BRITISH GEOLOGICAL SURVEY

TECHNICAL REPORT WA/90/1

Onshore Geology Series

Nottingham: A geological background for planning and development

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Cover illustrations

Front Typical sections in the Nottingham Castle Sandstone Formation are exposed around the base of Castle Rock, as here at Brewhouse Yard and the entrance to Mortimer's Hole.

Back 1 The Park Tunnel, opened in 1855, is cut into Nottingham Castle Sandstone

2 The headframe of the former Babbington (Cinderhill) Colliery stands behind a wall of Lower Magnesian Limestone (Cadeby Formation)

3 A sewer tunnel and cutting in Lower Magnesian Limestone (Cadeby Formation) run beneath a former railway at Cinderhill

4 The Beeston Canal and landfill form a man-made landscape at the Dunkirk Industrial area

5 Cliffs of Mercia Mudstones stand over the Trent as it flows over the weir at Radcliffe-on-Trent

6 Mudstones and siltstones with gypsum of the Gunthorpe Formation outcrop at Radcliffe-on-Trent weir

Geographical index

United Kingdom, central England, Nottinghamshire

Subject index

Land-use planning, thematic maps, Carboniferous, Permian, Triassic, Jurassic, Quaternary, resources , mining, hazards, engineering geology

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Maps and diagrams in this book use topography based on Ordnance Survey mapping

Bibliographic reference

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BRITISH GEOLOGICAL SURVEY

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PREFACE

This report describes the geology of the area of central and eastern Nottingham and its suburbs covered by the 16 Ordnance Survey 1:10 000 quarter sheets which comprise 1:25 000 maps SK 53, 54, 63 and 64. The geology is discussed in terms of its application to land-use planning and development. Parts of four 1:50 000 geological sheets, Nottingham (126), Derby (125), Melton Mowbray (142) and Loughborough (141) are included within the area. Primary survey at the 1:10 560 scale was by C Fox-Stangways, W Gibson, G W Lamplugh, R L Sherlock, B Smith, B S N Wilkinson and W B Wright between 1902 and 1906 and the constituent maps were published as Nottingham County sheets between 1905 and 1915. W N Edwards carried out a revision of County sheet Nottingham 42 NW in 1943 and an area in the west comprising National Grid sheets SK 54 NW, SW and 53 NW was resurveyed at the 1:10 560 scale by D V Frost in 1963 and 1964, with publication in 1968 and 1969.

The present study was commissioned in 1987 by the Department of the Environment, in a contract jointly funded with the British Geological Survey, to provide an up-to-date geological database. Field mapping at the 1:10 000 scale was carried out by K Ambrose (SK 64 NE), T J Charsley (SK 53 NE, SE), R G Crofts (SK 63 SW, SE), M T Dean (SK 54 SE), J R A Giles (part of SK 64 NW), A Howard (SK 53 SW), D J Lowe (SK 62 NW, NE and part of 64 NW) and P A Rathbone (SK 54 NE; 64 SW, SE). Additional field mapping of areas of man-made deposits on sheets SK 54 NW, SW and 53 NW, together with desk revision of the geological boundaries and structures in these areas, was carried out by J W Baldock and T J Charsley. The engineering geology study was carried out by A Forster, and a hydrogeological contribution provided by E Parry (National Rivers Authority) and R A Monkhouse. A sub-project, financed totally by the Department of the Environment, to document the many man-made 'caves' beneath Nottingham, was carried out by J F Owen and J C Walsby under the supervision of D J Lowe. The project leader was T J Charsley, the programme manager A J Wadge and the Department of the Environment nominated officer B R Marker.

The willing cooperation of landowners, tenants and quarry companies in allowing access to their lands and undertakings is gratefully acknowledged. We are also grateful to all the holders of data for allowing us to transfer them to the National Geosciences Data Centre. We are especially grateful to British Coal Deep Mines (East Midlands), the Opencast Executive, the Mining Records Office (Bootle), B P Petroleum Development Limited, Tarmac Roadstone Limited (East Midlands) and British Gypsum Limited for access to mine plans and exploration data. We acknowlege the assistance provided by the officers of the various local and district councils within the Nottingham area and of many other organisations, including the Severn-Trent Water Authority and British Rail, who have readily supplied information and advice.

F G Larminie, OBE
Director

31 January 1990

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EXECUTIVE SUMMARY

This study, carried out between 1987 and 1989, was commissioned by the Department of the Environment and funded jointly by the Department and the British Geological Survey. Its principal aim was to produce a synthesis of geological information relevant to the planning of land use and development in part of the Nottingham area. This report is aimed at those involved in planning and development. The results are presented in a style which, it is hoped, will meet the needs of both those with and without previous geological knowledge. Much of the information is provided on a series of sixteen thematic maps, each of which concentrates on a specific aspect of the geology relevant to the use of land. In addition to the information contained in the report, sources of other more detailed data are indicated.

The study area

The study area comprises the City of Nottingham, most of its major suburbs and a considerable tract of agricultural land; it covers an area of 400 km^2, bisected almost exactly by the north-easterly flowing River Trent. Except for a very small part in Derbyshire, the area lies within the county of Nottinghamshire. The City itself, due to its position on high sandstone ground close to suitable fording and bridging positions on a major navigable river, has been a settlement since Roman times or earlier. The rapid growth of urban Nottingham began in the 1870s following an expansion of coal mining and the incoming of major new industries such as the manufacture of pharmaceuticals, bicycles and cigarettes. Enlargement has taken place on all sides, and includes development in the rural areas of 'dormitory' housing. Redevelopment of the inner city has also been gaining in pace in the last 20 years.

Sources of information

The information used in the report was acquired in two main ways. Firstly, geological data was sought and compiled from various sources, most notably from the databases and archives of BGS, British Coal and the Severn-Trent Water Authority, and from several geotechnical consultants and private companies. This data was mostly in the form of memoirs, maps, underground mine plans, borehole, shaft and trial pit records, and site investigation reports. Secondly, a detailed field geological survey was undertaken by BGS geologists at a scale of 1:10 000. This covered over 80 percent of the area; the remaining part, having been surveyed in the 1960s, was subject to partial revision only.

Geology

The bedrock of the Nottingham area includes a wide variety of sedimentary rocks from conglomerates, sandstones, siltstones and mudstones to limestone, coal and gypsum, deposited in marine and onshore terrestrial environments. The age of deposition is broad, spanning the late Carboniferous to the early Jurassic periods of time from about 300 to 210 million years ago; older rocks are known to occur at depth.

Bedrock is the lowest layer of the three tiers of local geology. Overlying bedrock, the superficial or drift deposits comprise the loosely consolidated deposits of rivers, slope processes and glacial action in the form of clay, silt, sand and gravel. These deposits have been mapped in considerable detail, even though they are generally only up to a few metres thick because they have a strong influence on ground conditions for development. The final layer is entirely man-made and comprises deposited fill materials and disturbed bedrock and superficial materials. Maps at 1:25 000 showing the distribution of made and disturbed ground are included in the thematic map set.

The survey has resulted in a considerable improvement to the geological knowledge of the area. Much new detail has been added to the geological map so that, for an area thought to be little affected by geological structure, the new survey has shown that a fault belt, crossing from north-west to south-east, displaces not only the worked Coal Measures, but also the Triassic rocks at the surface. Modern stratigraphical nomenclature has been applied to the Permian, Triassic and Jurassic sequences. This careful definition of units has enabled resources of brick clay and gypsum to be closely tied to limited areas of outcrop. Detailed mapping has also been applied to the various river terrace deposits which are a major source of sand and gravel for construction.

Geological Resources

The Nottingham area is well endowed with mineral resources and underground water; other local resources influenced by ground conditions include soils, sound foundations and waste disposal sites. Special to Nottingham are man-made caves in the sandstone bedrock, which formed the subject of a contract extension, entirely funded by the Department of the Environment, to provide an up-to-date register of all known sites.

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

Underground mining for coal has a long history in the area, and is taking place at present from the Gedling and Cotgrave collieries in the High Hazles, Deep Hard and Blackshale seams. A considerable coal resource remains in the ground. Other minerals which could be extracted by mining are gypsum and sand, and the area has an oil potential.

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

Other resources are discussed in some detail. Nottingham's caves have potential for tourism, for educational interest and as emergency shelters. Waste disposal sites are provided by past and present mineral extraction. Geological sites of scientific and educational interest, additional to those already listed as Sites of Special Scientific Interest (SSSI) and Local Nature Reserves, are identified. Sound foundations and the soils of most use to agriculture are related to bedrock types.

Geological Constraints

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

The suitability of bedrock and superficial materials for foundations in the Nottingham area depends mainly on their geotechnical properties. The various parameters relating to the bearing strength of natural materials and to their reaction to engineering structures are reviewed in the report; additional details and tables of properties based on data from a total of over 5000 test or sample points are given in an annex.

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

A long history of shallow coal mining in the area has left a legacy of shafts, adits, shallow workings and backfilled opencast pits which present problems for land use. Much of this is poorly documented which means that to the west of the City unrecorded former workings may occur at shallow depths in any area where a coal thick enough to have been considered workable lies near the surface. Documented shafts and adits are shown on thematic maps, but responsibility for locating shafts at or close to these sites rests on the site owner or developer. The report contains information on subsidence related to deep mining, particularly the problems posed by geological faults with respect to differential subsidence, and dangerous gas migration.

Underground gypsum mining has taken place in the East Bridgford, Cropwell Bishop and Gotham areas. The areas known to be affected are identified; however, in view of the poor quality of the records, all development in these areas requires very careful geological investigations to ascertain whether there is any risk of subsidence.

The ever-present problem for development posed by the many man-made caves in the sandstone bedrock of the City is considered. Advice is given that all site investigations in areas underlain by Triassic sandstones should be carried out assuming that caves may be present. Ideally, site investigations for these should not be conducted until existing buildings are demolished and the site cleared to the former basement level.

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

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

Other geological factors examined include local geological structure and slope stability, the possible presence of gypsum solution cavities, possible risks to health from exposure to radioactive radon emanating from subsurface materials, and on, a regional scale, earthquakes. Many of these factors may give rise to problematical ground conditions which could then act as a constraint to development. Appropriate site specific investigation should always be carried out prior to development.

While not strictly in the field of geology, the problem of flooding is briefly reviewed. Maximum flood limits prior to much modern flood defence work are shown on the hydrogeological thematic map.

References, glossary, annexes and thematic maps

The report concludes with a reference list and glossary of terms used, together with annexes providing additional geological and geotechnical details, information on sources of borehole, trial pit and shaft data and a list of mineral industry operators.

The thematic maps which accompany this report are as follows:

- Map 1. Distribution of records
- Map 2. Bedrock geology
- Map 3. Distribution and thickness of superficial deposits
- Map 4. Distribution of made and disturbed ground(4 maps)
- Map 5. Geomorphology, drainage and slopes
- Map 6. Mineral resources, mining and quarrying (excluding coal)
- Map 7. Underground deep coal mining
- Map 8. Coal: Opencast mining, mine shafts and shallow mining (2 maps)
- Map 9. Hydrogeology and flood limits
- Map 10. Engineering geology
- Map 11. Caves

Copies of the report and its maps can be obtained from the British Geological Survey, Keyworth, Nottingham NG12 5GG. Archival data is held at the National Geosciences Data Centre at the same address.

Limitations

This report has been produced by the collation and interpretation of geological, geotechnical and related data from a wide variety of sources, the main ones of which are listed in Table 1.

The report aims to provide a general description of the geological factors relevant to land-use planning and development. The data on which it is based are not comprehensive and vary in quality, and this is inevitably reflected in the report. Local features and conditions may not be represented, and many boundaries shown may be only approximate. The dates of the geological mapping are shown in Table 4 and no information subsequent to these dates has been taken into account. For these reasons:-

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

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

Notes

All National Grid references in this report lie in the 100 km square SK. Grid references to specific localities are given to eight figures (accurate to within 10 m); more general locations are given to six figures.

Each borehole or shaft registered with BGS is identified by a four-element code (e.g. SK 53 NW 15). The first two elements define the 10 km square (of the National Grid) in which the borehole is situated; the third element defines the quadrant of that square, and the fourth is the accession number of the borehole.

INTRODUCTION

The data summarised in this report were obtained during a three year contract, commissioned by the Department of the Environment in 1987. The work was jointly funded by the British Geological Survey (BGS) and the Department of the Environment. A contract extension to produce a register of Nottingham's caves was entirely funded by the Department of the Environment.

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

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

Objectives

The aims of the project were twofold:

1. To produce new geological maps at 1:10 000 scale for that part of the area surveyed at the beginning of the century; that is all areas except for three western 1:10 560 sheets surveyed in the 1960s. These latter areas were partially revised as a desk study, but with a complete field survey to delineate areas of man-made and disturbed ground.

2. To produce a set of thematic maps at 1:25 000 or 1:50 000 scales, and to collate various geological, geotechnical and other relevant information in a report intended for use primarily by land use planners and developers. The thematic maps delimit areas and sites of specific geological characteristics. The information contained on these maps is highly selective as it is not possible to reproduce at the reduced scales all of the information present on the new 1:10 000 geological standards. Furthermore, the quality of data on some of the thematic maps is very variable. For example, the available information for the extent of underground coal mining was recorded over a period stretching from the middle of the nineteenth century to recent times, but information on earlier mining, which undoubtedly took place, does not exist.

Each thematic map highlights a particular aspect of the geology; they should be used in conjunction with the report. The maps are numbered as shown below:

Map 1.	Distribution of records (boreholes and trial pits)
Map 2.	Bedrock geology
Map 3.	Distribution and thickness of superficial deposits
Map 4A-D.	Distribution of made and disturbed ground
Map 5.	Geomorphology, drainage and slopes
Map 6.	Mineral resources, mining and quarrying (excluding coal)
Map 7.	Underground deep coal mining
Map 8.	Coal: Opencast mining, mine shafts and shallow mining
Map 9.	Hydrogeology and flood limits
Map 10A.	Engineering geology of bedrock materials
Map 10B.	Engineering geology of superficial (drift) deposits
Map 11.	Caves

The use of this report

It must be stressed that the information provided on the thematic maps and in the report is interpretive, of variable quality, and is distributed unevenly. Consequently, the maps and report should only be used for general planning purposes and desk studies. They cannot be considered as a substitute for on-site investigation. Rather, they should be used as a reference source providing a regional and background context to assist in the interpretation of detailed on-site observations. Furthermore, the report should act as a guide to other more detailed sources, e.g. the British Geological Survey archives of non-confidential boreholes and other data, including, most importantly, the 1:10 000/10 560 geological standards, open-file reports, and the original field-slips, which are the fundamental sources on which much of the report is based. Attention is drawn also to other sources of advice, including those which should be consulted in terms of water and mining interests. It is strongly recommended that the maps and report should be used in conjunction with one another. Each map has only a limited descriptive key; a fuller detailed description and indications of limitations on the information is contained in the report.

Study area

The study area (Figure 1) comprises the City of Nottingham, most of its major suburbs and a considerable tract of agricultural land; it covers an area of 400 km^2. Except for a small part of Derbyshire in the south-west between the Rivers Trent and Erewash, the area lies within the county of Nottinghamshire. All or part of the districts administered by the following councils are included in the study area:

Nottingham City Council
Ashfield District Council
Broxtowe Borough Council
Erewash Borough Council
Gedling Borough Council
Newark and Sherwood District Council
Rushcliffe Borough Council

The component 1:25 000 National Grid Sheets are shown in Figure 1, and 1:10 000/10 560 maps are listed in Table 4.

Geographical setting

Nottingham probably has its origin as an important settlement in Anglo-Saxon times during the 6th century AD, but its beginnings may go back to Roman or even pre-Roman times. Thereafter it was settled continuously through the Viking and Norman periods to become a major trading centre during the Middle Ages. Its importance was clearly related to its position on relatively

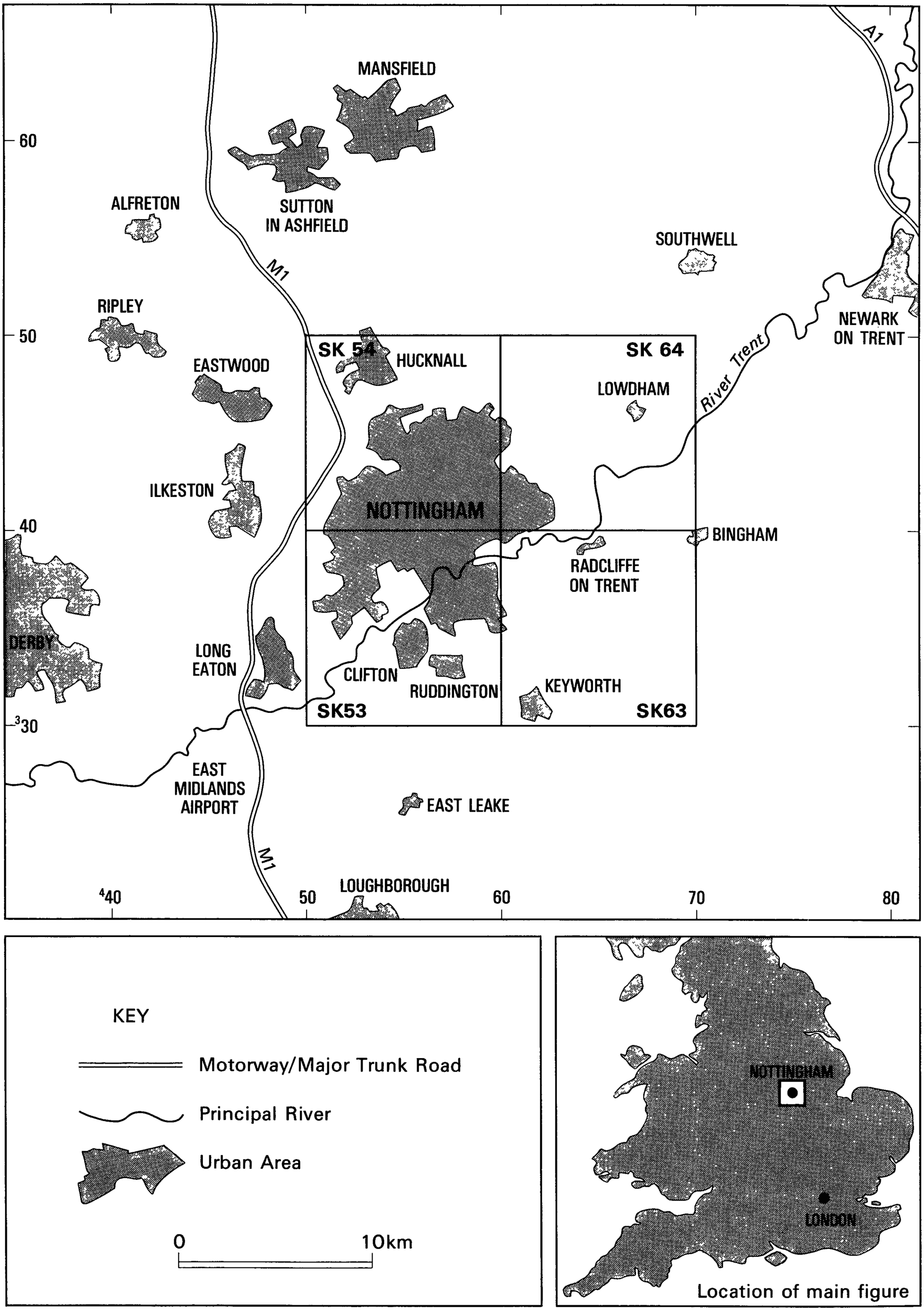


Figure 1. Map showing location of study area in its regional setting

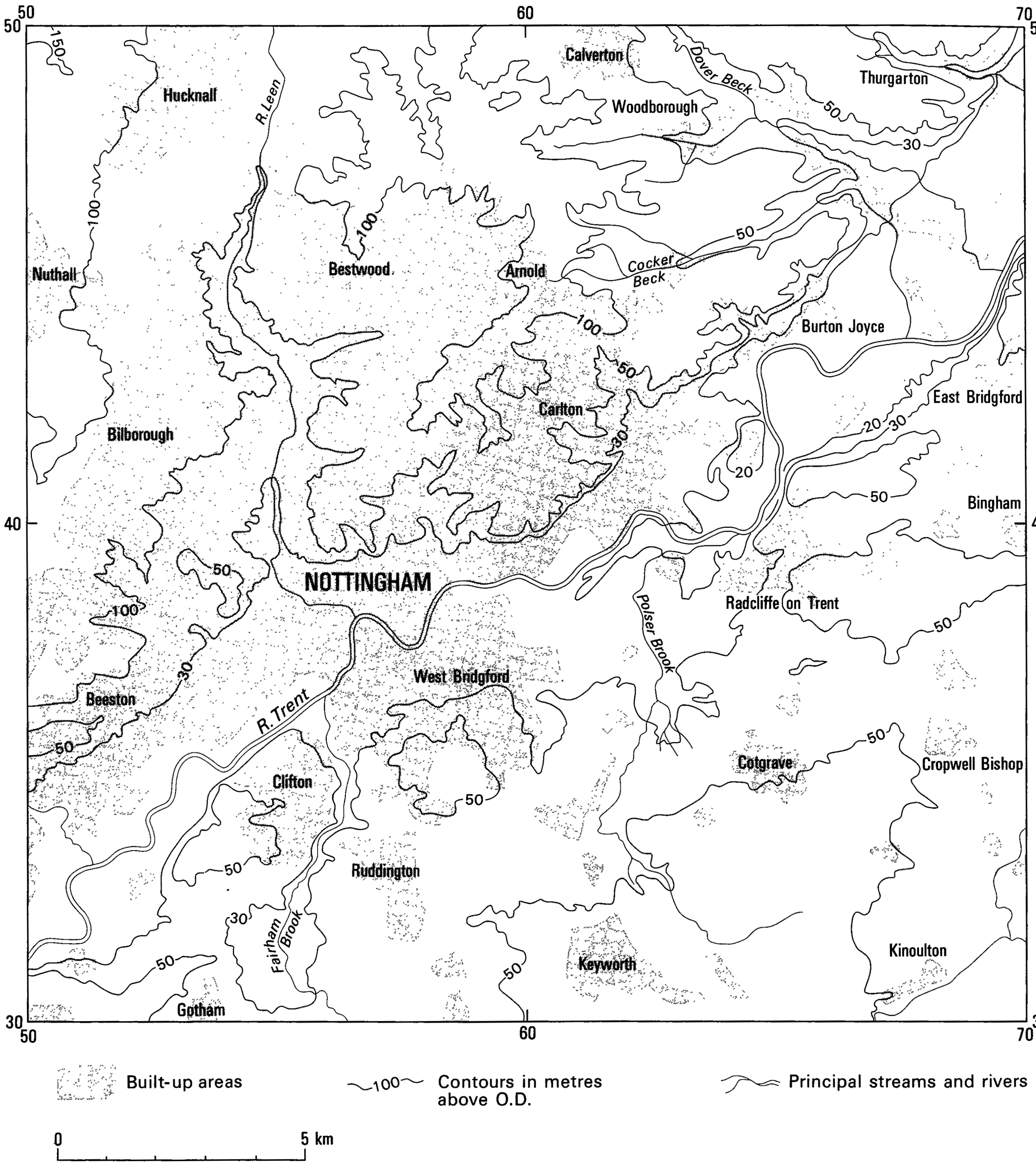


Figure 2. The Nottingham study area

high, dry sandstone ground close to suitable fording or bridging positions on a major navigable river. The 19th century saw the expansion of coal mining in the area and the development of major industries in the city, many of which survive today alongside older more traditional crafts such as lace-making. The city is now known mainly for the manufacture of pharmaceuticals, telecommunications equipment, bicycles and cigarettes, and the knitting and textile industries. In the area surrounding the city, coal mining, sand and gravel extraction and gypsum mining play an important role in the economy of the region as a whole; however, farming, particularly of arable crops, is still the mainstay of the rural economy.

The area is bisected almost exactly by the north-easterly flowing River Trent (Figure 2). The broad relatively flat expanse of the valley floor at c.15-30m above OD contrasts markedly with the dissected high ground to the north and south. North of the Trent the land rises to over 160m above OD west of Hucknall, while to the south the Nottinghamshire Wolds, which rise to about 97m above OD, overlook the Vale of Belvoir in the south-east corner of the area.

The rapid growth of urban Nottingham began in the 1870s and has continued since then with the expansion of the city on all sides, including south of the Trent at West Bridgford and Clifton. The period since the 1960s has also seen the rapid development of 'dormitory' housing, turning small villages, such as Keyworth, Radcliffe on Trent, Burton Joyce and Bingham, into populous suburban centres. Redevelopment of the inner city has also been gaining in pace during this time.

It is in the context of planning control of urban expansion, development and redevelopment that this report has been commissioned.

Sources of information

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

A major part of the project has been to remap at 1:10 000 scale that part of the area not covered by post-1950 geological mapping. Like all such mapping, the final maps represent the combined results of detailed field geological survey, archival data assessment and specialist interpretation. The inputs into the geological maps of Nottingham are shown diagrammatically in Figure 4.

Each map is published as a standard geological map at 1:10 000 scale and is accompanied by a technical report summarizing the geology of the district. The geologist responsible for each 1:10 000/10 560 map in the study area is listed in Table 4, together with the date of his survey, and the name of the accompanying report. All the maps and reports for the area are available from BGS Keyworth.

Table 1. Main sources of archival information

SOURCE	TYPE OF INFORMATION
British Geological Survey	Geological maps and memoirs, field slips and notebooks; dating from 1858. Borehole, well and trial pit logs; locations shown on Ordnance Survey 1:10 560 maps. Historical earthquake records. Geophysical data.
British Coal	Abandoned and working mine plans. Opencast site files. Geophysical exploration data.
Nottingham County Records	Various editions of Ordnance Survey maps.
Aerial photographs	Delineation of mineral workings and major new constructions.
Severn-Trent Water	Details of underground water supply including hydrographs and analyses. Flood limits.
Archaeology Section, Nottingham City Council	Cave records. Local knowledge.
Archaeology Dept. University of Nottingham	Cave records.

Table 2. Summary of history of previous published BGS geological mapping.

MAP SERIES	GEOLOGICAL SURVEYORS	DATE OF SURVEY	DATE OF PUBLICATION
Old Series (1 inch to 1 mile)	WT Aveline, E Hull, TR Polwhele	1855-1878	1879
County Sheet (6 inches to 1 mile)	C Fox-Strangways, W Gibson, G W Lamplugh, R L Sherlock, B Smith, W B Wright	1903-1906	1905-1915
National Grid Sheets (6 inches to 1 mile)	D Frost (SK54NW, 54SW, 53NW only)	1963-1964	1968-1969

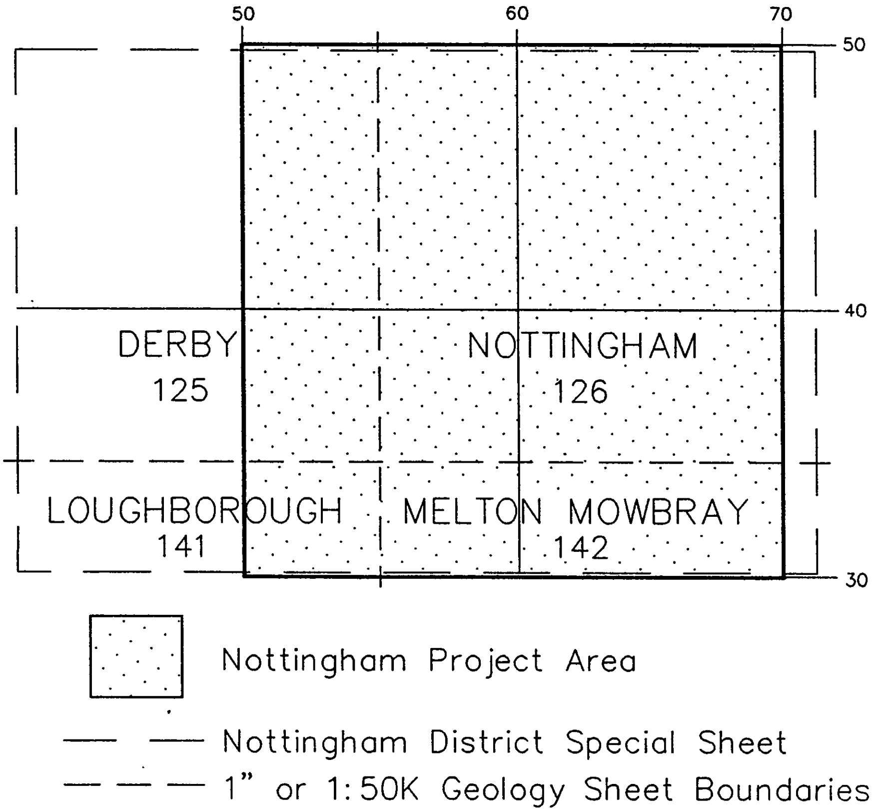


Figure 3. New Series: Published geological maps related to the Nottingham area

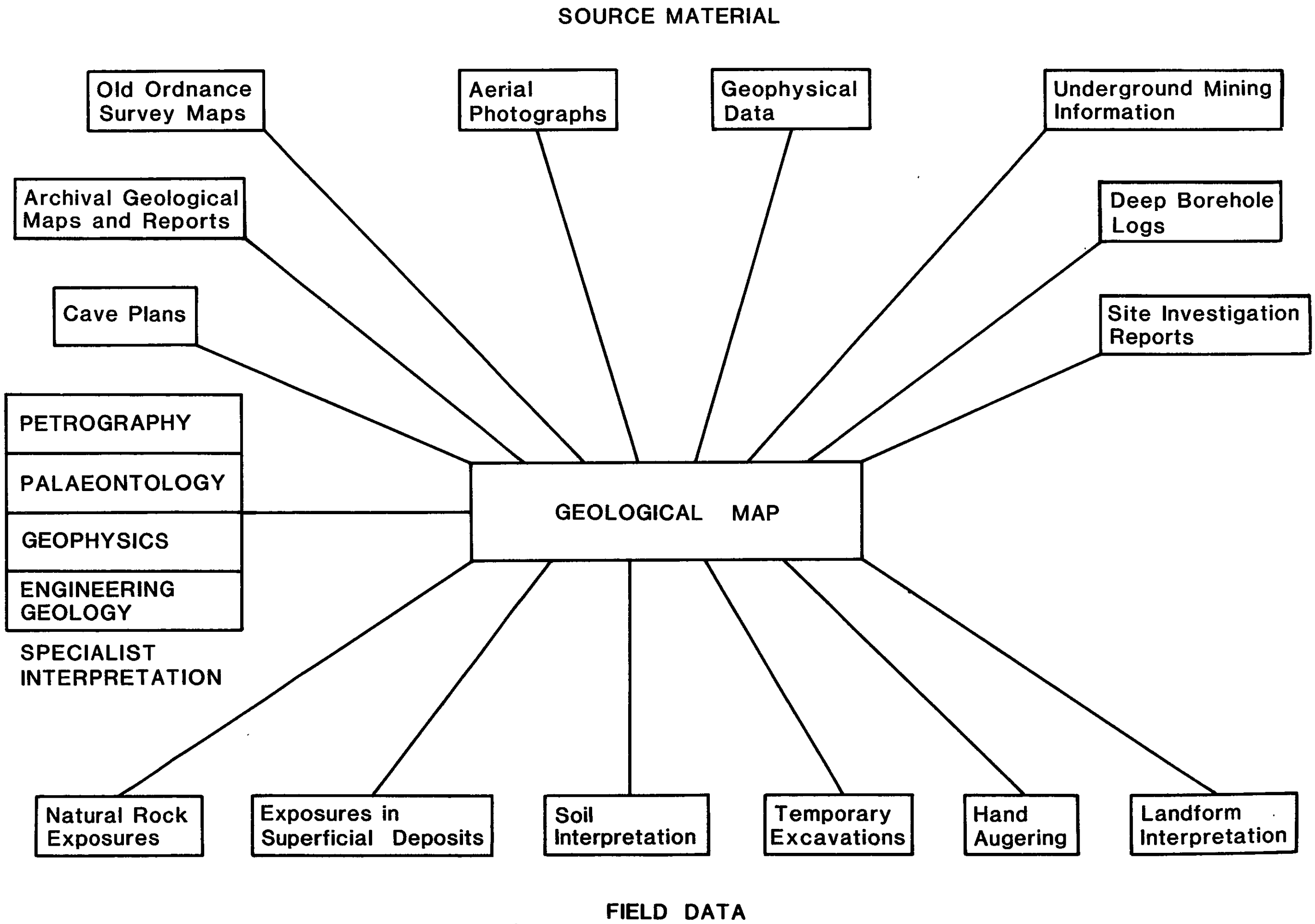


Figure 4. Diagram to show the main inputs into the geological maps of the Nottingham area

Table 3. Publication of Small-scale (1 inch to 1 mile and 1:50 000) maps covering the Nottingham area.

SHEET	NUMBER	1 INCH TO 1 MILE EDITIONS	1:50 000 EDITION*
Derby	125	1908 1963 (RP) 1967 (RP)	1972 (N)
Nottingham	126	1908 1959 (RP)	1972 (RC)
Loughborough	126	1904 1950 (A)	1976 (RC)
Melton Mowbray	142	1909 1959 (RP) 1969 (RP)	1976 (RC)
Nottingham District Special Sheet		1910	

(A) Amended and revised
(N) New survey
(RC) Reconstituted to 1:50 000 scale with minor amendments
(RP) Reprinted with minor amendments
* Available for purchase at bookshops

The published set of thematic maps at 1:25 000 and 1:50 000 have been compiled using these 1:10 000 and 1:10 560 geological maps and other data, and hence represent a summary of the very latest geological information available. The results of the present survey, together with planned additional geological mapping will be combined over the next few years to produce a completely revised colour-printed 1:50 000 geological map and accompanying Memoir for the Nottingham District (Sheet 126).

The ability to produce updated geological maps has very much depended on the borehole and trial pit database. Prior to the initiation of the project the database for the area held in the National Geosciences Data Centre (NGDC) at Keyworth comprised about 900 separate borehole logs and sections. By actively seeking data from local authorities, site investigation companies, geotechnical consultants and others the database was expanded to over 5000 items. The co-operation of those providing data is gratefully acknowledged. Sites of all boreholes and trial pits held in the NGDC database up to January 1989 are shown on Map 1, with a different symbol used for those deeper or shallower than 10m. Figure 5 is a summary map of the distribution of boreholes and trial pits for which data are held. It demonstrates both the

Table 4. Geological mapping responsiblity (1:10 000/1:10 560). 1963-1988), and names and publication dates of accompanying reports (see also references)

SHEET	SCALE	GEOLOGIST	DATE OF SURVEY	REPORT	REPORT NUMBER	PUBLICATION DATE
SK53NW	1 : 10 560	D Frost	1963-64	-	-	-
SK53NE		T J Charsley	1987- 88	Nottingham (South)	WA/89/4	
SK53SW	1:10 000	A S Howard	1987	Attenborough	WA/89/5	1989
SK53SE		T J Charsley	1987-88	Ruddington	WA/89/6	
SK54NW	1:10 560	D Frost	1963-64	-	-	-
SK54NE	1:10 000	P A Rathbone	1988	Bestwood	WA/89/7	1989
SK54SW	1:10 560	D Frost	1963	-	-	-
SK54SE		M T Dean	1988	Nottingham (North)	WA/89/8	
SK63NW		D J Lowe		Radcliffe on Trent	WA/89/9	
SK63NE				Cropwell Butler	WA/89/10	
SK63SW	1:10 000	R G Crofts	1987-88	Keyworth	WA/89/11	1989
SK63SE				Kinoulton	WA/89/12	
SK64NW		D J Lowe & J R A Giles		Calverton	WA/89/13	
SK64NE		K Ambrose	1988	Lowdham	WA/89/14	
SK64SW		P A Rathbone	1987-88	Carlton	WA/89/15	
SK64SE	1:10 560		1988	East Bridgford	WA/89/16	

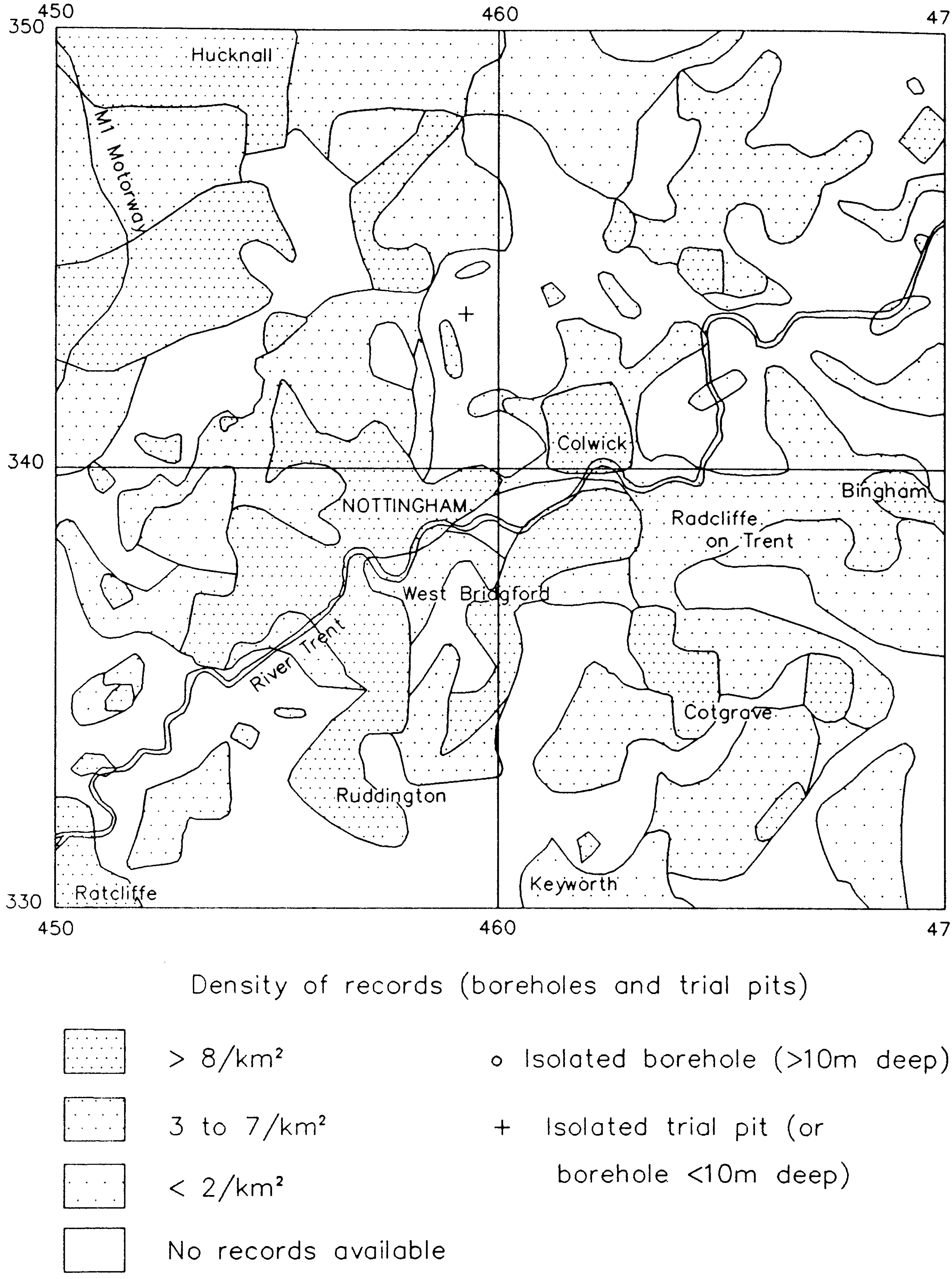


Figure 5. Summary map showing the distribution of borehole and trial pit records

concentration of information in certain areas and the lack of coverage, and hence the limitations on detailed knowledge of the subsurface, in others.

The sections of the report on underground water were contributed by E Parry of the National Rivers Authority, with additions by R A Monkhouse and T J Charsley.

GEOLOGICAL BACKGROUND

INTRODUCTION

The geology of an area influences many fundamental resources and constraints for land use. An appreciation of the geological background thus has considerable importance, especially in an area of such diverse geological materials as Nottingham. For any area the geology may be considered in three tiers – bedrock overlain by generally unconsolidated superficial or drift deposits with a relatively thin further layer of man-made and disturbed material at the surface. These three parts are considered separately in the following description, which ends with a brief summary of the relationship between the geological materials and the main landforms of the area (geomorphology).

BEDROCK GEOLOGY AND STRUCTURE

The bedrock of the Nottingham area includes a wide variety of sedimentary rocks from conglomerates, sandstones, siltstones and mudstones to limestone, coal and gypsum. The age of deposition is broad, spanning the late Carboniferous to the early Jurassic periods of time from about 300 to 210 million years ago; older rocks are known to occur at depth.

The rocks of each geological period are considered briefly in the following section, with some further detail in Annex 1. The rather complex outcrop pattern is shown on Figure 6 and in more detail in Map 2. The generalized vertical sections in Figure 7 set out the geological succession, and include all the bedrock units presently known from beneath the area. The form these formations take below the surface is presented in Figure 8 as a series of horizontal cross sections across the area.

Carboniferous

Following the end of Caledonian earth movements about 360 million years ago, the Carboniferous Sea covered the eroded Palaeozoic and Precambrian basement rocks of the Nottingham area. The oldest rocks proved are Dinantian limestones; they were deposited slowly on a 'shelf', in relatively shallow seas rich in animal life. At the same time, great thicknesses of mudstones, thinly bedded limestones and thin sandstones were being deposited in the south-west of the district, in the deeper, muddier waters of a basinal area known as the Widmerpool Gulf (Figure 17). During Namurian times, the Gulf was gradually filled in by sediments, including in the higher part three thick sandstone sequences, the Ashover Grit, the Chatsworth Grit and the Rough Rock, typical of the Millstone Grit. These are the deposits of river deltas which built out into the Gulf from the east and south-east. Throughout the district the precise position of the northern margin of the Gulf remains conjectural; its southern margin is well to the south of the district.

Towards the end of the Namurian, sedimentation periodically outpaced subsidence, and thickly vegetated peaty swamps were established. Fluctuations in the rate of subsidence are reflected by distinct cycles of sedimentation, each beginning with the deposition of marine or near-marine shales (including 'Marine Bands') which pass up through mudstones into deltaic siltstones and sandstones. At the top of each cycle are the products of the compaction and alteration of peats, other organic material and soils, namely the coals and seatearths.

Through Westphalian times, the same pattern continued but with increasing dominance of shallow-water muddy deposits. The cycles increased in number but became generally thinner. Periods when the area was above sea-level and with abundant land floras became more frequent and, in many cases, more prolonged, resulting in complicated patterns of coal seams.

The Coal Measures show a gradual regional thinning towards the east, where the succession locally contains substantial thicknesses of volcanic rocks; these become more common and also increase in thickness eastwards.

In the late Carboniferous (about 290 million years ago) regional uplift of the Pennine area took place as a result of major crustal movements known as the Variscan Orogeny. A long period of denudation continued into early Permian times when massive amounts of the Carboniferous strata were removed by erosion. The resulting land surface was subjected to tropical weathering and the denuded Carboniferous rocks were superficially reddened.

Local details

Carboniferous Limestone (Dinantian) and Millstone Grit (Namurian)

Very little data exist for the Carboniferous Limestone and Millstone Grit of the district; most of the data remain confidential. These strata lie concealed at depth and do not crop out in the district. Within the Widmerpool Gulf 152m of Dinantian limestone, sandstone and mudstone and up to 635m of Namurian strata have been proved in boreholes. For the shelf area up to about 18m of Dinantian limestone and about 200m of Namurian rocks have been recorded in boreholes.

Lower Coal Measures

The Lower Coal Measures have been proved at depth beneath most of the district, except in the south-west, where the upper part of the Lower Coal Measures was removed by late-Carboniferous and early-Permian erosion. The upper part of the Lower Coal Measures crops out in the extreme west of the district (Map 2). Where complete, the measures range in thickness from c.290-440m.

The main coal seams are shown in Figure 7, and details of the proved sequence of strata are generalized in the vertical section on Map 2.

Middle Coal Measures

The Middle Coal Measures have been proved at depth over much of the district. However, in the extreme west and south-west of the project area the upper part of or, less commonly, the entire sequence has been removed by late-Carboniferous and early-Permian erosion. The lower part of the Middle Coal Measures crops out in the extreme west of the district (Map 2). Where complete, the measures range in thickness from c.215-325m.

The main coal seams are shown in Figure 7, and details of the proved sequence of strata are generalized in the vertical section on Map 2.

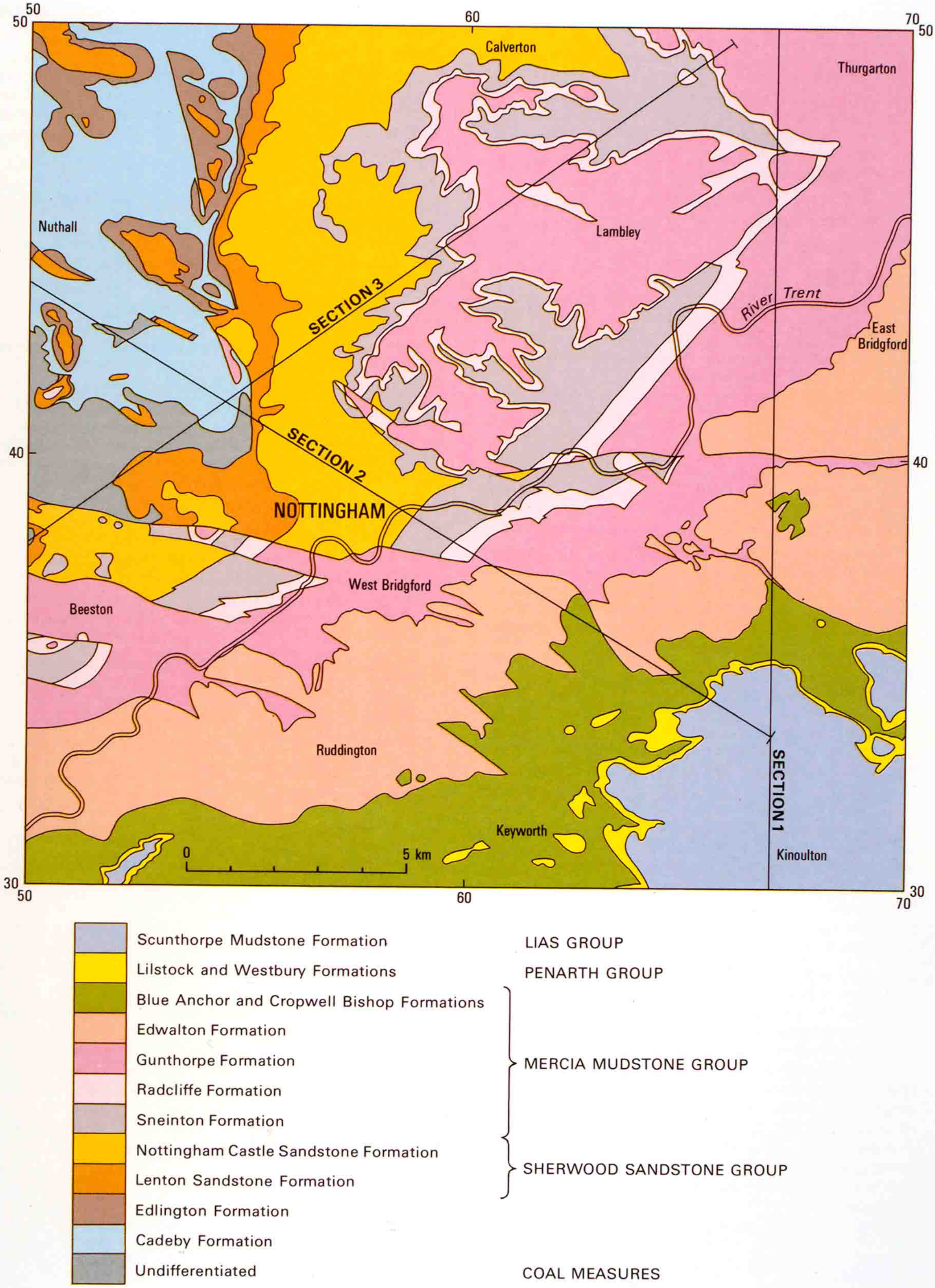


Figure 6. Simplified bedrock geological map of the Nottingham district

Upper Coal Measures

The thickness of Upper Coal Measures present at any locality is in large measure a reflection of the extent of late-Carboniferous and early-Permian erosion; but, as far as can be judged, these beds thicken to the north. The Upper Coal Measures do not crop out and they are not present, even at depth, in the extreme south and west of the district. The maximum recorded thickness is 172m. The Measures are separated into a lower 'Grey Measures' and an upper 'Red Measures' sequence.

The proved succession is generalized in the vertical section on Map 2.

Permo-Triassic

Following deposition of the Carboniferous strata and uplift of the Pennines, erosional conditions persisted during much of the Permian Period. The lowest Permian deposits are of continental origin, comprising breccias, formed by the mechanical weathering of local rocks, and other sediments transported by intermittent streams and rivers, commonly under flood conditions. These basal rocks rest upon the eroded, low-relief Carboniferous land surface and may range in age from early to late Permian. In late Permian times the area lay on the western margin of the shallow inland Zechstein Sea which covered much of the present area of the North Sea and northern Germany. This sea periodically expanded and shrank due to climatic variations. The Upper Permian deposits represent these phases, when either carbonate (Cadeby Formation carbonate facies: Lower Magnesian Limestone) was deposited from sea water, or siltstone and mudstone (Cadeby Formation mudstone facies: Lower Marl) were deposited by streams and rivers.

