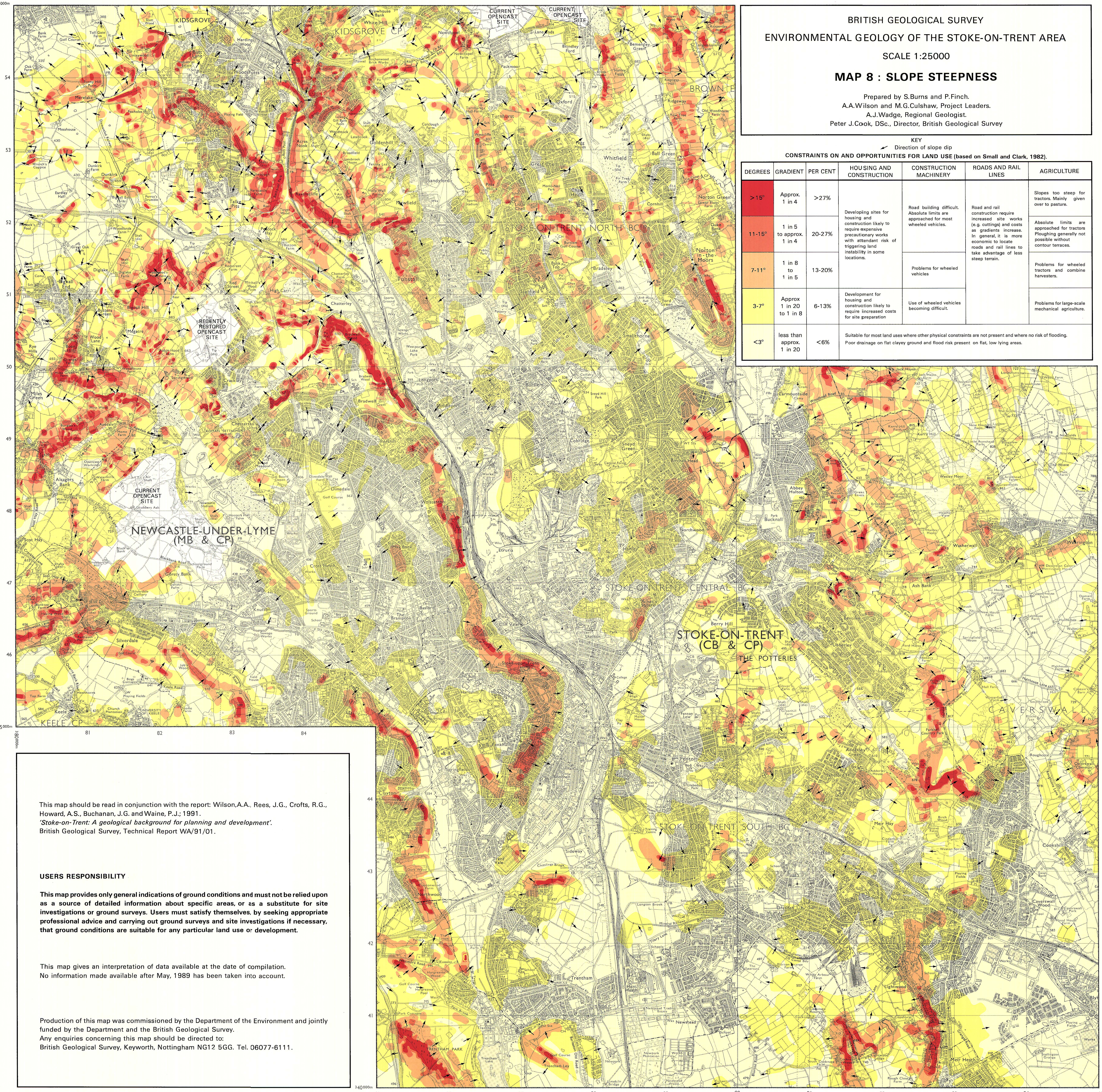
BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25000

MAP 8 : SLOPE STEEPNESS

Prepared by S.Burns and P.Finch.
A.A.Wilson and M.G.Culshaw, Project Leaders.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey



KEY

Direction of slope dip

CONSTRAINTS ON AND OPPORTUNITIES FOR LAND USE (based on Small and Clark, 1982).

DEGREES	GRADIENT	PER CENT	HOUSING AND CONSTRUCTION	CONSTRUCTION MACHINERY	ROADS AND RAIL LINES	AGRICULTURE
>15°	Approx. 1 in 4	>27%	Developing sites for housing and construction likely to require expensive precautionary works with attendant risk of triggering land instability in some locations.	Road building difficult. Absolute limits are approached for most wheeled vehicles.	Road and rail construction require increased site works (e.g. cuttings) and costs as gradients increase. In general, it is more economic to locate roads and rail lines to take advantage of less steep terrain.	Slopes too steep for tractors. Mainly given over to pasture.
11-15°	1 in 5 to approx. 1 in 4	20-27%				Absolute limits are approached for tractors Ploughing generally not possible without contour terraces.
7-11°	1 in 8 to 1 in 5	13-20%		Problems for wheeled vehicles		Problems for wheeled tractors and combine harvesters.
3-7°	Approx 1 in 20 to 1 in 8	6-13%	Development for housing and construction likely to require increased costs for site preparation	Use of wheeled vehicles becoming difficult.		Problems for large-scale mechanical agriculture.
<3°	less than approx. 1 in 20	<6%	Suitable for most land uses where other physical constraints are not present and where no risk of flooding. Poor drainage on flat clayey ground and flood risk present on flat, low lying areas.			

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BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 9 : ENGINEERING GEOLOGY OF BEDROCK

Prepared by P.J.Waine and J.R.Hallam.
M.G.Culshaw, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.