Towards the end of the Permian (about 250 million years ago) a low relief, desert landscape was increasingly affected by fluvial activity. Rivers carried progressively more sand into the depositional basin, such that the mainly mudstone sequence of the Edlington Formation passed upwards gradationally into the predominently sandstone formations of the Sherwood Sandstone Group. Deposition of the Lenton Sandstone, a unit which contains clay and silt beds locally, commenced in the Permian, but firm evidence of the age of the top of the formation is lacking. The overlying Nottingham Castle Sandstone comprises predominantly sandstones with pebbly layers, laid down by a major river system which flowed northeastwards and eastwards across the area from its source far to the south.

Increased aridity is indicated by many of the Mercia Mudstone Group sediments. Fast flowing rivers were succeeded by intermittent streams flowing into ephemeral lakes. Periodically, more extreme arid conditions similar to a modern continental saline mudflats were established, and gypsum deposits were formed. Throughout these episodes wind-blown dust provided a significant input to the thick mudstone sequences, and sheet floods, in times of increased rainfall, produced relatively thin but often widespread beds of sandstone or coarse siltstone, locally termed 'skerries'. The onset of a profound change of depositional environment is, however, indicated in the uppermost part of the Mercia Mudstone Group. Blue Anchor Formation sediments preserve features which confirm intermittent inundation by the sea (about 220 million years ago).

The rocks of the Penarth Group continue the transition between the essentially arid continental Mercia Mudstones and fully marine deposits which form the overlying Lias Group. They were probably deposited in shallow lagoons or inland seas with local or periodic connections to the open sea.

Local details

The **Basal Breccias**, possibly ranging in age from early to late Permian, show marked variation across the district; locally no breccia is present at the base of the Permian succession whereas up to 8m is recorded elsewhere. They are mainly sandy and contain a variety of rock fragments.

The **Cadeby Formation** is subdivided with a lower 'mudstone facies' and an upper 'carbonate facies', formerly the Lower Marl and Lower Magnesian Limestone respectively. At outcrop in the Nuthall area the mudstone facies is about 5m thick, decreasing to about 1m near Wollaton. Southwards the beds die out on the edge of the depositional basin; eastwards an increase in thickness up to 37m is proved by boreholes. Most of the rocks forming the Cadeby Formation carbonate facies are dolomites derived from original limestones. Locally the rock has the texture of a sandstone or coarse siltstone, and is composed of dolomite rhombs, with minor quartz grains. It was formerly well exposed in quarries at Bulwell and Cinderhill and in various small lime pits and railway cuttings (Back Cover), but most of these are now filled or obscured. Its thickness ranges from zero at the margin of the depositional basin in the south to a value of about 65m in the north-east.

The **Edlington Formation** is present at outcrop between Hucknall and Bulwell where up to 9m of red, purple-brown or yellow silty mudstone with green layers and thin beds of dolomitic sandstone or sandy dolomite is present. The formation thins to the south and disappears in the Wollaton/Stapleford area. North-eastwards, the formation is proved by shafts and boreholes to be up to 29m thick.

Sherwood Sandstone Group

In the Nottingham district two formations are recognised within the Sherwood Sandstone Group, each with its type locality within the district.

The **Lenton Sandstone** is generally bright red-brown with yellow mottling, fine- to medium-grained, and commonly friable or soft (Plate 1). It has a maximum local thickness of up to about 30m.

The **Nottingham Castle** Sandstone forms a conspicuous outcrop northwards from the city and through Sherwood Forest, but is best seen in the imposing crag below Nottingham Castle itself [569 394]. The rocks consists almost entirely of buff to pale red-brown sandstone with subordinate conglomerate, siltstone and mudstone. The many man-made caves, for which Nottingham has been noted since Mediaeval times, are excavated almost entirely in the Nottingham Castle Sandstone (Front Cover). Brief details of their nature and distribution are contained elsewhere in this report, but more data are contained in a separate register (Owen and Walsby, 1989).

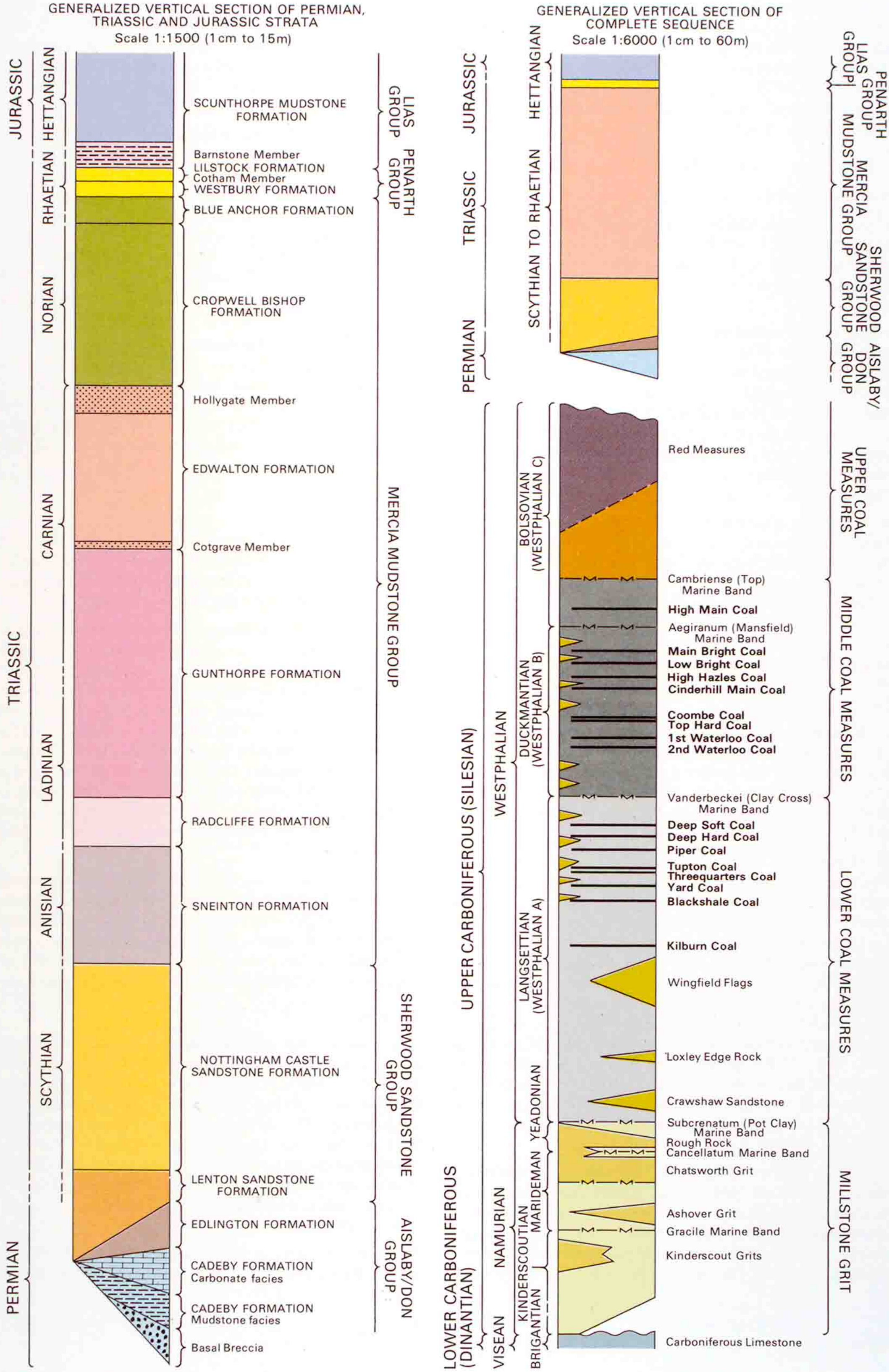


Figure 7. Generalized vertical sections for the bedrock formations of the Nottingham district

Eastward of its outcrop the formation has been proved to extend beneath younger deposits, thickening towards the north-east and thinning southwards. In the district the thickness ranges between about 150m in the north and 65m in the south. The Nottingham Castle Sandstone is freely water-bearing and, as described elsewhere in the report, the unit provides a major part of the water supply in the area.

Mercia Mudstone Group

The base of the Mercia Mudstones is taken at the change from predominantly sandy to silty and clayey sediments. It included all the rocks formerly referred to as 'Keuper Marl'. The group is divisible into formations as shown in Figure 7.

The **Sneinton Formation** is the near-equivalent of the former 'Keuper Waterstones' and 'Keuper Basement Beds'. The formation, which overlies the Nottingham Castle Sandstone, has its type area in Sneinton [592 397] on the east side of Nottingham. It consists of interbedded fine- to medium-grained sandstone, siltstone and mudstone. The beds are mainly red-brown, and micaceous laminae, ripple marks and cross-lamination are common throughout.

Generally the Sneinton Formation gives rise to an undulating, incised topography, wherein the more resistant sandstone beds locally produce marked features, but much of the outcrop is covered by alluvial deposits of the River Trent and subsidiary streams. It ranges in thickness between about 24m and 50m. On weathering the formation produces a characteristic silty, often sandy, loam soil. The Sneinton Formation has been quarried on a small scale to provide building stone, as described elsewhere.

The **Radcliffe Formation** comprises well-laminated red-brown, pink and grey-green mudstone and siltstone with subordinate fine-grained sandstone. Thicknesses of 10m to 16m are recorded. The most complete surface section of the formation (12m) is found in river cliffs at Radcliffe on Trent [646 398].

The **Gunthorpe Formation** comprises interlayered red-brown and grey-green mudstone, siltstone and very fine-grained sandstone. Thick beds of blocky silty mudstone are still exploited as brick clays (see p.36), but less extensively than in the past. Numerous tough dolomitic siltstone and fine-grained sandstone beds, referred to as 'skerries', commonly form upstanding topographic features. The formation ranges in thickness from 55m to 81m. North of the Trent the most complete section, entirely of the lower beds, is at Dorket Head Brick Pit [595 474] (Plate 2), and south of the river there are exposures of the higher strata in cliffs and bluffs near Radcliffe and Gunthorpe weirs [651 405 and 688 436] (Back Cover). In the latter sections there are intricate networks of gypsum veins.

At the base of the **Edwalton Formation** is the **Cotgrave Sandstone** 1.5m to 4m thick, which can be traced throughout the district. Above the Cotgrave Sandstone the formation comprises red-brown and grey- green silty mudstone and siltstone which is generally blocky or poorly laminated. The top 7m of the formation comprises the alternating sandstones and mudstones of the **Hollygate Sandstone.** The Edwalton Formation ranges in thickness between 35m and 54m. The Cotgrave Sandstone is best exposed in the river cliff at Clifton [541 349] and in old brick-pits at Edwalton [589 363] and Wilford [568 355]; the remainder of the formation is poorly exposed.

The **Cropwell Bishop Formation** comprises red-brown and, more rarely, grey-green mudstone and siltstone with some indurated siltstone or fine-grained sandstone 'skerries'. Gypsum is common and locally forms thick units such as the Newark and Tutbury gypsum beds, formerly and currently exploited by both opencast and underground mining (p.34). Exposure of the formation, which ranges in thickness between 37m and 54m, is generally poor with the exception of the working gypsum quarry at Cropwell Bishop [678 352] (Plate 3).

The **Blue Anchor Formation**, formerly called the 'Tea Green Marl', comprises 6m to 8m of grey-green to yellow-green dolomitic mudstone and siltstone. Found only in the south of the district, the formation is poorly exposed in a number of stream sections and small excavations cut in the steep lower slopes of the 'Rhaetic' escarpment.

Penarth Group

Argillaceous, calcareous and locally arenaceous formations of predominantly marine origin which occur between the Mercia Mudstone Group and the base of the Lias Group constitute the Penarth Group.

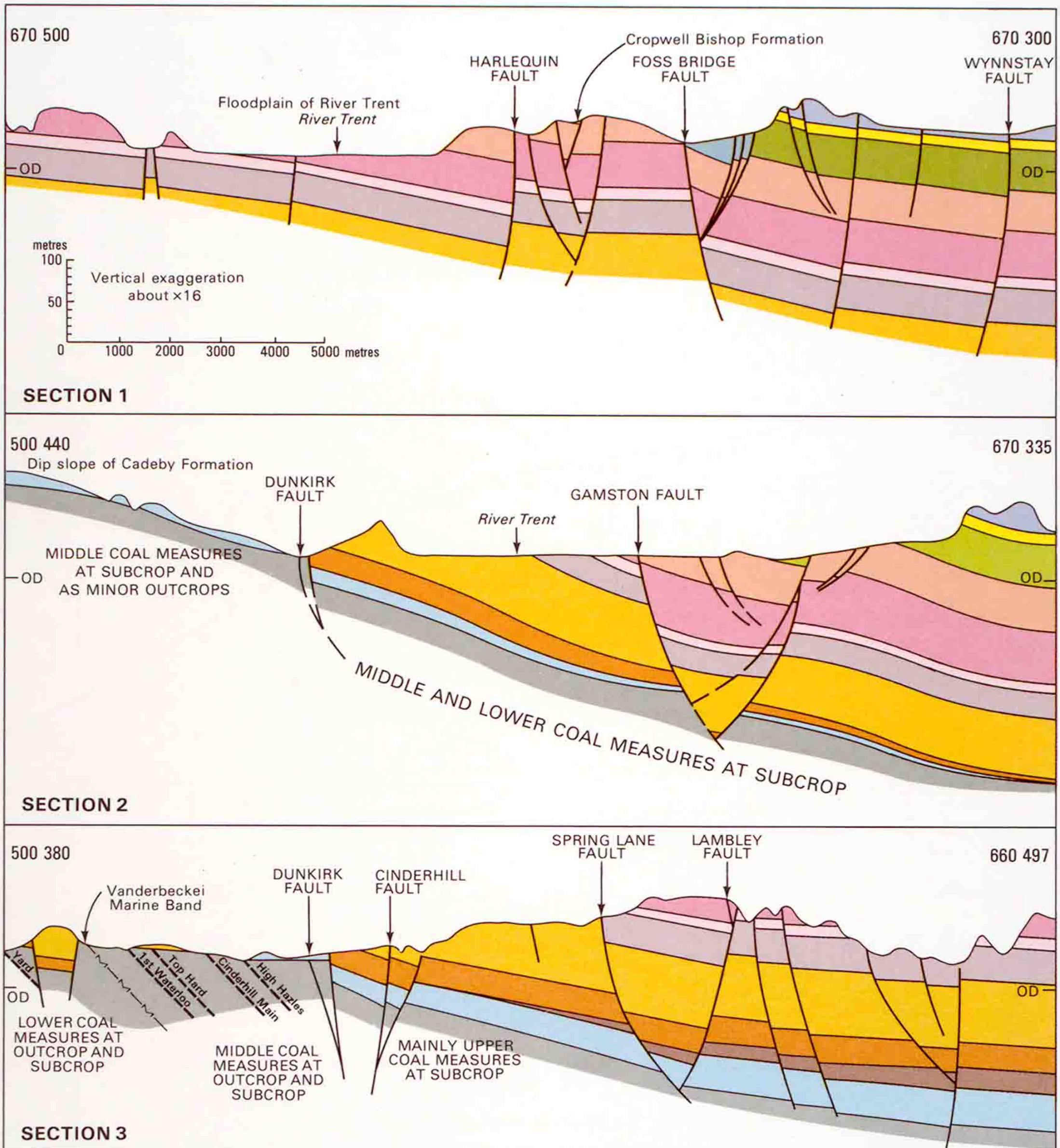
The base of the **Westbury Formation** in the Nottingham district is sharp and probably indicative of a period of erosion prior to its deposition. The formation consists of about 5m to 7m of dark grey to black fissile mudstone, with thin lenses of sandstone near the top. A thin bed, the 'Rhaetic Bone Bed', with fragmentary remains of fish and reptiles is sporadically present at the base. Much of the Westbury Formation outcrop occurs in the face of the prominent 'Rhaetic' escarpment in the south of the district, and is thickly covered by highly weathered material, some of which has moved downslope from less stable beds above.

In the Nottingham district the **Lilstock Formation** is represented only by the **Cotham Member**. It comprises pale grey blocky silty mudstone with discontinuous bands of limestone nodules, and forms a continuous outcrop in the south of the district capped by a 0.1m bed of hard limestone. 3m to 5m of strata are normally present.

Jurassic

The base of the Jurassic System is marked by the first appearance of fossil ammonites belonging to the genus *Psiloceras*. There is no obvious change in rock type across the system boundary which occurs within the rocks of the Lias Group. The Jurassic strata crop out in the southern part of the area (Figure 6), where they either cap a prominent escarpment or form extensive dip-slopes to the south-east of the Penarth Group outcrop. Much of the Jurassic outcrop in the 'Wolds' is covered by locally thick glacial deposits.

Towards the close of the Triassic (about 215 million years ago) fully marine conditions were established by the time



These cross-sections indicate the mapped disposition of the strata and main faults at the surface. In the subsurface the structure and sequence are constructed to provide broad agreement between the surface observations and scattered subsurface data. The vertical exaggeration (16×) is such that true thicknesses and angular relationships cannot be maintained and, thus, the stratigraphic dips and the dips of fault planes are shown schematically.

Figure 8. Generalized horizontal sections (Lines of section and key to colours are shown on figure 6)

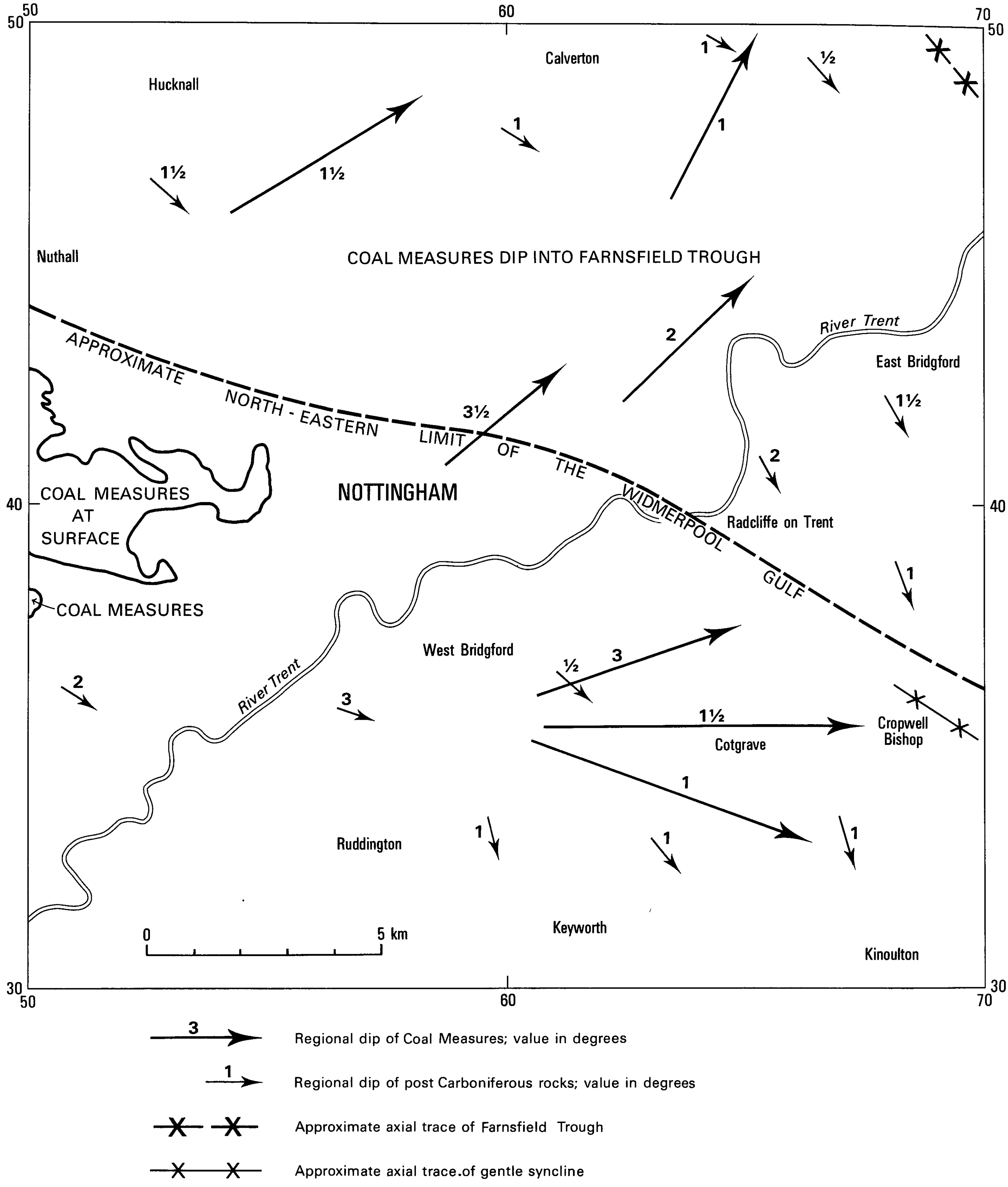
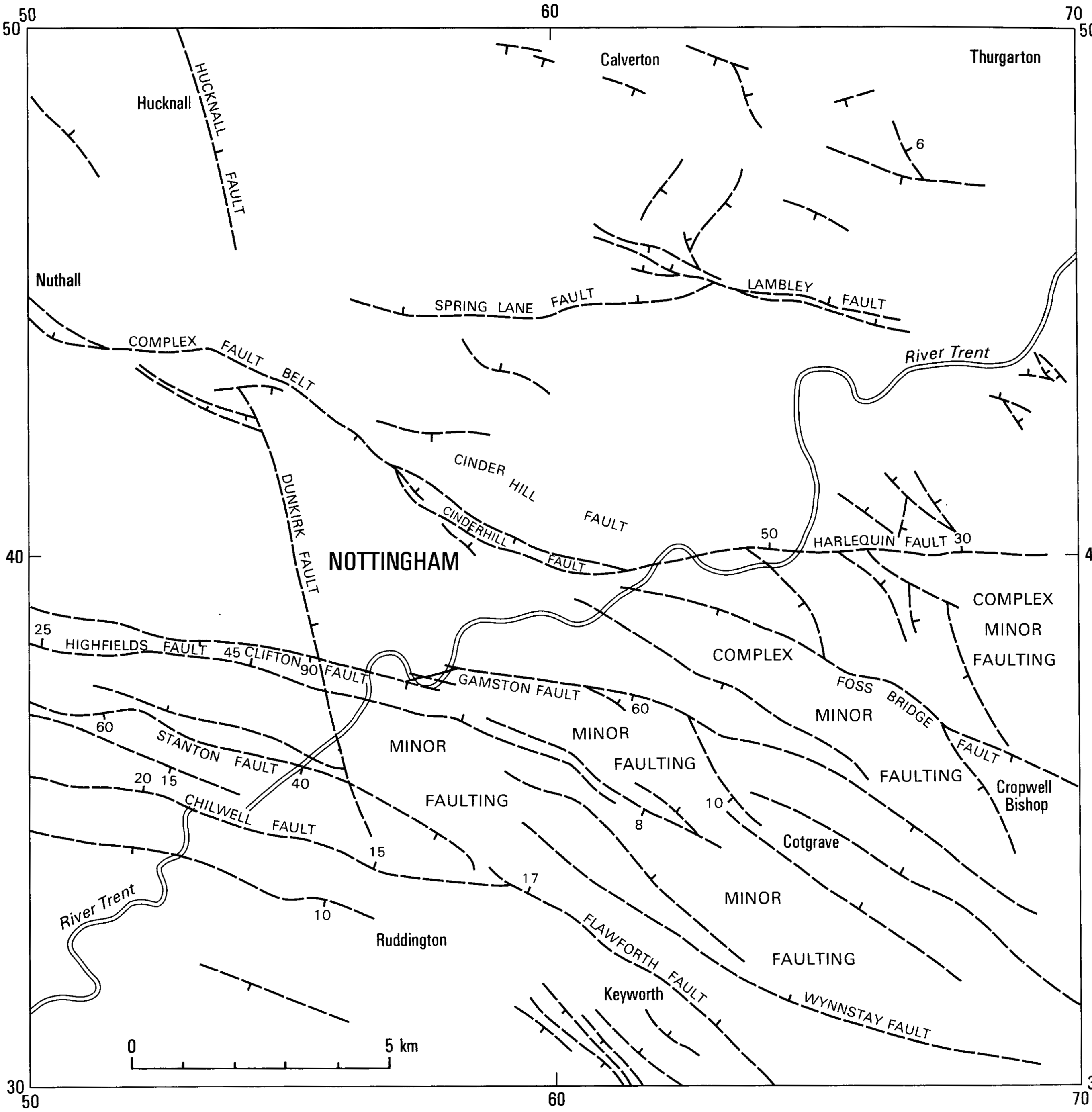


Figure 9. Generalized dip directions and values in the Nottingham district. The limit of the Widmerpool Gulf as shown is the farthest possible north-eastern extent. A zone south-west of this line was probably marginal to the gulf during Coal Measures deposition



Generalized fault line at surface; tick shows downthrow side; calculated throw in metres (20)

Numerous small faults are omitted within the complex fault zone between the Harlequin and Flawforth faults

Figure 10. The fault pattern in the Nottingham district as shown by major faults and selected minor fractures

the first strata of the Lias Group were deposited. The district lay beneath a shallow, open sea, sufficiently remote from the coast to be beyond the reach of coarse detritus and yet close enough to receive a constant supply of finer debris. When the sediment supply was copious, thick beds of mud were laid down, whereas periods of diminished sediment supply are indicated by bands of impure limestone, incorporating the shells and skeletal relics of the organisms which were able to colonise the temporarily clearer waters.

Local details

Lias Group

Only the lowest unit, the **Scunthorpe Mudstone Formation** is present in the district. At the base of this occurs the **Barnstone Member**, previously known as the 'Hydraulic Limestones', which locally caps the 'Rhaetic' escarpment. The member comprises alternating beds of calcareous mudstone and limestone, suitable for the manufacture of high quality hydraulic cement. It is about 6m thick in the Nottingham district. East of Cotgrave, the member lies below the highest part of the escarpment and is overlain by about 22m of younger beds of the Scunthorpe Mudstone.

Limestone is uncommon in these upper beds, and the outcrop, where free of glacial deposits, is usually characterised by stiff, grey clay soils with rare local concentrations of limestone debris.

Structure

During the Carboniferous, the Pennine Basin was part of a series of structurally controlled basins which strongly influenced sedimentation in the British Isles north of the Variscan Front. The Widmerpool Gulf (Figure 17), a major half-graben structure, passes through the south-west of the district and forms the southern margin of the Pennine Basin. Active south-westerly directed tilting of the half-graben considerably influenced sedimentation during Dinantian and Namurian times (see p.70).

During the Variscan Orogeny (mountain-building episode), from late Westphalian to early Permian times, basin inversion took place and the Carboniferous rocks of the region were uplifted; considerable faulting probably occurred at this time. Major faults may reflect older basement structures. Substantial erosion and planation of the Carboniferous rocks took place before the incursion of the Permian Zechstein Sea.

Evidence from areas to the east, particularly the North Sea, indicates that periodic tectonic activity continued during deposition of the Mesozoic strata. New faults formed and some older ones were reactivated, mainly during the late-Jurassic to early-Cretaceous period, and the strata were gently tilted and folded.

The Alpine Orogeny affected southern Britain in Tertiary times, peaking at about 38 million years ago; effects in the Nottingham district are uncertain and currently inseparable in detail from the Mesozoic tectonics mentioned above. The cumulative effects of all post-Variscan movements were gentle folding of the Permian, Triassic and Jurassic sequences and refolding of the underlying Carboniferous rocks. Faulting also took place. In some cases pre-existing faults within the Carboniferous rocks were reactivated and their effects propagated through the younger rocks. Additional fractures also formed, some of which affected the Carboniferous and younger rocks and some just the younger strata.

No further major tectonic activity has occurred since Tertiary times. Finally, and on a very much smaller scale than anything before, minor readjustment along pre-existing fault lines has occurred in recent times as a result of mining subsidence. Minor earthquakes also indicate sporadic fault movement (see p.54).

Superficial structures such as cambering and valley bulge have been recorded locally, particularly in the deeply-incised Mercia Mudstone Group terrain in the north-east of the district.

Broad structural details

The regional dip of the Carboniferous rocks in the district, the result of Variscan and later movements, is broadly towards the north-east at angles from 1.5 to 4 degrees (Figure 9). Overlying rocks were affected only by post-Variscan events and their regional dip is towards the south-east at angles which rarely exceed 2 degrees. Dip values vary locally due to gentle fold structures and drag adjacent to faults; angles up to 60 degrees are recorded in the latter situation. Super- imposition of many faults upon the gently dipping succession has disrupted the orderly south-eastward younging of the sequence and, particularly where incised topography has formed, outcrop patterns are locally intricate (Figure 6).

Folds

A broad regional syncline with gently dipping limbs and shallow plunge towards the east-south-east lies just south of Nottingham (Edwards, 1951), with complementary anticlines to the north and south. East of Cropwell Bishop the outcrop of the Penarth Group and basal Lias Group mark the lowest recognisable closure of the syncline on a local scale; mapping to the south in the same area confirms the adjacent anticline. These structures cannot be confirmed below the sub-Permian unconformity due to lack of data. Elsewhere sufficient data are available from the exposed and concealed coalfield to recognise the major folds in the Coal Measures. The general dip to the north-east is on the southern side of the Farnsfield Trough, a basinal structure with long axis trending roughly north-west to south-east across the north-east corner of the district. The Farnsfield Trough formed in pre-Permian times and its presence is not mirrored in the younger rocks. Limited data in the extreme south show the Coal Measures strike to swing from north-west/south-east to roughly north/south, indicating that an anticline is present within the pre-Permian rocks. This fold is approximately coincident with the north-eastern limit of the Widmerpool Gulf.

Faults

The fault pattern affecting the district is illustrated in Figure 10; major structures are named. The predominent fault trend ranges between approximately west/east and north-west/ south-east. A second set has a range of trends between north-west/south-east and north/south; a few faults trend between north/south and north-east/south-west. The number of faults of small throw in the district is unknown, but throws of 5 to 10m are common, and throws greater than 20m are relatively rare. About 90m displacement of Coal Measures strata is recorded in Clifton Colliery, but a slightly lesser throw is present at the surface. Many of the extensive fractures shown on the geological maps might be, in reality, en echelon fault systems; underground provings show major faults dying over short distances, the movement probably being taken up by adjacent fractures.

The underground positions of many faults in the Coal Measures are generally proved or indicated by mine plans, and borehole logs and surface mapping provide additional data. Many major faults in the Coal Measures are recognisable in the overlying rocks, though the amount of throw can differ appreciably.

Recent mapping has shown that the younger rocks are more heavily faulted than previously supposed. Recognition of mappable sub-divisions in the Mercia Mudstone has allowed faults to be identified at the surface and inferred between boreholes. In undermined areas most major faults which affect the younger rocks can be related to faults in the Coal Measures, but this is not always the case. These could be totally post-Variscan or reflect reactivation of Variscan faults. Trends are commonly similar in the older and younger rocks.

A belt of intense faulting, which is coincident with the north-east margin of the Widmerpool Gulf, occurs in the south-east of the district and is believed to include numerous minor, post-Variscan faults. Between the Harlequin Fault and the Flawforth Fault are several sub-parallel major structures on the Variscan trend. Between them are many smaller faults, most on a trend closer to north/south.

As might be expected in an area of moderately intense faulting, joints are common, and are particularly well seen in man-made exposures such as railway cuttings. No detailed study has been carried out.

SUPERFICIAL (DRIFT) DEPOSITS

Materials laid down during the Quaternary Period (the last 2 million years) which remain predominently unlithified, are termed superficial or drift deposits. The most extensive spreads occupy the Trent valley, tributary valleys north of the Trent, the Wolds and broad depressions south of the Trent. Distribution and generalized thickness of drift deposits are shown in Map 3; simplified limits are shown in Figure 11.

Little evidence remains of events which affected the area between early Jurassic and mid-Pleistocene times. During the latter part of this period a major river probably flowed eastwards, south of the present Trent valley. This river and its many tributaries eroded the solid rock sequence to produce the pre-Pleistocene landscape. Subsequently the district was profoundly affected by glacial and periglacial processes during the Pleistocene. Evidence for early events has been removed or obscured by more recent erosion and deposition, but many landforms and deposits formed during the last 400 000 years are recognised. Climate and processes broadly similar to those of today have operated throughout much of the Flandrian (Table 5); erosion and deposition, mainly in the rivers and streams, are continuing.

In general, superficial deposits are sub-divided on the basis of lithology, mode of deposition, landform, or combinations of all three, often with reference to relative age.

Superficial deposits recognised in the district include till, sand and gravel, silt, clay and organic material of various ages; they are described briefly below and in more detail in Annex 1. These were laid down in glacial, periglacial, lacustrine and fluviatile environments in climatic regimes which ranged from very cold to warm. Table 5 relates gross lithology, depositional environment, climate and

Table 5. Details of the Quaternary in the Nottingham area

PERIOD	EPOCH	STAGE	DEPOSIT REFERRED TO IN TEXT	ENVIRONMENT	CLIMATE
QUATERNARY	RECENT	Flandrian	Alluvium (silt, clay, sand, gravel); tufa	Fluvial	warm to cool
			Peat; Shell Marl; Lacustrine deposits (clay and silt)	mainly lacustrine	
		10000 years			
	PLEISTOCENE	Devensian	Holme Pierrepont, Leen and Bunny Sand and Gravel; Head	Fluvial and periglacial	mainly cold
		40000 years			
		early Devensian Ipswichian late Wolstonian	Beeston Sand and Gravel and Bassingfield Sand and Gravel	Periglacial and fluvial, possibly glacio-fluvial or glacio-lacustrine	mainly cold with temperate phases
		200000 years			
		Wolstonian or Anglian	Till and Sandy Till } "Boulder Clay" Glacial Sand and Gravel	Glacial and Glaciofluvial	very cold to cold

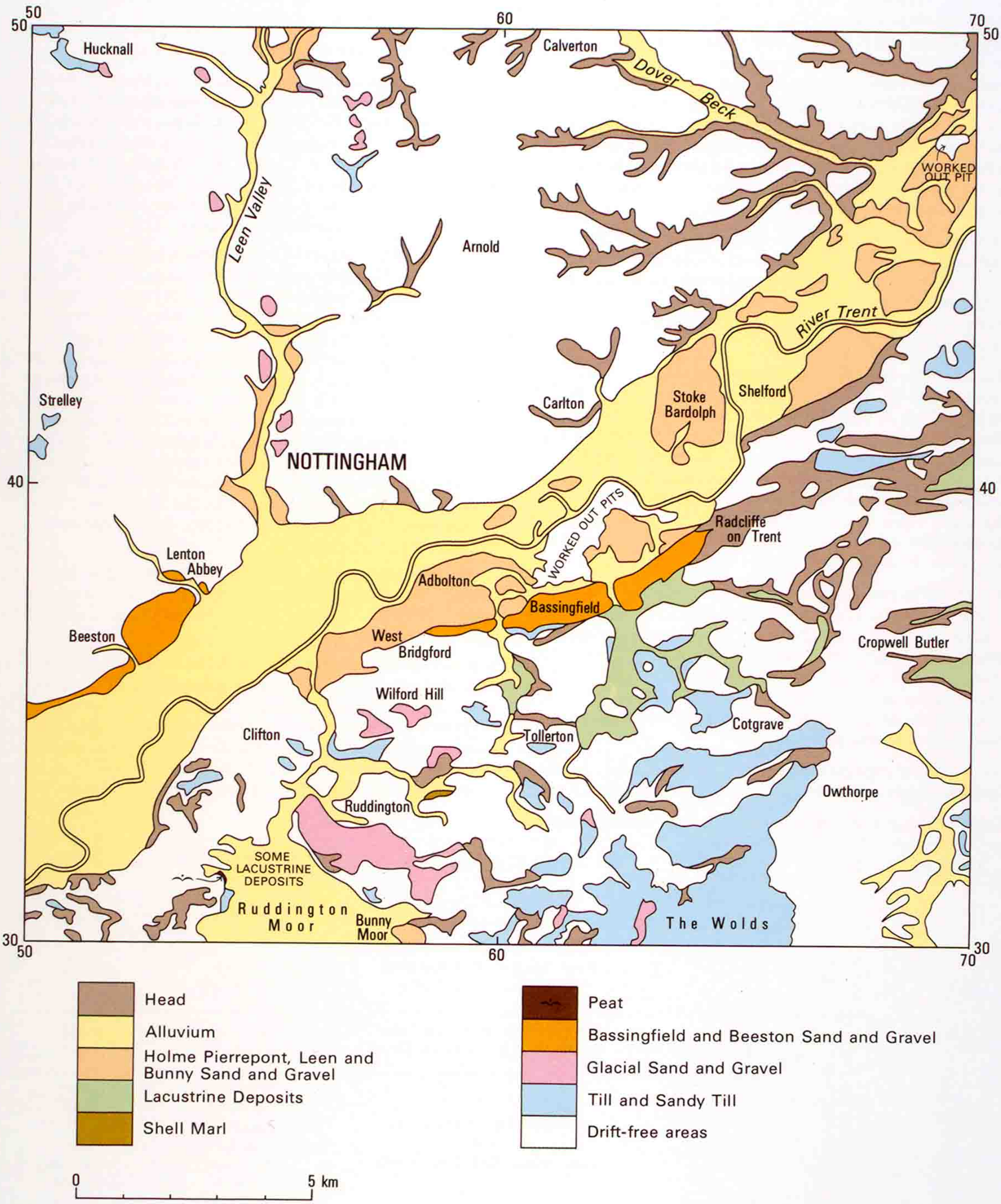


Figure 11. Simplified distribution of superficial deposits

age of the deposits; Figure 12 is a schematic cross section which illustrates the inter-relations of the deposits and their more common landforms.

Details of deposits

Till and Sandy Till

These glacial deposits occur mainly on the high ground of the Wolds and as isolated patches preserved in valleys and, less commonly, on hilltops (Figure 11). Generally, the smaller spreads are thin, but as much as 35m is reported in the Wolds. Broadly, the deposits consist of red-brown or grey silty or sandy clays with pebbles and cobbles of locally derived or exotic rock. If the sand content is small, the deposit is referred to as till (the traditional 'Boulder Clay'). Where sand is the major constituent the term sandy till is used. A spectrum of intermediate compositions occurs and these are locally intimately associated.

Glacial Sand and Gravel

Glacial Sand and Gravel deposits form limited outcrops in the district (Figure 11). Broadly, they are of two types related to their derivation from ice sheets which entered the district from the east and north respectively:

(a) Deposits of sand, with or without flint-bearing gravel, are present in the Ruddington-Bradmore area. The sand and gravel, up to 4m thick, is clayey or silty in places and overlies sandy, variably gravelly clay (till). Glacial Sand and Gravel on higher ground in the Wolds mainly comprises clayey sand with some gravel.

(b) To the north of these areas, relatively small patches of flint-free Glacial Sand and Gravel also occur at higher levels (up to about 120m AOD in the north). The deposits generally comprise pebbly sand with variable proportions of clay; 'blocks' of pebbly clay are present locally.

River Terrace Deposits

Deposits forming a broad ridge, standing up to 6m above the alluvium, stretching from Radcliffe on Trent to West Bridgford are referred to as the **Bassingfield Sand and Gravel** (Figure 11). They comprise orange-brown sand and sandy gravel which is locally clayey and includes discontinuous beds of red-brown clay. Several smaller patches north of the major outcrop, in the Adbolton to Holme Pierrepont area, stand above more recent deposits and are believed to be remnants of a former extensive spread of sand and gravel across the Trent valley.

The **Beeston Sand and Gravel** has an elongate outcrop along the north side of the Trent valley from Lenton Abbey to beyond the western margin of the district (Figure 11), at levels of up to about 6m above the alluvium. Formerly well exposed in gravel pits at Beeston [c.528 372], the deposit is up to 4m thick. The interbedded sand and well-rounded gravel is typically horizontally bedded but locally shows current bedding which indicates a sediment source in the north-west.

Large spreads of **Holme Pierrepont Sand and Gravel** are present at surface within the Trent valley from Clifton eastwards (Figure 11). Upstream of Clifton, similar deposits are present beneath more recent alluvium. Downcutting by the Trent has left low benches or terraces of Holme Pierrepont Sand and Gravel from < 1m to 2m

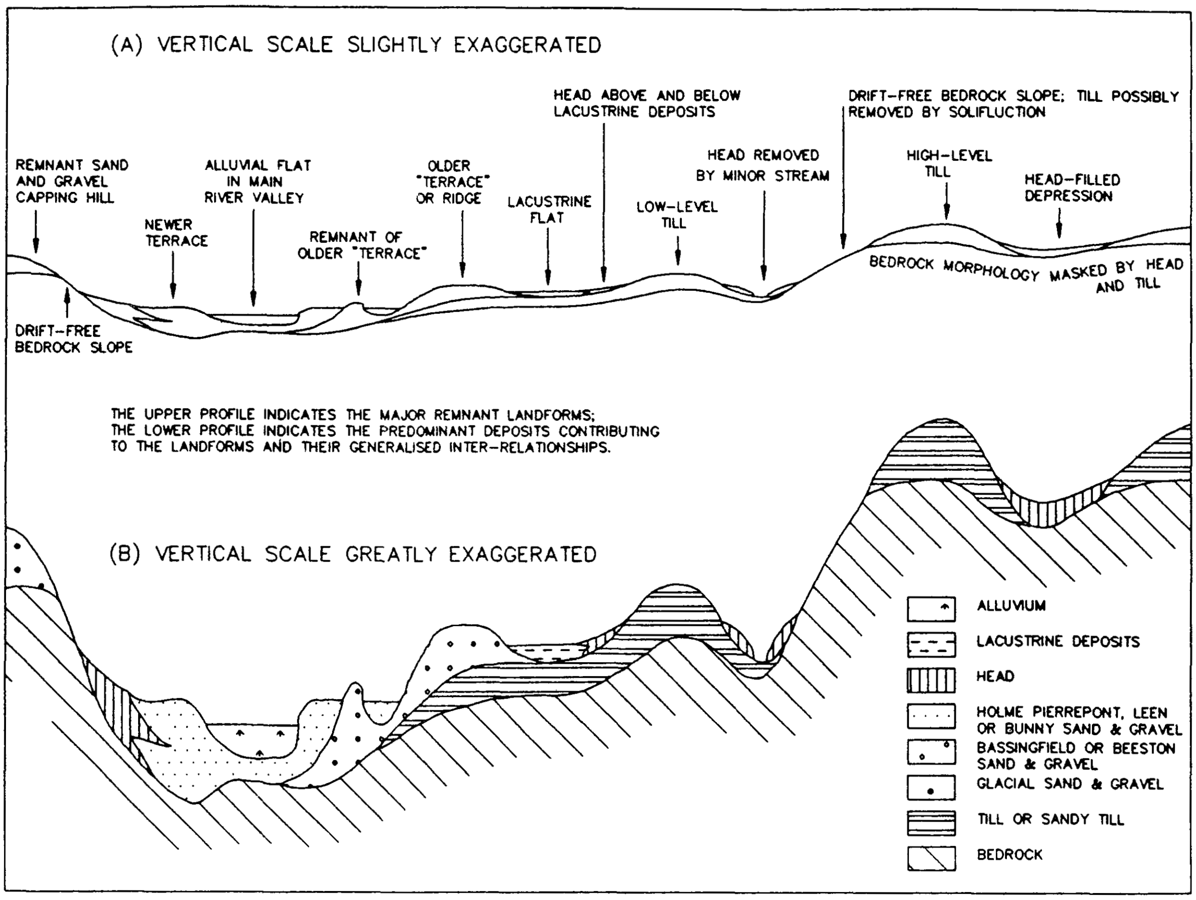


Figure 12. Diagrammatic cross sections to show the main drift deposits related to landform

above the alluvium, and the deposit was previously commonly referred to as the 'Flood-plain Terrace' The deposits comprise up to 8m of current-bedded sand and gravel, with impersistent silt or silty clay beds; typically a lesser thickness is present. The sands and gravels have been reworked periodically and redeposited by the modern, much smaller, River Trent.

Probably of similar age to the Holme Pierrepont Sand and Gravel, the **Leen Sand and Gravel** deposits represent the eroded remnants of a previously more extensive valley fill. Preserved outcrops lie on both banks of the River Leen and some of its tributaries (Figure 11). They consist of laterally variable deposits of sand and gravel up to about 4m in thickness.

The **Bunny Sand and Gravel** occupies a relatively small area on the edge of Bunny Moor [582 302] (Figure 11). Up to 1m of pebbly sand, clayey in part, is closely associated with Head deposits upslope and passes beneath alluvium to the west.

Head

The term Head (sensu stricto) is applied to deposits which are derived by mass wasting of pre-existing solid or superficial material, usually under periglacial conditions, and generally with some degree of downslope movement. Thin colluvial deposits which have washed downslope, usually to form valley bottom flats, have been included with Head during this resurvey. A veneer of Head is ubiquitous in most areas. Normally a minimum thickness of 0.5m to 1m has been adopted as the limit during survey; it may be more than 4m thick locally. Only the more extensive deposits are shown on Figure 11. Head is a highly variable deposit ranging from relatively pure sand or clay to chaotic mixed deposits of clay, silt, sand and gravel. Head deposits may be present above and below spreads of Flandrian lacustrine or fluviatile material indicating the continuance of Head deposition from Devensian to recent times.

Lacustrine deposits (including peat and shell marl)

These sediments began to accumulate in shallow depressions during the early Flandrian and are sporadically preserved south of the River Trent (Figure 11). Some of the former lakes or swamps are believed to correspond to parts of the Mercia Mudstone outcrops where gypsum solution gave rise to surface lowering. A number of depressions which contain predominently fluvial sediments, such as Ruddington Moor, probably supported temporary lakes during flood conditions (Plate 4).

Thicknesses up to 4m are recorded, though most sections show much less. In places the lowermost beds contain cryoturbated and reworked debris from underlying units and include sporadic pebbles and bone fragments. Overlying beds comprise predominently red-brown or grey-green silt and clay which is laminated or massive. They also contain scattered mammalian bones, crude stone artefacts and concentrations of molluscan shells, particularly freshwater gastropods. The fossil remains are of species which survive today. Locally the concentration of shell debris is so great that the horizon takes on a white or very pale grey colour and a clay matrix crammed with minute shell fragments surrounds more or less intact fossils; these beds are termed **Shell Marl**. Only one small outcrop is shown on the drift map [587 333] but laterally impersistent beds of Shell Marl are present within many lacustrine deposits. Also present in the upper levels of the lake deposits are beds of **Peat** or highly organic clay. These are the products of periodic swamps which became more extensive as the lakes drained. Only one small outcrop of peat [541 315] has been delineated, but sections have commonly revealed localised beds up to 0.8m thick.

Throughout the former lake areas, 'islands' of solid rock or earlier drift deposits were preferred sites for early settlements. Human intervention may indeed have accelerated drainage of the lakes, the surviving flats being drained by misfit streams and ditches.

Alluvium

Relatively recent fluvial deposits, comprising material ranging from clay to gravel grade, are present along the Trent valley and in many smaller valley bottoms (Figure 11). In places the deposits resemble the lacustrine sediments described above, and both lateral and vertical passage from one to the other occurs locally.

The alluvium almost invariably comprises silts and clays overlying sand and gravel. In the Trent valley it infills irregularities in the surface of older drift deposits and includes thick sand and gravel beds, mainly comprising older material which has been redeposited under flood conditions. It is commonly not possible to separate alluvial gravel from older gravels. Historically, human intervention has reduced the extent of flooding and armoured the river banks, such that reworking has become less significant. Peat beds are proved by boreholes within the alluvial sequence, commonly as lensoid bodies within the deposits of abandoned meanders, as along the Trent valley (Lamplugh and others, 1908).

Calcareous tufa

No deposits of tufa have been mapped, but the presence of pale brown 'cindery' tufa, brought to the surface by ploughing, was noted around a spring [627 353] north-east of Tollerton.

MADE AND DISTURBED GROUND

The influence of man on the geology of the heavily urbanised Nottingham area has been substantial. Figure 13 and Maps 4A-D indicate the wide extent of man-made deposits, such as Made Ground, backfill and colliery waste. Disturbance of the original ground surface has much wider ramifications, however, and includes all built-up and landscaped areas. The constraints imposed on planning and development by these deposits are dealt with fully later (p.44). The various deposits and categories of disturbed ground are defined and described below.