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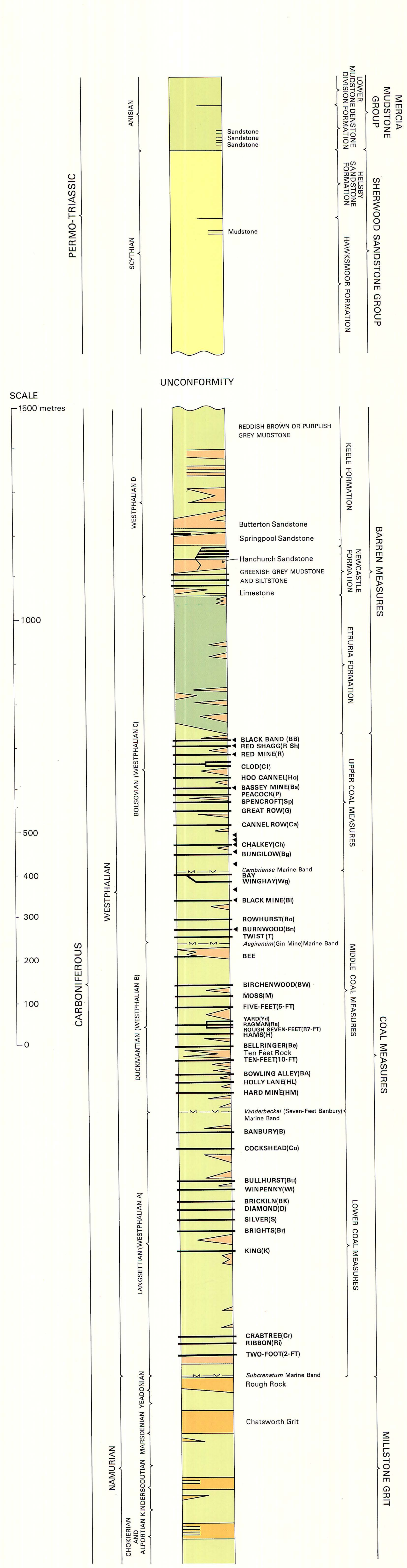
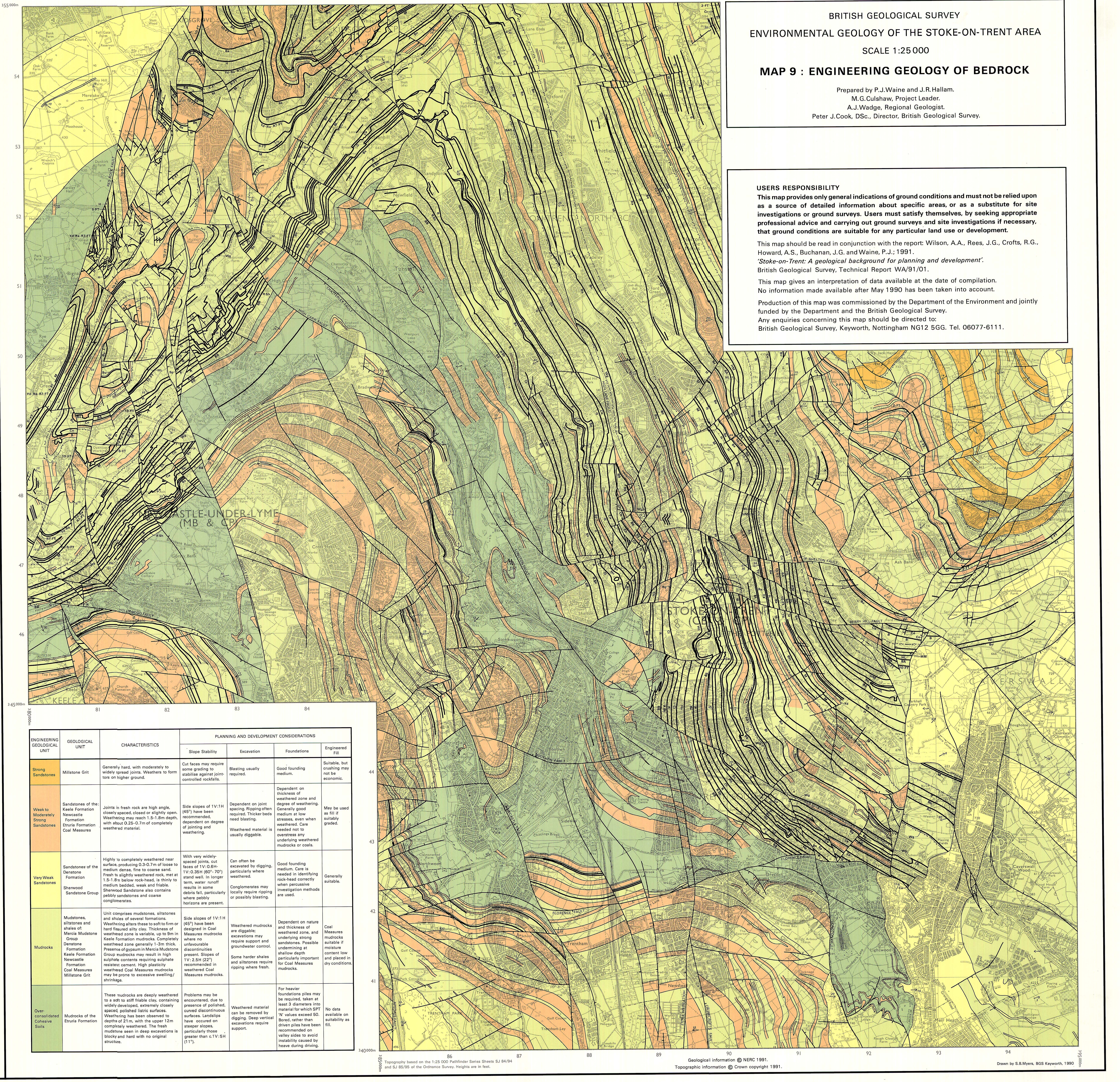
GENERALISED VERTICAL SECTION



◄ Denotes worked for ironstone

KEY

Inclined strata, dip in degrees
Geological boundary, Solid
Coal outcrop c= unnamed seam
Fault, crossmark on downthrow side
Marine faunal band



ENGINEERING GEOLOGICAL UNIT	GEOLOGICAL UNIT	CHARACTERISTICS	PLANNING AND DEVELOPMENT CONSIDERATIONS			
			Slope Stability	Excavation	Foundations	Engineered Fill
Strong Sandstones	Millstone Grit	Generally hard, with moderately to widely spread joints. Weathers to form tors on higher ground.	Cut faces may require some grading to stabilise against joint-controlled rockfalls.	Blasting usually required.	Good founding medium.	Suitable, but crushing may not be economic.
Weak to Moderately Strong Sandstones	Sandstones of the: Keele Formation Newcastle Formation Etruria Formation Coal Measures	Joints in fresh rock are high angle, closely spaced, closed or slightly open. Weathering may reach 1.5-1.8m depth, with about 0.25-0.7m of completely weathered material.	Side slopes of 1V:1H (45°) have been recommended, dependent on degree of jointing and weathering.	Dependent on joint spacing. Ripping often required. Thicker beds need blasting. Weathered material is usually diggable.	Dependent on thickness of weathered zone and degree of weathering. Generally good medium at low stresses, even when weathered. Care needed not to overstress any underlying weathered mudrocks or coals.	May be used as fill if suitably graded.
Very Weak Sandstones	Sandstones of the Denstone Formation Sherwood Sandstone Group	Highly to completely weathered near surface, producing 0.3-0.7m of loose to medium dense, fine to coarse sand. Fresh to slightly weathered rock, met at 1.5-1.8m below rock-head, is thinly to medium bedded, weak and friable. Sherwood Sandstone also contains pebbly sandstones and coarse conglomerates.	With very widely-spaced joints, cut faces of 1V:0.6H-1V:0.35H (60°-70°) stand well. In longer term, water runoff results in some debris fall, particularly where pebbly horizons are present.	Can often be excavated by digging, particularly where weathered. Conglomerates may locally require ripping or possibly blasting.	Good founding medium. Care is needed in identifying rock-head correctly when percussive investigation methods are used.	Generally suitable.
Mudrocks	Mudstones, siltstones and shales of: Mercia Mudstone Group Denstone Formation Keele Formation Newcastle Formation Coal Measures Millstone Grit	Unit comprises mudstones, siltstones and shales of several formations. Weathering alters these to soft to firm or hard fissured silty clay. Thickness of weathered zone is variable, up to 9m in Keele Formation mudrocks. Completely weathered zone generally 1-3m thick. Presence of gypsum in Mercia Mudstone Group mudrocks may result in high sulphate contents requiring sulphate resistent cement. High plasticity weathered Coal Measures mudrocks may be prone to excessive swelling/shrinkage.	Side slopes of 1V:1H (45°) have been designed in Coal Measures mudrocks where no unfavourable discontinuities present. Slopes of 1V:2.5H (22°) recommended in weathered Coal Measures mudrocks.	Weathered mudrocks are diggable; excavations may require support and groundwater control. Some harder shales and siltstones require ripping where fresh.	Dependent on nature and thickness of weathered zone, and underlying strong sandstones. Possible undermining at shallow depth particularly important for Coal Measures mudrocks.	Coal Measures mudrocks suitable if moisture content low and placed in dry conditions.
Over-consolidated Cohesive Soils	Mudrocks of the Etruria Formation	These mudrocks are deeply weathered to a soft to stiff friable clay, containing widely developed, extremely closely spaced, polished listric surfaces. Weathering has been observed to depths of 21m, with the upper 12m completely weathered. The fresh mudstone seen in deep excavations is blocky and hard with no original structure.	Problems may be encountered, due to presence of polished, curved discontinuous surfaces. Landslips have occured on steeper slopes, particularly those greater than c.1V:5H (11°).	Weathered material can be removed by digging. Deep vertical excavations require support.	For heavier foundations piles may be required, taken at least 3 diameters into material for which SPT 'N' values exceed 50. Bored, rather than driven piles have been recommended on valley sides to avoid instability caused by heave during driving.	No data available on suitability as fill.

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Drawn by S.B.Myers, BGS Keyworth, 1990