Made Ground

Made Ground consists of material deposited on top of the original land surface, though in some cases the top- and subsoil may have been removed first. It includes major road, railway and canal embankments, and other significant constructional areas. Within any development area such deposits are inevitably more widespread than can be realistically mapped. Only the more substantial

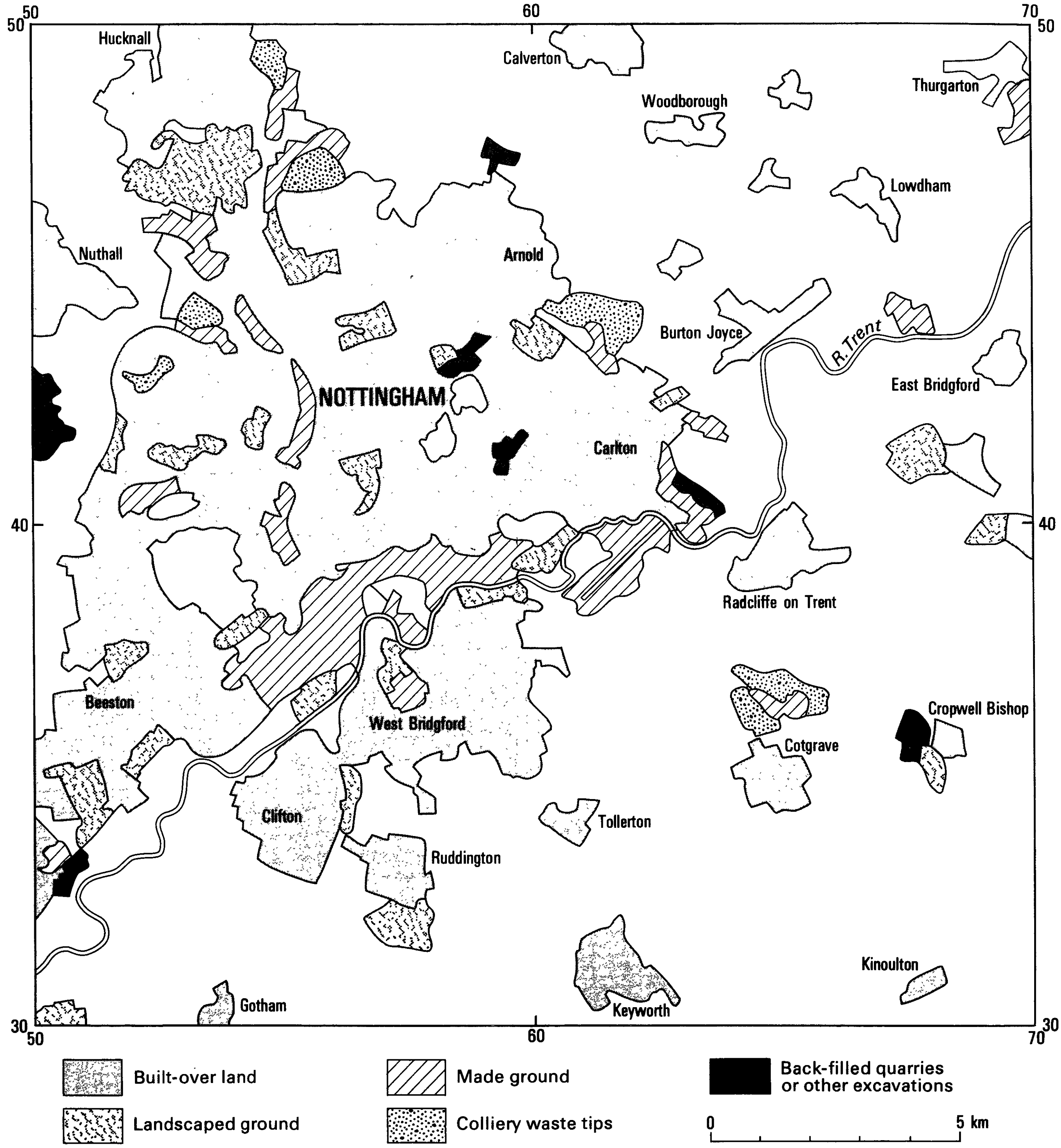


Figure 13. Distribution of main areas of made and disturbed ground

areas, generally those defined by a clear landform and at least 1 m thick, are recorded on the maps.

Made Ground comprises what is described elsewhere as fill or landfill (p.44), and includes a variety of rock waste and man-made materials, including building rubble, pulverised fuel ash (PFA) and, more importantly, industrial and domestic waste. The latter two types of waste may produce hazardous toxic leachates or gases, including potentially explosive methane

Many waste disposal sites contain a mixture of material, the nature of which is unreliably recorded. Archival data have proved inadequate to define the total distribution and limits of waste tips; it is inevitable that not all have been located. A general observation during the resurvey was that **most tips appeared to contain a wide variety of materials, including organic and some chemical wastes.** No categorisation of waste disposal sites by type of tipped material, either licenced or actual, has been attempted in this study, since it could lead to spurious assumptions of site safety. Many former tip sites have been reclaimed and landscaped or built over.

The most extensive spread of Made Ground is that between the Boots plc works at Beeston and the City Centre (Figure 13). This includes the Dunkirk-Lenton Lane industrial area [55 37] where thicknesses of over 10 m occur (Back Cover), and the site of the former Wilford Power Station and railway sidings between Castle Boulevard and Queen's Drive [56 38]. In these areas it is quite common for the Made Ground to be thicker than the alluvial deposits beneath. Other important areas include that south of Wilford Lane [57 36], where up to 6.5m of PFA occurs locally, and at the National Watersports Centre at Holme Pierrepont [61 38] in an area of former gravel working.

Backfilled quarries and other excavations

Backfilled excavations of various depth and size for coal, sand and gravel, sand, brick clay, marl, gypsum, building stone, limestone, embankment fill and ponds are widely spread across the area. The types of former quarries and pits and the special problems they present to development are discussed later in the report and presented in Table 19. Commonly there is no surface indication of their former extent or, in some cases, of their actual presence; in general, no information on the nature or state of compaction of the fill material is available.

Many of the statements made above regarding Made Ground and waste disposal apply equally to backfill materials. There is, though, the added risk of migration beyond the boundaries of the former excavation, of toxic leachates and gases, including methane (see also p.45). A special case of experimental backfill is in progress south-east of Netherfield where colliery waste slurry from Gedling is being pumped into former sand and gravel quarries [634 405] with a view to long term land reclamation.

Colliery waste tips

Colliery waste tips are a special category of Made Ground. Their generally steep slopes and well-defined boundaries make them easy to demarcate. All former and present collieries have waste tips nearby; the older ones have mainly been topsoiled and landscaped and are used either as amenity areas or for farming. Landscaping of the more recently abandoned and presently still operating tips is proceeding.

The material consists of inert mudstone, siltstone, less common sandstone, seatearth and ironstone, together with a considerable proportion of coal locally. Ash, slag and other materials, possibly including industrial and domestic waste, may also have been added to the tip in places during or after the period when the main colliery tipping was taking place. The dumping of large volumes of material onto an original land surface may produce drainage problems leading to potentially extremely hazardous conditions of slope stability (see also p.59). Some 'mine stone' has been sold for fill, and clearly a substantial resource of this material exists (p.38).

Landscaped ground

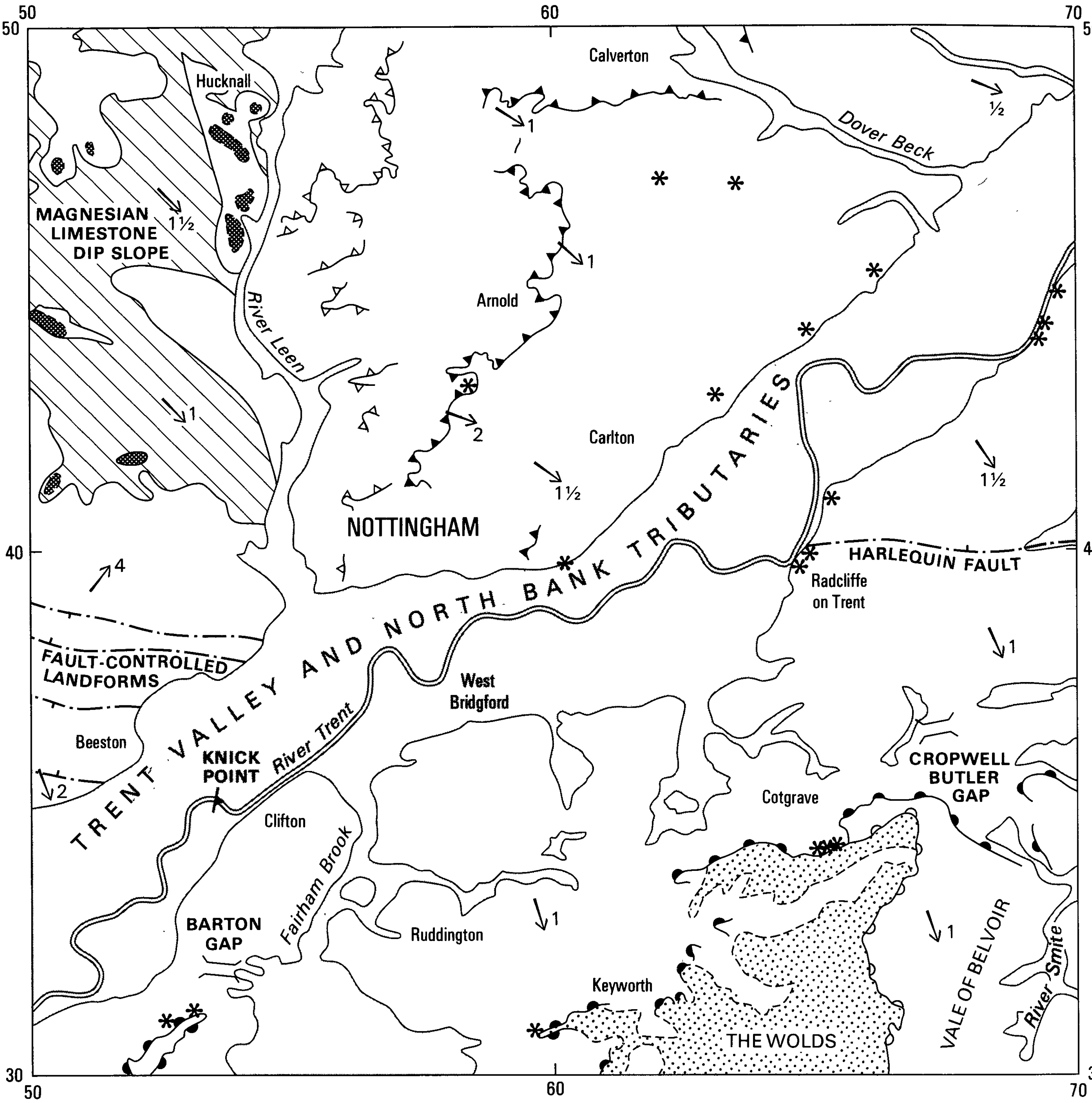
'Landscaped ground' covers all areas where the original land surface has been extensively remodelled by earthmoving and tipping, but where it is impractical or impossible to delineate individual deposits of made-up ground or backfill. In places, as around former gravel workings at Colwick and Holme Pierrepont, landscaping may have obscured former quarries and pits which then remain unrecorded. Made Ground is usually extensive in landscaped areas, and substantial thicknesses may be present locally. It consists mainly of topsoil, subsoil and reworked in situ material, but materials brought in from elsewhere including building rubble and mining spoil may be present locally. More rarely, organic waste capable of generating methane may be incorporated. Depth of reworking is unlikely to exceed 2m, except in certain embankments, terraces and mounds. Landscaping is ubiquitious in urban areas and should be expected where urban development is shown on the topographic base map.

Built-over ground

Built-over ground comprises those parts of the area, mainly of urban development, where considerable modification and disturbance of the land surface may have occurred during the construction stage, but for which there is little evidence for the distribution and thickness of made and disturbed ground. In general, this excludes extensively remodelled landscaped ground, but there may be considerable overlap between the two categories in places. Modern building methods, particularly of new housing estates and industrial sites, involve considerable excavation, backfill and earthmoving, giving rise to thicknesses of several metres of Made Ground or fill in parts; general disturbance of the top metre in such areas occurs almost everywhere. It cannot be ruled out that some areas of fill within built-over areas may contain small amounts of organic waste. The mapped boundary (Maps 4A-D) shows the limits of the built-over area at the date of survey; building work on former greenfield sites was in progress at that time in many areas.

GEOMORPHOLOGY

Geomorphology is the study of the landforms which we see around us in the landscape. The bedrock and drift geology around Nottingham is highly varied (Figures 6 & 11), and this is reflected in the diversity of local landforms,



Alluvial and lacustrine flats

Till (Boulder Clay), Wolds area only

Outlier of Sherwood Sandstone on Magnesian Limestone dipslope

Lower Lias escarpment

Upper Triassic (Rhaetic) escarpment

Mercia Mudstone escarpment

Sherwood Sandstone escarpment

Fault

2 Regional dip of strata, in degrees

* Landslip or unstable ground

Figure 14. Simplified geomorphological map

although unifying patterns have been readily identified. The main landforms are shown in Figure 14 (Map 5) and comprise:

- The Trent Valley and its north bank tributaries
- Alluvial and lacustrine flats south of the Trent Valley
- The Vale of Belvoir
- The Wolds
- Escarpments and dipslopes (cuestas)
- Fault-controlled landforms in the Beeston-Bramcote-University area

The Trent Valley and its north bank tributaries

Gaps, or low saddle-like depressions in ridges, at Barton [53 32] and Cropwell Bishop [67 36] are evidence that a precursor of the River Trent may have flowed to the south of its present course in an ENE direction. This route would have taken the river just to the south of high ground at Ruddington and Tollerton, across the Vale of Belvoir and possibly towards the Ancaster Gap in the Jurassic escarpment, north of Grantham (as proposed by Linton, 1951, and Straw, 1963). The shift to its present position is believed to have taken place during the waning stages of the penultimate glaciation (see also p.21). The marked cliffs and bluffs on both sides of the valley (leading to the stretch between Long Eaton and Newark being called the 'Trent Trench') attest to the dramatic downcutting of the Trent at this time.

The present valley lies approximately along the strike of the underlying Permo-Triassic strata, and so, whatever its origins, the river may now be considered to be well adjusted to structure. The only knick point is at Beeston Weir [535 353] which marks an abrupt level change in the river profile. The courses of both the Dover Beck and the River Leen are largely controlled by bedrock structure: the Dover Beck is parallel to the regional dip of the Mercia Mudstones, and the Leen lies along the foot of the Sherwood Sandstone escarpment.

Within the valleys, the rivers meander across relatively flat floodplains. In the Trent, and to a lesser extent in the Leen valley, low terraces with surfaces up to about 2m above the alluvium show the extent of Flandrian downcutting. Higher terrace remnants occur at Beeston and Bassingfield. The former has a relatively flat surface rising evenly towards it backwall, while the latter forms a marked ridge cut by several narrow outflow channels; both rise up to about 10m above the Recent alluvial flat.

Many of the shorter tributary valleys underlain by the Sherwood Sandstones or Mercia Mudstones are deeply incised and have flat bases and steep headwalls e.g. in The Park [564 398] and at Colwick [600 400]. They either contain small misfit streams or are dry, and are floored by Head or colluvium; locally, the valleys are described as 'dumbles'. The form of these valleys is similar regardless of bedrock type, pointing to their origin during periglacial conditions when permafrost would render all rocks impermeable. Freeze-thaw processes in the active upper layers accelerated mass wasting leading to rapid backwearing of slopes.

Alluvial and lacustrine flats south of the Trent Valley

Low-lying broad flat areas are a feature of the drainage courses south of the Trent Valley. They probably owe their existence to the lowering of the surface by gypsum solution (p.24), since most overlie the gypsiferous upper part of the Mercia Mudstones. Throughout this area a solution zone has developed to a depth of up to 30m below the ground surface (Elliott, 1961), from which considerable volumes of gypsum have been lost.

Alluvial and lacustrine deposits in these areas indicate long periods during the Flandrian when shallow lakes or ponds and marshes were present. Artificial drainage ditches have virtually removed the risk of flooding and turned most of the flats into useable arable land. Former rapid outflow of water from these areas to the Trent Valley has cut narrow overflow channels in a number of places. The ridge between West Bridgford and Radcliffe on Trent formed by the Bassingfield Sand and Gravel has four channels along its length, and the alluvium of the Fairham Brook occupying the outlet of the broad expanse of Ruddington-Gotham-Bradmore moors narrows to 110m between Clifton and Ruddington [559 337].

The Vale of Belvoir

Only the westernmost extremity of the Vale of Belvoir, part of the catchment of the River Smite, is included in the area. The origin of the Vale is controversial. Predominant among theories is that it originated as an ice-excavated hollow (Straw, 1963) which then became the site of a stagnant ice lobe during the latter part of the penultimate glaciation (Posnansky, 1960).

Whatever the origin for the entire Vale, that part of it in the area can be explained in more simple terms of backwearing of the Lower Lias escarpment (Figure 14) to the local base level of the Smite – Devon drainage system, under periglacial conditions. Backwearing appears to be still continuing, albeit at a much reduced rate.

The Wolds

The Wolds is an area of relatively high ground of low relief, rising up to 97m AOD, bounded almost entirely by the Upper Triassic and Lower Lias escarpments which are combined on the northern side (Figure 14). It is underlain by up to 35m of glacial till, and incised on its northwestern side by tributary streams of the River Trent. The cover of till conceals a bedrock surface which appears to be close to a dipslope inclined at about 1° SSE. The relatively flat surface of much of the Wolds was probably produced by periglacial planation during the Devensian acting on formerly more irregular glacial landforms.

Escarpments and dip slopes (cuestas)

Away from the valley the landscape is dominated by a succession of escarpments (scarps) and dipslopes; the main scarps are well defined by the distribution of slopes greater than 1 in 10 gradient (Map 5). Cuestas are typically the product of the differential erosion of gently inclined, alternating hard and soft beds. Of the four major scarps which can be identified, the Mercia Mudstone, Upper Triassic (Rhaetic) and Lower Lias ones are well developed, but that of the Sherwood Sandstone less so.

To the west of the River Leen, the Magnesian Limestone dipslope (inclined about 1½ ° SE) forms most of the ground with a lesser part underlain by Coal Measures. Several outliers of Sherwood Sandstone break up the landscape e.g. Catstone Hill [504 413], Long Hill [513 491] and Butler's Hill [545 484]. The Coal Measure outcrop is characterised by low undulating slopes subparallel to the dip of the rocks (approximately 4° NE), with rare small scarps developed on thin sandstones or other resistant beds.

The Sherwood Sandstone scarp has little continuity, except to the east of Bestwood village, due to the absence of persistent hard sandstone beds. The Mercia Mudstone Scarp, on the other hand, forms an almost continuous feature between Calverton and St. Ann's. The scarp face is developed in the mudstones of the Radcliffe and the Lower part of the Gunthorpe formations below a series of resistant 'skerries' – the 'Plains Skerry Group' of Elliott (1961) – which underlie the south-easterly sloping, plateau-like area of Mapperley Plains. Dissection of the dipslope (c½–2 ° ESE to SE) has been considerable with the creation of many 'dumbles' (Doornkamp, 1971), so that slopes of 1 in 10 or greater occupy a large part of the area (Map 5). The country between the Trent Valley and the Upper Jurassic scarp to the south is strongly faulted, but cuestas of limited extent are common throughout, formed by the more resistant 'skerries' and sandstones. The Harlequin Fault crosses the area between Radcliffe on Trent and Bingham; it repeats the geological sequence so that a Cotgrave Sandstone cuesta between Radcliffe and East Bridgford is matched to the south by one between Harlequin and Bingham. In detail, both are affected by minor faults. Regional dips in this area are generally c.1° SSE.

The Upper Triassic (formerly Rhaetic) scarp is best developed south of Cotgrave where it merges with the overlying Lower Lias scarp. Gotham Hill, in the southwest, is an outlier bounded by the Upper Triassic scarp. South of Cropwell Bishop the Upper Triassic scarp forms a low but discernible feature, whereas the Lower Lias scarp is very impressive west of Owthorpe and Kinoulton where it overlooks the Vale of Belvoir.

Fault-controlled landforms in the Beeston-Bramcote-University area

Major parallel faults crossing this relatively small area have juxtaposed rocks of differing character (Figure 14). Differential erosion has then produced landforms related to the various bedrock materials and possibly to the faults themselves. The linear steep slopes on the north side of the Bramcote Hills [51 38] are underlain by Sherwood Sandstones brought into faulted contact with more easily eroded Coal Measure mudstones. To the east, the steep slopes above the University Lake [54 38] are formed on the mudstones of a faulted outlier of the Radcliffe on Gunthorpe formations. Between Bramcote and Beeston, 'skerries' within the Gunthorpe Formation have produced scarp and dissected dip slope scenery similar to that in the north-east of the district.

GEOLOGICAL RESOURCES AND CONSTRAINTS RELEVANT TO PLANNING AND DEVELOPMENT

INTRODUCTION

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

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

GEOLOGICAL RESOURCES

Mineral deposits and underground water are the main geological resources of any area; other resources influenced by ground conditions include soils, sound foundations and waste disposal sites, while special to Nottingham are caves in the sandstone bedrock. The Nottingham area is well endowed with mineral resources, principally coal and water resources. To a large extent, the historical prosperity of the city was founded on their combination. Water was useful both for surface communications and for water supply from aquifers.

The area is still a major producer of coal, gravel, sand, gypsum and brick clay; it also includes a minor building stone quarry and a potential for oil production. In addition, groundwater obtained from the Sherwood Sandstones makes an important contribution to the water supply of Nottingham and its environs.

Mineral resources

For the purpose of this report mineral resources cover those minerals and other geological deposits which have a potential for economic exploitation. Mineral reserves, implying quantified deposits which could be economically extracted, are not considered here because many factors such as land values, extraction costs and proximity to markets have to be considered before reserves can be identified; this requires comprehensive evaluation and is well beyond the scope of this study. The mineral resource potential of the Nottingham area is almost entirely confined to those materials which are presently worked e.g. coal, gravel, sand, gypsum, brick clay, building-stone, mine stone, or those whose presence may be inferred and which may have the potential to be developed in the future e.g. oil. Other minerals not presently extracted of possible but limited economic potential are also briefly discussed.

With regard to planning, mineral resources fall into two categories, those that can be extracted by surface workings and those that can be mined or recovered at depth (see Table 6). In the former case, the planner may be presented with conflicting claims on the land from the extractive industry, agriculture or the urban developer; any construction will, of course, sterilise the resource for the foreseeable future. The workings themselves may present problems as to post-extraction land use, which are likely to be resolved only by resorting to geotechnical or hydrogeological advice. For instance, if backfilling and reinstatement is the aim, then a decision must be made as to which waste material can be used, bearing in mind ground conditions, to ensure limited or no environmental damage.

Underground mining may involve local subsidence damage and will produce waste material, the disposal of which commonly creates a demand for tip sites. The area tipped over becomes sterilised for shallow mineral extraction, and presents the planner with further problems regarding land use of the new artificial landforms. In addition, information on ground conditions can be used to ensure informed decisions are made prior to land allocation for tipping.

The mineral resources of the area are described in detail in the following sections, and their distribution is summarised in Figure 15.

Coal

Coal has been mined in the Nottingham area for hundreds of years. Up to the 15th or 16th century, mining was restricted to the working of coal from its crop or by using shallow 'bell pits' (see p.55). A desire to reach deeper reserves of coal resulted in the introduction of the 'pillar and stall' system. As the depth increased larger pillars were required to support the roof, thus reducing the amount of recoverable coal. A new approach to deep mining was eventually provided by the development of longwall mining, beginning in Shropshire in the 17th century; this is still the main method used today.

Opencast mining has developed since the 1940s, generally of a number of seams at a given site, to depths of over 100 m. These two developments, longwall deep mining and opencast mining, have meant that any area underlain by the Productive Coal Measures, even to depths of over 1000 m, can be considered as a resource area; this includes most of Nottinghamshire.

The coal outcrop in the study area is confined to the west of the city (Figure 6: Map 2), although coal also lies at relatively shallow depths (up to about 35m) beneath the outcrop of Permian rocks. The area of potential opencast coal mining is thus great; however, urban development has

Table 6. Mineral resources of the Nottingham area related to the main method of working.

Surface extraction	Mining or extraction at depth
Coal (small area in W only)	Coal
Gypsum	Gypsum
Sand	Sand
Gravel	Oil
Brick Clay	
Building Stone	
Mine Stone	

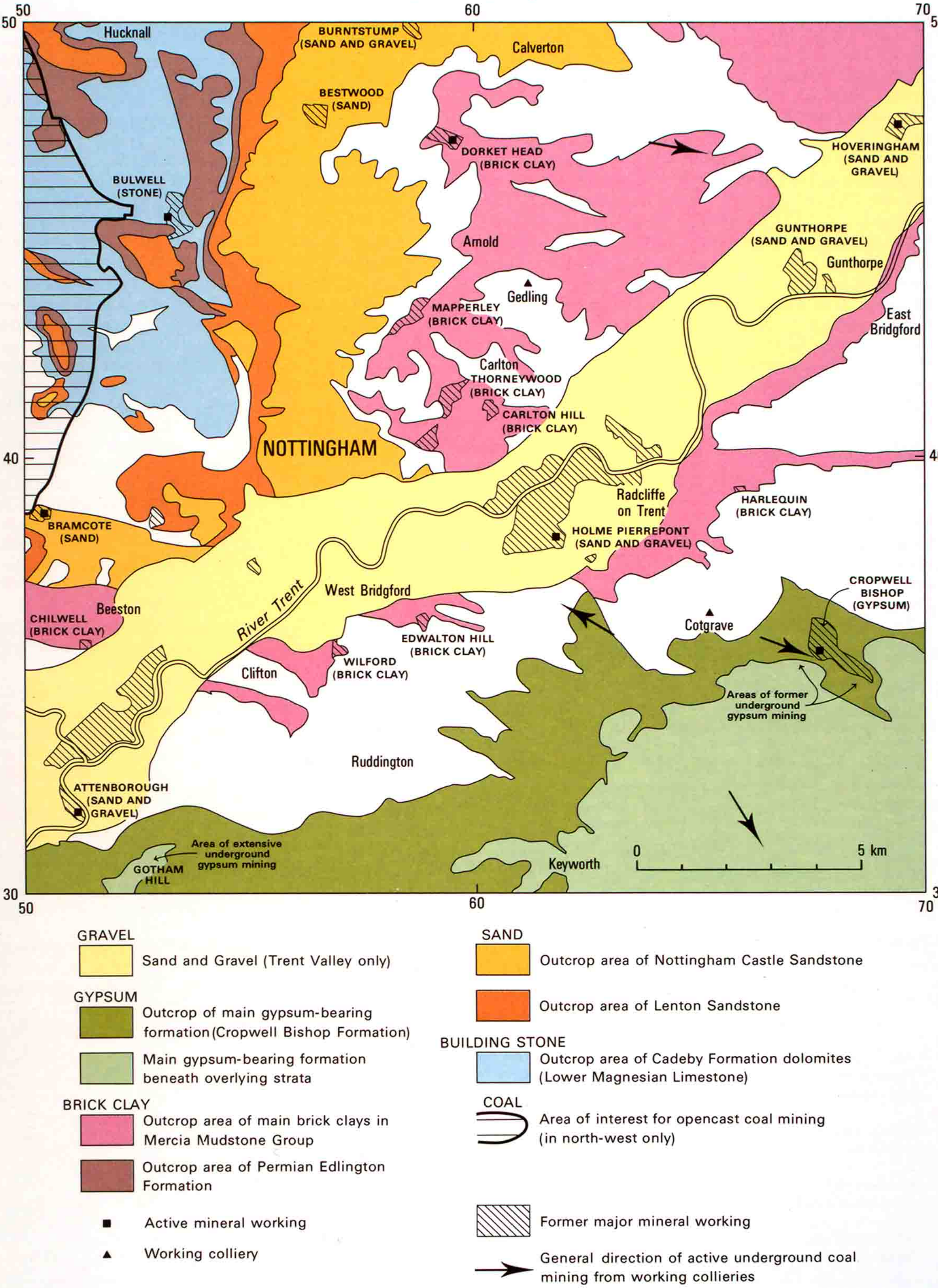


Figure 15. Mineral resources of the Nottingham district

sterilized a large part. At present, only a limited area adjacent to the M1 can be considered of interest for opencast coal extraction (Figure 15), and even within this area severe restrictions are placed by the presence of former opencast and shallow workings (Maps 8A-B), housing and access problems.

The economics of deep mining have undergone a succession of reviews since the 1950s resulting in progressive closure of older mines, as shown for the area in Table 7.

The only remaining collieries within the area are at Gedling and Cotgrave, opened in 1899 and 1964 respectively. Calverton, a working colliery just outside the area [603 501] has worked coal in the past southwards beneath Calverton and Woodborough. Present restructuring of the coal industry has put a question mark over the future of Gedling and Cotgrave collieries, and only three seams are still worked, the High Hazles from Gedling and the Deep Hard and Blackshale from Cotgrave. The present general direction of working in these seams is shown in Figure 15.

Coal resources beneath the area remain substantial, but any future exploitation depends mainly on economic factors and will not be reviewed here.

Sand and Gravel

Sand and gravel is produced in the area from three separate operations, at Attenborough, Holme Pierrepont and Hoveringham, while sand alone is worked at Bramcote (Figure 15: Map 6); the operators are listed in Annex 5. The extraction of gravel for use as aggregate is the primary reason for the three sand and gravel quarries. The gravel comes from superficial (drift) deposits along the Trent Valley (Figure 11: Map 3) in workings which provide sand (forming about 50 percent of the deposits) as an important, readily marketable by-product.

Table 7. Colliery closures in the study area since 1950

Colliery	Year Opened	Year Closed
Babbington (Cinderhill)	1842	1988
Bestwood	1871	1967/68
Clifton	1868	1968/69
Hucknall	1862	1987/88
New Hucknall	1876	1982
Radford/Wollaton	1874	1965
Watnall	1893	1950

The sand and gravel resource comprises deposits laid down by the present and former rivers occupying the Trent and Erewash valleys. These include gravel beneath the recent alluvium and those beneath river terraces flanking the modern floodplains. Although gravel also occurs beneath the alluvium and terrace deposits of other valleys in the area, extractable volumes are limited or the land has been extensively built over. Exceptions are an area of about 0.9 km^2 of Leen Sand and Gravel north of Bestwood and of about 0.25 km^2 of Bunny Sand and Gravel south of Bradmore (Figure 11).

The sand and gravel resources in the Trent Valley itself can be divided into two groups, the recent alluvium/lower terrace deposits (Alluvium/Holme Pierrepont Sand and Gravel) and the higher terrace deposits (Beeston Sand and Gravel/Bassingfield Sand and Gravel). The recent alluvium and lower terrace deposits are considered together since, firstly, present workings make no distinction between the two and, secondly, they are intimately related both vertically and laterally beneath the alluvium. The Beeston Sand and Gravel terrace which has been built over so that the resource, having an area of approximately 2 km^2 at Beeston, has been sterilized for the foreseeable future. Former workings in the Bassingfield Sand and Gravel show it to be clay-rich in part with a highly variable gravel content. Nevertheless, there is a resource area of about 1 km^2 not built over between Gamston and Radcliffe on Trent (Figure 15).

Table 8 shows the way building development has sterilized half of the sand and gravel resource in the area, with another one tenth worked out.

The main resources of sand and gravel in the area underlie the floodplain and lower terrace remnants of the River Trent in two areas separated by the urbanised area between Dunkirk/Wilford and Netherfield/West Bridgford (see Figure 15). In the south-west further expansion of existing workings along the north bank of the Trent is possible, but the main resource lies south-east of the river between Thrumpton and Barton in Fabis. The potential for the expansion of the Holme Pierrepont workings is limited to the west, but an untouched resource area lies eastwards towards Radcliffe on Trent.

Table 8. Sand and Gravel resources within the Trent Valley in the study area (area measurements are approximate).

	Total area	Worked out		Built over		Remaining resource	
	km^2	km^2	percent	km^2	percent	km^2	percent
Alluvium/Holme Pierrepont Sand and Gravel	68.5	7	10.2	35	51.1	26.5	38.7
Beeston Sand and Gravel	2.0	–	–	2.0	100	–	–
Bassingfield Sand and Gravel	2.5	0.1	4	1.3	52	1.1	44
All Trent Valley Sand and Gravel	73	7.1	9.7	38.3	52.5	27.5	37.8

Plate 1 Typical mottled sandstones of the Lenton Sandstone Formation, Bobber's Mill

Plate 2 Dorket Head Brick Pit

Downstream from Radcliffe towards the workings at Hoveringham considerable tracts on each side of the river remain as a substantial resource area.

The sand and gravel lies beneath an overburden of silt and clay with a general thickness of less than a metre but which has been recorded from channels to be over 5m thick (Spenceley, 1971). The overburden comprises a thin layer of topsoil over sandy or silty clay with less common organic clay or peat. Spenceley (1971) showed that between Colwick and Holme Pierrepont the thickness of the sand and gravel is independent of surface form (whether beneath the floodplain or a terrace), and is related to variations in the depth of the underlying bedrock surface. In general, however, the greatest thicknesses have been recorded from the central parts of the floodplain. Thicknesses vary between zero in places of deep clay – or silt-filled channels to maximum values of over 4.5m in the Colwick area (Spenceley, 1971), 10.8m in a borehole at Wilford [5742 3748] and about 10m near Hoveringham.

Few boreholes have been drilled in the greenfield resource areas so that the presence of gravel there is not well established. Any calculation of reserves is dependent on detailed surveys using a grid of boreholes sited on the basis of at least 1 borehole every 75m, together with geological and geophysical interpretation. Use of any published figures for sand and gravel yields per hectare may be misleading; potential yields should be established on an area by area basis prior to release of land so that areas of low yield can be avoided. In general, average yields for the Trent Valley are said to be 55000-65000 tonnes per hectare (George, 1988), although actual yields are between 30000 and 100000 tonnes per hectare (Nottingham County Council, 1984).

Sand

Sand is the main component of the Sherwood Sandstones from which it has been quarried widely in the past from weakly cemented parts. Former underground mining of sand has left extensive cave systems just north of the city centre adjacent to the Mansfield Road (the 'Peel Street Caves').

Sand with almost no pebble content is quarried from the Sherwood Sandstones at Bramcote (Figure 15: Map 6) for use in building and construction. The quarry is mainly in the Lenton Sandstone (Lower Mottled Sandstone) which was formerly worked both here and elsewhere for iron, brass and other metal foundaries e.g. at the Queens Medical Centre in Lenton [546 388] and Bobber's Mill [553 415]. The fine grain size and clay content were the characteristics which made the sand particularly suitable as a moulding material, but there is now very little demand for sand for this purpose. The remaining reserves of sand at Bramcote are limited, and the quarry is scheduled to be backfilled and restored by the mid 1990s.

Because of limited demand for sand, a virtually unlimited sand resource exists in the Sherwood Sandstones from its outcrop which extends from the city northwards to Bestwood and Calverton (Figures 15, 6 : Maps 2, 6). Both the Nottingham Castle Sandstone and the underlying finer grained Lenton Sandstone are mainly loosely consolidated and easily worked. It is important to note, however, that in general sands from the Sherwood Sandstones, particularly the lower part of the sequence, are finer grained and better rounded than those derived from the Trent Valley deposits; the former are more suitable for building and asphalting than the latter which are typically the 'sharp' coarser grained sands required for concrete.

A sand quarry near Bestwood [564 479] is being used as a waste disposal site, but an area close to the former working faces has been preserved implying that a decision to abandon sand extraction may not yet have been made. The working faces of the Burntstump Quarry [577 500] lie just to the north of the study area, and here both sand and gravel are extracted from the Nottingham Castle Sandstone; reserves in the area around the quarry are extensive.

Gypsum

Gypsum (hydrous calcium sulphate) was formerly worked from various parts of the Mercia Mudstones in the area; it is now extracted only from the upper part of the Cropwell Bishop Formation. The position of the main gypsiferous horizons in the sequence is summarized in Table 9 below.

Gypsum was formerly worked in the **East Bridgford** district from 17th or 18th century to about the 1940s (Firman, 1964), but no detailed records of the workings are known. The sites of six former shafts have been located in the village itself (see Map 6); others almost certainly

Table 9. Stratigraphical levels for main worked gypsum units

Group	Formation	Worked Gypsum
Mercia Mudstone Group	Blue Anchor	No workable gypsum
	Cropwell Bishop	Newark Gypsum Tutbury Gypsum
	Edwalton	'Main' East Bridgford Gypsum
	Gunthorpe	Minor satinspar veins
	Radcliffe	No workable gypsum (rare satinspar veins only)
	Sneinton	

exist. Gypsum was also probably worked from shallow pits near the Trent river cliffs north-east of East Bridgford and from local brickworks. It occurs mainly as veins crosscutting, but also concordant with the bedding. Veins are, exceptionally, up to 22cm, but more commonly much thinner. They are not confined to any particular stratigraphic levels but occur both in the lower parts of the Edwalton Formation and in the underlying Gunthorpe Formation. Examples of this type of occurrence can be seen in the river cliffs at Radcliffe on Trent and Gunthorpe Weir (Back Cover).

The mined gypsum in this area was of the fibrous satinspar variety and was used for beads and other ornaments as well as for flooring plaster (Lamplugh and others, 1908; Du Boulay Hill, 1932). Although resources of this type of gypsum are substantial the general thinness, impersistence and geometry of the veins mean that future extraction is unlikely.

The main mined gypsum in the East Midlands comes from the **Tutbury and Newark Gypsum** beds within the Cropwell Bishop Formation. The generalized vertical sections in Figure 16 show the relationship of the two units. The gypsum consists mainly of coarsely crystalline aggregates of nodules, and commonly contains inclusions of mudstone. The **Tutbury Gypsum** was formerly extensively mined beneath Gotham Hill from the Thrumpton, Barton, Clifton and Weldon Mines which were all finally abandoned in 1969. To the south of the study area gypsum is mined by British Gypsum plc from the Glebe Mine at Gotham, at East Leake and at Barrow upon Soar, the last of which was opened in 1988. The mine area on Gotham Hill is shown on Figure 15 and the positions there of shafts and adits are shown in more detail on Map 6. The Tutbury Gypsum comprises a composite unit of gypsum with subordinate mudstone up to 6m thick but which averages about 2.4m (Firman, 1964). Gypsum occurs as thick beds, nodules or lenticular masses which vary considerably in thickness and may be locally absent. It is mainly coarsely crystalline, and cores of anhydrite may occur in some thicker units. Other beds above the main horizon have proved workable locally, including a 'top bed' about 20m above the Tutbury Gypsum at Gotham.

The **Newark Gypsum** has been extracted by quarrying and underground mining around Cropwell Bishop since the 19th Century (Firman, 1964) (Figure 15: Map 6). Unlike the Tutbury Gypsum it comprises multiple beds each of which varies in form from layers of nodules ('balls'), lenticular masses ('bullets' or 'cakes') to beds. Individual gypsum – bearing layers have been given names in the belief that they can be traced between Cropwell Bishop and Newark; however, considerable caution should be exercised due to the impersistence of many of the beds. The gypsum 'seams' or beds recognised at Cropwell Bishop are listed below in stratigraphical order, the uppermost units first:

Red Fumblers
Cocks
Pinks
Cakes
Top Rock
Riders
Bottom White
Blue Rock
Rough Nodules
Rough Balls
Soft Floor
Bottom Nodules
Lower Bottom

The whole sequence of gypsum seams spans about 18m of the upper part of the Cropwell Bishop Formation. Purity varies both between and laterally within beds, but generally the best quality material comes from the Bottom White and Blue Rock gypsum. No bed is persistent over the whole outcrop and most show considerable variation in thickness over short distances. This is due partly to original local non-deposition and partly to post-depositional solution. The Cocks attains the greatest thickness, being up to 1.68m in places. Of the other beds, Pinks, in places comprising two separate beds, may be up to 0.88m thick; other seams typically range between 0.1-0.3m thick and are rarely more than 0.6m.

At the current Cropwell Bishop workings the topsoil is stockpiled, and the gypsum extracted by quarrying using a dragline or excavators and dump trucks (Plate 3). After the gypsum has been separated, the spoil is used as backfill so that at any time the open pit occupies a relatively small area (c15 hectares).

The entire Cropwell Bishop Formation is highly gypsiferous, and although certain parts have been exploited more than others, it is not possible to define closely the gypsum resources for the area without a detailed drilling programme. Gypsum is rarely present in the top few metres on the outcrop due to solution, so that surface mapping of gypsum beds is not possible. Between Gotham and Cropwell Bishop the Tutbury Gypsum loses its identity as a separate unit as does the Newark Gypsum in the opposite direction. There is insufficient information in the intervening area to delineate the outcrops of the two units.

The gypsum resource area is thus shown (Figure 15: Map 6) in two parts; firstly, the outcrop area of the Cropwell Bishop Formation where gypsum may be present as an exploitable reserve for quarrying or shallow mining, and, secondly, the area where the formation underlies other formations and exploitation of gypsum would have to be by deeper mining. In both cases, borehole drilling and careful logging is necessary to define resources more closely. Historically, the underground mining of gypsum has been by 'pillar and stall' methods, and this is still the practice at the new Barrow upon Soar mine. Generally, this does not lead to early subsidence because of the roof support provided by the pillars; however, solution of gypsum or degradation of mudstone in the pillars could lead to collapse, especially in the longer term where water may enter into or flow within disused shallow workings.

A poor quality alabaster was formerly obtained from near Thrumpton (Firman 1984), but there are no other records of alabaster quarrying in the area. Resources of material usable for carving of ornaments are confined to satinspar vein gypsum, but no use is made of this at present.

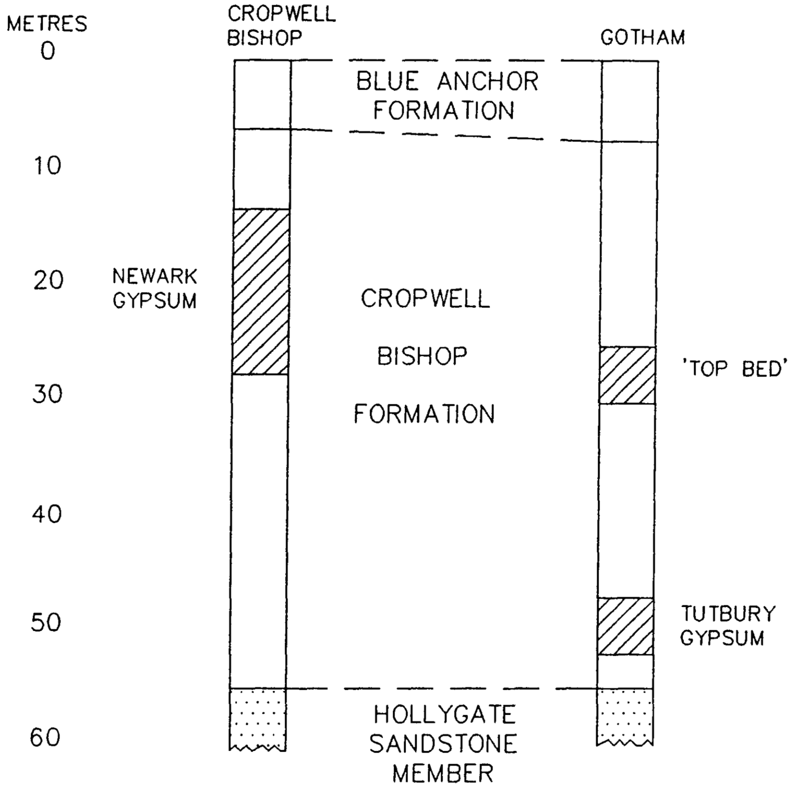


Figure 16. Generalized vertical section showing the main worked gypsum beds within the Mercia Mudstone Group

Brick Clay

Throughout the country brick clay is obtained mainly from weakly consolidated bedrock materials which may require some crushing and mixing with water to provide workable 'clays'. The main brick clays in the area occur in the Permian Edlington Formation (Middle Permian Marl) and the Triassic Mercia Mudstones (Keuper Marl); minor use was made formerly of the Middle Coal Measures.

The Edlington Formation mudstones and siltstones were formerly extensively dug in the north-west. The siting of some collieries, e.g. Watnall and Babbington, on or close to the outcrop of the formation provided the opportunity to exploit both coal and brick clay in close proximity; the coal providing a ready source of fuel to fire the kilns. There are no working brickworks based on the Edlington Formation; however, the formation at crop still retains a resource potential (Figure 15: Map 6), albeit somewhat limited by urbanisation.

The sole working brick pit is that run by the Nottingham Brick plc at Dorket Head [595 473] (Plate 2). Here mudstone and siltstone are dug from the lowest 15-20m of the Gunthorpe Formation. Elsewhere in the east and south the Gunthorpe Formation has also been the main source of brick clay for large scale brickmaking operations, although, locally, bricks have been made from clay dug from small pits located on most other parts of the Mercia Mudstone outcrop, in particular the Edwalton Formation.

Within the Gunthorpe Formation two levels have been traditionally favoured; the lowest part as worked at Dorket Head, and that just below the Cotgrave Sandstone at the top of the formation. This is due as much to the geomorphological requirements for extraction as to the suitability of the lithology. At both levels, the presence of overlying shallow dipping resistant beds results in a well-developed scarp slope, allowing easy access for extraction and creating only minimal overburden. The lithology in both cases is dominated by red-brown blocky silty mudstone with subordinate siltstone. Former notable brick pits were at Wilford [568 355], Edwalton [588 362], Harlequin [659 392], Carlton [604 411] and Thorneywood [595 414].

The outcrop of the Gunthorpe Formation is extensive in the north-east (Map 2), and, given that suitable steep slopes for ease of working are common and that limited sterilisation by building has occurred, this is an area with vast reserves (Figure 15: Map 6). Permitted reserves at Dorket Head are considerable, and permission to extend the pit has been granted subject to certain conditions including the requirement for progressive backfilling of the workings with domestic, commercial and non-hazardous industrial waste.

Limited local use was made also of mudstones and shales within the Middle Coal Measures; bricks were made from mining spoil at Wollaton [521 403] and Clifton [565 379] collieries.

Tiles and pottery as well as bricks were formerly produced locally. There is no present production, but should the demand arise it could be met by selection of suitable material from the brick clays.

Plate 3. Cropwell Bishop Gypsum Quarry

Plate 4. Profile in alluvium over cryoturbated Mercia Mudstones, Ruddington Moor

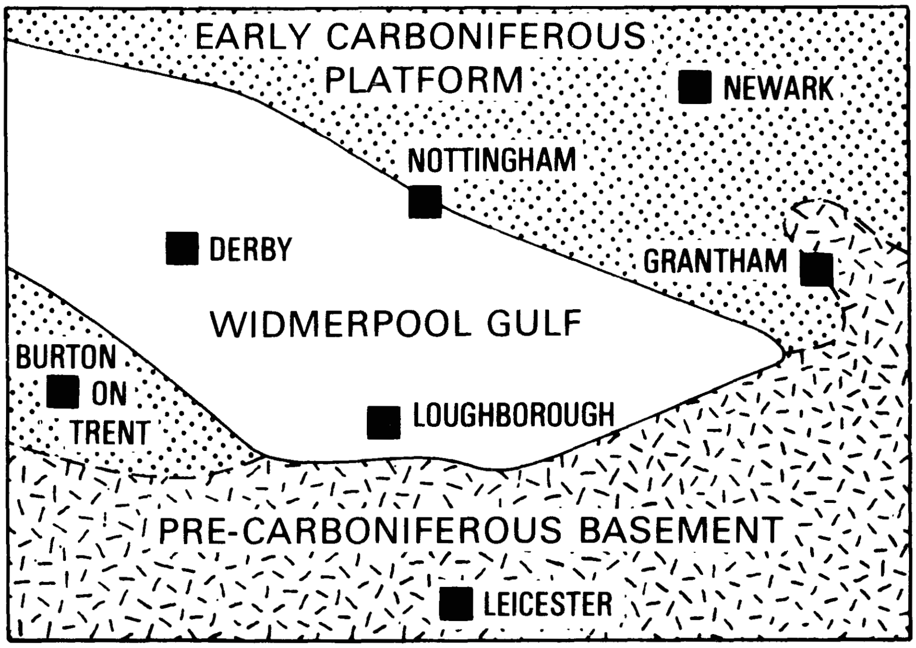


Figure 17. Map to show the situation of the Widmerpool Gulf in relation to the older Basement and the early Carboniferous platform

Building Stone

Stone has been quarried in the area since medieval times. It is believed that much of the sandstone for Nottingham's Norman Castle came from quarries at St. Ann's dug into the Sneinton Formation (Waterstones). However, the main building stone in the area, with probably as long a history of extraction, has been the Lower Magnesian Limestone (now referred to part of the Cadeby Formation). It has been extensively quarried formerly for building stone, roadstone and for burning to produce agricultural lime, but is presently quarried only at Bulwell [532 455] where the output is mainly used as rough blocks for ornamental purposes.

In view of the difficulty of working relatively thin beds within a mudstone/siltstone sequence, and of the trend to replace natural by reconstituted stone in construction, the Sneinton Formation sandstone has little or no potential as a source of building stone. The well-bedded dolomites of the Cadeby Formation on the other hand must be considered a mineral resource since:

a) there is still a working quarry in these beds
b) many buildings including Wollaton Hall and various churches and public buildings are built of the stone and repairs and additions may be required in the original stone to give visual compatibility.