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25 000

MAP 10 : RESOURCES

A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey

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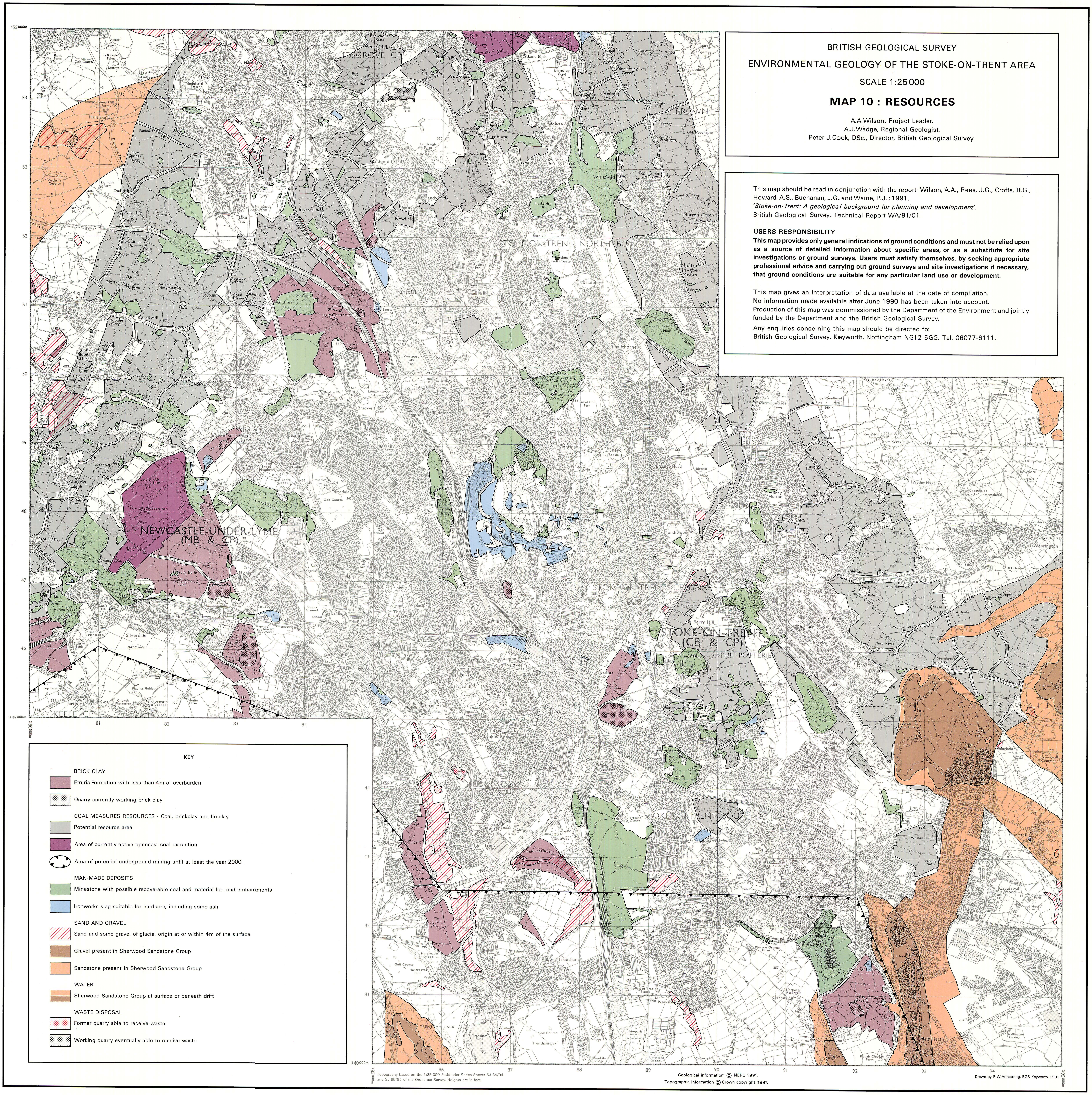

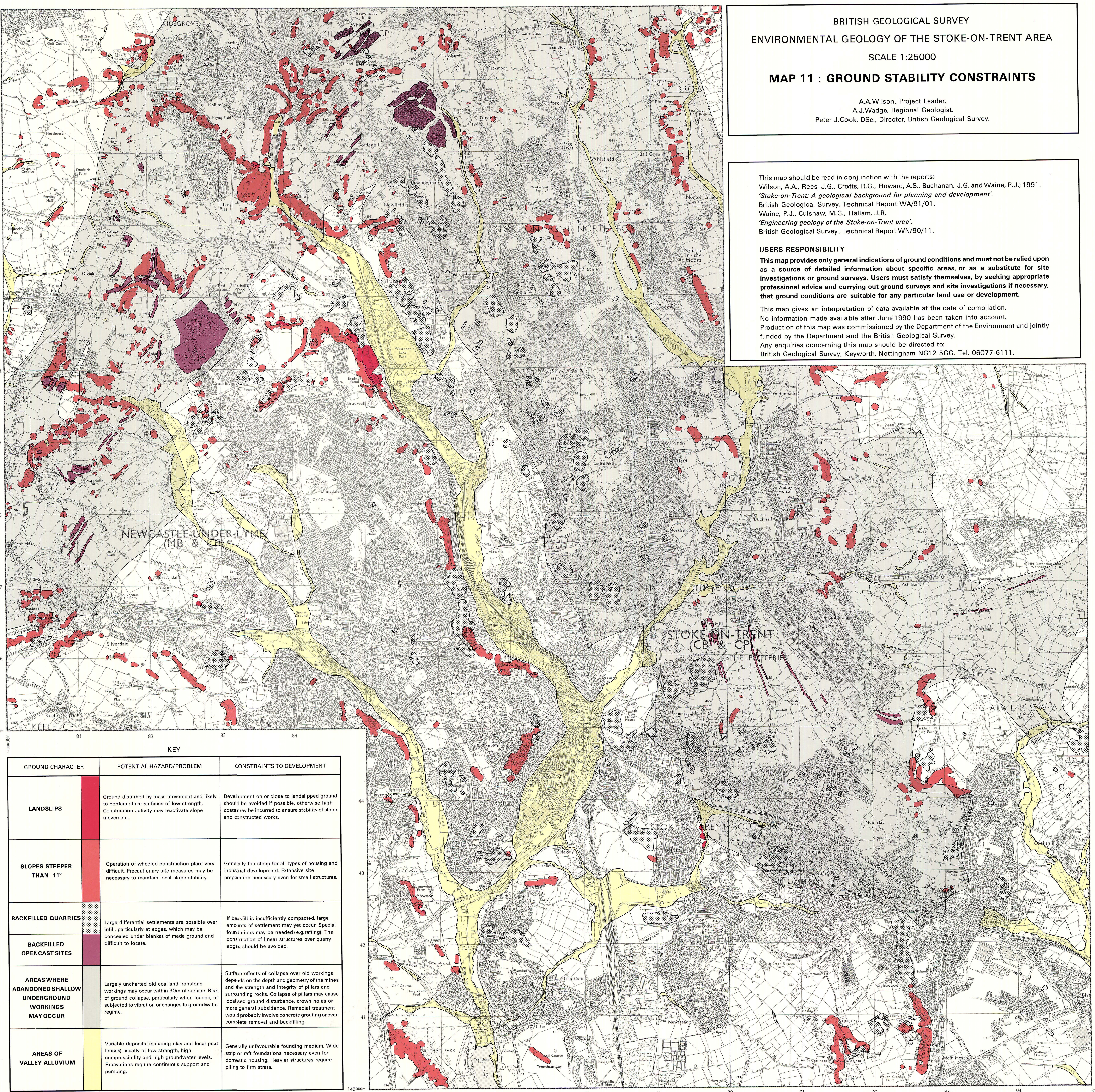

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25000

MAP 11 : GROUND STABILITY CONSTRAINTS

A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.

This map should be read in conjunction with the reports:

Wilson, A.A., Rees, J.G., Crofts, R.G., Howard, A.S., Buchanan, J.G. and Waine, P.J.; 1991. *'Stoke-on-Trent: A geological background for planning and development'.* British Geological Survey, Technical Report WA/91/01.

Waine, P.J., Culshaw, M.G., Hallam, J.R. *'Engineering geology of the Stoke-on-Trent area'.* British Geological Survey, Technical Report WN/90/11.

USERS RESPONSIBILITY

This map 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 carrying out ground surveys and site investigations if necessary, that ground conditions are suitable for any particular land use or development.

This map gives an interpretation of data available at the date of compilation. No information made available after June 1990 has been taken into account.

Production of this map was commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey.

Any enquiries concerning this map should be directed to:
British Geological Survey, Keyworth, Nottingham NG12 5GG. Tel. 06077-6111.