The outcrop area of the Cadeby Formation dolomites is shown in Figure 15 and Map 6. The formation covers a large area in the north-west, disproportionate to its thickness which varies from 6-12m over most of the outcrop but it thins southwards becoming absent around Wollaton. The main rock type is a flaggy granular-textured dolomite or calcareous dolomite resembling a sandstone (and commonly referred to in driller's logs as 'sandstone'). The grains comprise dolomite crystals (rhombs) with scattered quartz. In places the rock has recrystallised to give an even textured fine-grained well-cemented stone. A characteristic of the stone and well known to quarrymen is that the rock when first exposed is easily sawn and is friable, and that after a few days it becomes harder; this is due to a case hardening effect involving mineral salt deposition towards the outer surface of cut blocks.

Many small disused stone quarries occur throughout the outcrop, but a concentration of quarries around Bulwell made it an important centre for the extraction of stone for many years. The two largest quarries were 'McCarthy's' [535 452] and 'Jackson's' (also known as 'Wilkinson's') [534 458], which produced 'Bulwell Stone', widely used for walling, coping and as flagstones. Both quarries have now been almost completely backfilled.

There is little scope at the working quarry at Bulwell for an extension of reserves because of surrounding buildings and roads. Any renewed local interest in building stone extraction will be forced to look for reserves in the less heavily built-over area to the north and west.

Mine Stone

A feature of underground coal mining is the extraction of large quantities of spoil in the form of mudstone, shale, siltstone, sandstone, ironstone, waste coal/dirt and seat earth. This is collectively known as mine stone. All the larger former and present collieries in the area have extensive spoil tips adjacent to their shafts, which cover large areas as small steep-sided hills (Figure 13 : Maps 4A-D). Many of those close to abandoned collieries have been landscaped to a considerable degree; they have then been given over to agriculture or converted for recreational use. Tipping is in progress at Gedling and Cotgrave collieries, and it is from there that some mine stone is sold as fill for construction or landscaping purposes. Enormous reserves of mine stone exist in the area; however, many of the older tips now form landscape features and workings would be restricted. In addition, use of mine stone is limited to some extent by its mineralogy since it commonly contains pyrite, which may oxidise to produce sulphurous chemicals, and waste coal which can pose a problem with regard to combustion.

Oil

Nottingham lies to the south-west of the main producing oilwells of the East Midlands oilfield. The region has been actively explored for hydrocarbons since the First World War, but it was mainly the discovery of the Eakring, Duke's Wood, Caunton and Kelham Hills oilfields in the years 1939-43 which led the industry to realise that the area had considerable oil potential. The Nottingham area is of interest because of its position on the north-east side of the Widmerpool Gulf (Figure 17), an area of the sea during early Carboniferous times which was infilled by thick marine sediments at that time. The earliest of these sediments, both within the basin and as carbonate platforms marginal to it, of Dinantian age, are the main local source for oil which is searched for in accumulations in sandstones of Namurian to Westphalian age. The thick basinal sediments are bounded to the south by pre-Carboniferous basement rocks in which oil is unlikely to be found.

Extensive seismic exploration has been carried out in the area and eight deep oil exploration boreholes have been drilled, as follows (their location is shown on Map 6):

	Grid Reference	Depth m
Strelley	5052 4297	Confidential
Harlequin 1	6684 3981	668.73
Harlequin 2	6687 4026	795.53
Saxondale	6774 3930	1058.00
Cropwell Butler 1	6813 3869	980.54
Cropwell Butler 2	6797 3823	967.00
Kinoulton	6922 3011	1490.00
Wild's Bridge	6736 3245	935.00

No oilfield has yet been developed in the area, but small accumulations at Plungar, Langar and Rempstone indicate that there is a potential for minor oil production.

Limestone, dolomite and marl

Limestone, dolomite and marl were all previously exploited in the area; none is regarded as having a present-day economic potential.

The limestone was formerly burnt to produce lime. It occurs in the south-east as a succession of separate thin beds within the Barnstone Member (Hydraulic Limestones) of the Scunthorpe Mudstone Formation (Lias Group): former pits are shown on Map 6. Dolomite for calcining to a dolomitic lime and for experiments in calcium silicate brick manufacture was obtained locally in the north-west from the Lower Magnesian Limestone (part of the Cadeby Formation), the main economic use of which was a building stone (q.v.). 'Marl' pits abound on the outcrop of the Mercia Mudstone (Keuper Marl). The material was traditionally used in agriculture to improve sandy soil. Strictly, most of it does not contain sufficient calcium carbonate to be termed a marl, but this is a well-established local terminology. Some marl pits were also dug to supply small-scale brickmaking works or as a flooring material. Many of these are shown as clay pits on Map 6.

Mineralisation

Certain minerals which, if found in quantity, are of economic importance have been recorded from the area. The local occurrences are limited and seem to be of mineralogical interest only.

Secondary cementation by barytes of Triassic sandstone occurs in proximity to major faults in the Bramcote and Stapleford hills [50 38]. The well-known barytes-cemented Hemlock Stone lies just outside the area at [4995 3866].

In the former stone quarry known as Sankey's Pit at Bulwell [532 452] the top two inches of the Lower Magnesian Limestone was reported (King, 1968) to be mineralized by galena associated with an uraniferous hydrocarbon and wulfenite. The exposure has been obscured by the almost complete backfilling of the pit.

Within the Mercia Mudstones green spots within red-brown beds, traditionally known as 'fish eyes', have minute black cores composed of uranium and copper minerals (Aljubouri, 1972). They are commonly developed in the Cropwell Bishop Formation associated with gypsum. Rare occurrences of malachite, a hydrated copper carbonate mineral, have been recorded from gypsum workings at Cropwell Bishop.

Groundwater Resources

Contributed by E Parry of the National Rivers Authority and R A Monkhouse

Water is the resource without which development is impossible. Nottingham is particularly well endowed with both surface water and groundwater. The city itself lies astride the outcrop of the Sherwood Sandstones which form one of the most important aquifers in Britain, and more than two-thirds of the study area overlies these sandstones at depths of up to about 280m (Figure 18: Map 9).

The area is drained by the River Trent and its tributaries, which, together with a canal system, contributed historically both to water supply and communications. The hydrology of the surface water and drainage is beyond the scope of this report, and for these aspects the reader is referred to works by Downing and others (1970), Garland and Hart (1972) and Evans (1984). In addition, Severn Trent plc. and the National Rivers Authority (Severn-Trent Region) hold a large database of information on almost all matters pertaining to water in the area.

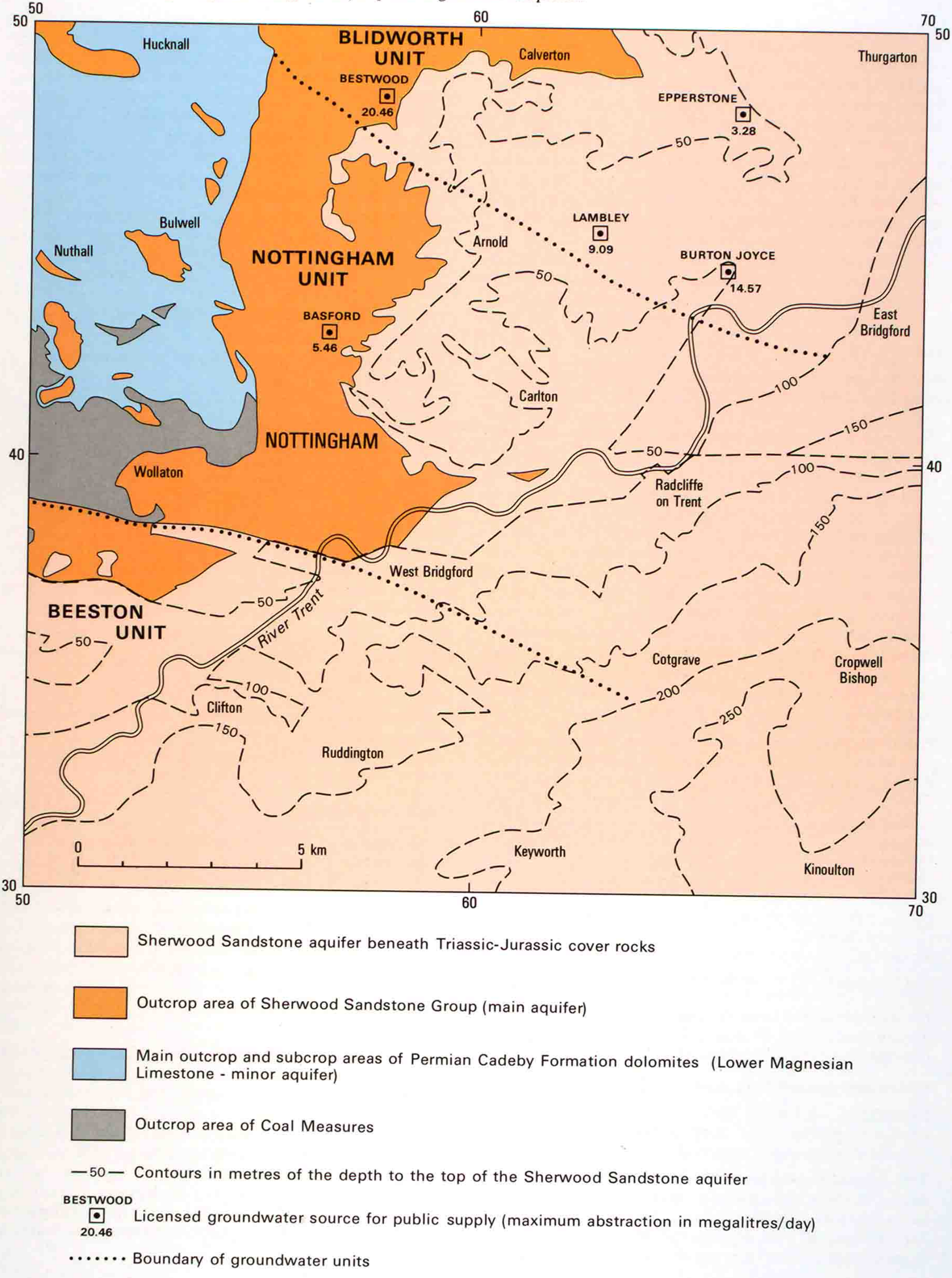


Figure 18. Map showing the main features of the hydrogeology of the Nottingham district

Nottingham and district lies within units 5 and 6 as defined in the groundwater resources report prepared for the Commission of European Communities (Monkhouse and Richards, 1982). As well as the major Sherwood Sandstone aquifer, the Lower Magnesian Limestone is a minor aquifer, whereas other formations have the potential to provide only extremely limited local supply; the near-surface water within various river valley deposits is not suitable for human consumption, but has some use in agriculture and sand and gravel washing.

Sherwood Sandstones

The Sherwood Sandstones have been extensively developed, both for public water supply and industry, in the Nottingham area. This has occurred mainly due to the high yielding nature of the sandstones and the generally excellent quality of the groundwater which, in the case of public supply, has only required basic chlorination treatment. The locations of all licensed groundwater abstractions and observation boreholes, which monitor long term changes in groundwater levels, and rest water levels are shown in Map 9. Specific details of the individual licences and groundwater levels are available from the National Rivers Authority, based at Solihull (021-711-2324).

For management and planning purposes the sandstone areas are divided into discrete groundwater units. In the study area three such units occur (Figure 18) and the assessed long term infiltration rate together with current licensed and actual abstractions are:

Unit	Assessed Resource	Licenced Abstractions	Actual Abstractions
Blidworth	62	110 (96)	88 (83)
Nottingham	19	22 (5)	14 (5)
Beeston	3	6	2

(In megalitres per day, 4.5 megalitres = 1 million gallons) (public water supply abstractions are bracketed)

Public water supply sources are heavily concentrated in the Blidworth Unit while in the other units private industry dominates abstraction (coal mining, laundries, brewing, bleaching and dyeing, pharmaceuticals).

Prior to 1963 there was a lack of a statutory body to control groundwater development and this led, in many areas, to an undesirable high concentration of abstraction. This was especially true of the study area where overabstraction resulted in depressed aquifer levels and reduced stream flows which are dependent on baseflow discharge from the aquifer. The headwater of the Dover Beck was especially adversely affected by overpumping. However, the introduction of the 1963 Water Resources Act enabled a belated policy of aquifer management to be introduced. The Act also entitled Licences of Right to be automatically issued for those sources which had been abstracting prior to the introduction of the Act. Detailed aquifer management policies introduced, after 1963 by the Trent River Authority and in 1974 by the Severn Trent Water Authority, had therefore to take into account the large existing imbalance between abstraction and resources. In the period 1963-87 no new licences were issued in an attempt to redress the imbalance.

Due to the progressive decline in industry dependent on groundwater within the built up areas some new licences have been granted since 1987, for the Nottingham and Beeston Units. Licensed abstractions for the large Nottingham Unit have declined from 35 Ml/d in 1965 to 22 Ml/d in 1989, while actual abstraction has reduced from 27 to 14 Ml/d in the same period. In contrast the reduction in licensed and actual abstractions for the Blidworth Unit has been marginal and there is a continuing embargo on the granting of new licences, the only exception being small-scale spray irrigation licences. However, in 1989 agreement was reached with Severn Trent plc which will reduce actual abstraction within the Blidworth Unit, down to 62 Ml/d by 2001.

Groundwater quality is generally good in both the urban and rural areas. However, high nitrate levels are experienced, primarily due to leaking sewers in urban areas, and to intensive agriculture, including the use of nitrogen-based fertilizers, in rural areas (see p.54). Only to the east where the sandstones are overlain by the Mercia Mudstone are nitrate levels low.

Lower Magnesian Limestone

Contrary to those of the Sherwood Sandstones, yields from the Lower Magnesian Limestone (Cadeby Formation carbonate facies) are very erratic, with the majority of boreholes only giving sufficient yields to meet the demands of very small factories or small farms (not requiring water for large scale spray irrigation). Only when a well-developed system of fissures is found in the Limestone will a satisfactory yield, to meet the requirements of a medium sized factory or large farm, be obtained. No public water supply boreholes draw from the rocks within the study area or the area to the north which extends to the Authority's boundary near Doncaster. The nominal resources of the Limestone in the study area have been assessed at 25 Ml/d but, due to the highly variable nature of borehole yields, development has and will always be very slow. Groundwater level fluctuations are relatively large with an annual range of up to 7m being recorded. Nitrates are high where the Limestone is exposed, and hardness is also usually high, in the range 400-600 mg/l. The aquifer contributes through natural discharge to the flow of the Leen and Erewash rivers.

The Middle Permian Marl, where present, forms an aquiclude between the Limestone and the overlying Sherwood Sandstone Group. No significant amounts of water are derived from the Marl.

Other formations

Only limited amounts of groundwater are obtained from the **Coal Measures**. The sequence is dominated by impermeable strata and only when sandstones occur in the sequence will any groundwater be obtained. Borehole yields are therefore generally poor, and little exploitation of the limited groundwater resources has taken place. Many of the sandstone beds occur at depth with no surface replenishment, long term pumping from these sandstones may therefore result in declining yields. Groundwater levels in the Measures tend to be variable with each sandstone bed having its own discrete water table. As with the Magnesian Limestone there are at present no objections, in principle, to the granting of groundwater licences.

The rocks of the **Mercia Mudstone Group** are regarded as an aquiclude confining groundwater in the underlying Sherwood Sandstones. Nonetheless, limited quantities of groundwater suitable for agriculture, other than spray irrigation, can often be obtained from sandstone and siltstone beds (skerries) within the mudstone sequence. These skerries tend to be discontinuous (except for the Cotgrave and Hollygate sandstones), and natural replenishment slow. Consequently, although initial yields can be fairly substantial, they tend to diminish with time as the storage is depleted. Groundwater quality is rather variable; total hardness ranges from 250 to more than 600 mg/l. and iron concentrations can exceed 1.0 mg/l. Concentrations of other ions are not normally excessive.

The strata of the **Penarth Group** do not form an aquifer, and are unreliable even for small supplies. The thin limestone beds in the **Lias Group** yield small supplies locally, but the water commonly contains high concentrations of sodium and sulphate.

Shallow perched groundwater occurs in alluvial and terrace sands and gravels along most rivers and streams. Groundwater is mostly within a few metres of the surface (see Map 9) so that yields, albeit generally small, are obtainable almost anywhere. There is a high risk of surface pollution, and the water is unsuitable for human supply.

Other resources

Foundations

Sound foundations for building are provided by most of the bedrock materials in the area. Problems posed locally are referred to later (p.44); these include the presence of steep slopes, peat beds, former excavations, caves, mine shafts, adits and undermined areas. In many areas, particularly on the Mercia Mudstone bedrock, small scale building work proceeds with a minimum of prior site investigation. While building in such circumstances has little case history of failure, preliminary site investigations should always be carried out by experienced professionals following guidelines such as those given in BS 5930:1981, "Code of Practice for Site Investigations". Unexpected factors contributing to ground instability may occur such as the presence of Head or other unconsolidated material resembling bedrock but with relict shear planes or loose sand pockets.

Caves

A register of all the caves of Nottingham for which documentary evidence has been located was prepared during the course of the study and is available separately (Owen and Walsby, 1989). This provides a major source of reference to more than 400 caves or cave systems for planners, building control officers, architects, engineers, developers and members of the public.

Man-made caves have been present under Nottingham for at least a thousand years; the distribution of known caves is shown on Figure 25 and Map 11. During this time they have been used for such diverse purposes as wells, cess-pits, store rooms for grain, wine, fish and meat, breweries and tanneries, dwellings and hideaways, routes of communication, decorative follies, shelters in time of war (both in Medieval times and in the Second World War) and as a source of building sand.

At present several of the caves are used for beer storage and as cellars under private properties. The more well-known are being promoted as tourist attractions. Table 10 lists caves in use at present and some which might be considered for development. Many of the caves in use at present have only limited public access and are little publicised; there exists a considerable opportunity for further tourist development

Other than for use in tourism, some of the caves still have potential to be converted into emergency shelters. It must also be remembered that the excavation of caves is a relatively simple and low cost operation and that extensions to existing caves or creation of new ones for various purposes is possible.

Waste disposal sites

The ideal site is a large excavation into dry impermeable strata which can be backfilled and compacted to the former ground level, and then used for construction or agriculture. Thus geology is important since, firstly, the site will be one where an economic mineral has been extracted and, secondly, the nature of the bedrock and its

Table 10. Sites of caves in use or of tourist and educational potential

Public houses known to use their caves for beer storage
Bell Inn
Generous Briton Inn
Golden Fleece Public House
Hand and Heart Public House
Horse and Groom Public House
Lord Nelson Public House
Red Lion Public House
Royal Oak Public House
Running Horse Inn
Salutation Inn
Trip to Jerusalem Inn
Public houses known to use their caves as public bars
Hand and Heart Public House
Trip to Jerusalem Inn
Site of cave containing water reservoir tanks
Shipstones Brewery
Sites of caves used for tourist & educational purposes
Brewhouse Yard Museum
Bridlesmith Gate
Broadmarsh
Mortimer's Hole, Nottingham Castle
Lord Nelson Public House
Robin Hood Tavern
Salutation Inn
Wollaton Hall
Sites of caves of potential for development
Pearson Brothers Limited (Long Row)
Peel Street
Shire Hall

structure must be suitable to preclude migration of toxic and explosive substances, including gases, out of the site to produce an environmental hazard. It may well be a major consideration in the economics of mineral extraction that the excavation can be used later for profitable waste disposal. In addition, backfilling and restoration of the site may be a condition for the granting of planning permission for the mineral working. It is common practice now to covert unfavourable geological sites into useful assets by the construction of sealed cells for the waste and by venting gases. This can, of course, be an expensive operation and will generally only be carried out for the more problematic, usually toxic or noxious, wastes.

The present and potential extraction of minerals in the Nottingham area provide a resource for waste disposal as outlined in the following table (Table 11).

The spreading of waste material on derelict, unused or low-lying waterlogged land has been widely followed in the area. The main spreads of made ground of this sort are in the Dunkirk/Lenton Lane industrial areas and along Wilford Lane (see Figure 13 and Maps 4A-D). Few sites for this type of waste disposal remain around Nottingham. It should be borne in mind, however, that such landfill may have the disadvantage of sterilising a resource, as it has in the above areas where no extraction of the underlying gravels is now possible, and in some locations there may be a conflict with nature conservation.

Soils

Soils and drainage are major aspects used in the classification of the quality of agricultural land. Both are, to a great extent, dependent on the underlying geology. Thus around Nottingham land quality varies from Grade 2 to Grade 4 with Grade 3 the most common (Dittmer, 1988). The soils and drainage contributing to the better Grade 2 land are developed mainly on the outcrops of the Triassic Mercia Mudstones and the Permian Edlington Formation and Lower Magnesian Limestone (upper part of the Cadeby Formation), while the poorer Grade 4 land is on the Coal Measure outcrop in the west. Grade 3 land is commonly developed on the outcrop of the Sherwood Sandstones. Predictions as to the quality of the soils for agriculture in a given area can be made by reference to the geological maps (Maps 2 and 3) where the above bedrock units may be identified and any cover of drift deposits noted.

Geological sites of scientific and educational interest

Exposures of rocks and superficial deposits which can demonstrate the geology and geomorphology of the area are a considerable resource for educational and research purposes. The main way such sites can be preserved is by their being made into Sites of Special Scientific Interest (SSSI) or Local Nature Reserves (LNR). Within the study area there are a number of these sites, most of which have been created primarily for their ecological importance rather than their geology. However, many of these also display notable geological features; all the SSSIs and LNRs in the area are listed in Table 12 with their geological interest indicated.

Geological site recording for Nottinghamshire has been carried out by staff at the Wollaton Natural History Museum, run by the Nottingham City Council, as part of the National Scheme for Geological Site Documentation (NSGSD), initiated in 1977 and financed by the Nature Conservancy Council. The aim of the scheme is to provide a source of information for planners, educationalists, researchers and others. For planners in particular, the educational value of a site is a consideration should a conflict of land use arise.

Table 11. Mineral extraction and waste disposal possibilities in the Nottingham area

Mineral Extraction	Volume Created	Bedrock Character	Special factors in waste management
Brick Clay	Very Large	Impermeable	Deep excavation
Gypsum	Small (after backfill of spoil)	Impermeable	Presence of sulphate-rich groundwater
Coal	Small (after backfill of spoil)	Limited permeability	May be deep and narrow excavation
Sand and Gravel	Very large	Permeable	High water levels
Building Stone	Moderate, minor spoil backfill	Permeable	Carbonate bedrock susceptible to solution
Sand (Sherwood Sandstones)	Moderate	Permeable	Bedrock is major aquifer

Some fine geological sites, which are not preserved or protected at present in any way, occur in the study area. Many parts of the geological sequence can be demonstrated at natural exposures which are unlikely to be destroyed or covered e.g. the cuttings in the Lenton Sandstone behind the Queen's Medical Centre [545 387] or the type section of the Nottingham Castle Sandstone at Castle Rock [569 394]. Others, equally important, but which are more at risk are listed below:

1. Wall of bedded dolomites ('Lower Magnesian Limestone') at site of former Babbington Colliery [532 435] (Back Cover).
2. Former quarry for Bulwell Stone in bedded dolomites ('Lower Magnesian Limestone') in Bulwell [534 454].
3. Sections in aeolian sand dunes in former moulding sand quarry at Bobber's Mill [553 415]. (Also includes sections in periglacially disturbed glacial sand and gravel).
4. Section at boundary between Lenton Sandstone and Nottingham Castle Sandstone in the yard of former Bestwood Colliery [558 474].
5. Type section of the Sneinton Formation in former railway cutting off Colwick Road [592 357].
6. Section in Hollygate Sandstone in former railway cutting at Edwalton [590 356].
7. Sections in Blue Anchor Formation, Westbury Formation and glacial till in railway cuttings between Normanton and Stanton-on-the-Wolds [625 322– 635 312].
8. Section in Barnstone Member in former quarry near Owthorpe [675 341].

Planners and developers should be aware that, given suitable treatment by landscaping schemes, the presence of a rock section of geological interest may enhance the amenity value of a site. Geological advice should be sought for any development which includes rock exposures; these are likely to be found mainly in the sides of former excavations and cuttings. Information is readily available from either the National Scheme for Geological Site Documentation records or the BGS, and advice can be obtained from the Nature Conservancy Council.

GEOLOGICAL CONSTRAINTS

Potentially adverse ground conditions are the main geological constraint for consideration in planning and development. Although most ground problems can be overcome by appropriate engineering or construction works, the early recognition of problems which may arise is of great importance, not the least because, in some cases, solutions may be prohibitively expensive. Assessment of ground conditions includes not only the properties and stability of bedrock and superficial materials, but also the changes to the subsurface brought about by man, such as mining and any consequent subsidence, quarrying and landfill. These two aspects, the natural geological properties and man-made modifications, are considered separately below.

Properties and stability of bedrock and superficial materials

The suitability of bedrock and superficial materials for foundations depends mainly on their geotechnical properties. The various parameters relating to the bearing strength of natural materials and to their reaction to engineering structures are reviewed below. Consideration is also given to fill treated as a geologically significant deposit. Large scale landfill operations are a relatively recent development, made necessary by a massive increase in industrial and domestic waste. Fill commonly includes chemical and organic wastes, each of which may provide difficult or, sometimes, hazardous conditions locally.

In considering the stability of engineering structures several geological factors, in addition to geotechnical properties, must be examined. These include local geological structure and slope stability, the possible presence of solution cavities, or, on a regional scale, earthquakes. Any of these may give rise to problematical ground conditions which then act as a major constraint to development. **Site specific investigations should always be carried out prior to development.** A further aspect to be considered is the possibility of risks to health from exposure to radioactive radon gas emanating from subsurface materials.

These factors are reviewed in detail in the following section.

GEOTECHNICAL PROPERTIES

Contributed by A Forster

The engineering geological assessment of the superficial and bedrock units in the area was based on information abstracted from published scientific papers and 301 site investigation reports. Data from a total of 5012 test or sample points in 1411 pits or boreholes were used. No new sampling or testing was undertaken so that data points are to a large extent concentrated in areas where development has taken place. Sample coverage of geological units is generally good except for the Blue Anchor Formation, Penarth Group and Lias Group in the south-east. Full details of the coverage and quality of data, the methodology used in processing the data, the limitations of results and analysis of geotechnical properties are provided in a separate report (Forster, 1989).

The description of geotechnical properties which follows deals with materials in three groups:

Fill
Superficial (drift) deposits
Bedrock

Fill

Fill is a general term for man-made deposits, mainly within planned areas of landfill or backfill, but including a patchy veneer beneath most built-over areas. **All geotechnical investigations must allow for the presence of fill overlying drift or bedrock.** The distribution of various categories of man-made or disturbed ground is shown on Maps 4A-D and generalized in Figure 13.

The geotechnical properties of fill differ widely and are difficult to predict. The behaviour of fill depends upon the nature of the material and how it is compacted during placement. When fill is placed as part of an engineering project, the material used should be selected for its geotechnical behaviour, placed in a controlled manner and compacted to a specified density. When fill is placed as part of a waste disposal operation it may vary from relatively inert, inorganic waste such as mine spoil or brick rubble to organic domestic refuse. The geotechnical properties of such a site will depend upon the nature of the tipped material and, in the case of organic waste, will vary with time as decay proceeds. The decay of organic material in domestic refuse may cause a loss of volume of up to 50 percent and the generation of methane and toxic leachate. Migration of these substances may then take place through the deposit or into adjacent strata, by way of pores or open fissures.

The bearing capacity is commonly very low and is likely to vary over short distances leading to highly uneven settlement. Bearing capacities quoted for domestic landfill sites in the past may not be applicable to current or future sites because the nature of domestic refuse changes with social and technological change. For example over the last fifty years the amount of ash has decreased while the amount of paper and plastic has increased. It is essential that possible chemical and biological hazards which may be present (including methane) are also assessed. Methane in an explosive concentration (5 to 15 percent in

Table 12. Sites of Special Scientific Interest and Local Nature Reserves in the Nottingham area and their geological interest

Name	Grid Reference (SK)	Main reason for special site status	Geological Interest	SSSI or LNR
Attenborough Gravel Pits	522 341	Terrestrial, marsh and aquatic habitats	Some sections in former gravel pits	SSSI
Bulwell Wood	518 463	Plants related to soils	Plants related to underlying geology	"
Colwick Cutting	600 397	'Type' section of Colwick Formation (Elliott 1961)	Section shows boundary between Sneinton and Radcliffe formations	"
Gotham Hill Pasture	532 307	Grassland	Spoil tips, shafts, adits and subsidence related to former Weldon Gypsum Mine	"
Holme Pierrepont Orchard	626 394	Grassland and Orchard	On low terrace deposits	"
Holme Pit	536 345	Marsh, reedswamp and open water habitats	10.9m section in mudstone and siltstone with gypsum (Gunthorpe Formation)	"
Kimberley Railway Cutting	504 453	Palaeobotany of Permian flora	Permian Cadeby Formation with basal breccia over Coal Measures	"
Kinoulton Marsh and Canal	678 305	Open water and marsh vegetation	Former clay pit in Jurassic mudstones	"
Martin's Pond, Wollaton	526 402	Wildlife refuge	None	LNR
Normanton Pastures	625 332	Grassland with ridge & furrow	Gravelly till occupying bedrock hollow	SSSI
Sellers Wood, Bulwell	523 455	Plants related to soils	Former clay pits in Edlington Formation	"
Wilford Clay Pits	571 355	Marsh and mire plants	Exposures of Cotgrave Sandstone and other skerries in Mercia Mudstone	"
Wilwell Farm Cutting	567 348	Grassland and marsh bird habitat	Exposures of Cotgrave Sandstone and overlying skerries in Mercia Mudstone	"

air) may be ignited by a spark or a shock wave, either of which may be generated during pile-driving or dynamic compaction operations.

Where past industrial activity has left contaminated ground, tests for chemical and biological contamination should be included in the site investigation. Potential hazards to people, including those undertaking building excavation work, and possible corrosive leachate attack on services and buried concrete (Eglinton, 1979), should be assessed.

Superficial (drift) deposits

The classification of these deposits is shown in Table 13, and their distribution shown in Map 10B. In general, an engineering soil is a material formed of an aggregation of rock particles which can be separated by gentle mechanical means and excavated by digging. Cohesive soils are fine-grained soils such as clays and silts, and non-cohesive soils are coarse-grained soils such as uncemented sands and gravels.

Head may be cohesive or non-cohesive and is dealt with separately, as are organic soils, including peat

Head

Head is derived by the weathering and downslope movement of pre-existing deposits; it may be of periglacial origin as a solifluction deposit or result from hillwash processes (as colluvium). Its composition is highly variable, and reflects the upslope source material. It may be crudely stratified, but is generally massive in appearance; this could be deceptive since relict sub-horizontal shear planes may exist, and these may be reactivated if disturbed during excavation, causing landsliding.

Head may be composed of cohesive material of a soft to stiff consistency or of non-cohesive material with a loose to dense relative density. Standard penetration tests and undrained cohesion values offer net bearing capacity in the range of 100-300 kPa, suitable for domestic or light industrial structures on normal spread foundations, with medium to high compressibility.

Head is commonly a thin surface deposit which is usually removed before foundations are placed. If it is not removed or is of greater than usual thickness, its low strength and high compressibility can lead to excessive settlement.

Head on slopes may suffer instability problems due to its inherent weakness and/or the reactivation of relict shear surfaces. Movement may be instigated by undercutting at the foot of the slope, loading at the top or the build-up of high pore water pressures within the slope.

Excavations in Head will require support, and water inflow may cause collapse.

Organic Soils

Organic soils, including peat, shell marl and clay, silt or sand rich in organic matter, occur mainly as channel infills within alluvium and river terrace deposits, or associated with lacustrine deposits.

The geotechnical properties of local peats, which are summarised in Annex 4, correspond with those of peats found elsewhere (Hobbs, 1986).

Engineering problems caused by peat and very organic soils are due to low strength, high compressibility and aggressive groundwater content. The moisture content may be as high as 420 percent.

Because peat occurs in relatively small discrete bodies, foundations may be laid partly on highly compressible peat and partly on less compressible materials. Ensuing differential settlement may cause severe structural damage to the building. Excessive settlement of peat along the line of a former stream has been a problem in the Beeston area. Concrete foundations may suffer damage due to sulphate or acid attack by the groundwater. Organic soils generate methane and their burial may introduce a considerable risk of explosive gas build-up.

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

Any excavations will require support.

Cohesive Soils

Alluvium (excluding gravel) and lacustrine clay

The alluvium and lacustrine clay are composed mainly of normally consolidated clay and silt, but may be sandy and pebbly locally. They contain organic-rich layers and channels in places and may incorporate rare beds or pockets of peat, and shell marls.

They are of low to high plasticity, soft to firm consistency and medium to high compressibility. Standard penetration tests, undrained cohesion and consolidation results indicate net allowable bearing pressures of 0-200 kPa with medium to very high consolidation. The moisture content typically ranges from 10-50 percent, with the more organic-rich soils ranging up to several hundred percent. Moisture content usually falls between the liquid and plastic limits of the material.

Sulphate content is generally within class I of the B.R.E. classification (see Annex 4, Table 2b) with some samples (20 percent) falling in class II and a few (10 percent) in classes III and IV; higher sulphate values may result from groundwater contamination from nearby fill. The pH values range from 4.8 to 10.5, but are usually between 6 and 9.

Engineering problems associated with alluvium and lacustrine clay are commonly due to their low shear strength and high compressibility which may require special foundations such as a raft or piles. Lateral and vertical differences in composition will be reflected by variations in geotechnical properties.

Sulphate and acid attack on buried concrete is not a common problem but occasionally concrete conforming to class II sulphate conditions may be required; rarely class III and class IV conditions may be encountered.

Excavations will require support and may encounter running sand below the water table.

Till (Boulder Clay)

Till is poorly represented in the database; the sixty samples described come mainly from an area to the east of Hucknall and from near Keyworth. These may be atypical since outside the Wolds area and the north-west, the till is very sandy, and has been mapped locally (at 1:10 000 scale) as 'sandy till commonly associated with other complex drift deposits' (see also later). The 'other deposits' include sands and gravels.

The tills for which data are available are generally sandy clays, with variable pebble content, of low to intermediate plasticity, medium compressibility and coefficient of consolidation in the range 0.1 – $10 m^2/yr$

The till from near Hucknall shows greater cohesion (100 – 350 kPa), greater bulk density (2.1 – 2.3 Mg/m^3) and lower moisture content than the samples from near Keyworth where bulk density is in the range 1.8 – 2.1 Mg/m^3 and moisture content between 15 and 30 percent. These differences may be related to the state of weathering, topography or simply the time of year when sampling was carried out, or more likely are due to differences in origin, as lodgement or melt-out tills, or composition reflecting variation in parent material.

The net allowable bearing capacity based on cohesion data indicates a range of 200-600 kPa in the Hucknall area and 50-200 kPa in the Keyworth area.

Sulphate content of the till indicates that class I conditions for sulphate attack on concrete apply; but, in a small number of samples, class III conditions apply and sulphate resisting concrete mixes will be needed for structures below the water table.

Table 13. Engineering geological classification of superficial deposits.

Engineering Geological Unit		Lithostratigraphical Unit	
HEAD		Head	
ORGANIC SOIL		Peat	
COHESIVE SOIL	Weak	Alluvium (excluding gravel)	
		Lacustrine clay	
	Strong	Till (Boulder Clay)	
NON-COHESIVE SOIL		Alluvial gravel	
		Holme Pierrepont Sand & Gravel	Deposits of lower river terraces
		Leen Sand & Gravel	
		Bunny Sand & Gravel	
		Beeston Sand & Gravel	Deposits of upper river terraces
		Bassingfield Sand & Gravel	
		Glacial Sand and Gravel	
		Sandy Till	

Non-cohesive soils

Alluvial Gravel

Extensive deposits of alluvial gravel are present in the Trent valley below a capping of silty clay alluvium. They commonly comprise gravels with some sand lenses; silt or clay are rare components. The sand content varies from about 30 to 50 percent.

Standard penetration tests show gravels of three distinct relative densities to be present. A mainly medium dense unit with average S.P.T. values of 25 overlying a very dense unit with S.P.T. values of over 50. At the surface a third deposit of loose density may be present with an S.P.T. value of about 10.

Density and moisture content data for the gravels should be treated with caution due to the difficulty in obtaining samples of gravel in an undisturbed state.

Sulphate test results indicate that the groundwater in the gravels normally conforms to class I conditions for sulphate attack, but in 25 percent of the tests class II conditions were indicated and a single determination recorded class III conditions. The average pH of the groundwater was 7.5 with values ranging from 5 to 10. Precautions against acid attack on buried concrete are unlikely to be required.

The gravels are composed mainly of quartzite and quartz with only minor chert or flint; problems with alkali aggregate reaction are unlikely when used in concrete aggregate.

The gravels have a high to medium permeability (6.2×10^{-2} – 6.2×10^{-4} m/sec). Excavations into the gravels will require support and control of groundwater inflow will be necessary below the water table.

Good foundation bearing capacity is offered by the gravels; net allowable/permissible bearing capacity is in the range 100 to 600 kPa, with low compressibility.

Deposits of river terraces

These deposits are poorly represented in the database, with only 44 samples from two areas, Gamston and Clifton Bridge, both situated on the Holme Pierrepont Sand and Gravel. The geotechnical data are restricted mainly to S.P.T. values and moisture content.

The sampled material is composed of gravel, sand and sandy gravelly clay. S.P.T. values indicate it to be of medium dense to dense, occasionally very dense, relative density. The clay fraction of the clay rich components has low to intermediate plasticity. The very limited information on sulphate content (3 values) indicate class I conditions. S.P.T. and undrained cohesion values indicate a net allowable bearing capacity in the range 100 – 400 kPa for gravel/sand lithologies. Considerable differences in properties are to be expected for sands and gravels underlying river terraces elsewhere.

Although medium dense to dense, terrace sand and gravels become loose on disturbance so that excavations require support.

Glacial Sand and Gravel and Sandy Till

Little geotechnical information is available. In general they are likely to have similar properties to the river terrace deposits and as such are presumed to offer good bearing capacity with low settlement characteristics. Excavations will require support.

Bedrock materials

The classification of these deposits is shown in Table 14 and their distribution in Figure 19.

Mudstone

This material comprises predominantly overconsolidated mudstone with some siltstone, fine sandstone and limestone, weathering to produce variably silty and sandy clay. Mudstone is of three types (Table 14, A, B and C), determined by its properties as encountered in near-surface geotechnical investigations; the distribution of the different types is shown in Figure 19 and Map 10B.

Type A mudstone generally comprises clay of high to very high plasticity with some nodular or thinly bedded limestone. Little geotechnical information is available for this type. It may be subject to slope instability, high compressibility, shrinkage and swelling problems. Excavations can generally be carried out by digging; ripping may be necessary in limestone. Water may flow along joints in limestone beds causing flooding to excavations.

Type B mudstone generally comprises stiff to hard silty clay of low to intermediate plasticity with some siltstone and sandstone which weather to clayey silts and sands. The net allowable bearing capacity is in the range of 100-600 kPa, with moderate, rarely high, settlement. Sulphate attack on buried concrete is possible, so that class II or class III, rarely class IV or V, concrete mixes may be required locally. Excavations can generally be carried out by digging, or ripping in harder parts, and support is required in weathered material. Slopes of 60° and ten metres high have been cut, though 30-40° is more usual.

Type C mudstone generally comprises firm to very firm stiff clay of intermediate to high plasticity. The net allowable bearing capacity is in the range 100-600 kPa with moderate setttlement. This type includes thin sandstone, coal and seatearth with unconfined compressive strengths of about 25, 7 and 4 MPa respectively. Sulphate attack on buried concrete is unlikely; class II concrete mixes may be necessary locally. Excavations can be carried out by digging, but ripping may be required for sandstone; support will be required in weathered material. Coal Measures may have been mined from crop in shallow workings (p.30), the location of which requires investigation so that appropriate foundations can be designed.

Interbedded Sandstone/Mudstone

Only the rocks of the Sneinton Formation fall into this category. They comprise an interbedded sequence of overconsolidated mudstone, siltstone and fine-grained sandstone which weather to firm clay and dense sand. Standard penetration test values are moderate to high (25-50+); undrained cohesion for clay averages 59 kPa (weathered) to 25 MPa (unweathered). This indicates a net allowable bearing capacity of 200-400 kPa (clays) and in excess of 2000 kPa for unweathered sandstone, but in an interbedded sequence the weakest unit is the controlling factor. Settlement is moderate in clay, to low in sandstone. Sulphate attack on buried concrete is unlikely.

California Bearing Ratio results indicate that some sandstones are excellent for road sub-base material. Excavation in weathered rock can be carried out by digging, but ripping in sandstone and unweathered bedrock may be required. Support is required in weathered material. Slopes of 35° have been used in cuttings where there is adequate protection from surface water to avoid erosion.

Sandstone

This category comprises generally weak to moderately strong fine-, medium- and coarse-grained, sometimes pebbly sandstone, weathering to sand. The depth of weathering ranges up to about 8m; standard penetration values range from low (3), in weathered, to high (50+) in unweathered material. Likewise, unconfined compressive strength ranges from 1 MPa (weathered) to 22 MPa (unweathered), indicating a net allowable bearing capacity between 400 and 2000 kPa. Sulphate attack on buried concrete is unlikely.

Excavation is usually possible by scraper/bulldozer with ripping necessary in harder beds and where bedding and jointing are widely spaced; blade wear rate is commonly high due to abrasive quartz grains. Sub-vertical faces (70°) are stable in the short term, though cuts at 35°, if protected from runoff, are required for long term stability. Excavated material can be used for road sub-bases. The sandstone may contain man-made excavations at shallow depth which may be empty or rubble filled; the problem of caves is separately discussed on p.61.

Lower Magnesian Limestone

The Lower Magnesian Limestone (the upper part of the Cadeby Formation) is strictly a dolomite with thin silty mudstone layers. It is commonly described in site investigation reports as sandstone weathering to silty or gravelly sand with clay. At the surface a widely developed overlying remanié clay deposit up to about 1m thick results from partial solution of the carbonate. This wide range in lithology gives rise to considerable variation in geotechnical properties.

Standard penetration test values range from 20 to 50+ at depth. These and moisture content results suggest that there is an abrupt change in geotechnical properties at the boundary between the weathered and unweathered material. Plasticity data for fine-grained weathered material show it to have low plasticity with undrained cohesion in the range 30-370 kPa. The rock itself has a compressive strength in the range 22-32 MPa, and gives an average RQD value of 31 percent but ranges from 0-80 percent. The indicated net allowable bearing capacities range from 150-400 kPa (clays) to in excess of 2000 kPa for unweathered material, with moderate to low settlement. Sulphate attack on buried concrete is unlikely.

The rock is well jointed and the joints are commonly a focus for solution, reducing the rock to a granular dolomitic sand along the joint. Further solution may take place resulting in enlarged fissures and cavities, but few of more than a few centimetres in width are known from the area. In valley sides cambering may have opened joints to form fissures which may be filled with superficial material or may remain open at depth but bridged with rubble at the surface. A similar effect has been observed where mining subsidence has opened pre-existing fractures.

Geological Structures

Two types of geological structure may have a major affect on foundation conditions, deep-seated faults and folds or superficial structures confined to the few metres below the ground surface. The bedrock geological map of the area (Figure 6: Map 2) and the simplified structural map (Figure 9 & 10) show major fault zones across the area; folding is, however, of little importance, being mainly of very low amplitude with most bedrock dips less than 4°. Faults commonly juxtapose rock types of different geotechnical properties so that loading by buildings which straddle them may cause differential settlement. In areas of undermining, collapse of old workings on one side of a fault may lead to extensive subsidence damage along the line of the fault (see p.55). Movement on deep basement faults may cause earthquakes (see p.54); it is also possible that faults may exert some control on the area of potential damage due to earthquakes, but this is not documented for the area.

Site investigations should attempt to locate precisely any faults whose presence is suspected from surface or underground information. It is advisable not to site structures across faults, but if this is unavoidable then appropriate engineering solutions allowing for differential settlement should be adopted. No differential movement along faults other than that induced by mining subsidence has been noted in the area.

Table 14. Engineering geological classification of bedrock materials

Engineering Geological Category		Lithostratigraphical Unit
MUDSTONE of various plasticity with some siltstone, fine sandstone and limestone	A	Scunthorpe Mudstone Formation Cotham Member Westbury Formation Blue Anchor Formation
	B	Cropwell Bishop Formation Edwalton Formation Gunthorpe Formation Radcliffe Formation
	C	Edlington Formation Cadeby Formation (mudstone) Middle Coal Measures Lower Coal Measures
INTERBEDDED SANDSTONE & MUDSTONE		Sneinton Formation
SANDSTONE		Nottingham Castle Formation Lenton Sandstone Formation
LOWER MAGNESIAN LIMESTONE		Cadeby Formation (dolomite)

Joints, which are fractures along which no displacement has taken place, are common in the more massive sandstones and in the dolomites of the Cadeby Formation (Lower Magnesian Limestone). They may have a direct effect on the stability of rock slopes where water or tree roots may induce slab failure, as at Castle Rock (see p.51 and Figure 20). Mining-induced differential subsidence may widen joints to produce open fissures; this has been widely reported in the Lower Magnesian Limestone, with joints widened to 5cm or more e.g. in the Blenheim area [527 458]. The effects of solution along or of squeezing of material into open joints must be considered in foundation design in areas likely to be affected.

Superficial structures are of common occurrence in the area. These include folds and faults not attributable to deep-seated tectonic causes, as well as cryoturbation structures. Mudstone or clay-rich drift deposits are the materials in which these structures are most common. Folds and faults occur in many of the deep steep-sided valleys, especially in the Mercia Mudstones of the north-east. The folds are mostly asymmetrical with wavelengths of only a few metres, and trend almost invariably parallel or subparallel to the valley sides. Minor faulting is commonly associated with the folds; locally, bedding may be almost vertical. The structures are caused by valley bulging, which may be associated with cambering on the valley sides; most probably they originated under periglacial conditions in the Devensian. These structures indicate potential instability and possible residual stress in the bedrock; they are of particular importance where deep excavations in mudstone are planned within narrow valleys.

Periglacial cryoturbation has affected weathered rock and superficial deposits close to the ground surface. Convoluted fold structures are locally present (Plate 4), and many profiles show stones turned so that their long axes are vertical. Generally, cryoturbated materials have less strength than their parent deposits.

Slope Stability

The stability of slopes is dependent on three main factors

a) the slope angle

b) the nature, structures and strength of the underlying material (bedrock, superficial deposits or fill)

c) the influence of water

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.

Slopes of various steepness are common in the Nottingham area (Map 5), and include cliffs and bluffs flanking the Trent Valley. In most places they present little hazard to development if undercutting by rivers or human agencies is avoided; however, former landslips and incipient unstable ground have been recorded from various locations (Fig. 19). For this study, slopes have

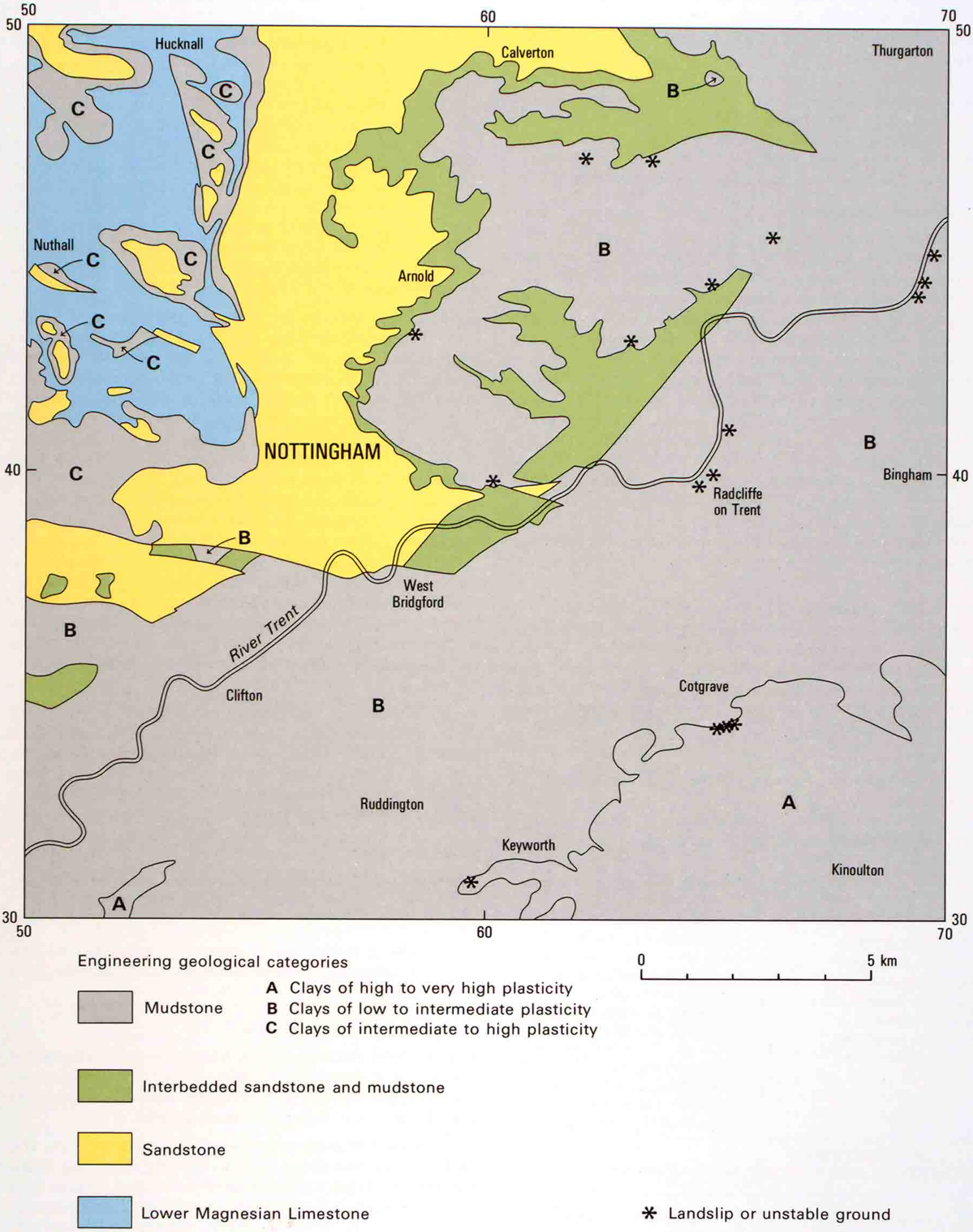


Figure 19. Map showing the distribution of engineering geological categories of bedrock

been divided into three categories (see Map 5) defined as shown in Table 15.

The geotechnical properties of bedrock, including strength and stability characteristics have already been reviewed (pp.47–48). The main engineering geological categories are mudstone, interbedded mudstone and sandstone, sandstone and Lower Magnesian Limestone. Clay is a major constituent of the mudstone and interbedded mudstone and sandstone which underlie over two-thirds of the area (Figure 19), and is the material most susceptible to mass movement effects. The stability of slopes developed on clay is related mainly to local structural and hydrogeological conditions. Figure 21 shows in diagrammatic form the three relationships between bedrock, structure and groundwater flow found most commonly in mudstone and interbedded rocks.

The geomorphology around Nottingham (Figure 14 : Map 5) is dominated by scarps and dip slopes which give rise to the more stable situation of Figure 21a over much of the area. The landslipping at Cotgrave [651 343] is an example of the setting indicated in Figure 21b with the unstable top of the slope developed in the Blue Anchor Formation and Penarth Group rocks which weather to clays of high to very high plasticity (Engineering Geological Category A, Figure 19). Landslipping and instability along the cliffs and bluffs facing the River Trent is mainly caused by undercutting by the river; however, mass movement of head, colluvium and talus overlying bedrock on the steep face is a contributory factor (Figure 21c).

In general, mudstone and interbedded mudstone and sandstone are strong enough to sustain steep slopes without failure. Deeply weathered bedrock and material derived from it, such as head, is much weaker and has a reduced permeability. The weathered zone of slopes is therefore susceptible to movement if there is increased ingress of water from natural or artificial sources. Under the present climate natural water input is not generally sufficient to promote movement, except near spring lines. However, under the wetter freeze-thaw periglacial conditions during the Devensian, movement may have occurred as shallow landslips or solifluction. The degraded results of these processes may be preserved unrecognised and may include relict shear surfaces which could be reactivated by loading or undercutting slopes, or by introducing water into the slope from drains or soakaways.

Within the bedrock lithologies without significant clay, i.e. the Sherwood Sandstones and the dolomites of the Cadeby Formation (Lower Magnesian Limestone), the main modes of slope failure are by rockfall, slab displacement or undercutting of steep faces. All these types of failure have been noted to occur on the exposed sandstone rock faces in Nottingham; Figure 20 shows the problem in diagrammatic form. Potential causes of failure are generally related to major planar structures such as joints, faults, bedding planes and cross-bedding. The best-documented failure occurred in January 1969 when a slab weighing about 18 tons fell from beneath Castle Rock. Remedial work required the construction of concrete buttresses and rock bolting. Wedging by tree roots, widening of joints by flowing water or undercutting by erosion are the main causes of such failure. Erosion of sandstone faces by granular disintegration is presently taking place so that the undercutting of faces and overlying walls can presents a considerable hazard and these should be kept under observation (Figure 20b).

Vertical faces in the dolomites of the Cadeby Formation occur in cuttings and former quarries in the north-west (Back Cover). No evidence of instability has been recorded, but the types of failure noted in the Sherwood Sandstones are a potential problem in newly cut excavations. The outcrop area has been extensively undermined (Figure 24) so that joints and faults may have been widened locally due to subsidence, leading to increased risk of instability. Acid rain attack on free faces may also lead to widening of joints and undercutting due to solution.

Gypsum solution

Due to its solubility in freely flowing groundwater, extensive dissolution of gypsum has taken place within the Mercia Mudstone in a zone (the so-called solution zone) several metres thick below the base of the subsoil or superficial deposits (Elliott, 1961). Much of the solution seems to have been accomplished by groundwater flow along bedding planes, joints and fissures (Firman and Dickson, 1968). Although most of the solution of gypsum is believed to have taken place during glacial or periglacial conditions, the process may be continuing, albeit much more slowly, today (Firman and Dickson, 1968). In borehole cores retrieved from below the base of the solution zone, gypsum veins and nodules may constitute over 30 per cent of the total thickness in parts of the sequence. However, almost no gypsum is exposed at crop in the Nottingham area, except in areas where the rate of erosion exceeds the rate of solution, for example on river cliffs or in man-made excavations (Firman and Dickson, 1968).

The depth of the solution zone is mainly controlled by groundwater circulation conditions. Normally, the zone is only a few metres thick. However, in the vicinity of faults and heavily jointed areas, the depth of the solution zone may be as much as 30m (Elliott, 1961). In areas where the solution zone is deep, lowering of the land surface will be greater due to the removal of a greater volume of gypsum from the sub-surface. Solution depressions created by this process have been mapped in several parts of the Nottingham area, principally on the crop of the Cropwell Bishop Formation (Fig. 15 : Map 6). Irregular, often closed depressions, not explainable by normal patterns of surface erosion, are common on the crop of this formation; these are particularly well developed in the area between Plumtree and Bradmore and north-west of Gotham Hill.

In the Ripon area, North Yorkshire, solution of Permian gypsum has proved a major subsidence problem (Cooper, 1986, 1988). No similar examples are known in the Nottingham area; however, this may be due to the paucity of urban development on the outcrop of the Cropwell Bishop Formation, the principal gypsiferous level of the Mercia Mudstone.

There are four possible circumstances in which gypsum solution may produce a geotechnical hazard in this area:

Table 15. Categories of slopes (after Demek 1972, Young 1972, Crofts 1973, and Small and Clark 1982).

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

a) Collapse of underground solution voids

This factor is the principal cause of subsidence in the Ripon area (Cooper, 1986) where groundwater solution along joints in thick beds of gypsum produces large underground caves; these subsequently collapse, causing foundering of overlying strata. This mechanism is much less likely to occur in the Nottingham area for two main reasons. Firstly, groundwater flow within the gypsum beds and adjacent strata in the Cropwell Bishop Formation seems to be considerably less than in the Permian of the Ripon area, considerably limiting the rate of solution taking place at present. Secondly, although gypsum makes up a fairly large proportion of the Cropwell Bishop Formation by thickness, most of it is disseminated as thin veins or small nodules, limiting the potential size of cavities. Only in the thick Tutbury and Newark Gypsum could significant cavities form; a cavity occupying the full thickness of the Tutbury Gypsum could, in theory, have a maximum height of 4m. However, in view of the probable very slow rate of gypsum solution, it is unlikely that such a large cavity could develop under natural groundwater-flow conditions. Furthermore, there is little field evidence of subsidence hollows produced by sudden collapse of any such cavities on the crop of the Cropwell Bishop Formation: those subsidence depressions that are present reflect fluctuations in the depth of the gypsum solution zone and were probably formed by gradual lowering of the land surface. It is possible, however, that some steep-sided hollows near Bradmore were formed by sudden collapse.

b) Collapse of former gypsum mine workings

Former underground mining of gypsum has taken place in the East Bridgford, Cropwell Bishop and Gotham areas (see p.34). Extraction of gypsum was by bell-pitting or pillar-and-stall methods, and, as there is little surface evidence for collapse of the workings, voids can be assumed to be present. Since most are below the water table and groundwater flow is probable, solution of the remaining pillars or of disseminated gypsum in the walls or roof of workings may lead to collapse in places, with dramatic surface subsidence effects. Subsidence of this type has occurred at Chellaston in Derbyshire in an area overlying underground workings in the Tutbury Gypsum.

c) Slow solution of gypsum

Slow solution of gypsum below a structure could cause uneven settlement resulting in damage.

d) Unconsolidated "pocket" sediments

Unconsolidated sediments deposited within natural solution depressions ("pocket" deposits) may be highly compressible and could cause excessive, and possibly uneven, settlement leading to damage.

Gypsum occurs throughout the Mercia Mudstones but the potential risk due to solution is small for all but the Cropwell Bishop Formation. An exception is the East Bridgford area when satinspar gypsum was mined from the Gunthorpe and Edwalton formations. There is a risk here from collapse of old workings (see Map 6) due to solution.

Earthquakes

Earthquakes present a considerable hazard to development in certain parts of the world. In a country of low seismicity, such as Britain, much historical research is required to assess seismic risk. Earthquakes whose effects were felt around Nottingham are listed in Table 16.

A simple guide to the degree of disturbance for each intensity of the MSK scale is as follows (after Burton, Musson and Neilson, 1984):

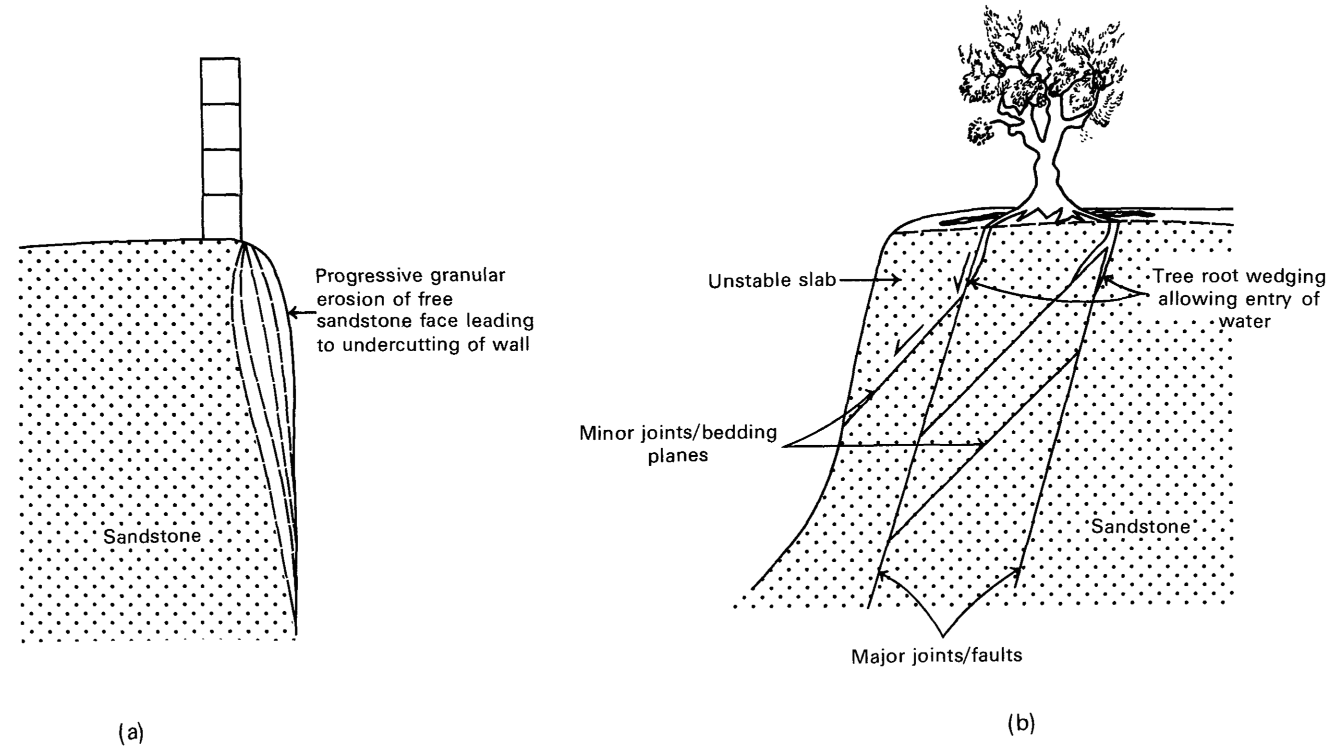


Figure 20. Diagrams showing types and causes of problems in sandstone rock faces in Nottingham

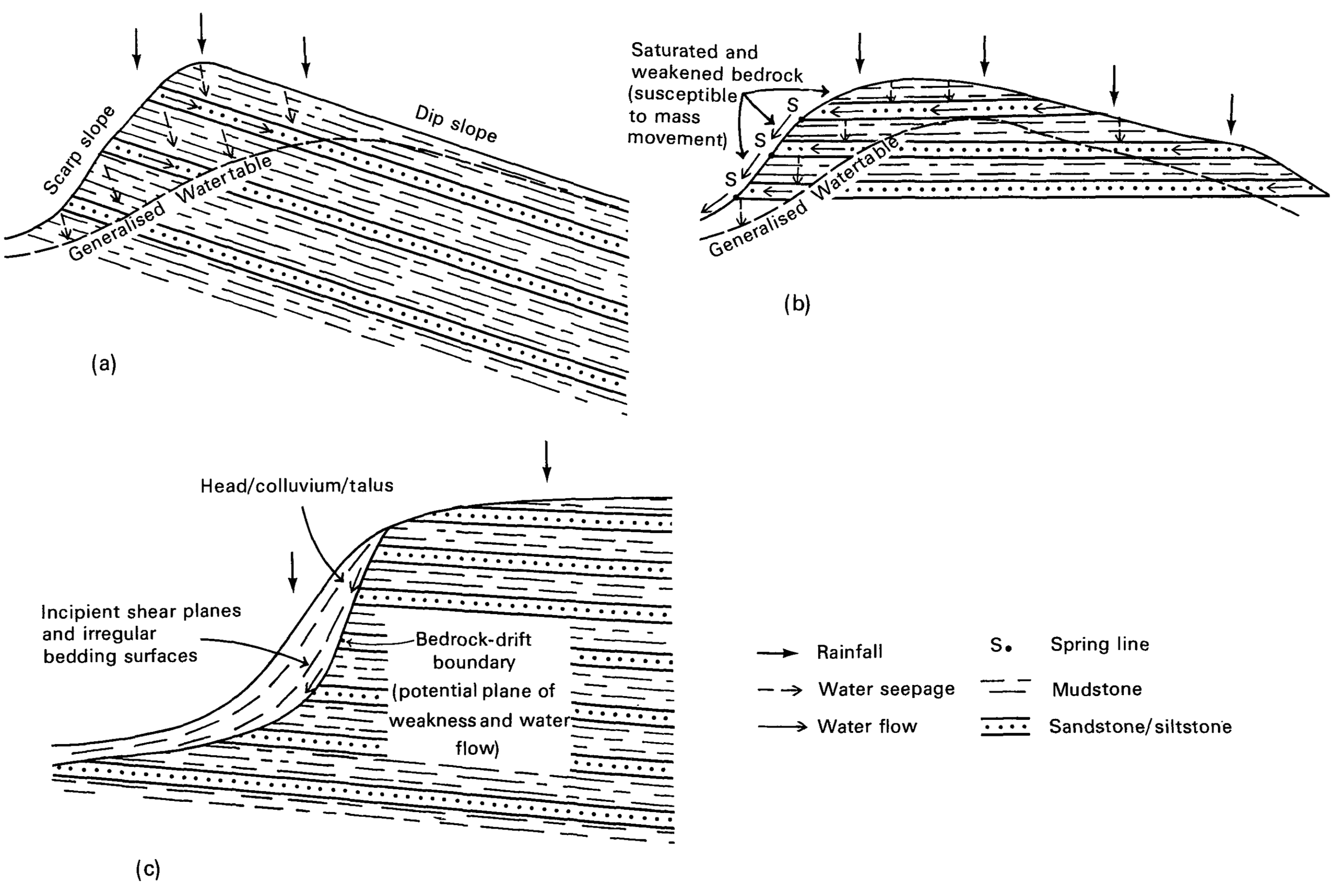


Figure 21. Diagrams showing the relationship between bedrock structure and groundwater flow in common situations in the Nottingham district

1	Not noticeable
2	Scarcely noticeable (very slight)
3	Weak
4	Largely observed
5	Effects noticed widely (strong)
6	Slight damage
7	Damage to buildings
8	Destruction of buildings
9-12	Widespread devastation

The main seismic risk in the area is a repeat of the intensity 6-7 earthquake of the 11th February 1957. During this earthquake the worst damage consisted of movement and cracks in the masonry of a dam near Loughborough, chimney stack collapses and falls, cracks in roofs and ceilings, tiles falling from roofs, cracked walls and broken windows. No burst water or gas mains were reported.

A slightly lesser effect was produced by the earthquake of 30th May 1984, which had an instrumental epicentre close to County Hall, West Bridgford and was of magnitude 3.1 on the Richter Scale. Its maximum felt effect, measured in terms of intensity, was 5 MSK in the area between Loughborough and Leicester, with an intensity 3-4 in the Nottingham-Hucknall area.

Movement on major faults at depth is believed to be the cause of earthquakes. The 1984 West Bridgford earthquake had its focus at a depth of 15 km which implies movement within the pre-Carboniferous basement. The 1984 Bulwell earthquake, however, had a focus at only 6.5 km, which means it was probably caused by movement on the Cinderhill Fault or a closely related fracture. Since the Nottingham area is crossed by several major faults extending into the pre-Carboniferous basement, further seismicity is to be expected.

Detailed analysis of local seimic risk to major constructions can be obtained from the BGS Global Seismology Unit.

Radon

It has long been known that radon, a naturally occurring radioactive gas, resulting mainly from the decay of uranium, may be the cause of a high incidence of lung cancer amongst miners in various parts of the world (Eisenbud, 1987). The National Radiological Protection Board (NRPB) have established that the population may be exposed to relatively high levels of radon within certain buildings; estimates suggest that radon exposure may be responsible for up to 6 percent of lung cancer cases in Britain (Clarke and Southwood, 1989; Hughes and others, 1988).

The radon originates from geological materials, soil and groundwater with only a minor contribution from building materials; thus the problem is mainly confined to buildings of up to two-storeys. NRPB monitoring has shown enhanced radon levels may occur in areas outside the predictably high levels recorded in granitic regions or those where uranium mineralisation is found. During a countrywide survey a single high value was recorded in Nottingham. Much additional research is required to pinpoint the geological reasons for these higher than average radon levels. The need for further action should be assessed when the original measurement has been fully explained. The situation should, however, be kept under review.

Groundwater

Contributed by E Parry of the National Rivers Authority and R A Monkhouse.

Groundwater presents a constraint to land use in the Nottingham area in two ways. Firstly, by placing restrictions on developments which might cause pollution to the Sherwood Sandstone or the other minor aquifers, and, secondly, in the form of rising groundwater levels beneath parts of the city, which may cause problems for building foundations.

There are five public water supply boreholes in the study area (Figure 18), all drawing water from the Sherwood Sandstones (see also p.39). It is the responsibility of the National Rivers Authority (NRA) to ensure that existing and potential groundwater resources are adequately protected. The risk of pollution is increasing both from the disposal of waste materials and from the widespread use of potentially polluting chemicals by industry and agriculture. Groundwater vulnerability to nitrate pollution has been the subject of a special study for the Mansfield -north Nottingham area (Palmer, 1987).

The NRA has a detailed aquifer protection policy which enables it to meet its statutory responsibilities for the protection of groundwater from pollution. Further specific details on the various aspects of the policy are available from the NRA. The policy recognises different categories (called zones) of land which require different degrees of protection, depending on the proximity to a public supply borehole and the hydrogeological parameters of the rock. Zone 1 is that area on the Sherwood Sandstones outcrop within 1 km radius of existing or designated future groundwater sources for public supply; in this zone the Authority will usually object in principle to all development proposals which would result in pollution of a groundwater source. Zone 2 comprises the areas of outcropping sandstone excluding those in Zone 1. The areas comprising Zone 2 will also receive a high degree of protection, but the controls are not as stringent as those for Zone 1. Activities to which an objection would normally be made include:

a) Waste disposal sites intended to receive substances hazardous to water supplies.

b) Major industrial developments which involve the use, protection, storage, or handling of toxic materials, unless adequate protective measures are agreed.

c) The disposal of sewage effluents by aquifer recharge.

All of the Limestone outcrop area is classified as being in Zone 2 of the Aquifer Protection Policy. The aquifer tends to be vulnerable to surface pollution whereby fissures allow rapid transmission of water down to the water table.

Zone 3 comprises the minor aquifers; these aquifers occasionally yield locally important small quantities of water but have no potential to be developed to yield major additional supplies. Controls are not as stringent as in Zones 1 and 2 and each development proposal is considered in the light of proximity to existing licensed and unlicensed sources; in all cases the Authority will endeavour to agree precautions and protective measures to minimise the risk of contamination to the groundwater resource. The Coal Measures fall within Zone 3 of the Aquifer Protection Policy.

The decline in groundwater abstraction within the built-up areas has led to a rise in groundwater levels as illustrated by the hydrographs for Shipstones Brewery and York House (Figures 22 and 23). In some parts of the city this has led to an ingress of water to some of the deeper basements and caves. The effect of this on stability and safety has already been referred to (p.61). A short term solution of direct pumping has been adopted where the problem is at its worst, but should levels continue to rise generally then some remedial dewatering boreholes may have to be commissioned.

Human activities affecting ground conditions

Modification of the land surface and subsurface by human activities takes two forms. Firstly, excavation and removal of material leaving voids or pits, as in mining and quarrying, and, secondly, addition of material as fill either into former excavations or purely as constructed landfill. Many constraints are placed on development by these changes, and particular care must be exercised by developers in the Nottingham area since many of these activities started before written records were kept. Shallow coal mining especially has left a legacy of potential hazard in the form of very poorly documented bell pits and shafts. In addition, man-made caves pose an ever-present problem for development in the parts of the city underlain by sandstone bedrock.

The following sections review the constraints imposed by former land use and mining.

Coal Mining

Coal has been mined west of Nottingham since at least the Middle Ages and probably considerably earlier. Much of the wealth of the Willoughby family, who constructed Wollaton Hall in the 16th century, and other Nottingham landowners was founded on coal mining in the area of exposed and shallowly concealed coalfield west of the Hall. This long history has left a legacy of shafts, adits, shallow workings and backfilled opencast pits which present problems for land use.

The earliest workings were from the coal crop itself or from bell pits. Later, deeper seams were extracted by the pillar-and-stall method with 40-50 percent extraction. Panel working, introduced in the 18th century, gave way to longwall mining which considerably increased the recovery ratio and which is still used today. These methods of coal mining and the problems they pose for land use are listed in Table 17.

Possibly the most serious problem presented by former workings is the general lack of knowledge of their number, location, extent and depth. Prior to the late 19th century few mines were documented, and those plans which exist are likely to be inaccurate in detail. Although, following the 1872 Coal Mines Regulation Act, accurate plans were lodged with the Mines Inspectorate, these only showed the extent of mining and did not record levels or geological information. Similarly, the position of many of the associated shafts, adits and bell pits are unknown or poorly recorded, and these may remain open below a surface capping.

The sites of known or suspected shafts and adits are shown in detail on Maps 8A and B; **other shafts or adits may exist**. These have been taken from BGS and British Coal records and include a large number which have been located only by studies of air photographs without ground survey. **Responsibility for locating shafts at or close to these sites rests on the site owner or developer**. The boundary of the area of non-colliery based mining is generalized and approximate. It is important to remember that unrecorded former workings may occur at shallow depths in any area where a coal thick enough to have been considered workable lies near the surface. The sites of opencast pits are taken from British Coal records; in considering particular sites original documents must be consulted.

A large part of the area surrounding the inner city has been under mined from collieries (Figure 24 : Map 7), and commonly more than one seam has been extracted beneath a given site. Records of this activity for the period since 1872 are lodged with the Nottinghamshire Area Mines Record Office (see Annex 3). The worked coals for which records exist are given below (Table 18).

Subsidence is assumed to have almost totally ceased from all but the most recent workings of the Gedling and Cotgrave collieries. The present general direction of workings from these collieries is shown in Figure 15.

Surface subsidence is mainly a function of the thickness of the extracted seam and the depth to the workings. In general, the greater the depth of the workings the wider the effects of differential subsidence are spread at the surface and the lesser is the damage to property. Other factors affecting subsidence include dip of the seam, method of waste stowage and the nature and structure of overlying strata. Subsidence starts within hours of extraction, but its full effects are transmitted upwards more slowly. It may be more than 10 years before the surface is completely stable (McLean and Gribble, 1985). Even then collapse of formerly supported sections such as some roadways may still take place. Dramatic differential subsidence may occur when a fault plane is reactivated by subsidence, especially when coal has been extracted to one side of a fault only. Such subsidence tends to be most intense when workings approach the fault on the upthrow side. **These effects should be carefully considered when planning sites which straddle faults**. Generally, faults are not single planes, but consist of a series of sub-parallel fractures forming a complex fault zone which may be tens of metres wide (see also p.21). During mining from Clifton Colliery in the 1950s, some houses in West Bridgford suffered severe structural damage associated with differential subsidence along major fault planes viz. in the area between Melton, Boundary and Ellesmere roads. The effect of subsidence on surface structures with reference to geological factors has been the subject of a detailed study in the area north west of the city (Breeds, 1976).

Following the abandonment of workings, dangerous gases such as methane and carbon monoxide may accumulate in any voids remaining after subsidence. Escape of these gases along faults and from shafts is a remote but real possibility, even from deep mines.

Table 16. Main earthquakes (after1750) affecting the Nottingham area (after Neilson, Musson and Burton 1984, Marrow 1984).

Date	Macroseismic epicentre	Maximum intensity in area MSK scale	Location where felt in Nottingham area
23.8.1750	?Off coast of Lincolnshire	3-4	Nottingham
30.9.1750	Uppingham	?3-4	Notingham
1795	Derby	?	?
17.3.1816	Mansfield area	5-6	Bingham, Carlton, Nottingham
4.8.1893	A few km NW of Leicester	?3-4	Cropwell Bishop
24.3.1903	A few km NE of Ashbourne	4-5	Bingham, Bulwell, East Bridgford, Hucknall, Nottingham
3.7.1904	SW of the Peak District	3-4	Nottingham and district
27.8.1906	Matlock Bath area	4	Nottingham and district
14.1.1916	Chebsey district	?3-4	Nottingham and district
3.3.1924	Sutton-in-Ashfield	3	Hucknall
6.3.1924	Kirkby-in-Ashfield	5	Gedling, Hucknall, Mapperley, Nottingham
4.4.1924	South Normanton	4	Nottingham
20.4.1924	South Normanton	5-6	Hucknall
10.1.1956	Area NW of Leicester (?Charnwood Forest)	?5	Bramcote, Nottingham
11.2.1957	Castle Donington - Blackbrook area	6-7	Beeston, Bramcote Hills, Hucknall, Nottingham, West Bridgford
12.2.1957	?Derby area	5	Arnold, Bingham, Clifton, Epperstone, Hucknall, Nottingham, Radcliffe on Trent, West Bridgford
2.6.1981	North of Arnold [58 48]	3+ (Magnitude 2.7)	Nottingham
16.3.1983	Gunthorpe [688 441]	2+ (Magnitude 1.7)	Woodborough
22.3.1984	East Retford	? (Magnitude 3.2)	Arnold
30.5.1984	County Hall, West Bridgford [58197 38008] (Depth 15 km)	4-5 (Magnitude 3.1)	Nottingham and district
23.8.1984	Bulwell [535 451]	(Magnitude 2.2)	

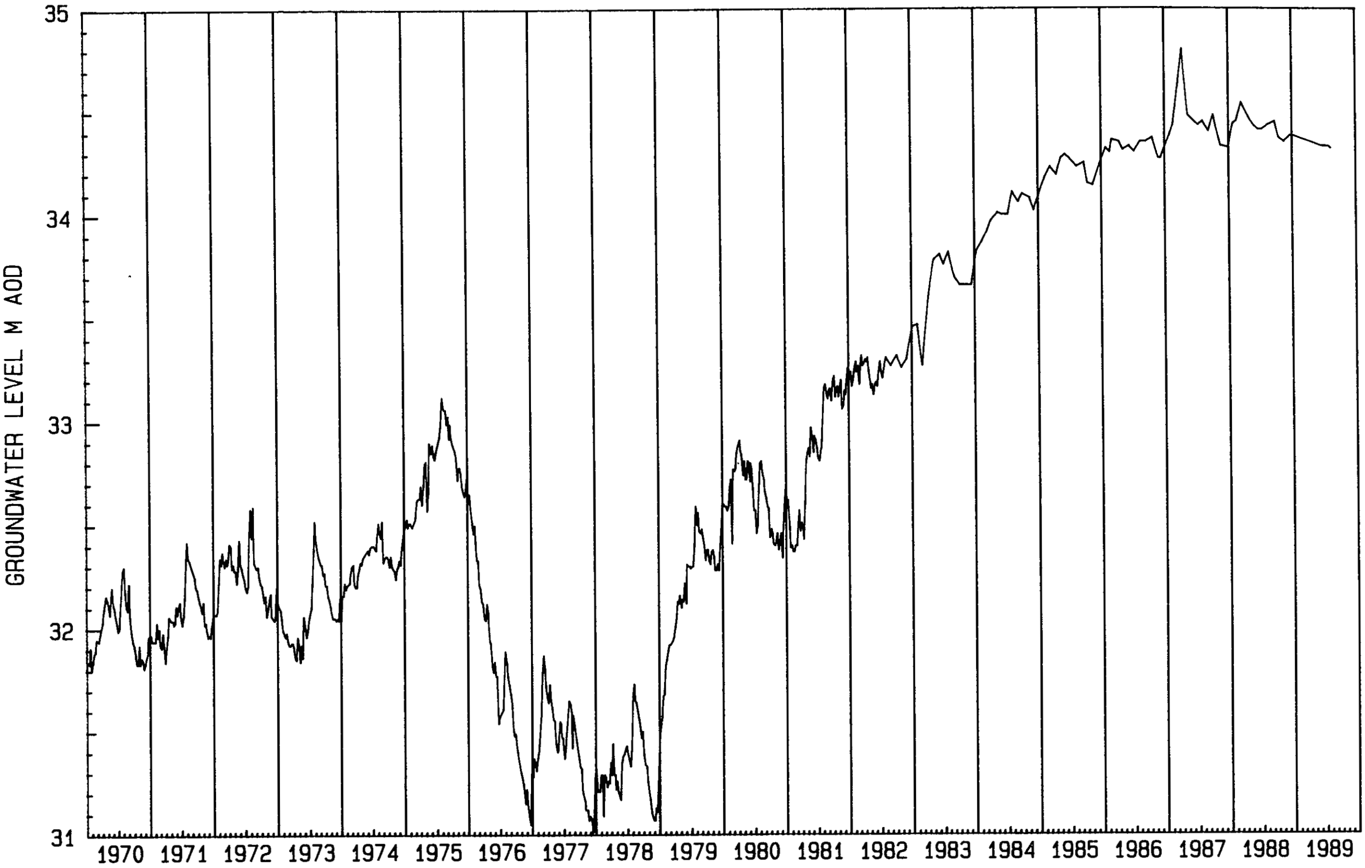


Figure 22. Well hydrograph for Shipstone's Brewery [SK 5568 4208]
(Reproduced by permission of Severn-Trent Water Authority)

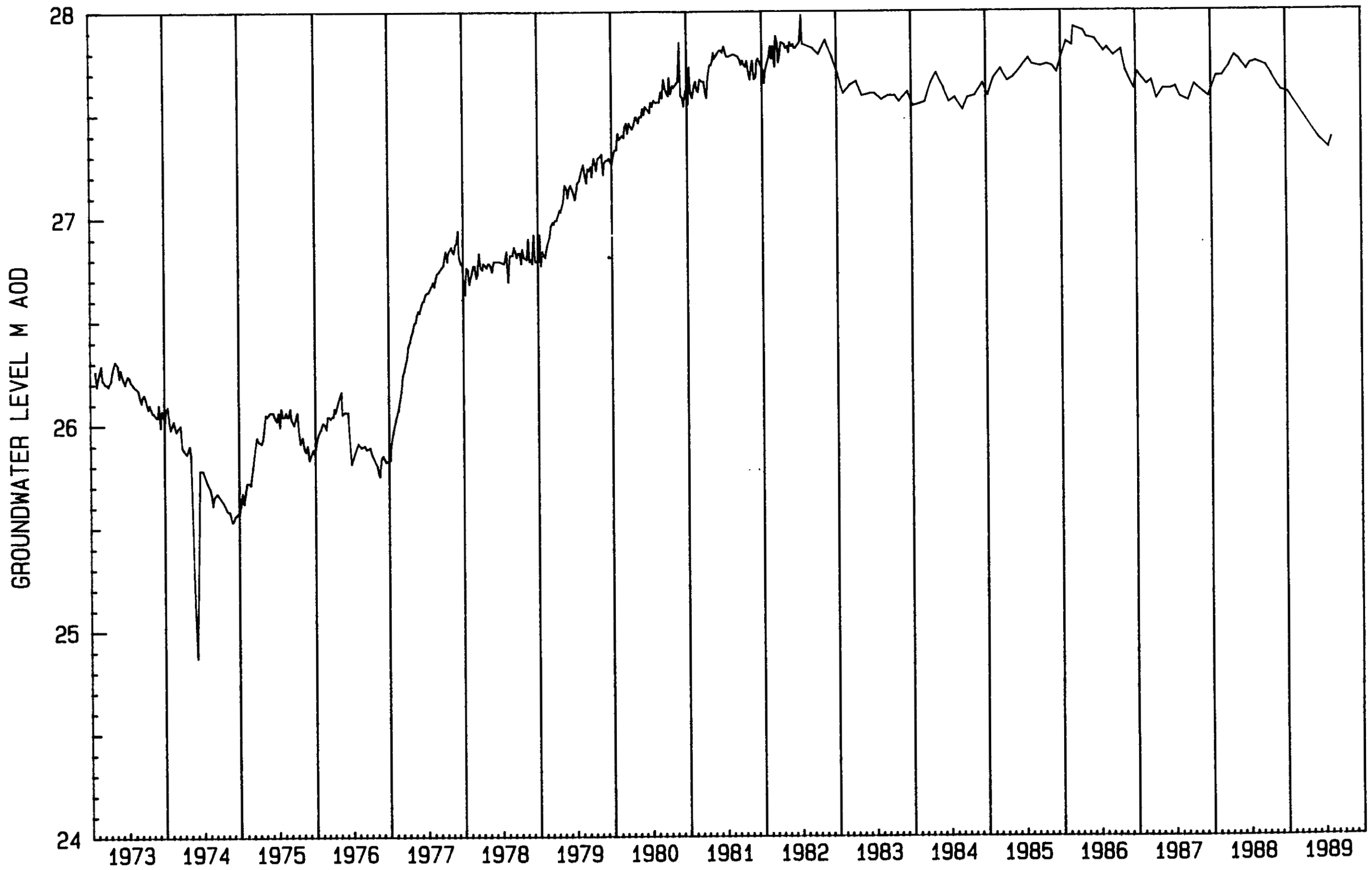


Figure 23. Well hydrograph for York House [SK 5730 4040]
(Reproduced by permission of Severn-Trent Water Authority)

Coal mining produces large quantities of spoil, and although some is sold as mine stone for fill (p.38), the bulk of it remains in waste tips. All the major producing collieries of the last fifty years have nearby tips (Figure 13 : Maps 4A-D). Given the large areas that the tips cover they present both an opportunity and a constraint for development. Some have been converted to amenity areas, providing green fields in the midst of areas of dense housing e.g. Broxtowe [525 430], some are used for agriculture e.g. Hucknall [530 477], while uses are being sought for others e.g. Babbington (Cinderhill) [533 441] (Back Cover). The tips are mainly steep-sided and composed of compacted shale, mudstone, siltstone and sandstone; internal drainage is poor. Combustion of contained fragmentary coal can take place leading to heat generation and subsidence. For these reasons the tips are considered unsuitable sites for building and their potential instability may place a constraint on the use of the surrounding land for construction, unless extensive and costly engineering works are undertaken.

Underground gypsum mining

Former mining and resources of gypsum have already been reviewed (p.34). Underground mining has taken place at East Bridgford, Cropwell Bishop and on Gotham and Thrumpton hills. As with coal, a continued risk of subsidence is associated with areas of former shallow gypsum mining. A cautious approach to development of such areas is required.

Little is known of the extent of mining at East Bridgford, but the sites of six former shafts have been located (Map 6); others almost certainly exist. Satinspar gypsum was mined here for plaster and small ornaments. It occurs as narrow impersistent veins, lying parallel to or cross-cutting the bedding. As in other types of vein mining, it is probable that mining followed the better veins rather than adopting a more uniform pattern of extraction such as the pillar-and-stall method. Voids left by mining may thus be highly irregular in shape and be near the surface locally. The depth of the workings is not generally known; however, at one site [6947 4323] the Primary County Series Geological Map records, "Satinspar mine 25 feet to gypsum bed which is 9 inches thick, fibrous and remarkably bright and pure", and this may be typical. The risk of collapse of unlocated or incompletely backfilled shafts or of subsidence into old workings may be high. **Further development should be conditional on site investigations establishing the extent of former workings and whether voids are present**. Where development

Table 17. Summary of types and methods of coal mining and associated problems for land use

Type of mining (Period used)	Area	Method	Problems for Land Use
Crop working (Middle Ages and earlier)	Exposed coalfield	Direct working of coal at surface	1. Very shallow workings 2. Line of subsidence along crop
Bell pits (Middle Ages)	Wollaton, Trowell, Strelley	Shaft c. 1.25 m diameter, up to 12 m deep; radial working to 10 m from shaft	1. Risk of voids remains 2. Shaft sites poorly known 3. Shaft infilling variable and doubtfully compacted
Pillar and stall (From 15th to 17th century)	Wollaton, Trowell, Strelley, Nuthall	Coal cut along grid of roads with rectangular pillars left for support	1. Up to 60% coal may be left, so site investigation may not detect workings 2. Overlying beds of high strength (such as Magnesian Limestone) may have resisted collapse, leaving large voids 3. Collapse of pillars may result in cavities and breccia pipes in rock above 4. Shaft sites poorly known 5. Shafts variably backfilled and doubtfully compacted
Panel working and longwall mining (From 18th century)	Progressively deeper workings from collieries on, and later to east of, exposed coalfield. Present working in east only	Coal extracted along continuous coalface (up to 200 m wide). Temporary support of roof then collapse of all except lateral roadways	1. Collapse of face underground produces subsidence and lowering of ground surface. Effects usually immediate and assumed to be over within a few years 2. Differential subsidence along faults as surface can lead to severe damage 3. Variable backfilling and capping procedures applied to shafts
Opencast mining (From 1940s)	Wollaton, Strelley	Excavation of pit, extraction of coals, backfill with spoil, restoration of site	1. Compaction may be incomplete locally on earlier sites 2. Differential settlement possible along sides of former workings 3. Natural drainage altered

already exists on such areas special note should be taken of any evidence of structural distress in properties.

The undermined area at Cropwell Bishop can be relatively well-defined using mine abandonment plans (see Map 6); however, there is a possibility of extension of workings to the north of those documented. Extraction of gypsum was probably from several levels within the Newark Gypsum (p.35) by a combination of mining out from the base of a shaft (similar to bell-pitting) and the pillar-and-stall method. Risk of subsidence in the undermined area or where shafts occur is high. Even where support from pillars appears sound, long-term solution of gypsum in the pillars or wall rocks may induce collapse (p.52). There is also the often-encountered problem that site investigation boreholes may penetrate pillars leading to an underestimation of the extent of former workings.

Extensive underground mining has taken place from a series of adits and shafts around Gotham Hill and towards Thrumpton; shallow crop workings are also common in this area. Mining was finally abandoned in 1969 with the closure of the Weldon Mine where gypsum had been extracted using a rectangular grid of pillar-and-stall workings. Prior to the development of the latter mine, extraction had been more dependent on the search for large nodular masses of gypsum than on a more planned approach. The earlier workings thus mainly comprise a series of randomly oriented tunnels and chambers. There is little surface evidence for the collapse of former workings except where adits run close beneath the ground surface. Major voids thus exist in this area, any of which has the potential to collapse either due to loading from above or removal of support by solution or other failure below. Records of the earlier mining are very poor and only the abandonment plan for the Weldon Mine is in the public domain. Other (incomplete) records are held in confidence by British Gypsum p.l.c.

In view of the potential for subsidence, all development around Cropwell Bishop and in the Gotham Hill-Thrumpton areas requires very careful geological and geotechnical investigations.

Quarries and pits

Constraints to development from former excavations are related to:

(a) geotechnical problems of variable ground conditions, including drainage, between the natural surface and the fill,

(b) the risk of failure of the artificially steep slopes created by the excavation

(c) the properties and nature of the backfilled material (p.44) and any risks associated with the migration of gases, including potentially explosive methane, or leachates from the fill into the surrounding geological deposit.

Knowledge of the presence and type of former excavations can resolve most problems for development at the planning stage.

Until well into the present century, the surface extraction of minerals in the area was almost entirely from a number of small operations; this pattern has changed so that present workings for sand and gravel, brick clay and gypsum are centred on a few large scale excavations. Former quarries, pits and artificially dug ponds are present throughout the area (Maps 4A-D and 6); many have been backfilled, others are partially filled and degraded, some are flooded while a few remain in their quarried state with steep backwalls and limited fill in their bases. Former quarries, pits and ponds have been sited using BGS archives and old editions of Ordnance Survey maps; **other excavations certainly exist.** The boundaries of those delineated are based on the best information available and are likely to be imprecise in detail. **In areas where former workings are known or where a resource exists, site investigations should allow for the possible presence of backfilled excavations.** Table 19 summarises the types of former excavation, their distribution and present state, and the problems they may pose to development.

The increasing use of quarries and pits for waste disposal has produced a widely developed, but localised, hazard from toxic leachates and dangerous gases. Liquid toxic residues, either as a primary component of fill or generated secondarily by chemical or biological reactions can migrate both within the deposit or into adjacent permeable strata. This is potentially a serious hazard at landfill sites situated on deposits in hydraulic continuity either with the Sherwood Sandstone aquifer or, in the case of gravels, with the River Trent or its tributaries. Toxic and explosive gases, particularly methane, can be generated within waste tips and landfill sites. Such gases can migrate, sometimes through adjacent porous strata or

Table 18. Colliery-worked coals in the Nottingham area

Middle Coal Measures	High Main Main Bright Low Bright *High Hazles Cinderhill Coombe Top Hard 1st Waterloo 2nd Waterloo	Lower Coal Measures	Deep Soft *Deep Hard Piper Tupton (Low Main) Threequarters Yard *Blackshale Kilburn

* Seams worked at present

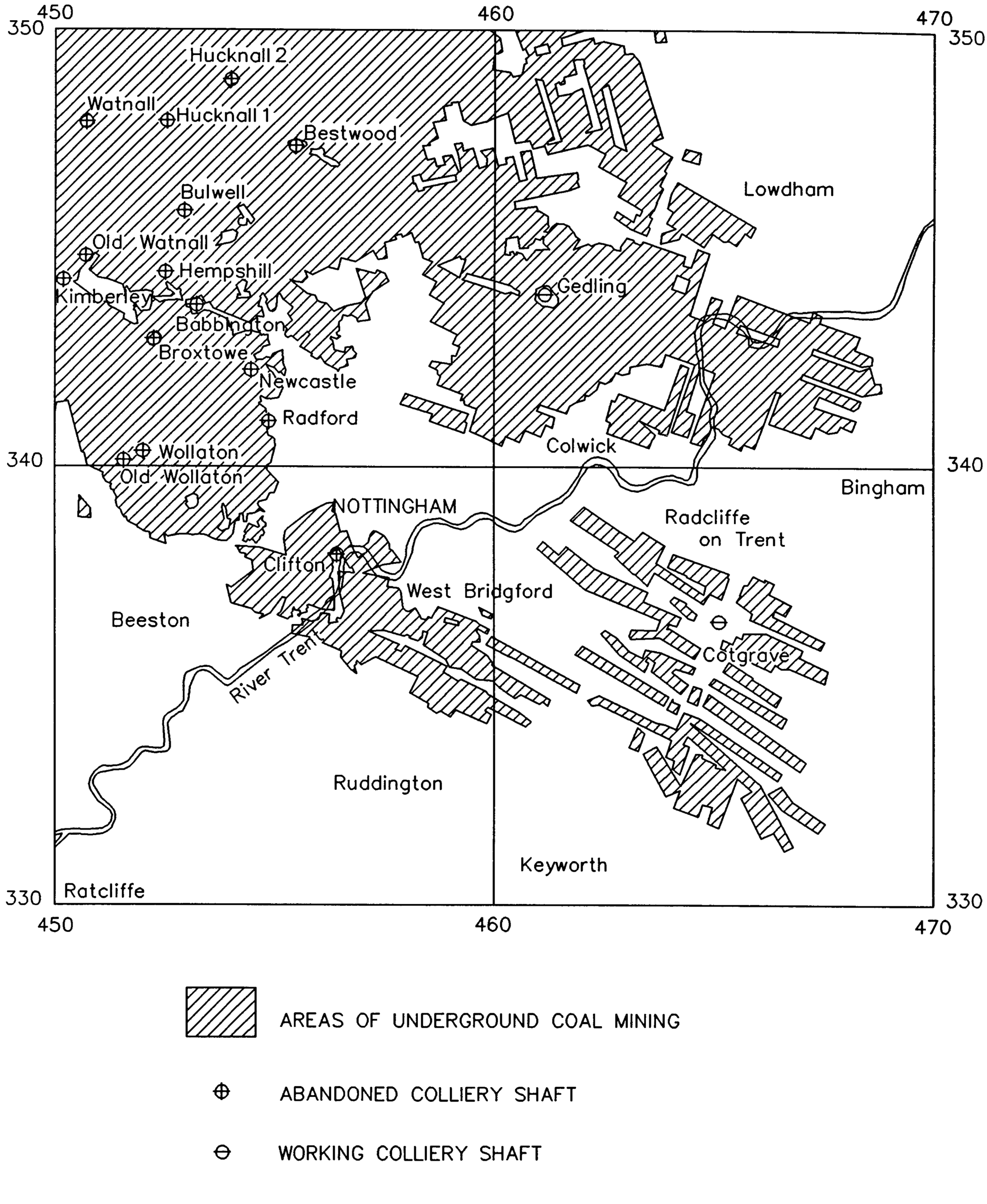


Figure 24. Map showing the distribution of colliery-based underground coal mining

along fissures, and accumulate within buildings or excavations either nearby or some distance away, as occurred at Loscoe in Derbyshire in 1986 when an explosion resulted (Aitkenhead and Williams, 1987).

Constructional landfill

Where fill is placed onto an original ground surface an artificial landform is created. The most obtrusive form is the colliery spoil tip; the problems posed by these tips have been discussed (p.55). Elsewhere road, rail, canal and flood protection embankments are present throughout the area (Maps 4A-D), and may form distinctive landforms. Less obvious are major spreads of fill such as those in the Dunkirk-Lenton Lane area [55 37] and south of Wilford Road [57 36]. These latter have significantly altered the local landscape by forming artificial terraces several metres above the floodplain of the River Trent. Landscaping schemes have also produced artificial mounds and terraces of fill in places and involved excavation of bedrock in others. The levelling of playing fields or amenity areas is ubiquitous.

Constraints to development occur where the fill is composed of materials of low strength or high compressibility (p.45) or of organic wastes, which may generate methane, other noxious gases, or toxic residues (see also p.45). Additional problems exist where artificially steep slopes have been created as on some embankments and the edges of major constructional landfill sites. Poorly managed groundwater flow can produce catastrophic failure of poorly compacted embankments, spoil heaps and other steep-sided landforms. Consideration must also be given to the nature of the former underlying surface. Both the Dunkirk-Lenton Lane areas were low-lying and prone to flooding prior to tipping; marshy conditions and ponds were common. Settlement of peat, organic soils and alluvial clays beneath the cover of fill and generation of methane from decaying organic material are probable in these areas.

Caves

The sandstone beneath most of central Nottingham would provide sound reliable foundations almost everywhere were it not for the presence of man-made caves. An additional study was commissioned by the Department of the Environment to collect all obtainable information into a register. This is available as a source of reference to more than 400 caves or cave systems for planners, building control officers, engineers, developers and members of the public (Owen and Walsby, 1989). Caves considered as a resource rather than a constraint are reviewed elsewhere (p.42).

The distribution of caves (Figure 25 : Map 11) reflects closely the outcrop of the 'Nottingham Castle Sandstone Formation' (Figure 6 : Map 2), although they are not confined to that formation. The sandstone can be easily carved or excavated, yet stands in vertical cuts and is strong when compressed or loaded. It is soft and friable, and component grains can be scraped away with a penknife. Weathering may weaken what little intergranular cement there is, and can cause grain by grain erosion of a free face, while jointing may initiate instability in steep faces (see also p.49).

The first caves were almost certainly cut into the bluffs and cliffs facing the River Trent, as human shelters and byres. From about the 13th century the Broadmarsh or Drury Hill cave system was developed, where in the 16th century a tanning works existed with access to the Trent floodplain. Later developments were mainly of caves excavated directly downwards into the Sandstone for storage, waste disposal or as cellars for houses, particularly beneath public houses as beer or wine cellars. The Victorians, especially during the development of the Park area in the mid 19th century (Back Cover), dug many caves as decorative follies, with intricate and fine carvings of biblical and mythical figures. Many of the caves were modified or extended during the Second World War when they were used as air raid shelters.