KEY

GROUND CHARACTER	POTENTIAL HAZARD/PROBLEM	CONSTRAINTS TO DEVELOPMENT
LANDSLIPS	Ground disturbed by mass movement and likely to contain shear surfaces of low strength. Construction activity may reactivate slope movement.	Development on or close to landslipped ground should be avoided if possible, otherwise high costs may be incurred to ensure stability of slope and constructed works.
SLOPES STEEPER THAN 11°	Operation of wheeled construction plant very difficult. Precautionary site measures may be necessary to maintain local slope stability.	Generally too steep for all types of housing and industrial development. Extensive site preparation necessary even for small structures.
BACKFILLED QUARRIES	Large differential settlements are possible over infill, particularly at edges, which may be concealed under blanket of made ground and difficult to locate.	If backfill is insufficiently compacted, large amounts of settlement may yet occur. Special foundations may be needed (e.g.rafting). The construction of linear structures over quarry edges should be avoided.
BACKFILLED OPENCAST SITES		
AREAS WHERE ABANDONED SHALLOW UNDERGROUND WORKINGS MAY OCCUR	Largely uncharted old coal and ironstone workings may occur within 30m of surface. Risk of ground collapse, particularly when loaded, or subjected to vibration or changes to groundwater regime.	Surface effects of collapse over old workings depends on the depth and geometry of the mines and the strength and integrity of pillars and surrounding rocks. Collapse of pillars may cause localised ground disturbance, crown holes or more general subsidence. Remedial treatment would probably involve concrete grouting or even complete removal and backfilling.
AREAS OF VALLEY ALLUVIUM	Variable deposits (including clay and local peat lenses) usually of low strength, high compressibility and high groundwater levels. Excavations require continuous support and pumping.	Generally unfavourable founding medium. Wide strip or raft foundations necessary even for domestic housing. Heavier structures require piling to firm strata.

Refer also to Map 4 for numerous additional areas of made ground where fill may be differentially compacted, with consequent implications for foundation design.

Topography based on the 1:25 000 Pathfinder Series Sheets SJ 84/94 and SJ 85/95 of the Ordnance Survey. Heights are in feet.

Drawn by R.W.Armstrong, BGS Keyworth, 1991.

BRITISH GEOLOGICAL SURVEY

ENVIRONMENTAL GEOLOGY OF THE STOKE-ON-TRENT AREA

SCALE 1:25000

MAP 12 : CONSTRAINTS CAUSED BY LEACHATES AND GASES

A.A.Wilson, Project Leader.
A.J.Wadge, Regional Geologist.
Peter J.Cook, DSc., Director, British Geological Survey.