The long history of excavation and the large number of caves now recorded point to the presence of unrecorded sites, particularly in the central parts of the City and certain outlying areas such as Arnold. Scanning of the cave plans in the register (at a scale of 1:2500) serves the dual purpose of showing the distribution of known caves and of indicating the gaps between groups of caves where others may be found.

Although collapse of roads into caves has occurred occasionally, there is no record of building subsidence. Modern building construction in the City has invariably allowed for the presence of caves; some have been filled, others left as a feature. However, given the known extent of cave networks and the lack of a complete record of caves, the possibility of localised subsidence is always present.

All site investigations in areas underlain by Triassic sandstone, particularly the Nottingham Castle Sandstone, should be carried out **assuming that caves will be present.** The aim of the investigation will then be to prove the absence of caves by a programme of borehole drilling, trial pitting and trenching and geophysical methods such as ground probing radar. Ideally, **site investigations should not be conducted until existing buildings are demolished and the site has been cleared to the former basement level.** Accurate evaluation of the often intricate patterns of cellars, passages and deeper levels of caves can then be made, and new buildings designed accordingly.

The engineering solutions most commonly adopted for foundations where caves are present are:

(a) infilling of the cavities by concrete

(b) total excavation to the lowest cave floor level and incorporating deep basements in the design.

Alternative approaches which may be possible locally and are likely to be less costly are to use pad and stem foundations founded on the floors of caves or to straddle the caves with a thick concrete raft. Both these methods have the added advantage that the caves are preserved for present use or for future research.

Recent rises in the watertable beneath the City (see p.54) have resulted in the flooding of some caves retained as basements, threatening the stability and safety of premises above. Free standing water will have a deleterious effect on pillars and walls, and may cause undermining of foundations. In places where the rock surrounding a cave is loadbearing, pumping to reduce water levels, as carried out in the Broadmarsh system, is recommended. The effect of groundwater flow beneath cave systems at different levels may also reduce the strength of the sandstone by removing natural cementing materials. Changes to the ventilation of caves as water levels rise could lead to accumulations of stale air and harmful gases or the expulsion of such gases into adjacent caves or buildings. The underground water regime beneath the lower lying parts of the city needs to be carefully monitored.

Table 19. Types of former quarries and pits in the Nottingham area and the special problems they present to development

Mineral	Geographical distribution	Type of working	Present State	Special Problems for development
Coal	Wollaton Trowell Strelley	Opencast pit	Complete backfill	Differential settlement. Drainage problems
Sand and Gravel	Trent Valley	Shallow gravel pits (most below watertable)	Most flooded, some partially or completely backfilled	Limited potential use, other than recreational, due to high watertable. Drainage problems where backfilled. Risk of migration of leachate
Sand	Bramcote Basford Bestwood	Small to large quarries above watertable	Partial or complete backfill	Waste disposal poses pollution risk to underlying Sherwood Sandstone aquifer. Porous rock surrounds quarry (risk of gas or leachate migration)
Brick Clay	Wide distribution except in south east	Cut into hillslopes. Larger pits deep	Limited backfill of many larger pits. Small pits partial to complete backfill	Slope failure of steep backwall or talus on side slopes. Drainage problem of clay fill in base and sides
Marl	East and south	Shallow cuts on hillslopes	Mostly degraded and partially backfilled	Limited due to small size
Gypsum	Cropwell Bishop	Pits of various depths	Partial to complete backfill	Drainage problems due to impermeable clay fill. Differential settlement
Building Stone	Bulwell and St. Ann's	Quarries	Partial to complete backfill	Differential settlement. Porous rock surrounds quarries (risk of gas or leachate migration)
Limestone	The Wolds	Small quarries	Partial backfill	Limited due to small size

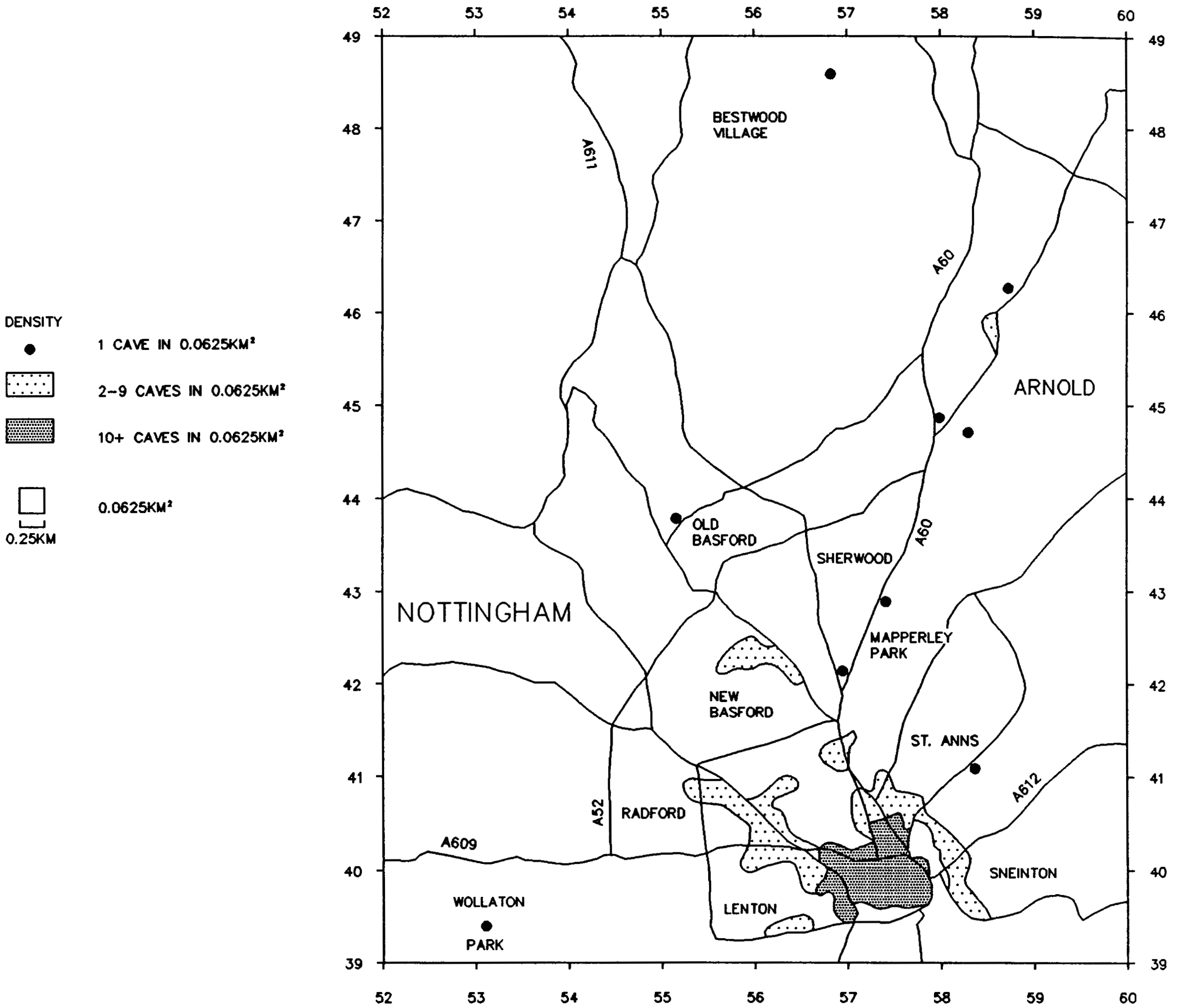


Figure 25. The distribution of known cave sites in and around Nottingham

Flooding

Flooding and surface water in general are not strictly in the field of geology, although they are influenced by geological factors. However, the preparation of the hydrogeological map showing, amongst other things, areas of shallow groundwater along the River Trent and its tributaries (Map 9) provided an opportunity to show maximum flood limits, as requested by the Department of the Environment. The limits shown are those taken from data supplied by the former Severn Trent Water Authority and exclude the exceptional 1947 floods. They show the area likely to be flooded under peak flow conditions, but do not take into account much modern flood defence construction. All matters regarding rivers, floods and land drainage in the area should be referred to the National Rivers Authority (Severn-Trent Region). Sewers remain the responsibility of Severn-Trent plc.

Peak flow conditions in rivers may result in flooding unless protective measures are taken. The last major flooding of urban areas occurred in 1947, and it was after this advent, in the 1950s that a programme of flood protection works was initiated. Peak flows were recorded in 1955, 1960 and 1977, but these did not result in serious flooding of built-up areas. A detailed treatment of river flow and various flood protection schemes in the area is provided by Evans (1984).

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GLOSSARY

ANHYDRITE A mineral consisting of anhydrous calcium sulphate ($CaSO_4$); it represents GYPSUM without its water.

ANTICLINE A rock structure in which beds are folded convexly upwards.

AQUICLUDE A body of relatively impermeable rock that does not readily transmit water.

AQUIFER A body of rock that is sufficiently permeable to yield groundwater to boreholes, wells or springs.

BARYTES (BARITE) A mineral consisting of barium sulphate ($BaSO_4$).

BASEMENT ROCKS The undifferentiated complex of rocks underlying Carboniferous and younger rocks in the area.

BEDDING The arrangement of sedimentary rocks in beds or layers of varying thickness and character.

CAMBERING The process whereby beds are folded into an arch (camber) inclined towards a topographic low, generally on valley sides.

CONTINENTAL DEPOSITS Sedimentary deposits laid down on land rather than in the sea.

CRYOTURBATION Disturbance to soil or rock material resulting from frost action.

CUESTA A hill or ridge with a gentle slope (DIP-SLOPE) on one side and a steep slope (ESCARPMENT) on the other.

DIP-SLOPE The generally gentle slope which conforms closely to the dip of the underlying strata; marking one side of a CUESTA.

DOLOMITE The mineral consisting of calcium magnesium carbonate ($CaMgCO_3$).

DRIFT Synonym of SUPERFICIAL DEPOSIT.

DUMBLE Local term for a short, deeply incised, tributary valley with a flat base and steep headwall, which contains only a small stream or is dry.

ESCARPMENT The slope marking the steep side of a CUESTA; generally formed by the resistance to erosion of a rock unit towards the crest.

EXPOSURE An area of a rock unit that is unobscured by soil or other materials.

FACIES The characteristic feature of a rock unit, including such things as lithology, fossil content and sedimentary structures.

FAULT A fracture in rock along which displacement of one side relative to the other has taken place.

FLANDRIAN The most recent period of time, from about 10 000 years ago, equivalent to the Holocene.

FLUVIAL Of or pertaining to a river.

FORMATION Distinctive unit of sedimentary rock with defined and mappable boundaries.

GALENA A mineral consisting of lead sulphide (PbS).

GLACIAL Of or relating to the presence of ice or glaciers; formed as a result of glaciation.

GROUNDWATER Water contained in saturated soil or rock below the water-table.

GYPSUM The mineral consisting of hydrous calcium sulphate ($CaSO_4.2H_2O$).

JOINT A surface of fracture or parting in a rock, without displacement; commonly planar and part of a set.

KNICK POINT An abrupt break in the gradient of a river.

LAMINATED Applied to very thin bedding less than 10 mm thick.

LITHOLOGY The characteristics of a rock such as colour, grain size and mineralogy.

MARL Strictly a calcareous clay, but commonly applied to the red-brown soft silty clay of the Mercia Mudstones.

MASS WASTING A general term for the dislodgement and downslope transport of soil and rock material, mainly by gravity.

MEMBER A distinctive, defined unit of strata within a FORMATION.

METHANE A colourless, odourless, inflammable gas (CH_4); forms an explosive mixture with air.

OROGENY The process of mountain building involving rock deformation over a long period of time.

OUTCROP The area over which a particular rock unit occurs at the surface, whether exposed or not.

OVERFLOW CHANNEL A watercourse cut by the draining of a lake.

PERCHED GROUNDWATER Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone.

PERIGLACIAL Said of an environment beyond the periphery of an ice sheet influenced by severe cold, where permafrost and freeze-thaw conditions are widespread.

PERMAFROST Any soil, superficial deposit or bedrock in which a temperature below freezing has existed continuously for a long time.

PERMEABILITY The property or capacity of a rock, sediment or soil for transmitting a fluid.

PLEISTOCENE The first epoch of the Quaternary Period prior to the Flandrian; from about 2 million years to 10 000 years ago.

RIVER TERRACE Approximately planar surface in a valley above the present river level, representing the dissected remnant of an abandoned floodplain produced during a former stage of deposition.

SATINSPAR A white translucent, fibrous variety of GYPSUM characterized by a silky lustre.

SHEAR PLANES A series of closely spaced, parallel surfaces along which differential movement has taken place.

SKERRY A well-cemented grey-green or buff very fine-grained sandstone or siltstone which commonly forms a resistant landform feature.

SOLIFLUCTION The slow, viscous downslope flow of waterlogged surface material, especially over frozen ground.

SUPERFICIAL DEPOSIT A general term for an unconsolidated deposit of Quaternary age overlying bedrock.

SYNCLINE A rock structure in which beds are folded concavely upwards.

TERRESTRIAL Said of a deposit or environment occurring on land above the tidal reach.

TILL Unsorted mixture of clay, silt, sand, gravel and boulders deposited from melting ice without subsequent reworking by meltwater.

UNCONFORMITY A substantial break in a sedimentary sequence where strata are missing and there may be an angular relationship between strata above and below the surface of unconformity.

VALLEY BULGING The process whereby rocks are plastically deformed so that a downward movement on valley sides produces an upward movement and folding of strata within the valley.

VEIN A mineral infilling of a fault or other fracture in a rock; usually sheet-like.

WULFENITE A mineral consisting of lead molybdate ($PbMoO_4$).

Acknowledgements

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ANNEX 1

GEOLOGICAL DETAILS

Details of Carboniferous rocks

Classification

The classification of Carboniferous rocks is illustrated in Table 20.

Palaeogeography

Following the Caledonian earth movements, the Carboniferous Dinantian Sea transgressed the eroded Palaeozoic and Precambrian basement rocks of the Nottingham area. No Courceyan rocks are known in the district, but their presence at depth may be inferred. The oldest rocks proved are Brigantian limestones; they were deposited slowly on a 'shelf', in relatively shallow seas rich in animal life. At the same time, great thicknesses of mudstones, thinly bedded limestones and thin sandstones were being deposited in the south-west of the district, in the deeper, muddier waters of a basinal area known as the Widmerpool Gulf (Kent, 1966) (Figure 17). The Widmerpool Gulf is one of three fairly narrow, broadly ESE-WSW trending, belts of expanded Dinantian and Namurian successions in the East Midlands. A reef belt, in which sedimentation kept pace with subsidence, sporadically developed between the basin and shelf facies. In the Widmerpool Gulf, two main depositional environments are represented within the Namurian succession, the change occurring near the base of the Marsdenian Stage. The lower part of the sequence indicates deep water muddy conditions with periodic influxes of turbiditic sands, and episodes of volcanic ash deposition. The higher part of the succession includes three thick sandstone sequences, the Ashover Grit, the Chatsworth Grit and the Rough Rock. These are upper delta slope and fluvial channel deposits of a river system which prograded into the Gulf from the east and south-east (Jones, 1980). In the subsurface, the margins of the gulf have been defined by the zones across which the Namurian strata are most greatly thickened (Kent, 1966; Aitkenhead, 1977; Frost and Smart, 1979). This is adequately controlled in only a few locations, commonly by boreholes and seismic data that remain confidential. Throughout the district the precise position of the northern margin of the gulf remains conjectural; its southern margin is well to the south of the district.

After Marsdenian times, sedimentation periodically outpaced subsidence and coal swamps were established. Fluctuations in the rate of subsidence are reflected by distinct cycles of sedimentation, each beginning with the deposition of marine shales which pass up through mudstones into deltaic siltstones and sandstones.

In Westphalian times, the Namurian pattern continued but with increasing dominance of shallow-water argillaceous deposits. The cycles increased in number but became generally thinner. Emergence, with the establishment of land floras, became more frequent and, in many cases, more prolonged, resulting in coal complexes.

The Coal Measures do not appear to thicken into the gulf, but instead show a gradual regional thinning towards the east. The Westphalian A succession locally contains substantial thicknesses of volcanic rocks; these become more common and increase in thickness eastwards (Burgess, 1982).

Stratigraphy

Gulf Succession

The pre-Marsdenian rocks are predominantly argillaceous, comprising dark grey mudstones with very subordinate sandstones and siltstones. These beds are characteristic of deposits laid down by turbidity currents (Bouma, 1962). Thin beds of K-bentonite containing waterlain volcanic ash have been recorded from nearby districts. In Marsdenian times deltaic deposition commenced and continued during the remainder of the Namurian and into the Westphalian. Strongly cyclic sedimentation occurred under these conditions. Cycles, which are locally incomplete, are typically as follows (Smith and others, 1967):

Coal
Seatearth
Sandstone or siltstone
Grey mudstone becoming silty at top
Dark mudstone, commonly marine at or near base

There are three thick sandstone sequences in the district, the Ashover Grit, the Chatsworth Grit and, close to the top of the Namurian, the Rough Rock. The term 'grit' is

Table 20. General classification of the Carboniferous sequence

System	Subsystem	Series	Stage
CARBONIFEROUS	DINANTIAN	(TOURNAISIAN)	COURCEYAN
		(VISEAN)	CHADIAN
			ARUNDIAN
			HOLKERIAN
			ASBIAN
			BRIGANTIAN
	SILESIAN	NAMURIAN	PENDLEIAN (E1)
			ARNSBERGIAN (E2)
			CHOKERIAN (H1)
			ALPORTIAN (H2)
			KINDERSCOUTIAN (R1)
			MARSDENIAN (R2)
			YEADONIAN (G1)
		WESTPHALIAN	LANGSETTIAN (WESTPHALIAN A)
			DUCKMANTIAN (WESTPHALIAN B)
			BOLSOVIAN (WESTPHALIAN C)
			WESTPHALIAN D
		STEPHANIAN	

Table 21. Summary of the lithostratigraphy of the Permian rocks (below the Sherwood Sandstone Group) of the Nottingham area.

Nottingham Aveline (1877, 1880)	Nottingham Lamplugh and Gibson (1910)	Institute of Geological Sciences (1972)	North Notts Smith and others (1974)	West Notts-Derby Frost and Smart (1979)	Yorkshire Province Smith and others (1986)		This Report	
Permian or Middle Marls	Permian Marl	Middle Permian Marl	Permian Middle Marls	Middle (Permian) Marl	Aislaby Group	Edlington Formation	Aislaby/ Don Group	Edlington Formation
Lower Magnesian Limestone	Magnesian Limestone	Lower Magnesian Limestone	Lower Magnesian Limestone	Lower Limestone	Don Group	Cadeby Formation		Cadeby Formation (Lower Magnesian) Carbonate Facies
Shales	(with Marl Slates in Lower Part)		Lower Marl	Lower (Permian) Marl				Cadeby Formation (Lower Marl) Mudstone Facies
Breccia	'Basement' Breccia		Breccia	Breccia				Basal Breccia

retained for historical reasons and has no relation to the coarseness of the sandstones. The Ashover Grit sequence comprises at least two parts in the district. The Chatsworth Grit and Rough Rock are locally combined. Up to c.635m of Namurian strata have been proved in the gulf succession. Four named marine bands, the Gracile, Superbilingue, Cancellatum and Cumbriense, have been recorded above the Kinderscoutian.

Shelf Succession

Within the shelf succession, the pre-Marsdenian sequence is greatly condensed. The beds comprise sandstone and mudstone; they include marine bands and sandstones assigned to the Kinderscout Grit. It is uncertain whether Namurian beds older than Kinderscoutian are present in the district.

The Marsdenian and younger deltaic deposits were laid down without any significant lithological differences compared to these in the gulf succession. The location of the gulf areas is only revealed by the thickness increase of the lower Marsdenian rocks. Up to about 200m of Namurian strata have been proved in the shelf succession.

Westphalian (Coal Measures)

Westphalian strata (Coal Measures) crop out in the west of the area and are unconformably overlain by Permo-Triassic rocks throughout the remainder of the district. They form the southern part of the Yorkshire and East Midlands Coalfield, and occupy part of the Pennine Basin.

The beds belong to the Lower, Middle and Upper Coal Measures; the stratigraphical classification and a generalized vertical section showing the main coal seams and marine bands, are simplified in Figure 7. Strata consisting predominantly of grey mudstone and siltstone with subordinate ironstone, sandstone, seatearth, and coal were deposited in repetitive cyclic sequences. Lithologies are closely comparable with these found elsewhere in the Pennine Basin, comprehensive accounts of which have been given by Trueman (1954, pp.1-29), Smith and others (1967, pp.80-83) and Murchison and Westall (1968, pp.71-85).

The Lower and Middle Coal Measures of the East Midlands are noteable for their relatively small content of sandstone compared with other coalfields. The sandstones are mainly thin, impersistent, fine-grained sheets. Four thick, more persistent, named sandstones have been proved, the Crawshaw Sandstone, Loxley Edge Rock, Wingfield Flags and Tupton Rock (Figure 7).

Forty-four named, as well as numerous thin unnamed, coal seams have been proved in the area; some comprise multiple seams. In the past, numerous seams have been worked; however, by 1989 only three seams were being worked, the High Hazles from Gedling Colliery, the Deep Hard and Blackshale from Cotgrave Colliery.

The coals generally cap upward-coarsening sedimentary cycles, and are underlain by gleyed palaeosols ('seatearths'). The measures are dominantly non-marine, but twelve named marine bands have been proved in the district. Many non-marine bivalve horizons, together with 'Estheria' *(Euestheria)* bands and fish fragments have also been proved. Non-marine bivalve horizons are most abundant in Westphalian B (Duckmantian) strata; whilst 'Estheria' *(Euestheria)* and fish debris are common in Westphalian A (Langsettian) and C (Bolsovian) strata. Plant debris is common throughout the grey measures. Red beds occur in the higher part of the Upper Coal Measures.

In general, sedimentation kept pace with active subsidence of the Pennine Basin; with major faults playing a periodically important role. Marine influence was minimal except when the deltaic environment was periodically drowned by major marine transgressions and more local marine incursions. Coal Measure sedimentology has been the subject of numerous studies, most recently in the Pennine Basin by Guion (1978, 1987) and Guion and Fielding (1988), and is not discussed in

Table 22. Summary of the lithostratigraphy of the Triassic rocks

MIDLANDS HULL (1869)		NOTTINGHAM LAMPLUGH AND OTHERS (1908/10)	NOTTINGHAM SWINNERTON (1918) SMITH (1912)	NOTTINGHAM ELLIOTT (1961)		NORTHEASTERN MIDLANDS KENT (1968)		NOTTINGHAM WARRINGTON AND OTHERS (1980)		NOTTINGHAM PROJECT (1989)	
KEUPER	Rhaetic or Penarth Beds	"White Lias"/ Upper Rhaetic		KEUPER		UPPER RHAETIC	Cotham Beds	PENARTH GROUP	Lilstock Formation Cotham Member	PENARTH GROUP	Lilstock Formation Cotham Member
		Avicula contorta shales				LOWER RHAETIC	Westbury Beds		Westbury Formation		Westbury Formation
	NEW RED MARL	Tea Green Marl			Parva Formation			MERCIA MUDSTONE GROUP	Blue Anchor Formation	MERCIA MUDSTONE GROUP	Blue Anchor Formation
		KEUPER MARL							Glen Parva Formation		Cropwell Bishop Formation
					Trent Formation				Trent Formation		
					Hollygate Skerries				Hollygate Skerries		Hollygate Sandstone
					Edwalton Formation				Edwalton Formation		Edwalton Formation
					Cotgrave Skerry				Cotgrave Skerry		Cotgrave Sandstone
					Harlequin Formation				Harlequin Formation		Gunthorpe Formation
					Carlton Formation				Carlton Formation		
					Radcliffe Formation				Radcliffe Formation		Radcliffe Formation
	Waterstones	Keuper Waterstones	Keuper Waterstones		Waterstones				Colwick Formation		Sneinton Formation
	Building Stones		Keuper Basement Beds		Woodthorpe Formation				Woodthorpe Formation		
	Basement Beds										
BUNTER	Upper Red and Mottled Sandstone	Bunter Pebble Beds	BUNTER	BUNTER				SHERWOOD SANDSTONE GROUP	Nottingham Castle Formation	SHERWOOD SANDSTONE GROUP	Nottingham Castle Sandstone Formation
	Conglomerate or Pebble Beds										
	Lower Red and Mottled Sandstone	Lower Mottled Sandstone							Lenton Sandstone Formation		Lenton Sandstone Formation

great detail here. Briefly, the depositional sedimentary environments of the Coal Measures have been interpreted as shallow-water delta/lower delta plain in the early part of Westphalian A, passing gradationally into upper delta plain conditions in late Westphalian A times and continuing as such throughout the majority of Westphalian B (Guion and Fielding, 1988). A reversion to lower delta plain conditions probably began in late Westphalian C. The highest Westphalian C beds in the district result from the onset of red-bed depositional conditions (Besley, 1988), and may include part of the Etruria Formation.

Volcanism was widespread in late Namurian and Westphalian A times in the Vale of Belvoir area, and locally limited the extent of the main sandstones. Later igneous activity took the form of sill intrusion. Igneous intrusions have been recorded in the Lower Coal Measures; they comprise two distinct petrographic types: (a) analcite-olivine-dolerites, allied to teschenites and (b) olivine-dolerites (Dunham, in Edwards, 1951).

Classification of Permo-Triassic rocks

The lithostratigraphical nomenclature applied to rocks of Permian age within the Nottingham district includes formations proposed by Smith and others (1986) which form part of two previously established groups (Smith and others, 1974). Detailed chronostratigraphical affiliation of these beds, the upper part of the sequence in particular, is uncertain in this area. The currently unresolved problem of locating the boundary between the Permian and Triassic systems is discussed by Smith and others (1974) and Warrington and others (1980). As the lithological facies are almost certainly diachronous across the system boundary, it is unknown whether the chronostratigraphical boundary coincides with the base of a recognised lithostratigraphical unit within the Nottingham area. A comparison of the terminology used in this report with earlier classifications is given in Table 21.

Within the district the Permian rocks are all considered to be of Upper Permian age. The deposits represent the sediments of alternate transgressive and regressive phases of the Zechstein Sea, belonging to two depositional cycles referred to as EZ1 and EZ2 (Smith and others, 1986). In areas to the north rocks attributed to three later Permian cycles (EZ3-EZ5) are recognised; however, no unconformity is apparent in the local sequence. On the contrary, towards the southern limit of the Zechstein depositional basin the essentially muddy rocks of the Edlington Formation pass gradually upwards by increase in sand content into rocks which form part of the Sherwood Sandstone Group. These beds may also in part be of Permian age.

A revised classification of the Triassic rocks in the British Isles was proposed by Warrington and others (1980). Its main innovation was the abandonment of the terms 'Bunter', 'Keuper' and 'Rhaetic', which carried mixed chronostratigraphical and lithostratigraphical implications, and the formal introduction of three major lithostratigraphical divisions, in ascending order, the Sherwood Sandstone Group, the Mercia Mudstone Group and the Penarth Group. The Sherwood Sandstone Group broadly includes rocks formerly assigned to the 'Bunter Sandstone' and the sandy (lower) beds of the 'Keuper'. Most of these rocks are of Triassic age, but locally, as in the Nottingham area, Permian strata are included in the lower part. The Mercia Mudstone Group is equivalent to the former 'Keuper Waterstones' and 'Keuper Marl', and is entirely of Triassic age. The Penarth Group includes argillaceous, calcareous and locally arenaceous strata; it overlies the Mercia Mudstone Group and is overlain by rocks of the Lias Group which are partly Triassic but dominantly Jurassic in age.

The recent BGS resurvey found that only three of the formations comprising the Mercia Mudstone Group of Elliott (1961) and Warrington and others (1980) were consistently mappable. New nomenclature was adopted to cover the remaining strata (Charsley and others, in prep.); comparison of the terminology used in this report with earlier sub-divisions is provided by Table 22.

Classification of Jurassic rocks

A broad modern classification of the British Lower Jurassic was presented by Cope and others (1980). More recently, Brandon and others (in press) have described a revised nomenclature for early Jurassic rocks in south-west Lincolnshire, and their lithostratigraphy has been found applicable to the Nottingham district. In earlier usage the sequence overlying the Penarth Group was referred to broadly as the 'Lower Lias' and in use this term grew to encompass chronostratigraphical and biostratigraphical as well as its original lithostratigraphical implications. The 'Lower Lias' now forms part of the Lias Group (Powell, 1984), a name which is unequivocally lithostratigraphical. Only the basal – Scunthorpe Mudstone – formation of the Lias Group, part of which was previously referred to as the 'Angulata Clays' (Swinnerton and Kent, 1949), occurs in the area. The lower part of the Scunthorpe Mudstone is lithologically distinct from the remainder of the division, and these beds, formerly known as the 'Hydraulic Limestone Series', now comprise the Barnstone Member.

With regard to chronostratigraphy, the base of the lowest, Hettangian, stage of the Jurassic System is marked by the first appearance of ammonite fossils belonging to the genus *Psiloceras*. In the Nottingham area, as elsewhere in Britain, this chronostratigraphical boundary lies within a lithostratigraphical unit, such that the basal few metres of the Lias Group are regarded as Triassic in age and the beds immediately above are Jurassic (Cope and others, 1980; Warrington and others, 1980). As there is no obvious lithological change across the system boundary, the small thickness of Triassic rocks within the Lias Group have been considered together with the Jurassic sequence.

Additional details for some superficial (Drift) deposits

Till and sandy till

In the Wolds area, the till is mainly grey or grey-brown and contains abundant quartzite and flint pebbles with lesser amounts of sandstone and limestone and local concentrations of chalk debris. Elsewhere in the district, the deposits are mainly red-brown with quartzite the dominant clast lithology; quartz, sandstone, igneous rocks, limestone and flint are less common and chalk is typically absent. Clast size ranges from coarse sand to boulders, but the latter are rare and the gravel fraction is most common. Most clasts are rounded or well-rounded with the exception of flints, which generally preserve some angularity, and the locally-derived fragments included within the basal till. Locally, the till is severely cryoturbated. In places the base of the till includes reworked bedrock material, considered to be indicative of deposition beneath an advancing or static ice-sheet (lodgement till). Elsewhere the till includes sand and appears to pass laterally or vertically into sand and gravel deposits, possibly indicating formation under ice decay conditions (flow and melt-out tills). The till of the Wolds represents material deposited by an ice-sheet from the east or north-east, whilst that elsewhere is at least in part laid down by ice from the north or north-west. Whether the two ice-sheets were part of the same glacial advance is uncertain.

Glacial Sand and Gravel

a) Sands and gravels in the Ruddington – Bradmore and Wolds areas are generally closely associated with till. They probably represent laterally impersistent melt-out deposits produced during the decay of the main eastern ice-sheet.

b) Sands and gravels to the north of this area contain pebbles and clasts of Triassic-derived quartzite, Carboniferous rock and igneous material, probably derived from the Lake District (Lamplugh and Gibson, 1910). These gravels are regarded as melt-out or ice-marginal deposits from a major northern ice-sheet.

Bassingfield Sand and Gravel

The gravel comprises fine to medium or, less commonly, coarse sub-rounded to rounded pebbles. Quartzite is the most common clast; quartz, sandstone (?Carboniferous) and flint are fairly abundant and dark igneous material is less common. During the resurvey these deposits were poorly exposed, but former exposures showed up to 4m of sand and gravel which was locally highly contorted, probably due to periglacial cryoturbation. More recent trench sections at Gamston [c.602 373] showed up to 3m of the deposit, but a maximum thickness below the ridge crest has not been proved. The Bassingfield Sand and Gravel passes down into sandy pebbly clay, with a variable degree of intercalation of the two deposits. Wherever seen, the underlying beds are highly weathered, but appear to be complex glacial melt-out material. The Bassingfield Sand and Gravel was probably deposited in a glacio-fluvial environment during a major ice-decay and outwash phase, the earlier stages of which laid down the melt-out deposits upon which the sand and gravel rests.

Beeston Sand and Gravel

The gravel comprises pebbles which are mainly quartzite and quartz, with abundant flint and lesser amounts of Carboniferous sandstone and Triassic rock. As with the Bassingfield deposits the upper part of the Beeston Sand and Gravel is contorted, probably due to cryoturbation. The Bassingfield and Beeston deposits lie at similar levels above the Trent alluvium and, in the past, they were considered correlatives. This is now considered unlikely. The deposits differ lithologically and display differing relationships to underlying formations; their landform morphology is also dissimilar. Additionally the Beeston deposits have been more definitely correlated with sequences elsewhere in the region (cf Brandon and Sumbler, 1988, and Frost and Smart, 1979) which contain mammalian faunas indicative of an inter-glacial, probably Ipswichian, age. No mammal remains have been found in the Bassingfield deposits, which are now considered to be older than the fossiliferous Beeston gravels. The Beeston Sand and Gravel is, at least in part, a fluvial deposit laid down during relatively warm conditions, but might include material deposited during later periglacial phases.

Holme Pierrepont Sand and Gravel

This deposit was previously called the 'Flood-plain Terrace' (eg. Posnansky, 1960) or the 'Floodplain Sand and Gravel' (Brandon and Sumbler, 1988). Lithologically, the deposits are not unlike those of the Beeston Sand and Gravel. The deposit comprises fine to coarse sandy gravel with discontinuous lenses of generally medium-grained sand. Sedimentary structures indicate point bar growth associated with migrating meanders; rare masses of silt and clay within the gravels are probably redeposited overbank sediment. Deposition of the Holme Pierrepont Sand and Gravel probably commenced under ice-melt flood conditions at the end of the Devensian cold stage (about 10 000 years ago).

Leen Sand and Gravel

The sand is described as being red or, more rarely, white, grey or yellowish; lamination was noted in some exposures. The gravel is poorly described but includes beds of sand at some exposures and is commonly iron stained. As with the Holme Pierrepont deposits, the Leen Sand and Gravel probably originated as late Devensian flood deposits which formerly occupied the entire Leen valley.

Bunny Sand and Gravel

Pebbles in the deposit include flint, chalk, Jurassic limestone and fossil Gryphaea, which indicate an easterly derivation. The age and origin of the Bunny Sand and Gravel are similar to those of the Holme Pierrepont and Leen deposits, the material being lain down by limited local flood waters at the end of the Devensian. On the basis of its lithology, the material probably derives from the reworking of till and other glacial deposits on the Wolds.

ANNEX 2. BOREHOLE, SHAFT AND TRIAL PIT DATA

The following table lists the number of records of boreholes, shafts and trial pits currently held in the National Geosciences Data Centre (NGDC) for each 1:10 000 sheet within the study area.

Plans showing the location of all registered sites and the records themselves can be examined by prior appointment at the NGDC, British Geological Survey, Keyworth, Nottingham NG12 5GG, Tel. 06077-6111.

ANNEX 3. MINESHAFT LOCATIONS AND UNDERGROUND MINE PLANS

Records and detailed plans showing the sites of known or suspected coal mine shafts in the study area are held by British Coal, Nottinghamshire Area, Edwinstowe House, Edwinstowe, Mansfield, Nottingham NG21 9PR. Coal mine abandonment plans for the Nottinghamshire Coalfield are held by British Coal at the Mining Records Office, Newstead Colliery, Newstead, Nottinghamshire NG15 0DA. Details of former opencast coal mining are kept by the Opencast Executive, Central East Region, British Coal, Cinderhill Road, Bulwell, Nottingham NG6 8RY.

Plans of abandoned gypsum mines in the Cropwell Bishop and Gotham areas are held by the Health and Safety Executive, Mining Records Office, St Peter's House, Balliol Road, Bootle L20 3LZ. Further information on former gypsum mining may be obtainable from the Exploration Department, British Gypsum, East Leake, Loughborough, Leicestershire LE12 6JG.

ANNEX 4

GEOTECHNICAL DETAILS

Contributed by A Forster

GEOTECHNICAL TESTS AND THEIR APPLICATIONS

The geotechnical tests referred to in the descriptions of the engineering geology maps are explained here, together with their application.

Density tests

Bulk density is calculated by dividing the total mass of soil (solids and water) by its total volume. It may be determined by the sand replacement method (in the field) or the core cutter method. In each of these a measured volume of soil at its natural moisture content is weighed and its density calculated.

Dry density is calculated by dividing the mass of soil after drying at 105°C to constant weight (i.e. solids only), by its total volume before drying.

Saturated density is calculated by dividing the mass of soil with its pore space filled with water, by its volume. Full details of the determination of soil density are given in BS 1377 "Methods of testing soils for civil engineering purposes". The density of soil in its various states of saturation are basic soil properties which are used in a variety of calculations including assessing overburden pressure, slope stability, surcharge pressure, and earth pressure on retaining walls.

Moisture content

The moisture content of a soil is defined as the mass of water in a soil divided by the mass of solids in a soil expressed as a percentage. It is determined by weighing a sample before and after drying to a constant weight at a temperature of 105°C (details are given in BS 1377). Moisture content is a basic soil property and influences soil behaviour with regard to, for example, compaction, and plasticity.

Atterberg or consistency limits

As the moisture content of cohesive soil increases it will pass from a solid state to a semi-solid state in which changes in moisture content cause a change in volume. The moisture content at this change is the shrinkage limit. As the moisture content is increased further the soil will become plastic and capable of being moulded; the moisture content when this change takes place, is the plastic limit. Ultimately, as moisture content is increased, the soil will become liquid and capable of flowing under its own weight. This change takes place at a moisture content called the liquid limit.

The plasticity index is defined as the liquid limit minus the plastic limit and gives the range of moisture content over which the soil behaves as a plastic material. The methods and apparatus for determining the consistency limits are described in BS 1377.

The factors which control the behaviour of the soil with regard to consistency are the nature of the clay minerals present, their relative proportions and the amount and proportions of silt, fine sand and organic material. If plasticity index is plotted against liquid limit a soil may be classified in terms of its plastic behaviour. The consistency limits also give an indication of soil strength and compressibility.

Particle size analysis

The particle size distribution of a soil is determined by sieving and sedimentation. A sample of soil is dried, weighed and sieved to remove the fraction greater than 20mm in size. It is then immersed in water with a dispersing agent such as sodium hexametaphosphate to break up soil aggregates. The sample is then wet sieved to remove particles less than 0.063mm. The fraction retained on the 0.063mm sieve is dried and passed through a nest of sieves of mesh size ranging from 20mm to 0.063mm. The fraction retained on each sieve is weighed and the cumulative percentage passing each sieve is calculated. A grading

Sheet	Number of Records	Sheet	Number of Records
SK 64 NW	52	SK 54 NW	414
SK 64 NE	79	SK 54 NE	132
SK 64 SW	237	SK 54 SW	547
SK 64 SE	72	SK 54 SE	444
SK 63 NW	312	SK 53 NW	380
SK 63 NE	142	SK 53 NE	851
SK 63 SW	95	SK 53 SW	152
SK 63 SE	70	SK 53 SE	174

Total number of records held 4153

curve of percentage passing against sieve size is plotted. The fines which passed through the 0.063mm sieve are graded by sedimentation. A representative subsample is made up into a suspension with distilled water placed in a tall jar and made up to a volume of 500 ml. It is then agitated vigorously and allowed to settle. Samples are removed by pipette from a given depth at specific times. The samples are dried and the contained solids weighed. The size distribution can then be calculated using Stokes' Law which relates settling time to particle size. The entire grading curve for coarse and fine material can then be plotted. Full details are given in BS 1377. An alternative method, for the fine fraction, using a hydrometer is also described in BS 1377.

Particle size distribution is used for classifying soil in engineering terms (BS 5930: "Code of practice for site investigation", 1981). Particle size distribution curves will indicate soil behaviour with regarding to permeability, susceptibility to frost heave or liquefaction, and will give some indication of strength properties. Particle size analysis does not, however, indicate structure and will not distinguish between a sandy clay and a laminated sand and clay which may behave very differently.

The Standard Penetration Test (S.P.T.)

The standard penetration test is a dynamic test carried out at intervals during the drilling of a borehole. A standard 50mm diameter split barrel sampler is driven into the soil at the bottom of the hole for a distance of 450mm by the blows of a standard weight (65kg), falling through a standard distance (0.76m). The number of blows (N) required to drive the last 300mm is recorded. Details are given in BS 5930.

A modification of the test for hard material and coarse gravel uses a solid cone instread of a cutting shoe and is called a cone penetrometer test (C.P.T.).

Although it is a field test which is subject to operational errors, the S.P.T. is widely used to give an indication of the relative density of granular soils (very loose – very dense) and the consistency of cohesive soils (very soft – hard). Correlations have also been made between S.P.T. and the bearing capacity of a soil.

California Bearing Ratio (C.B.R.)

The California Bearing Ratio test is a penetration test carried out in the field or in the laboratory which compares the resistance of a soil to penetration by a standard plunger to the resistance to penetration shown by a standard crushed stone.

A series of samples are compacted in a 152mm diameter mould at moisture contents around the optimum moisture content for maximum compaction. A surcharge weight is placed on the soil which is then immersed in water for four days. The mould is placed in a load frame and a plunger 48.5mm in diameter is forced into the sample to a penetration of 2.5mm and 5mm. The C.B.R. value is determined as the higher of the ratios of the resistance at 2.5mm and 5mm penetration to the standard resistance of crushed stone at the same penetrations. Details are given in BS 1377. In the field the plunger is jacked into the ground again the reaction of a heavy lorry (field values are usually lower than laboratory values). The results of the C.B.R. test are used to assess the suitability of soil for use as base, sub-base and subgrade in road construction.

Permeability

The permeability of a soil is its capacity to allow water to flow through it. It may be measured in the laboratory using samples or in the field using boreholes.

In the laboratory two tests are commonly employed, the constant head test for coarse grained soils and the falling head test for fine grained soils. In the constant head test a sample of granular soil is confined in a perspex tube, a constant head of water is applied to one end and water is allowed to flow though the sample. Manometers are connected through the cylinder walls to monitor the pressure along the flow path. Permeability may then be calculated, using Darcy's Law, the path length, pressure difference, cross-sectional area of the sample and the quantity of water passed in a given time.

In a falling head test a sample of fine grained soil containing clay or silt is placed in a cylinder standing in a tray of water. A glass standpipe is connected to the top of the sample and filled with water. The time taken for the water level in the standpipe to drop a given distance is then measured. Permeability may then be calculated from the time, the drop in height, the cross-sectional area of the standpipe, the cross-sectional area of the sample and the length of the sample. Details are given in BS 1377.

Laboratory tests do not take account of the structural differences in the soil, such as fissuring, and may not give a true permeability of the ground in situ. Pumping tests using boreholes give a more representative value but are more expensive.

In a field permeability test, water is pumped out of a borehole and the effect on the water level in adjacent boreholes is monitored, or if a single borehole is being used it may be pumped out and the water level recovery time recorded. An alternative approach is to pump water into a borehole under pressure and measure the volumes of water flowing into the borehole at a number of different pressures (details are given in BS 5930). The information obtained from either method enables a coefficient of permeability for the ground as a whole to be calculated.

Permeability is used to predict the inflow of water during excavations or tunnelling and to design groundwater control schemes to deal with it. Permeability is important when assessing waste disposal sites, and the siting and construction of water retaining structures such as dams, lagoons and canals. The assessment of potential well yields requires field permeability determination for the formations concerned.

Consolidation test

If a saturated cohesive soil is subjected to an increase in loading the pressure of the water in the pore spaces will increase by the same amount as the applied stress. The water will therefore tend to flow away to areas at a lower pressure at a rate controlled by the soil permeability. The removal of water causes a decrease in volume of the soil. The process is called consolidation.

The consolidation parameters are measured in the laboratory by placing a disc of soil, confined in a metal ring, in a water filled cell. A constant axial load is applied to the disc via porous end platens, and its decrease in thickness measured with time. When it reaches a constant thickness for a given load, the load is increased (usually doubled) and the readings repeated. The loading is continued depending on the soil type and the structure for which the data is required. The coefficient of volume compressibility can then be calculated. This is a measure of the amount of volume decrease that will take place for a given increase in stress. The coefficient of consolidation, which is a measure of the rate at which the volume change will take place for a given increase in stress, is also calculated.

Consolidation test results are important for designing the foundations of a structure and calculating the settlement that will take place during and after construction to ensure that settlement is neither excessive nor uneven under the foundation. It may also be important to ensure that the settlement (consolidation) which is caused by an early stage of construction has ceased before a second stage is started.

Triaxial Compression Test

The triaxial compression test is the most widely used test for determining the shear strength of cohesive soils, and a number of different methods may be used depending on the application of the results.

In the simplest most common method (quick undrained) a cylindrical specimen (usually 76mm x 38mm) is placed between rigid end-caps and covered with a rubber membrane. The assembly is then placed in a triaxial cell which is filled with water and all air removed. The water pressure in the cell is then maintained at a prescribed constant value while the axial load on the specimen is increased at a constant rate of strain. The test continues until either the specimen shears or a maximum vertical stress is reached. Vertical displacement, axial load and pore water pressure within the sample are measured during the test. The test is repeated on two further specimens from the same sampling point but at two different confining pressures. The results obtained from the three tests enable the undrained shear strength to be calculated as C_u, the apparent cohesion, and $Ø_u$, the angle of shearing resistance. The parameters obtained from this test may be used to determine the immediate bearing capacity of foundations in saturated clay.

Other variations on the test are suited to different applications. In the consolidated undrained test, free drainage of the specimen is allowed under cell pressure for 24 hours before testing (i.e. consolidation). Drainage is then prevented and the rest carried out as before. This test is applicable to situations where a sudden change in load takes place after a period of stable conditions, for example where rapid drawdown of the water behind a dam takes place.

In the drained triaxial test, free drainage is allowed during the consolidation phase and also during the test itself. The results obtained would be applicable to long term slope stability assessment.

Chemical Tests

Sulphate

The sulphate content of soil is determined by leaching a weighed sample of soil with hydrochloric acid, and precipitating the dissolved sulphate by the addition of an excess of barium chloride. The precipitate is then filtered, ignited in a furnace and weighed.

The sulphate content of groundwater or an aqueous soil extract is determined by passing the water through a column of ion exchange resin which converts the sulphate content to hydrochloric acid. The acid content, and hence sulphate, is then determined by titration with sodium hydroxide. Details are given in BS 1377.

It is important to know the sulphate content of groundwater and soil because ordinary Portland cement deteriorates in the presence of sulphate. Knowledge of the sulphate concentraction present enables a suitable sulphate-resisting or high alumina cement to be used in appropriate concrete mixes for applications below ground level.

pH

About 30 grams of soil are weighed and placed in 5ml of distilled water in a beaker. The mixture is stirred and allowed to infuse overnight. A glass electrode connected to a pH meter is then placed in the stirred mixture and the pH reading is taken. The electrode and meter may also be used to determine the pH of groundwater samples; pH may also be determined colorimetrically. Details are given in BS 1377.

The pH of soil or groundwater is important when designing concrete structures below ground surface. Ordinary Portland cement is not recommended in situations with a pH below 6, high alumina cement can be used down to pH 4, and supersulphated cement has been used to pH3.5. Acidic groundwaters can also cause corrosion in buried iron pipes.

Test Data

Detailed statistics of geotechnical data for bedrock and superficial materials are given in Tables 23A and B and 24A and B. Summaries of index tests (SPT, density, moisture content, liquid limit, plastic limit) and particle size analysis, and strength and chemical tests (undrained triaxial compression, consolidation, sulphate class, pH and allowable bearing capacity) are included.