This map should be read in conjunction with the report: Wilson,A.A., Rees, J.G., Crofts, R.G., Howard, A.S., Buchanan, J.G. and Waine, P.J.; 1991.
'Stoke-on-Trent: A geological background for planning and development'.
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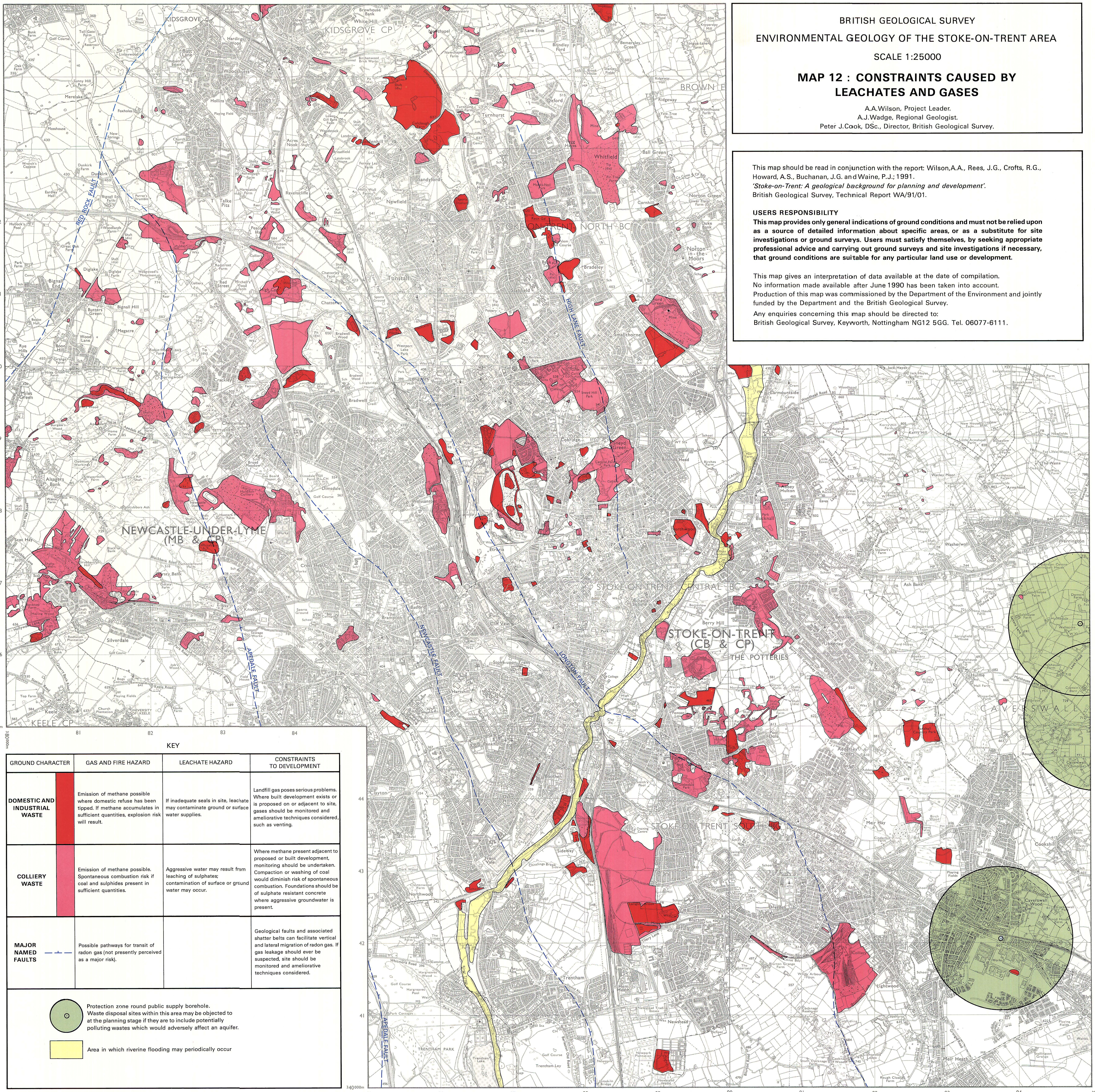

KEY

GROUND CHARACTER	GAS AND FIRE HAZARD	LEACHATE HAZARD	CONSTRAINTS TO DEVELOPMENT
DOMESTIC AND INDUSTRIAL WASTE (red)	Emission of methane possible where domestic refuse has been tipped. If methane accumulates in sufficient quantities, explosion risk will result.	If inadequate seals in site, leachate may contaminate ground or surface water supplies.	Landfill gas poses serious problems. Where built development exists or is proposed on or adjacent to site, gases should be monitored and ameliorative techniques considered, such as venting.
COLLIERY WASTE (pink)	Emission of methane possible. Spontaneous combustion risk if coal and sulphides present in sufficient quantities.	Aggressive water may result from leaching of sulphates; contamination of surface or ground water may occur.	Where methane present adjacent to proposed or built development, monitoring should be undertaken. Compaction or washing of coal would diminish risk of spontaneous combustion. Foundations should be of sulphate resistant concrete where aggressive groundwater is present.
MAJOR NAMED FAULTS (— ⊥ —)	Possible pathways for transit of radon gas (not presently perceived as a major risk).		Geological faults and associated shatter belts can facilitate vertical and lateral migration of radon gas. If gas leakage should ever be suspected, site should be monitored and ameliorative techniques considered.

Protection zone round public supply borehole. Waste disposal sites within this area may be objected to at the planning stage if they are to include potentially polluting wastes which would adversely affect an aquifer.

Area in which riverine flooding may periodically occur

Topography based on the 1:25 000 Pathfinder Series Sheets SJ 84/94 and SJ 85/95 of the Ordnance Survey. Heights are in feet.

Drawn by R.W.Armstrong, BGS Keyworth, 1991.