Table 23a. Bedrock materials: index texts and particle-size analysis data

Engineering geological unit		Lithostratigraphical unit	S.T.P. N	Density: Dry Mg/m³	Density: Bulk Mg/m³	Moisture content %	Liquid limit %	Plastic limit %	Particle-size analysis: Gravel %	Particle-size analysis: Sand %	Particle-size analysis: Silt %	Particle-size analysis: Clay %
Mudstone of differing plasticity with some siltstone and fine sandstone	A High to very high plasticity	Scunthorpe Mudstone Formation				1 21	5 60 46–67	5 26 2–27				
		Cotham Member				4 31 29–32	4 63 49–78	4 25 24–28				
		Westbury Formation										
		Blue Anchor Formation			4 1.78 1.19–2.03	20 15 (8) 6–42	8 33 25–48	7 19 15–30				
	B Low to intermediate plasticity	Cropwell Bishop Formation; Edwalton Formation; Gunthorpe Formation; Radcliffe Formation	430 49 8–50+	158 1.75 (0.17) 1.29–2.12	862 2.02 (0.15) 1.7–2.42	1027 20 (7) 3–53	488 36 (10) 14–83	478 20 (5) 6–36	37 13 (26) 0–97	37 28 (20) 2–84	37 43 (23) 1–80	37 15 (14) 0–43
	C Intermediate to high plasticity	Edlington Formation	4 29 11–50+	8 1.80 (0.11) 1.62–2.00	68 2.05 (0.10) 1.63–2.23	83 20 (6) 12–48	40 46 (12) 18–67	40 20 (5) 10–31				
		Cadeby Formation mudstone					8 22 15–31	9 31 10–31				
		Middle Coal Measures	68 50 2–50+	18 1.71 (0.26) 1.00–2.11	79 2.11 (0.14) 1.37–2.36	123 17 (6) 5–50	59 44 (11) 23–74	59 21 (6) 14–57	9 2 0–10	9 4 0–16	9 44 17–89	9 49 17–89
		Lower Coal Measures		9 1.67 (0.19) 1.3–1.9	14 2.05 (0.12) 1.81–2.24	18 18 (9) 1–39	4 35 26–54	4 22 19–28				
Interbedded sandstone, mudstone		Sneinton Formation	21 50+ 24–50+	3 1.74 1.70–1.77	49 1.98 (0.12) 1.72–2.42	70 19 (4) 11–28	39 29 (5) 21–43	38 20 (3) 14–30	3 9 0–23	3 49 42–57	3 42 35–53	3 0
Sandstone		Nottingham Castle Formation	299 50+ 3–50+	5 1.70 1.58–1.75	18 1.98 1.86–2.17	31 14 2–26	4 33 26–41	4 19 18–22	127 13 (20) 0–86	127 77 (18) 14–100	127 10 (8) 0–45	127 1 (2) 0–15
		Lenton Sandstone Formation	91 50+ 8–50+		7 2.06 2.00–2.16	11 17 (8) 3–26	6 26 22–35	6 17 15–19	16 33 (38) 0–99	16 64 (38) 1–100	16 3 (3) 0–12	16 0
Lower Magnesian Limestone		Cadeby Formation carbonate	18 40 2–50+	13 2.24 (0.39) 1.71–2.78	21 2.27 (0.31) 1.80–2.92	31 16 (13) 1–57			20 26 (24) 2–86	20 38 (20) 6–81	20 29 (9) 2–64	20 8 (6) 0–20

Key

N A (SD) $V_1 - V_2$

N = number of values
A = average value
SD = standard deviation
$V_1 - V_2$ = range of values

The standard deviation is not quoted where the dataset numbers less than 10

Table 23b. Bedrock materials: strength and chemical-test data

Engineering geological unit		Lithostratigraphical unit	Undrained Triaxial Compression Test: Cu kPa	Undrained Triaxial Compression Test: ø°	Consolidation: M_V class	Consolidation: C_V class	Sulphate class	pH	Allowable bearing capacity* kPa
Mudstone of differing plasticity with some siltstone and fine sandstone	A High to very high plasticity	Scunthorpe Mudstone Formation					6 1 1–3	6 8.0 7.5–8.5	150
		Cotham Member							
		Westbury Formation							
		Blue Anchor Formation	4 68 0–110	4 9 0–36			3 1 1	3 6.1 5.5–6.7	
	B Low to intermediate plasticity	Cropwell Bishop Formation; Edwalton Formation; Gunthorpe Formation; Radcliffe Formation	875 151 (105) 0–862	869 5 (9) 0–42	60 3 2–4	65 3 1–5	134 1 1–5	90 7.8 5.5–9.3	100–600
	C Intermediate to high plasticity	Edlington Formation	68 101 (64) 7–241	49 8 (9) 0–42	16 3 2–4	10 3 2–3	14 1 1–2	14 7.5(0.5) 6.6–8.5	150–300
		Cadeby Formation mudstone	10 178 (117) 31–370	8 7 (7) 0–17	1 3	1 3	5 1 1–2		150–400
		Middle Coal Measures	86 186 (132) 8–645	66 0.2 (1.5) 0–12	8 3 2–3	3 3 2–4	15 1 1–3		100–600
		Lower Coal Measures	10 143 (53) 50–207	10 7 (11) 0–33					100–400
Interbedded sandstone, mudstone		Sneinton Formation	46 59 (35) 0–134	46 9 (10) 0–35	14 3 3	11 5 3–5	17 1 1–2	17 6–7.9	50–400
Sandstone		Nottingham Castle Formation	Unconfined compressive strength (MN/m^2) 28 10 (5) 1–22				25 1 1–2	20 7.3(0.4) 6.8–8.0	400–1600
		Lenton Sandstone Formation			6 1 1–2	6 4 4–5	3 1	3 7.2 7.0–7.6	100–400
Lower Magnesian Limestone		Cadeby Formation carbonate	5 27 22–42		1 3		5 1 1–2	4 7.3 6.8–7.8	150–400

Coefficient of consolidation (C_V) (after Lambe and Whitman, 1979)

Class	C_V m^2/year	Plasticity index range
1	<0.1	Greater than 25
2	0.1–1	
3	1–10	25–5
4	10–100	15 or less
5	>100	

Coefficient of volume compressibility (M_V) (after Head, 1982)

Class	Description of compressibility	C_V m^2/MN
5	Very high	>1.5
4	High	0.3–1.5
3	Medium	0.1–0.3
2	Low	0.05–0.1
1	Very low	<0.05

Sulphates in soils and groundwaters (after Building Research Establishment, 1975)

Class	Total SO_3	SO_3 in soil: 2:1 water extract	In groundwater
1	<0.2%	<0.1 g/l	<30 parts in 100000
2	0.2–0.5%	0.1–1.9 g/l	30–120 parts in 100000
3	0.5–1.0%	1.9–3.1 g/l	120–150 parts in 100000
4	1.0–2.0%	3.1–5.6 g/l	250–500 parts in 100000
5	>2.0%	>5.6 g/l	>500 parts in 100000

Key

N A (SD) $V_1 - V_2$	N = number of values A = average value SD = standard deviation $V_1 - V_2$ = range of values

* Allowable bearing capacity estimated from cohesion and S.P.T. results using a safety factor of 3.

Table 24a. Superficial materials: index texts and particle-size analysis data

Engineering geological unit	Lithostratigraphical unit	S.T.P.	Density		Moisture content	Liquid limit	Plastic limit	Particle-size analysis			
		N	Dry Mg/m³	Bulk Mg/m³	%	%	%	Gravel %	Sand %	Silt %	Clay %
Fill	Fill	207 15(12) 1–50+	65 1.67 (0.18) 1.02–1.98	115 1.94 (0.20) 1.38–2.27	177 22 (11) 3–85	68 35 (12) 16–70	68 20 (5) 10–41	39 25 (28) 0–98	39 38 (24) 2–90	39 31 (26) 0–81	39 5 (9) 0–37
Head	Head	22 27 (14) 6–50+	9 1.65 1.24–1.79	53 2.00 (0.14) 1.39–2.23	80 20 (8) 3–48	50 33 (11) 16–68	50 18 (5) 10–37	12 26 (27) 0–90	12 32 (21) 2–84	12 25 (15) 0–47	12 16 (21) 0–60
Organic soil	Peat	very low	5 0.40 0.23–0.71	13 1.17 (0.13) 0.99–1.49	18 209 (113) 53–416	11 189 (111) 60–390	10 125 (87) 39–314				
Cohesive soil	Alluvium	160 18 (15) 1–50+	65 1.49 (0.42) 0.32–2.27	422 1.85 (0.24) 0.83–2.46	605 37 (40) 2–416	359 52 (39) 16–39	354 27 (24) 8–314	62 27 (30) 0–95	62 41 (24) 0–91	62 21 (17) 0–65	62 11 (15) 0–70
	Till			5 2.11 (0.09) 1.82–2.34	54 15 (5) 7–30	10 35 (9) 25–50	10 16 (4) 11–22				
Non-cohesive soil	Lower Terrace Gravel	1326 top: 25 (5) 1–49 bottom: 50+	4 1.85 1.62–2.05	18 1.89 (0.28) 1.03–2.22	111 13 (10) 1–54	8 35 20–76	8 17 2–28	588 65 (23) 0–100	588 32 (21) 0–100	588 2 (4) 0–25	588 <1 0–15
	Upper Terrace Gravel	32 32 (16) 7–50+		4 1.78 1.19–2.03	20 15 (8) 6–42	8 33 25–48	7 20 15–30				
	Glacial Sand and Gravel	4 50+ 50+		2 1.96 1.90–2.02	2 5 4–7						

Key

Key
N A (SD) $V_1 - V_2$

N = number of values
A = average value
SD = standard deviation
$V_1 - V_2$ = range of values

Table 24b. Superficial materials: strength and chemical-test data

Engineering geological unit	Lithostratigraphical unit	Undrained Triaxial Compression Test		Consolidation		Sulphate class	pH	Allowable bearing capacity* kPa
		Cu kPa	ø°	M_V class	C_V class			
Fill	Fill	105 67 (55) 0–324	94 6 (10) 0–32	7 3 3–4	8 3 3–4	73 1 1–4	66 7.5 (0.7) 6.5–10	0–300
Head	Head	44 89 (64) 10–265	38 7 (12) 0–38	3 4 3–4	3 3 3–4	10 1 1		50–300
Organic soil	Peat	13 25 (18) 0–60	13 2 (6) 0–15	6 5 5	6 3 2–4	4 2 1–4	3 5.8 4.8–6.5	very low
Cohesive soil	Alluvium	427 57 (54) 0–440	409 4 (8) 0–49	98 4 1–5	97 3 2–5	166 1 1–4	142 7.4 (0.7) 4.8–10.5	0–300
	Till	52 167 (103) 13–350	52 9 (6) 0–32	3 3 3–4	6 3 2–3	13 1 1–3	10 8 (0.5) 7.5–8.7	100–600
Non-cohesive soil	Lower Terrace Gravel	18 58 (75) 0–270	17 13 (15) 0–38	5 3–4		132 1 1–3	124 7.5 (0.5) 5.8–10.0	100–600
	Upper Terrace Gravel	4 68 0–110	4 9 0–36			3 1		100–400
	Glacial Sand and Gravel	2 41	2 36 33–40					

Key

N
A (SD)
V_1-V_2

N = number of values
A = average value
SD = standard deviation
V_1-V_2 = range of values

* Allowable bearing capacity estimated from cohesion and S.P.T. results using a safety factor of 3.

Coefficient of consolidation (C_V)
(after Lambe and Whitman, 1979)

Class	C_V m^2/year	Plasticity index range
1	<0.1	Greater than 25
2	0.1–1	
3	1–10	25–5
4	10–100	15 or less
5	>100	

Coefficient of volume compressibility (M_V)
(after Head, 1982)

Class	Description of compressibility	C_V m^2/MN
5	Very high	>1.5
4	High	0.3–1.5
3	Medium	0.1–0.3
2	Low	0.05–0.1
1	Very low	<0.05

Sulphates in soils and groundwaters
(after Building Research Establishment, 1975)

Class	Total SO_3	SO_3 in soil: 2:1 water extract	In ground-water
1	<0.2%	<0.1 g/l	30 parts in 100000
2	0.2–0.5%	0.1–1.9 g/l	30–120 parts in 100000
3	0.5–1.0%	1.9–3.1 g/l	120–150 parts in 100000
4	1.0–2.0%	3.1–5.6 g/l	250–500 parts in 100000
5	>2.0%	>5.6 g/l	>500 parts in 100000

ANNEX 5. LIST OF MINERAL INDUSTRY OPERATORS

Brick Clay
Nottingham Brick PLC
Dorket Head
Lime Lane
Arnold
Nottingham NG5 9PZ

Tel: 0602-263331

Building Stone
Hendon Demolitions Ltd
Stone Quarries
Milford Close
Bulwell
Nottingham

Tel: 0602-276291

Coal
British Coal
Nottinghamshire Area
Edwinstowe House
Edwinstowe
Mansfield
Nottingham NG21 9PR

Tel: 0623-822481

Gypsum
British Gypsum PLC
East Leake
Loughborough
Leicestershire LE12 6SQ

Tel: 0602-214161

Sand and Gravel
British Industrial Sand Ltd (Bramcote Quarry)
Coventry Lane
Beeston
Nottingham

Tel: 0602-222789

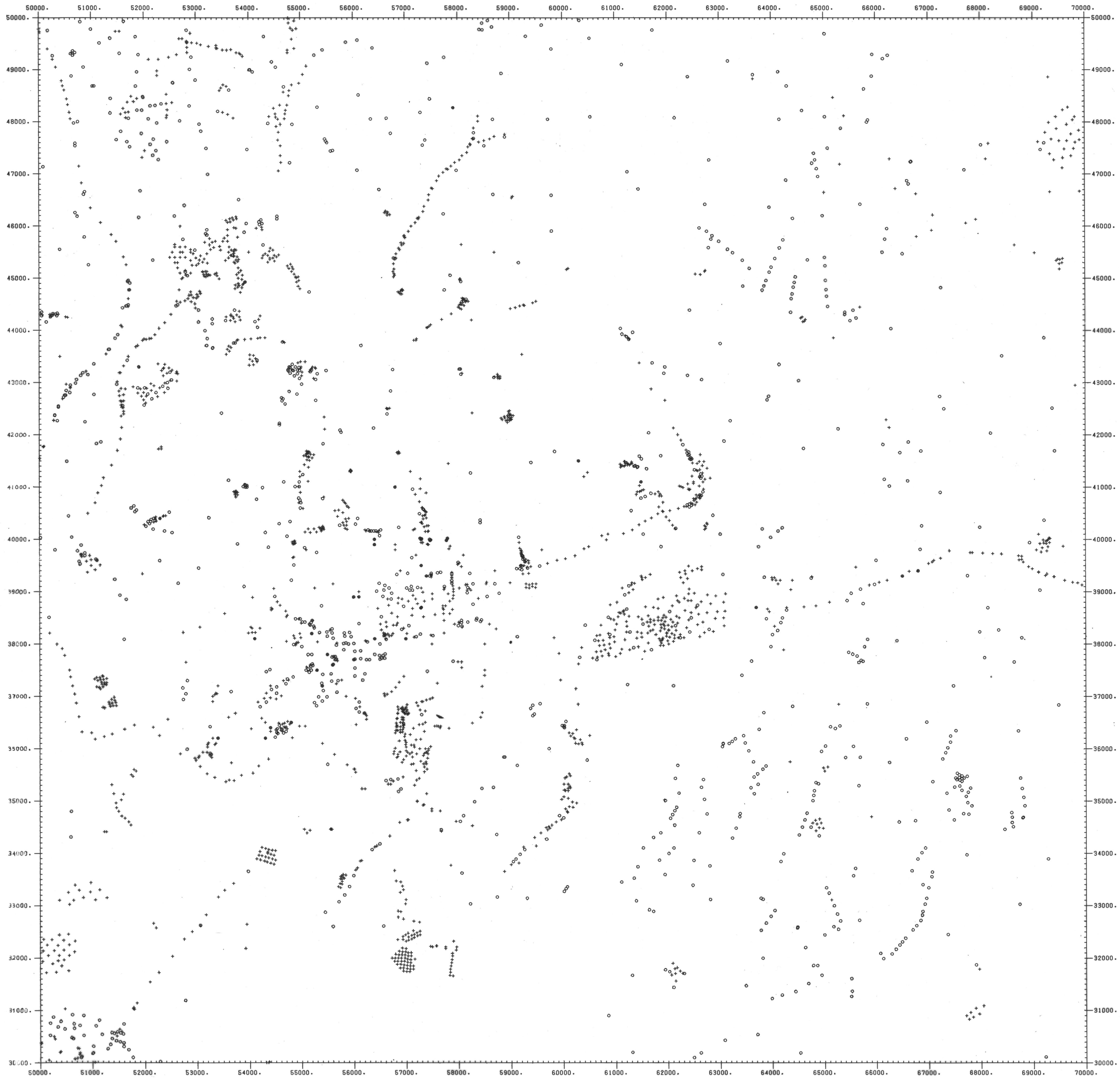
RMC – Butterley Aggregates Ltd
(Attenborough Quarry)
Long Lane
Attenborough
Beeston
Nottingham

Tel: 0602-221221

Tarmac-East Midlands Ltd
(Bestwood, Hoveringham and Holme Pierrepont Quarries)
John Hadfield House
Dale Road
Matlock
Derbyshire DE4 3PL

Tel: 0629-3456

Typeset and Printed in England by Saxon Printing Ltd., Derby.



BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Scale 1:50 000

MAP 1. DISTRIBUTION OF RECORDS (BOREHOLES AND TRIAL PITS)

Compilation from NGDC records by T.J.Charsley in 1989.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE., Director, British Geological Survey.

INDEX AND EXPLANATION

○ Borehole or shaft section, 10m or more in depth

\+ Borehole or trial pit, less than 10m deep

The plots on this map are computer-generated from references held in the National Geoscience Data Centre (NGDC) database at the British Geological Survey, Keyworth, Nottingham.
Site plans at 1:10 560 showing more precise locations, if known, together with records of individual boreholes, shaft sections and trial pits are held by the NGDC. A prior appointment is necessary to consult these records.

Marginal numbers refer to the National Grid square with the NW corner point at SK450000/350000.

This map should be used in conjunction with the report: Charsley T.J., Rathbone P.A. and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

USER'S 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 September 1988 has been taken into account.

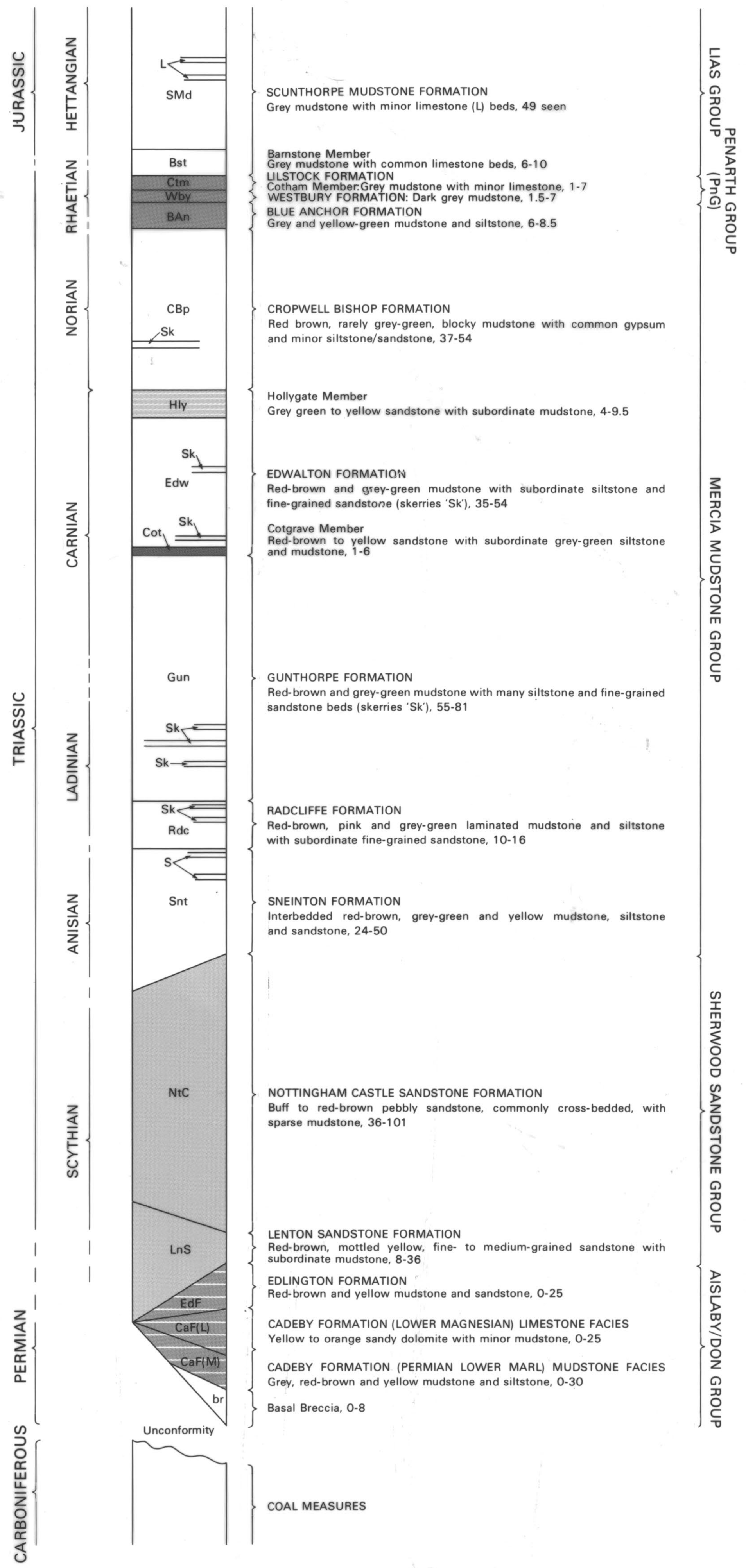
Production of this map was commissioned by the Department of the Environment and jointly funded by the Department and the British Geological Survey.

Geological Overprint © NERC 1990.

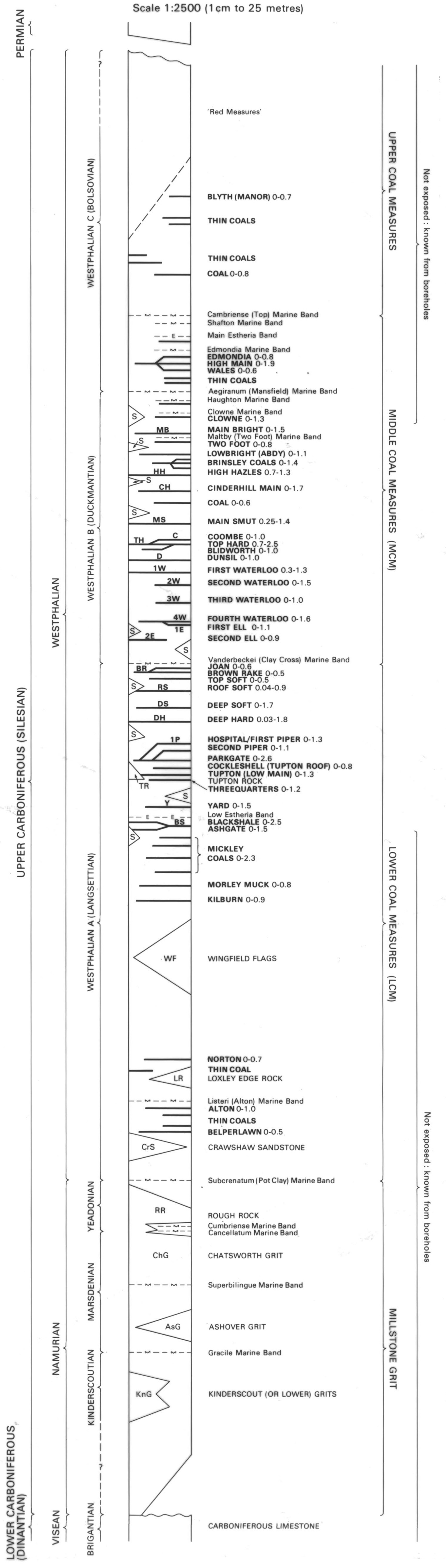
Any enquiries concerning this map should be directed to:
British Geological Survey, Keyworth, Nottingham NG12 5GG. Tel 06077-6111.

GENERALIZED VERTICAL SECTIONS

Scale 1:1500 (1cm to 15 metres)



Scale 1:2500 (1cm to 25 metres)

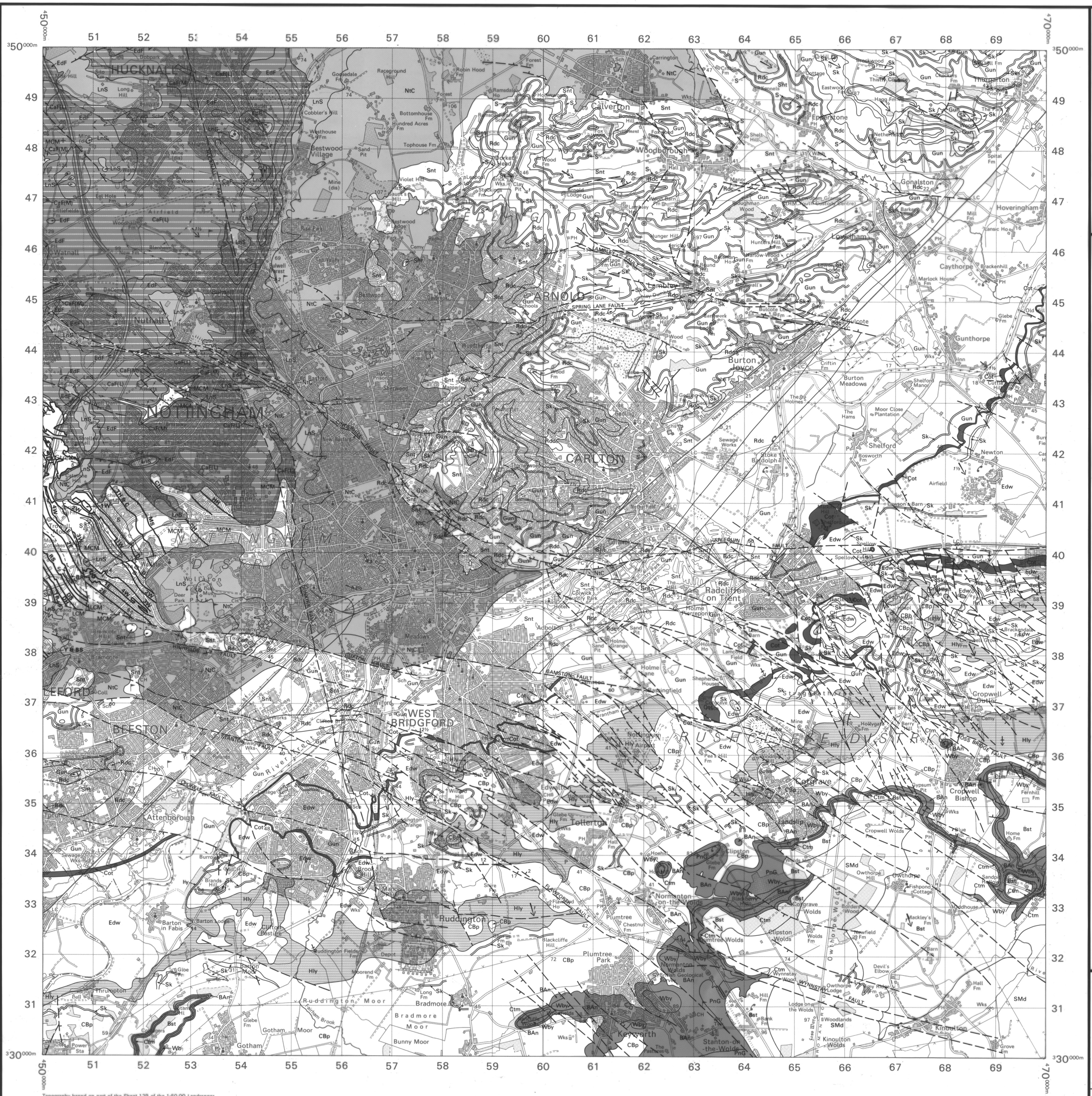


DESCRIPTION OF UPPER CARBONIFEROUS ROCK TYPES

GROUP	LITHOLOGY
COAL MEASURES	'Red Measures' Undifferentiated primary red-brown mudstone, siltstone and sandstone and secondarily reddened 'grey measures'.
	'Grey Measures' Grey mudstone, siltstone and subordinate sandstone (S) with marine fossiliferous shales (Marine Bands), coals, seatearths and ironstones.
MILLSTONE GRIT	Grey mudstone, siltstone and common sandstone (including 'grits') with marine fossiliferous shales (Marine Bands), minor coals, seatearths and ironstones.

DOLERITES INTRUDED INTO LOWER COAL MEASURES

COAL OR MARINE BAND INTERVAL	MAXIMUM THICKNESS DOLERITE(S) (in metres)
DEEP HARD — YARD	45
YARD — BLACKSHALE	63
BLACKSHALE — KILBURN	38
KILBURN — Listeri M.B.	50
Listeri M.B. — Subcrenatum M.B.	20



Topography based on part of the Sheet 129 of the 1:50 000 Landranger Series of the Ordnance Survey of Great Britain.
Heights are in metres.
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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Scale 1:50 000

MAP 2: BEDROCK GEOLOGY

Based on geological survey at 1:10 560 by D.V.Frost in 1963-64 and at 1:10 000 by K.Ambrose, T.J.Charsley, R.G.Crofts, M.T.Dean, J.R.A.Giles, A.S.Howard, D.J.Lowe and P.A.Rathbone in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE., Director, British Geological Survey.

INDEX AND EXPLANATION

- \+ Horizontal or near-horizontal strata
- ↔ Gently inclined strata
- 2← Inclined strata, dip in degrees
- ←2 Regional dip of strata
- —— Geological boundary, Solid
- — — 10 Fault at surface, or at rockhead if below Drift; crossmark indicates downthrow side; approximate throw of fault where known is given in metres at the point indicated.

Broken lines denote uncertainty

- Coal seam, with commonly used name
- Marine Band
- Estheria Band
- RR Named sandstone
- S Unnamed sandstone
- Sk Skerry (siltstone or fine-grained sandstone forming a topographic feature)
- L Limestone (in Scunthorpe Mudstone Formation)

Thicknesses are given in metres

Abbreviations:

cm.........centimetres
L...........Limestone
M..........Mudstone
m..........metres
MB........Marine Band
S...........Sandstone
Sk.........Skerry

Note:

This map should be used together with Map 3 (Distribution and thickness of drift deposits) and Maps 4A-D (Distribution of made and disturbed ground) for a correct interpretation of the geology of a given area.

SK 54 NW	SK 54 NE	SK 64 NW	SK 64 NE
SK 54 SW	SK 54 SE	SK 64 SW	SK 64 SE
SK 53 NW	SK 53 NE	SK 63 NW	SK 63 NE
SK 53 SW	SK 53 SE	SK 63 SW	SK 63 SE

Diagram showing component 1:10 000 National Grid sheets. Sheets geologically surveyed by D.V.Frost in 1963-64 are stippled; the remaining sheets were surveyed in 1988-89.

This map should be used in conjunction with the report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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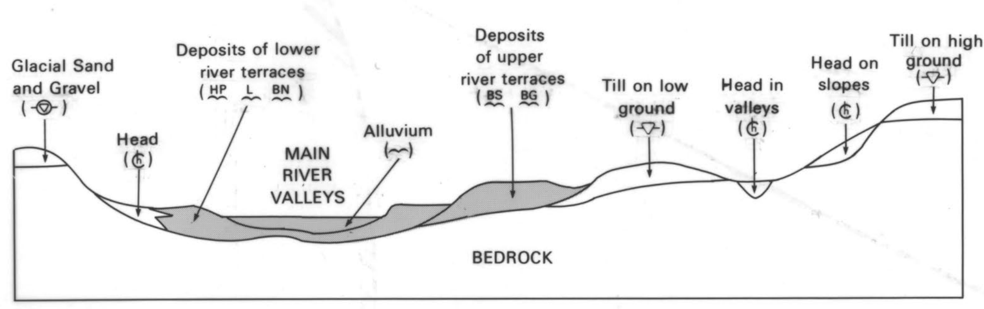
GEOLOGICAL AGE AND RELATIONSHIPS OF DRIFT DEPOSITS

PERIOD	EPOCH	STAGE	DEPOSIT
QUATERNARY	RECENT	FLANDRIAN	Alluvium
			Peat, Shell Marl, Lacustrine Clay (Cold-Temperate)
		—10 000 years—	
	PLEISTOCENE	DEVENSIAN	Head; Holme Pierrepont Sand and Gravel, Leen Sand and Gravel, Bunny Sand and Gravel (Periglacial)
		—? 40 000 years—	
		EARLY DEVENSIAN IPSWICHIAN- LATE WOLSTONIAN-	Beeston Sand and Gravel, Bassingfield Sand and Gravel (Periglacial-Interglacial-Periglacial)
		—? 200 000 years—	
		ANGLIAN OR WOLSTONIAN	Till (Boulder Clay), Glacial Sand and Gravel

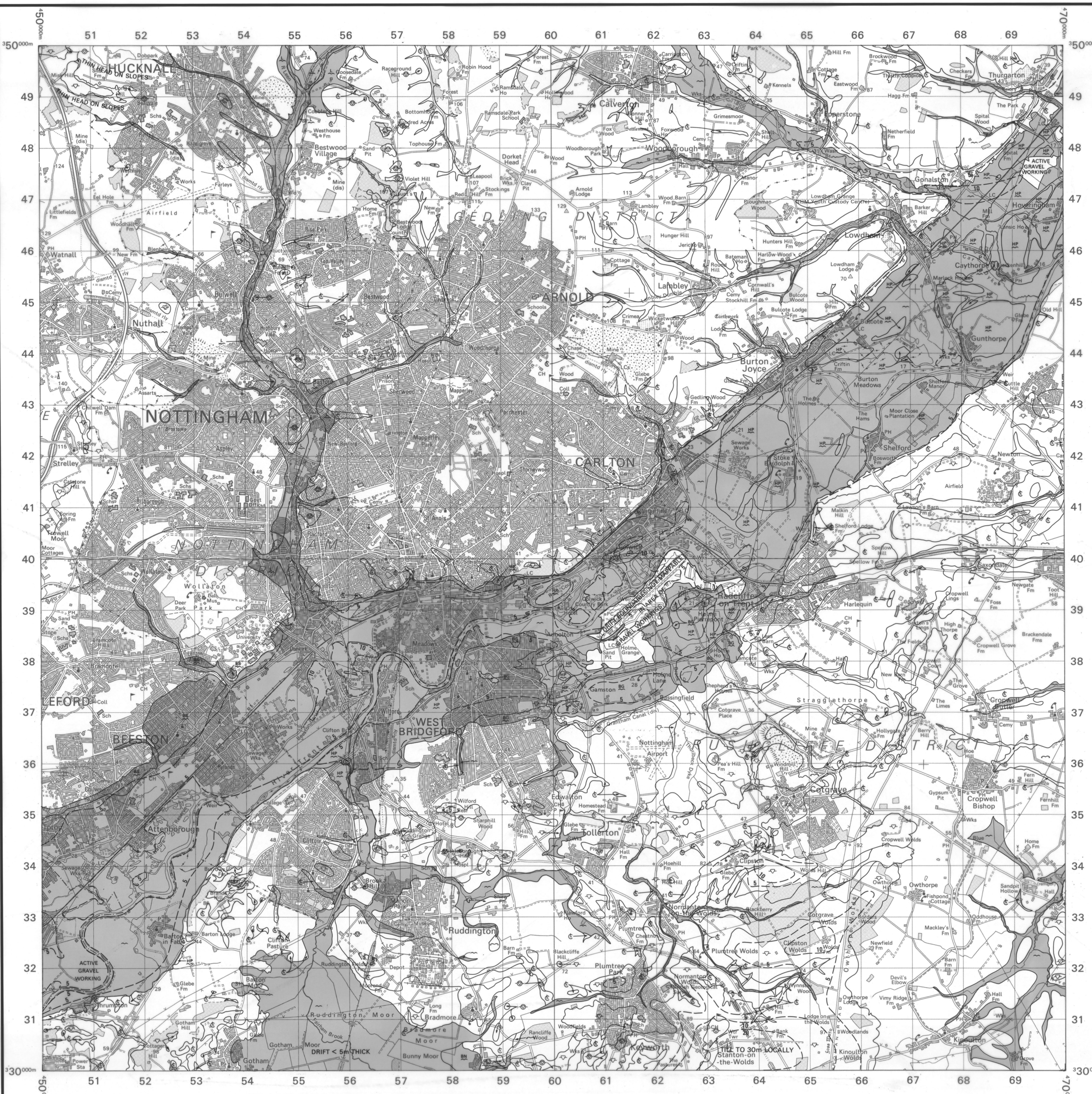


Diagrammatic cross section to show main drift deposits related to landform

Diagram showing main areas (grey) where drift exceeds 5m in thickness.

SK 54 NW	SK 54 NE	SK 64 NW	SK 64 NE
SK 54 SW	SK 54 SE	SK 64 SW	SK 64 SE
SK 53 NW	SK 53 NE	SK 63 NW	SK 63 NE
SK 53 SW	SK 53 SE	SK 63 SW	SK 63 SE

Diagram showing component 1:10 000 National Grid Sheets. Sheets geologically surveyed by D.V. Frost in 1963-64 are stippled; the remaining sheets were surveyed in 1988-89.



Topography based on part of the Sheet 129 of the 1:50 000 Landranger Series of the Ordnance Survey of Great Britain.
Heights are in metres.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

SCALE 1:50 000

MAP 3: DISTRIBUTION AND THICKNESS OF DRIFT DEPOSITS

Based on geological survey at 10 560 by D.V. Frost in 1963-64 and at 1:10 000 by K. Ambrose, T.J. Charsley, R.G. Crofts, M.T. Dean, J.R.A. Giles, A.S. Howard, D.J. Lowe and P.A. Rathbone in 1987-88.
A.J. Wadge, Regional Geologist.
F.G. Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

MASS MOVEMENT

- Head (mixed deposit of clay,silt, sand and gravel derived from upslope deposits of weathered bedrock or drift)

ORGANIC

- Peat
- Shell Marl

LACUSTRINE

- Lacustrine Clay (may include layers and lenses of peat, shell marls and sand)

FLUVIAL

- Alluvium (generally clay, silt and sand over gravel)
- Holme Pierrepont Sand and Gravel
- Leen Sand and Gravel
- Bunny Sand and gravel
- Beeston Sand and Gravel
- Bassingfield Sand and Gravel

(Holme Pierrepont, Leen, Bunny: Deposits of lower river terraces; Beeston, Bassingfield: Deposits of upper river terraces)

GLACIAL

- Glacial Sand and Gravel
- Till (Boulder Clay, commonly sandy and associated with other complex drift deposits

Areas without symbols have bedrock at or near the surface (generally less than 1m of cover). Areas of Made Ground and backfilled excavations (maps 4A-D) are not taken into account.

— 5 — Contours (isopachytes) joining points of equal thickness (in metres). The number is shown on the side of the contour where the thickness is greater.

Note: Contours give a generalized view of the combined thickness variations of both drift and Made Ground. Areas with no or very thin drift deposits have not been contoured even though they may be overlain by Made Ground more than 5m thick.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

USERS RESPONSIBILITY

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 54

Scale 1:25 000

MAP 4A: DISTRIBUTION OF MADE AND DISTURBED GROUND

Based on geological survey at 1:10 000 by T.J.Charsley, M.T.Dean and P.A.Rathbone in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

- Areas of minimum disturbance to the land surface (reworking confined to agriculture)
- Made ground
- Backfilled quarries and other excavations
- Colliery waste tips
- Landscaped ground
- Built-over ground
- Quarry or pit (W waterfilled)
- Site of small scale mineral working

Nature of former mineral working or excavation

C	Clay (Marl)	Co	Coal
BC	Brick Clay	G	Gravel
BI	Building Stone (Magnesian Limestone)	S	Sand
BS	Building Stone (Triassic Sandstone)	P	Backfilled pond
Bw	Borrow (for fill)		

Notes

1. Isolated buildings, including farms of limited extent, and most roads have not been separately delineated.

2. Made Ground deposits are generally 1-2m thick, but may exceed 3m locally. Ground disturbance beneath Landscaped and Built-over ground is mainly limited to 0.7-1.5m, but substantial thicknesses of Made Ground not separately shown may underlie these areas.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 64

Scale 1:25 000

MAP 4B: DISTRIBUTION OF MADE AND DISTURBED GROUND

Based on geological survey at 1:10 000 by P.A.Rathbone, K.Ambrose, D.J.Lowe and J.R.A.Giles in 1987-88.
A.J.Wadge , Regional Geologist.
F.G. Larminie, OBE, Director, British Geological Survey

INDEX AND EXPLANATION

- Areas of minimum disturbance to the land surface (reworking confined to agriculture)
- Made Ground
- Backfilled quarries and other excavations (includes partial backfill)
- Colliery waste tips
- Landscaped ground
- Built-over ground
- Quarry or pit (W Water filled)
- Site of small scale mineral working

Nature of former mineral working or excavation

C	Clay (Marl)	Gy	Gypsum
BC	Brick Clay	N	Not known (clay, sand or stone)
G	Gravel	P	Backfilled pond

Notes

1. Isolated buildings, including farms of limited extent, and most roads have not been separately delineated.
2. Made Ground deposits are generally 1-2m thick, but may exceed 3m locally. Ground disturbance beneath Landscaped and Built-over ground is mainly limited to 0.7-1.5m, but substantial thicknesses of Made Ground not separately shown may underlie these areas.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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Heights are in metres.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 53

Scale 1:25 000

MAP 4C: DISTRIBUTION OF MADE AND DISTURBED GROUND

Based on geological surveys at 1:10 000 by J.W.Baldock, T.J.Charsley, M.T.Dean and A.S.Howard in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

- Areas of minimum disturbance to the land surface (reworking confined to agriculture)
- Made Ground
- Backfilled quarries and other excavations (includes partial backfill)
- Colliery waste tips
- Landscaped ground
- Built-over ground
- Quarry or pit (W-Water filled)
- Site of small scale mineral working

Nature of former mineral working or excavation

C	Clay (Marl)	Gy	Gypsum
BC	Brick Clay	L	Limestone
Co	Coal	S	Sand
G	Gravel	P	Backfilled Pond

Notes

1. Isolated buildings, including farms of limited extent, and most roads have not been separately delineated
2. Made Ground deposits are generally 1-2m thick, but may exceed 3m locally. Ground disturbance beneath Landscaped and Built-over ground is mainly limited to 0.7-1.5m, but substantial thicknesses of Made Ground not separately shown may underlie these areas.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 63

Scale 1:25 000

MAP 4D: DISTRIBUTION OF MADE AND DISTURBED GROUND

Based on geological survey at 1:10 000 by R.G. Crofts and D.J. Lowe in 1987-88.
A.J. Wadge, Regional Geologist.
F.G. Larminie, OBE, Director, British Geological Survey

INDEX AND EXPLANATION

- Areas of minimum disturbance to the land surface (reworking confined to agriculture)
- Made Ground
- Backfilled quarries and other excavations (includes partial backfill)
- Colliery waste tips
- Landscaped ground
- Built-over ground
- Quarry or pit (W Water filled)
- Site of small scale mineral working

Nature of former mineral working or excavation

C	Clay (Marl)	Gy	Gypsum
BC	Brick Clay	L	Limestone
Co	Coal	S	Sand
G	Gravel	P	Backfilled pond

Notes

1. Isolated buildings, including farms of limited extent, and most roads have not been separately delineated.
2. Made Ground deposits are generally 1-2m thick, but may exceed 3m locally. Ground disturbance beneath Landscaped and Built-over ground is mainly limited to 0.7-1.5m, but substantial thicknesses of Made Ground not separately shown may underlie these areas.

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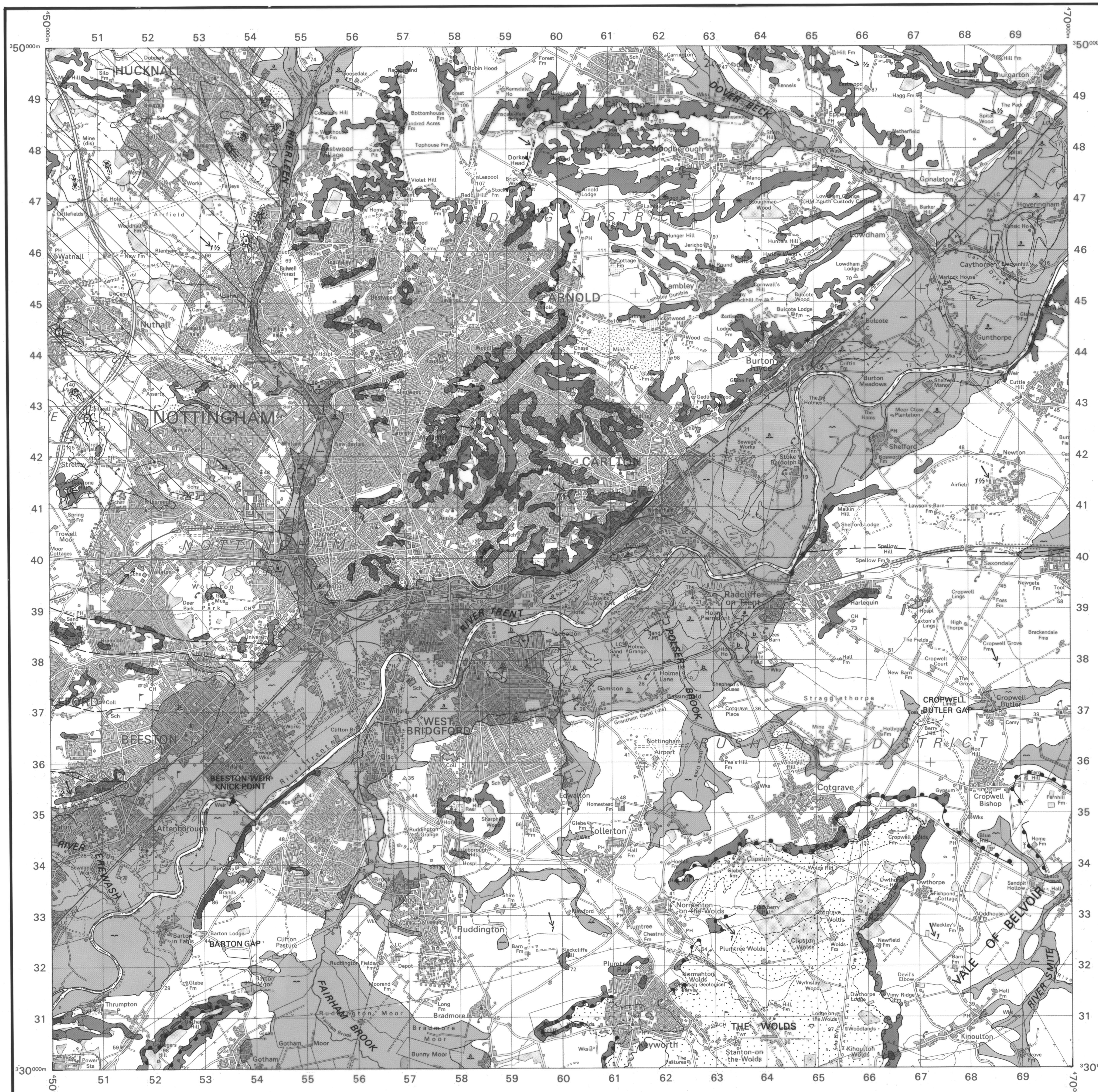

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

SCALE 1:50 000

MAP 5: GEOMORPHOLOGY, SLOPES AND DRAINAGE

Geomorphology and slopes drawn by J. Walsby and T.J. Charsley. Geological linework based on surveys at 1:10 560 by D.V. Frost in 1963-64 and at 1:10 000 by K. Ambrose, T.J. Charsley, R.G. Crofts, M.T. Dean, J.R.A. Giles, A.S. Howard, D.J. Lowe and P.A. Rathbone in 1987-88.
A.J. Wadge, Regional Geologist.
F.G. Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

- Alluvial and lacustrine flats
  Very low slopes, generally <<1°
- Low river terraces
  Generally very low slopes; 1-2m above alluvial flats
- Higher terraces
  Commonly irregular surface, generally very gentle slopes <2°, 6-12m above alluvial flats
- Slopes with gradients between 1 in 10 and 1 in 3 (5.7°-18.4°)
- Slopes with gradients greater than 1 in 3 (18.4°)
- Magnesian Limestone (Cadeby Formation) dip slope (c. 1.5°SE)
- Till (boulder clay), Wolds area only
- Sherwood Sandstone escarpment
- Mercia Mudstone escarpment
- Upper Triassic (Rhaetic) escarpment
- Lower Lias escarpment
- Major faults controlling local landform
  (In University - Bramcote - Beeston - Chilwell - and Radcliffe on Trent - Saxondale areas)
- 2 Regional dip of strata
- Gaps (cols)
  Low ground between hills at drainage divide
- Outlier of Sherwood Sandstone on Magnesian Limestone dip slope
- Beeston Weir knick point
  Marked slope change in gradient of river
- Landslip or unstable ground

Note: The boundaries of the two classes of slope (<1 in 10 and <1 in 3) have been drawn manually using the 10m contours on the 1:50 000 Ordnance Survey base map for the area (Landranger 2nd Series Sheet 129). Locally slopes may exceed the values shown, especially in the faces of former mineral workings (see Maps 4A-D and 6).

This map should be used in conjunction with the report: Charsley T.J., Rathbone P.A. and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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MINERAL RESOURCES

GRAVEL

Gravel resource area (variable thickness of sand and gravel beneath overburden)

GYPSUM

Outcrop area of main gypsum-bearing formation (Cropwell Bishop Formation)

Main gypsum-bearing formation beneath overlying strata (Blue Anchor Formation, Penarth and Lias Groups)

Mine shaft, abandoned

Adit, abandoned, showing direction of entry

Known extent of underground workings, boundaries approximate (Cropwell Bishop area)

BRICK CLAY

Outcrop area of main brick clays in the Triassic Mercia Mudstone Group (Gunthorpe Formation)

Outcrop area of brick clays in the Permian Edlington Formation (formerly the Permian Middle Marl)

SAND

Outcrop area of Nottingham Castle Formation

Outcrop area of Lenton Sandstone Formation (including main moulding sand resource)

BUILDING STONE

Outcrop area of Cadeby Formation dolomites (formerly the Lower Magnesian Limestone)

Former stone quarries in sandstones in the Sneinton Formation

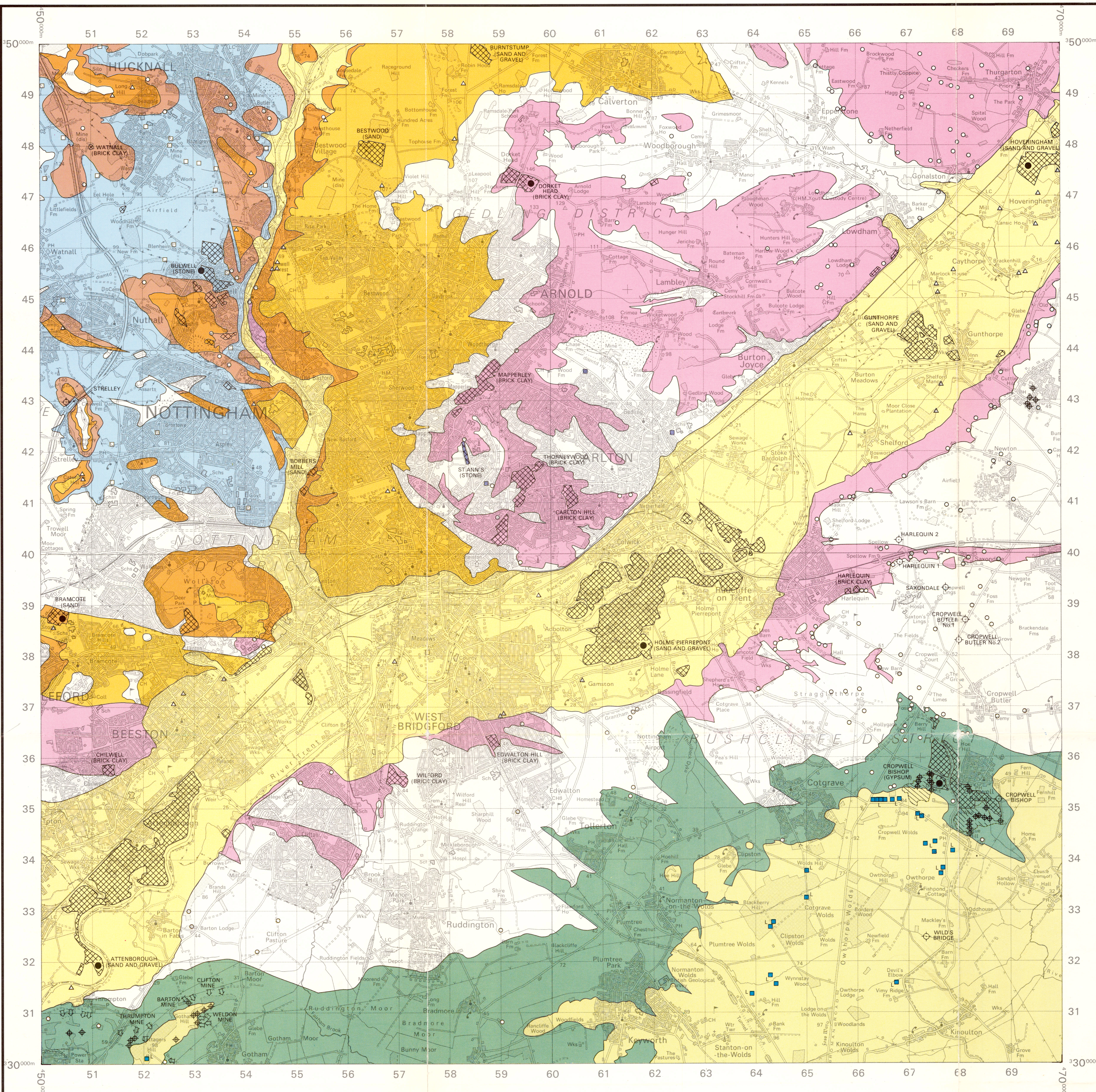
LIMESTONE

L Disused pit or quarry for Liassic limestone, of limited extent

OIL EXPLORATION

STRELLEY

Exploratory borehole for oil



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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

SCALE 1:50 000

MAP 6: MINERAL RESOURCES, MINING AND QUARRYING (EXCLUDING COAL)

Based on geological survey at 1:10 560 by D.V.Frost in 1963-64 and at 1:10 000 by K.Ambrose, T.J.Charsley, R.G.Crofts, M.T.Dean, J.R.A.Giles, A.S.Howard, D.J.Lowe and P.A.Rathbone in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

Active or disused quarry or pit (may be partially or wholly backfilled, built over or water filled)

DORKET HEAD (BRICK CLAY) — Mineral working, active

Small-scale mineral workings, abandoned:
- ○ Clay
- △ Sand and/or gravel
- □ Stone

Boundary of resource area, position approximate

Notes:

1. Resource areas (coloured) comprise those areas known to be underlain wholly or in part by rocks or other deposits containing the mineral or rock material in question.
2. Resource areas have not been defined by borehole drilling and therefore no assessment of the amount of mineral present or its precise location is possible.
3. Resources are indicated beneath urban areas since
   a) there is a possibility for future extraction during or after redevelopment,
   b) unrecorded former mineral workings are more likely to occur within these areas than outside.
4. Underground workings for gypsum in the Gotham-Thrumpton area are extensive, but have not been delineated due to the poor quality and incompleteness of some records and the confidentiality to British Gypsum of others.

This map should be used in conjunction with the report: Charsley T.J., Rathbone P.A. and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey, Technical Report, WA/90/1.

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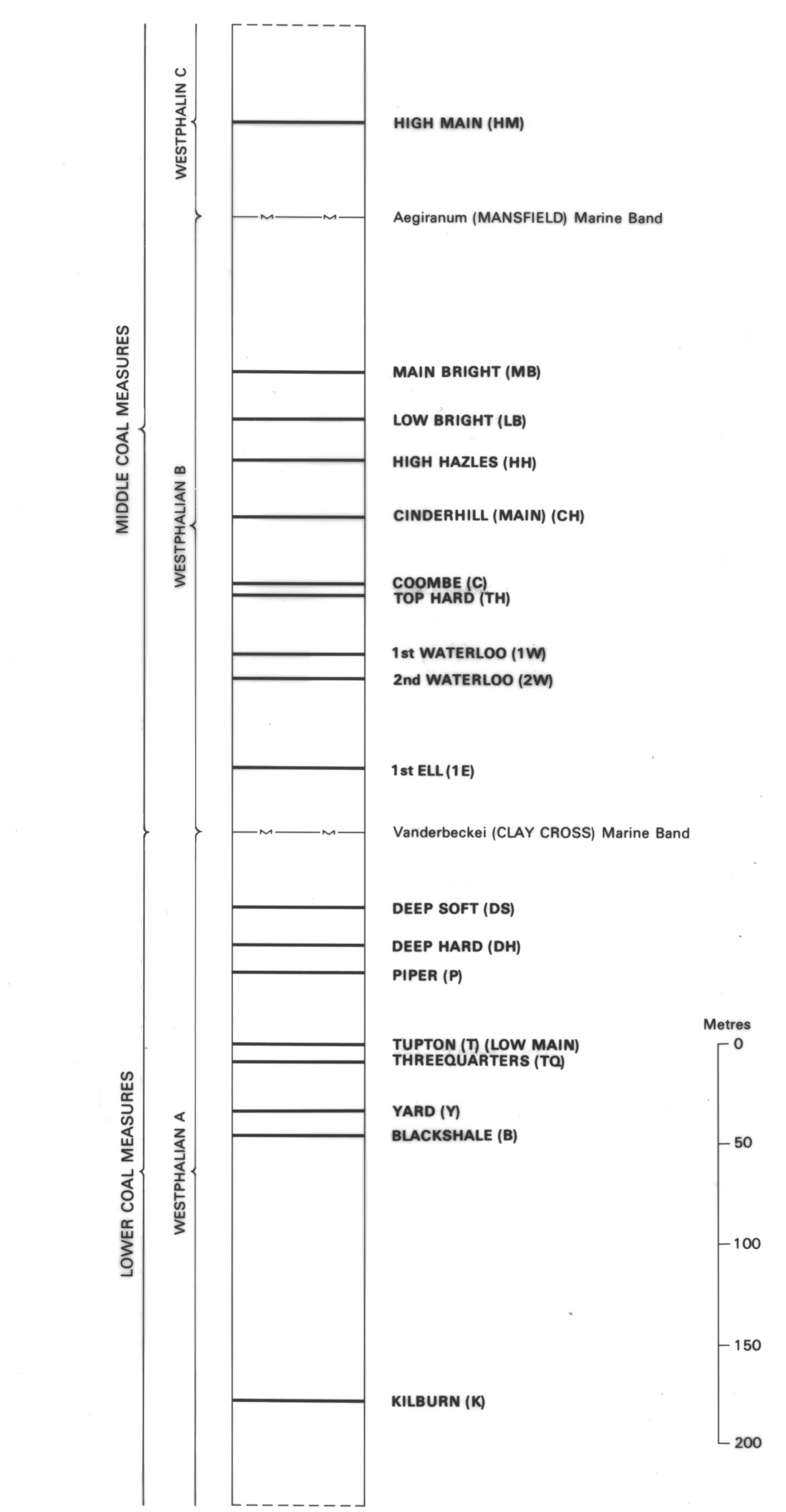
GENERALIZED VERTICAL SECTION THROUGH COLLIERY-WORKED COALS



LIST OF COLLIERIES

Plans of workings from the following collieries have been used in this compilation:

A. Within area

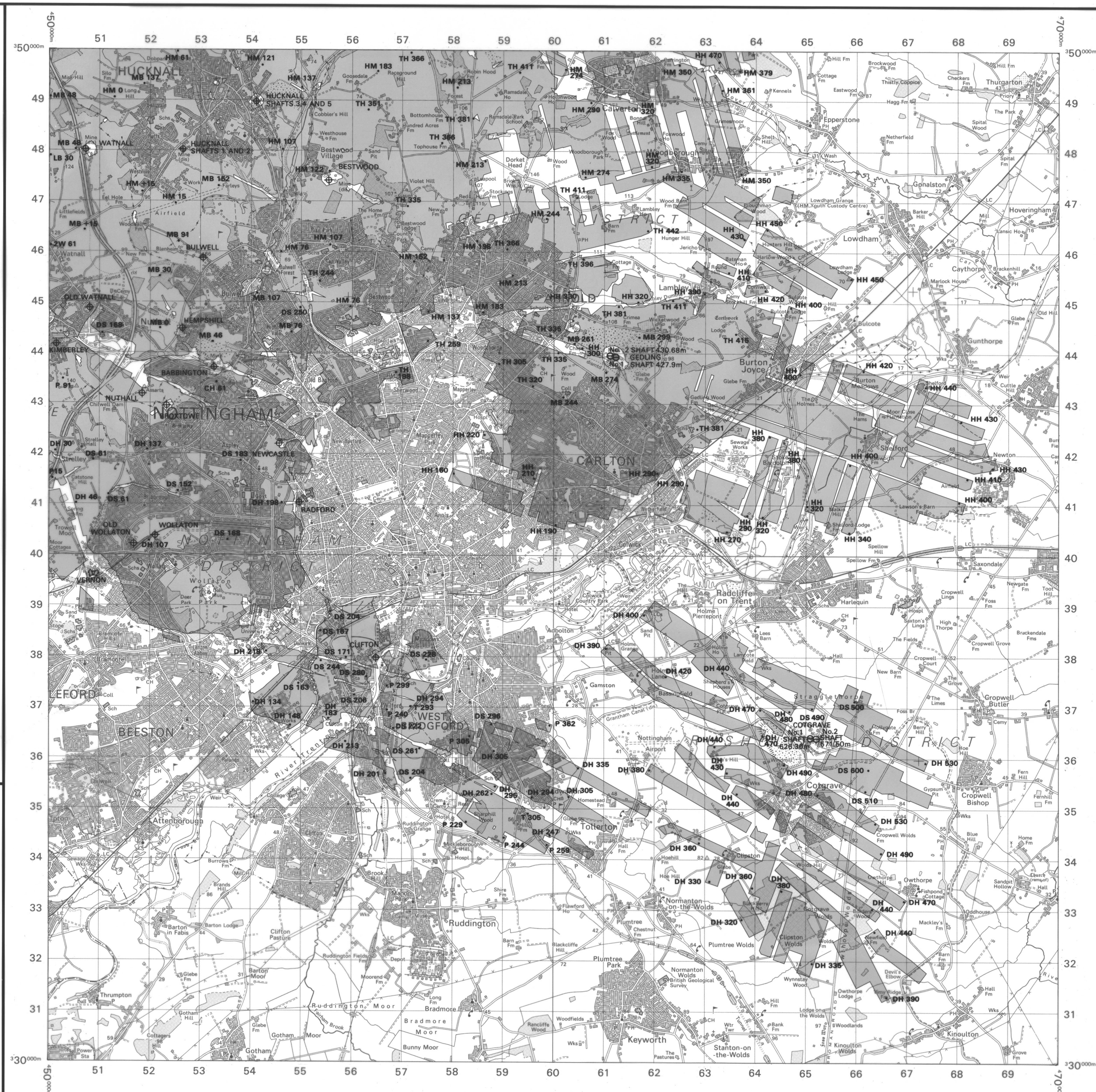
- Babbington (Cinderhill)
- Bestwood
- Bulwell
- Clifton
- Cotgrave
- Gedling
- Hempshill
- Hucknall
- Kimberley
- Old Watnall
- Old Wollaton
- Newcastle (Whitemoor)
- Nuthall
- Radford
- Vernon
- Watnall
- Wollaton

B. Outside area but working coals beneath area

- Calverton
- Cossall
- Linby
- Moorgreen

Working collieries (in 1989) are underlined, other collieries are closed

Note: Areas shown as not mined in the Trowell Moor area on the western side of the map may have been mined from former poorly-recorded shallow workings. For a full evaluation of mined areas this map should be used in conjunction with maps 8A and 8B and consultations with British Coal.



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BRITISH GEOLOGICAL SURVEY
GEOLOGY OF THE NOTTINGHAM AREA

Scale 1:50 000

MAP:7 UNDERGROUND COLLIERY-BASED COAL MINING

Compiled from abandoned mine plans and British Coal records by T.J. Charsley; M.T. Dean and K.M. Bardell
A.J. Wadge Regional Geologist
F.G. Larminie, OBE, Director, British Geological Survey

(grey shaded area)	Areas of underground coal mining (all seams)
⊖ No.1 SHAFT 626m	Working colliery shaft, depth in metres
⌖ RADFORD	Abandoned colliery shaft (generally more than one shaft at each site)
HM	Letter symbol for seam (see generalized vertical section)
• **MB193**	Depth in metres below OD to worked coal seam (+ indicates above OD) ;other seams may also have been worked at site

This map is compiled from abandoned mine plans and other records obtained from British Coal. The delineation of mined areas has been generalized and is only approximate. For detailed local information original surveyor's plans held by British Coal must be consulted.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 54

Scale 1 : 25 000

MAP 8A : COAL : OPENCAST MINING, SHAFTS AND SHALLOW MINING

Based on 1:10 000 geological survey by D.V. Frost in 1963-64, M.T.Dean, P.A.Rathbone and T.J.Charsley in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, O B E, Director, British Geological Survey

INDEX AND EXPLANATION

- Outcrop area of Permo-Triassic rocks overlying Coal Measures
- Outcrop area of Coal Measures. Former shallow workings in outcropping coal seams are widespread in this area, but are rarely documented
- Backfilled opencast coal workings
- Abandoned mine shaft (Coal)
- Abandoned adit
- Approximate eastern boundary of area of non colliery-based former coal mining from directly below Permo-Triassic cover rocks
- Geological boundary
- Fault with direction of throw. Shown only where isopachs are affected
- —100— Lines of equal thickness (isopachs) of cover rocks overlying Coal Measures. Depth given in metres to Coal Measures: lines are smoothed through minor irregularities in surface relief and some faults

Broken lines denote uncertainty

Notes

1 For a full evaluation of mined areas this map should be used in conjunction with Map 7 (which shows the extent of mainly deeper colliery-based coal mining). British Coal should be consulted if development is contemplated in areas affected or potentially affected by coal mining.

2 The shaft locations shown are based mainly on data obtained from British Coal. For more precise locations and detailed information, plans and other records held by British Coal must be consulted.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Sheet SK 53

Scale 1 : 25 000

MAP 8B : COAL AND GYPSUM : OPENCAST MINING, SHAFTS AND SHALLOW MINING

Based on 1:10 000 geological survey by D.V. Frost in 1963-64, T.J.Charsley, A.S.Howard and J.W.Baldock in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, O B E Director, British Geological Survey.

INDEX AND EXPLANATION

Outcrop area of Permo-Triassic rocks overlying Coal Measures

Outcrop area of Coal Measures
Former shallow workings in outcropping coal seams are widespread in this area but are rarely documented

Backfilled opencast coal workings

Abandoned mine shaft (Coal)

Abandoned mine shaft (Gypsum) (SW corner only)

Abandoned adit

Approximate eastern boundary of area of non colliery - based former coal mining from directly below Permo-Triassic cover rocks

Geological boundary

Fault with direction of throw. Shown only where isopachs are affected

—100— Lines of equal thickness (isopachs) of cover rocks overlying Coal Measures. Depth given is in metres to Coal Measures : lines are smoothed through minor irregularities in surface relief and some faults.

Broken lines denote uncertainty

Notes

1 For a full evaluation of mined areas this map should be used in conjunction with Map 7 (which shows the extent of mainly deeper colliery-based coal mining). British Coal should be consulted if development is contemplated in areas affected or potentially affected by coal mining.

2 The shaft locations shown are based mainly on data obtained from British Coal or British Gypsum Ltd. For more precise locations and detailed information, plans and other records held by British Coal or British Gypsum Ltd. must be consulted.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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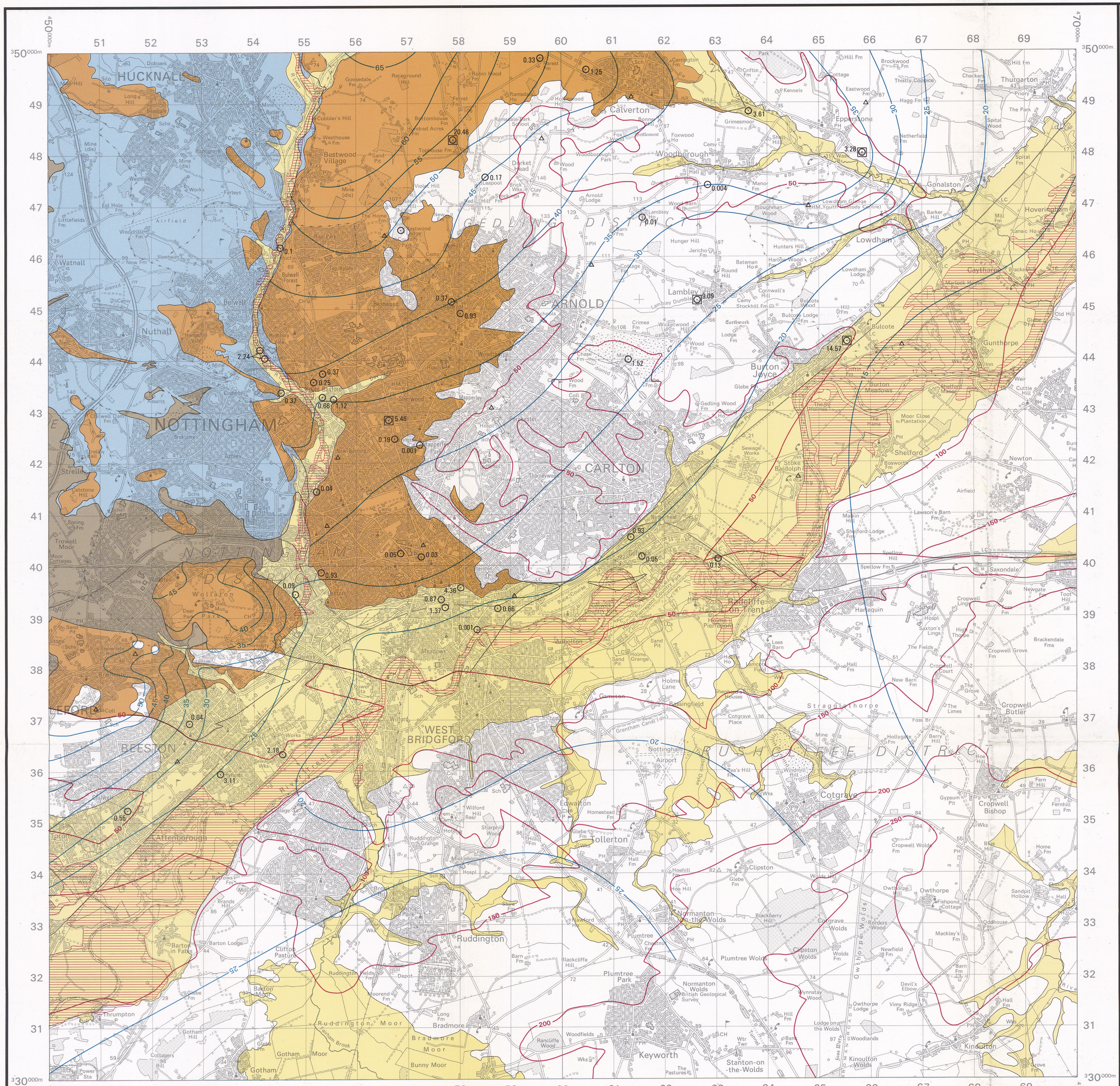

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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

Scale 1:50 000

MAP 9: HYDROGEOLOGY AND FLOOD LIMITS

Based on geological survey at 1:10 560 by D.V.Frost in 1963-64 and at 1:10 000 by K.Ambrose, T.J.Charsley, R.G.Crofts, M.T.Dean, J.R.A.Giles, A.S.Howard, D.J.Lowe and P.A.Rathbone in 1987-88.
Map prepared by T.J.Charsley and R.M.Monkhouse in 1989.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

INDEX AND EXPLANATION

- Sherwood Sandstone aquifer beneath Triassic-Jurassic cover rocks
- Outcrop area of Sherwood Sandstone Group (includes areas of thin drift cover and alluvium)
- Main outcrop and subcrop area of Permian Cadeby Formation dolomites (Lower Magnesian Limestone) (minor aquifer)
- Outcrop area of Permian Cadeby Formation mudstones and siltstones (Permian Lower Marl) and Coal Measures
- Main areas of alluvium and other valley fill deposits where perched groundwater is within 5m of ground level.
- —35— Contours in metres above OD on rest water level, at March 1987, for the area underlain by Triassic strata (equivalent to the level to which water will rise in a well sunk to the Sherwood Sandstone aquifer)
- —100— Contours in metres of the depth to the top of the Sherwood Sandstone aquifer
- ⊙3.61 Licensed groundwater source (number gives maximum licensed abstraction in megalitres per day)
- ⊡20.46 Licensed groundwater source for public supply
- △ Observation site for monitoring groundwater level
- Area of maximum recorded flooding of the Rivers Trent, Leen and Erewash (prior to much modern flood defence construction)

Note: Licensed abstraction data and flood limits are published with the permission of the Severn Trent Water Authority to whom further enquiries on these aspects should be directed. Flood limits exclude the freak condition flooding of West Bridgford and other nearby areas in 1947.

This map should be used in conjunction with the Report: Charsley T.J., Rathbone P.A., and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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ENGINEERING GEOLOGY OF SUPERFICIAL MATERIALS

Head

Generally a weak heterogeneous material of loose to medium density (sandy material) or soft to stiff consistency (clays) of variable composition and properties. Standard penetration test results and undrained cohesion values indicate allowable bearing capacity of 100-300 kPa, with medium to high compressibility. Uneven settlement may be a problem. Sulphate attack is unlikely. Excavations in Head will require support, water inflow may cause collapse. Head may contain relict shear surfaces which may be reactivated by loading or undercutting of slopes. The introduction of water onto Head covered slopes could start slippage or flow.

Organic soils

Peat. Mappable peat occurs on Barton Moor, smaller deposits of peat and organic silts, sands and clays occur in the alluvium and river terrace deposits. Peat and highly organic soils have very low bearing capacity and are highly compressible. Settlement may be uneven over lenticular or channel deposits. Special foundations (raft, piled) or removal and replacement of organic material may be required. Acidic groundwater may attack buried concrete. Excavations will require support.

Cohesive soils

Alluvium. A normally consolidated clay, silt, silty clay, or sandy clay, occasionally organic with some sands and gravels. It is of low to high plasticity, soft to firm consistency, and medium to high compressibility. Standard penetration tests, undrained cohesion and consolidation results indicate net allowable bearing pressures of 0-200 kPa with medium to very high consolidation. Uneven settlement over short distances may be caused by variation in composition. Commonly thin, average thickness is about two metres. Chemical attack on buried concrete is unlikely but class II sulphate resisting concrete mixes may be necessary, more rarely class III or IV. Construction on alluvium may require raft or piled foundations. Excavations will require support and may encounter running sand below the water table.

Till. Generally an overconsolidated sandy clay, sometimes silty, of soft to very stiff consistency, intermediate to low plasticity and medium compressibility. It is presumed to offer allowable bearing pressure in the range 50-350 kPa with medium compressibilty. Sulphate attack on buried concrete is unlikely.

Non-cohesive soils

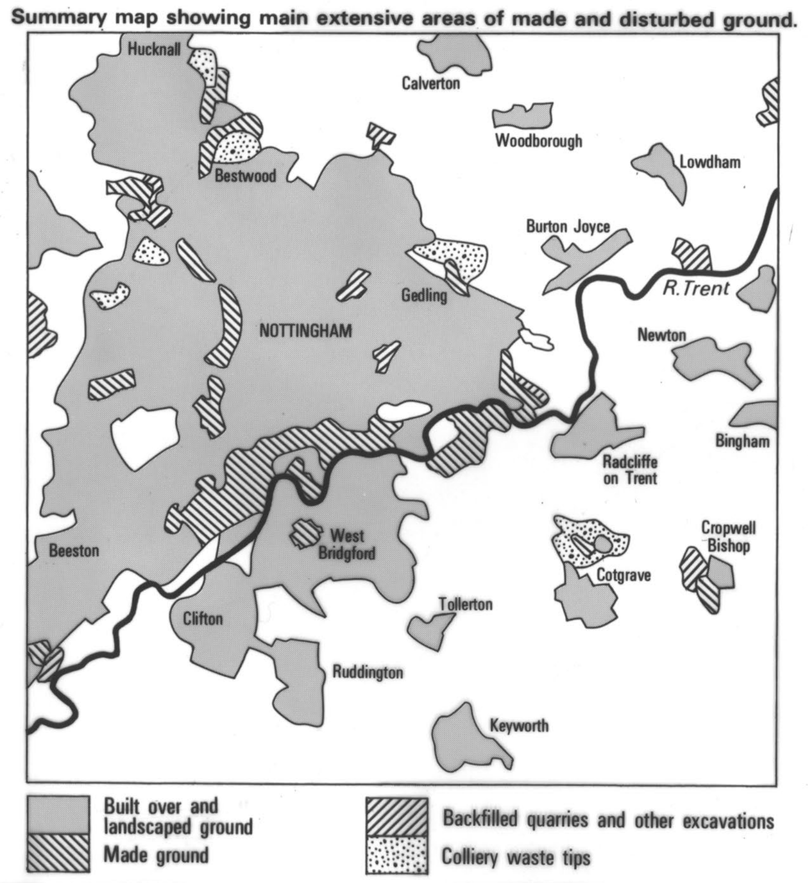
Gravel. Generally clean, uniform medium dense to very dense gravels with some sand lenses occur in the Trent valley commonly below a thin capping of alluvial sand, silt or clay. The average composition is 70% gravel, 30% sand. Standard penetration test data from lower terrace gravels suggest a bearing capacity of about 100 kPa in the thin superficially loosened top of the gravel, rapidly increasing to 100-400 kPa with depth. At greater depth bearing capacities in excess of 500 kPa are predicted. Upper terrace gravels are medium to dense. Standard penetration test results indicate a bearing capacity of 100-450 kPa. Settlement will be slight. Sulphate attack on buried concrete unlikely, class II mixes sometimes required. The gravels are suitable for use as aggregate in concrete, and should not cause alkali aggregate reaction. Excavations will require support; below the water table dewatering will be necessary.

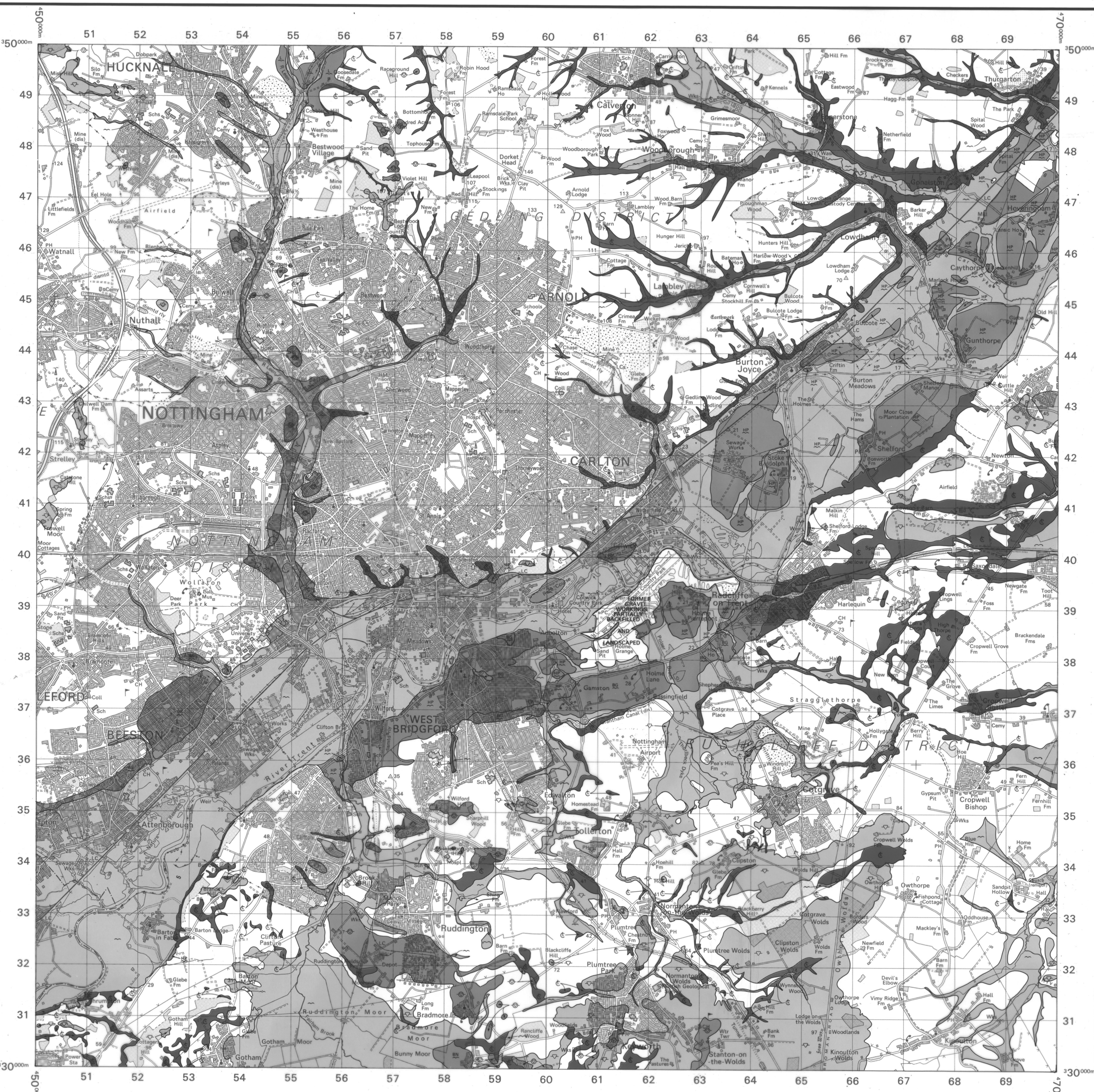
Glacial Sand and Gravel. Little geotechnical information available, they are presumed to offer good bearing capacity with low settlement characteristics. Excavations may require support.

Fill

Fill is a general term for man-made deposits, mainly within planned areas of landfill or backfill, but including a patchy veneer beneath most built-over areas. **All geotechnical investigations must allow for the presence of fill overlying drift or bedrock.** The distribution of various categories of man-made or disturbed ground is shown in detail on Maps 4A-D and generalized below. The composition of fill may vary from domestic rubbish high in paper, plastic and organic content, to mine spoil of sandstone and mudstone. Geotechnical properties are highly variable. Bearing capacity may be very low and vary over short distances with high uneven settlement. Voids due to poor compaction or combustion may be present. Excavations will require support and precautions against suffocation from CO_2 or toxic gases. Methane may present an explosive hazard. Corrosive leachate may attack buried concrete and services.

Summary map showing main extensive areas of made and disturbed ground.





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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

SCALE 1:50 000

MAP 10A: ENGINEERING GEOLOGY OF SUPERFICIAL (DRIFT) DEPOSITS

Engineering geology by A.Forster based on geological survey at 1:10 560 by D.V.Frost in 1963-64 and at 1:10 000 by K.Ambrose, T.J.Charsley, R.G.Crofts, M.T.Dean, A.J.Howard, D.J.Lowe and P.A.Rathbone in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

ENGINEERING GEOLOGY UNIT		LITHOSTRATIGRAPHIC UNIT	
HEAD		Head	
ORGANIC SOIL		Shell Marl	
		Peat	
COHESIVE SOIL	Weak	Lacustrine Clay	
		Alluvium	
	Strong	Till (Boulder Clay)	
NON-COHESIVE SOIL		Holme Pierrepont Sand and Gravel	Deposits of lower terraces
		Leen Sand and Gravel	
		Bunny Sand and Gravel	
		Beeston Sand and Gravel	Deposits of upper terraces
		Bassingfield Sand and Gravel	
		Glacial Sand and Gravel	

In general an **engineering soil** is a material formed of an aggregation of rock particles which can be separated by gentle mechanical means and excavated by digging.
Cohesive soils are fine-grained soils such as clays and silts.
Non-cohesive soils are coarse-grained soils such as uncemented sands and gravels.

Notes:

1. This map is one of a pair describing the engineering geology of bedrock and drift deposits. The other map is Map 10B: Engineering geology of bedrock materials.
2. For a full evaluation of foundation conditions relevant to planning and development, this map should be used in conjunction with others in the series of applied geological maps accompanying the report: Charsley T.J., Rathbone P.A. and Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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ENGINEERING GEOLOGY OF BEDROCK MATERIALS

Mudstones

Predominantly overconsolidated mudstones with some siltstones and fine sandstones, weathering to clay, silty clay and sandy clay; thin limestones are present in the south-east. The area may be subdivided into three zones.

Zone A. Generally clays of high to very high plasticity with some nodular and thin limestones. Little geotechnical information is available. May be subject to slope instability, high compressibility, shrinkage and swelling problems. Excavations generally by digging. Ripping may be necessary in limestone. Limestones may transmit water, causing flooding of excavations. Sulphate attack on buried concrete unlikely.

Zone B. Generally stiff to hard, silty clays of low to intermediate plasticity with some sandstones which weather to sand and clayey sand. Net allowable bearing capacity in the range 100-600 kPa with moderate settlement, occasionally high. Sulphate attack on buried concrete unlikely; occasionally class II or class III, rarely IV or V concrete mixes required. Excavation by digging, ripping in harder parts, support required in weathered material. Slopes of 60° and ten metres high have been cut, 30°-40° is more usual.

Zone C. Generally firm to very stiff clays of intermediate to high plasticity. Net allowable bearing capacity is in the range 100-600 kPa with moderate settlement. Includes thin sandstones, coals and seat earth with unconfined compressive strenghts of about 25, 7, 4 MPa respectively. Sulphate attack on buried concrete unlikely; class II concrete mixes sometimes necessary. Excavation by digging, but ripping may be required for sandstone, support required in weathered material. The collapse of shallow coal workings may affect the ground surface and require appropriate foundations and service connections. Methane generation and its passage through fractured rock may be a hazard.

Interbedded Sandstone/Mudstone

An interbedded sequence of overconsolidated mudstone, siltstone and fine sandstone weathering to firm clays and dense sands. Standard penetration test values are moderate to high (25-50+), undrained cohesion (clay) averages 59 kPa, average unconfined compressive strengths for sandstone ranges from 10 MPa (weathered) to 25 MPa (unweathered). This indicates net allowable bearing capacity of 200-400 kPa (clays) and in excess of 2000 kPa for unweathered sandstone, but in an interbedded sequence the weakest unit may be the controlling factor. Settlement is moderate (clays) to low (sandstone). Sulphate attack on buried concrete is unlikely.

California Bearing ratios indicate the sandstones are excellent for road sub-base. Excavation in weathered material by digging, ripping in sandstones and unweathered material may be required. Support required in weathered material. Slopes of 35° have been used in cuttings with protection from surface water to avoid erosion.

Sandstone

Generally weak to moderately strong, fine, medium and coarse, sometimes pebbly sandstones weathering to sand. The depth of weathering varies up to about eight metres. Standard penetration test results range from low (3) to high (50+) increasing with depth.

Unconfined compressive strength ranges from 1 MPa (weathered) to 22 MPa (unweathered), indicating net allowable bearing capacity in the range 400-2000 kPa depending on the state of weathering. Sulphate attack on buried concrete is unlikely.

Excavation usually possible by scraper/bulldozer with ripping in harder beds; bedding and jointing are widely spaced; wear rate is high due to abrasive quartz content. Sub-vertical faces (70°) are stable in short term; 35° slopes protected from run-off are better for long term. Excavated material is suitable for road sub-base. The sandstones may contain artificial cavities (caves, see Map 11) at shallow depth which may be empty or rubble filled.

Magnesian Limestone

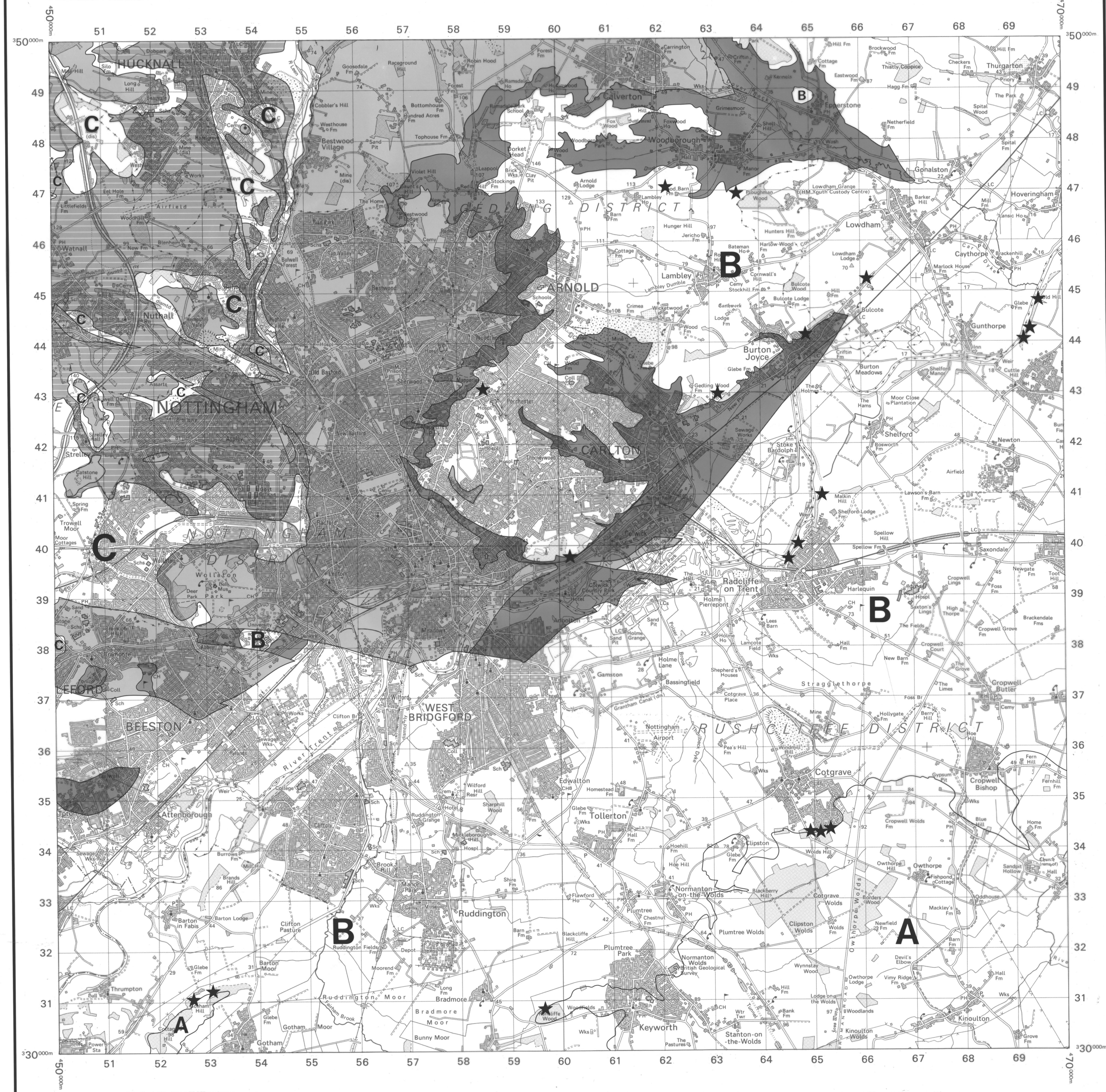
A granular dolomitic limestone with silty clay bands up to a few centimetres thick. It weathers to a dolomitic sand or silty clayey sand. Standard penetration test values are high (20-50+) and, together with moisture content variation with depth, suggest a sharp boundary between weathered and unweathered material.

The fine material is of low plasticity with undrained cohesion in the range 30-370 kPa, unconfined compressive strength for limestone is in the range 22-42 MPa. This indicates net allowable bearing capacities of 150-400 kPa (clays) and in excess of 2000 kPa for the limestone (unweathered) with moderate to low settlement. Sulphate attack on buried concrete is unlikely.

Excavations in weathered material by digging and may need support, in unweathered limestone ripping will be needed. Excavated material is suitable for road sub-base. Solution cavities or gulls in cambered strata may be present and be empty or rubble filled. May be frost susceptible.

Landslips

Landslipping is generally due to a combination of factors such as high slope angle, high water content, a susceptible mineralogy and unfavourable structural planes in the rock mass. In the Nottingham area these factors rarely combine to give slope instability problems. The high slope angles of the river cliffs of the Trent and the steep sided valleys to the north of the Trent are sufficiently steep to have caused landslipping in zone B mudstone. The high plasticity clays of the zone A mudstones have given rise to instabilities on the slopes of their outcrop in the south-east of the area.



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BRITISH GEOLOGICAL SURVEY

GEOLOGY OF THE NOTTINGHAM AREA

SCALE 1:50 000

MAP 10B: ENGINEERING GEOLOGY OF BEDROCK MATERIALS

Engineering geology by A.Forster based on geological survey at 1:10 560 by D.V.Frost in 1963-64 and at 1:10 000 by K.Ambrose, T.J.Charsley, R.G.Crofts, M.T.Dean, A.J.Howard, D.J.Lowe and P.A.Rathbone in 1987-88.
A.J.Wadge, Regional Geologist.
F.G.Larminie, OBE, Director, British Geological Survey.

ENGINEERING GEOLOGICAL CATEGORY			LITHOSTRATIGRAPHIC UNIT
MUDSTONE of various plasticity with some siltstone and fine sandstone	CLAYS OF HIGH TO VERY HIGH PLASTICITY	A	Scunthorpe Mudstone Formation Cotham Member Westbury Formation Blue Anchor Formation
	CLAYS OF LOW TO INTERMEDIATE PLASTICITY	B	Cropwell Bishop Formation Edwalton Formation Gunthorpe Formation Radcliffe Formation
	CLAYS OF INTERMEDIATE TO HIGH PLASTICITY	C	Edlington Formation Cadeby Formation (mudstone) Middle Coal Measures Lower Coal Measures
INTERBEDDED SANDSTONE AND MUDSTONE			Sneinton Formation
SANDSTONE			Nottingham Castle Sandstone Formation Lenton Sandstone Formation
LOWER MAGNESIAN LIMESTONE			Cadeby Formation (dolomite)

★ Site of landslip or slope instability

—— Boundary between engineering geological categories

Notes:

1. This map is one of a pair describing the engineering geology of bedrock and drift deposits. The other map is Map 10A: Engineering geology of superficial (drift) deposits.
2. For a full evaluation of foundation conditions relevant to planning and development, this map should be used in conjunction with others in the series of applied geological maps accompanying the report: Charsley T.J., Rathbone P.A. and Lowe D.J. 1990. Nottingham. A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

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BRITISH GEOLOGICAL SURVEY

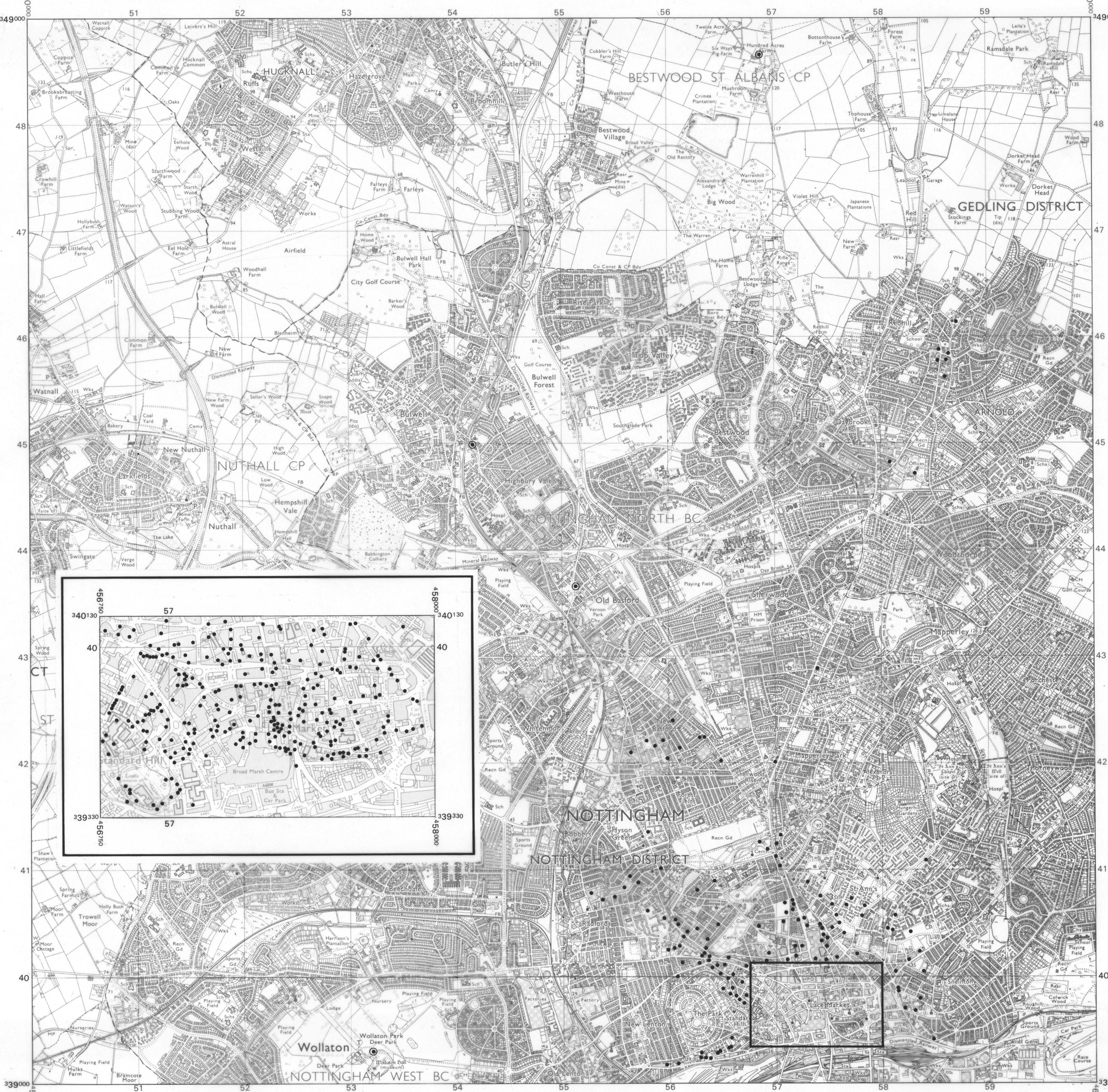
GEOLOGY OF THE NOTTINGHAM AREA

Parts of Sheets SK 54 and SK 53

Scale 1:25 000

MAP 11: CAVES

Cave sites plotted by J.C. Walsby and J.F.Owen
A.J. Wadge, Regional Geologist
F.G. Larminie, OBE, Director, British Geological Survey



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EXPLANATION

• Cave site

◉ Outlying cave sites are enhanced by circling

▭ Area enlarged at 1:10 000 scale

This map is part of a series to accompany the geological report:
Charsley T.J., Rathbone P.A., Lowe D.J. 1990. Nottingham: A geological background for planning and development. British Geological Survey Technical Report, WA/90/1.

The cave locations given on this map are recorded in more detail in a special report:
Owen, J.F. and Walsby, J.C. 1990. A register of Nottingham's caves.
British Geological Survey Technical Report, WA/90/1.

USERS RESPONSIBILITY

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